ME589/GEOC589
Advanced Topics

Geology of Critical Minerals

Introduction

Virginia T. McLemore

Safety

- Start each class with a safety moment
  - Each student will be responsible for the day's safety moment
- Note where the restrooms are, emergency exits
- Call 911 in case of an emergency

Safety—cont

- **Always make sure that you have full instructions for the job to be done.**
  - Always know your objectives before starting your job.
  - Make sure you have read the SOPs relating to your job ahead of time.
    - **WHAT ARE SOPs?**
  - Make sure that you have copies of the SOPs with you.

Virginia T. McLemore

- Principal Senior Economic Geologist with the New Mexico Bureau of Mines and Mineral Resources (NMBGMR) since 1980
- Adjunct Professor with the Departments of Earth and Environmental Sciences, and Mineral Engineering at New Mexico Tech
- Worked on mineral-resource assessments and research projects on mineral resources in NM since 1980, including REE, uranium, and beryllium and other critical minerals deposits in NM
- Published more than 400 journal articles, books, and other reports
- New Mexico Tech, B.S. 1977, M.S. 1980; University of Texas at El Paso, Ph.D. 1993; Certified Professional Geologist CPG #7438

Class introductions

Name, where from, graduated, degree here
What do you expect to learn from this course?

CLASS REQUIREMENTS

On my web page

[Critical (nmt.edu)](https://geoinfo.nmt.edu/staff/mclemore/teaching/Critical.html)

https://geoinfo.nmt.edu/staff/mclemore/teaching/Critical.html

Goals in this class

- Importance, geology, mining, processing of critical minerals
- What is involved from exploration thru production thru marketing
- field notes
- presentations
- Where to look for information
- Research needed
- Sustainable development
    - We can mine within public concerns
    - Social license to operate

Other

- Field trips will examine Critical Minerals deposits in New Mexico
- Lab exercises will examine drill core and hand specimens
- Discuss how sampling plans are developed
- SOPs and sampling plans
- Mine safety

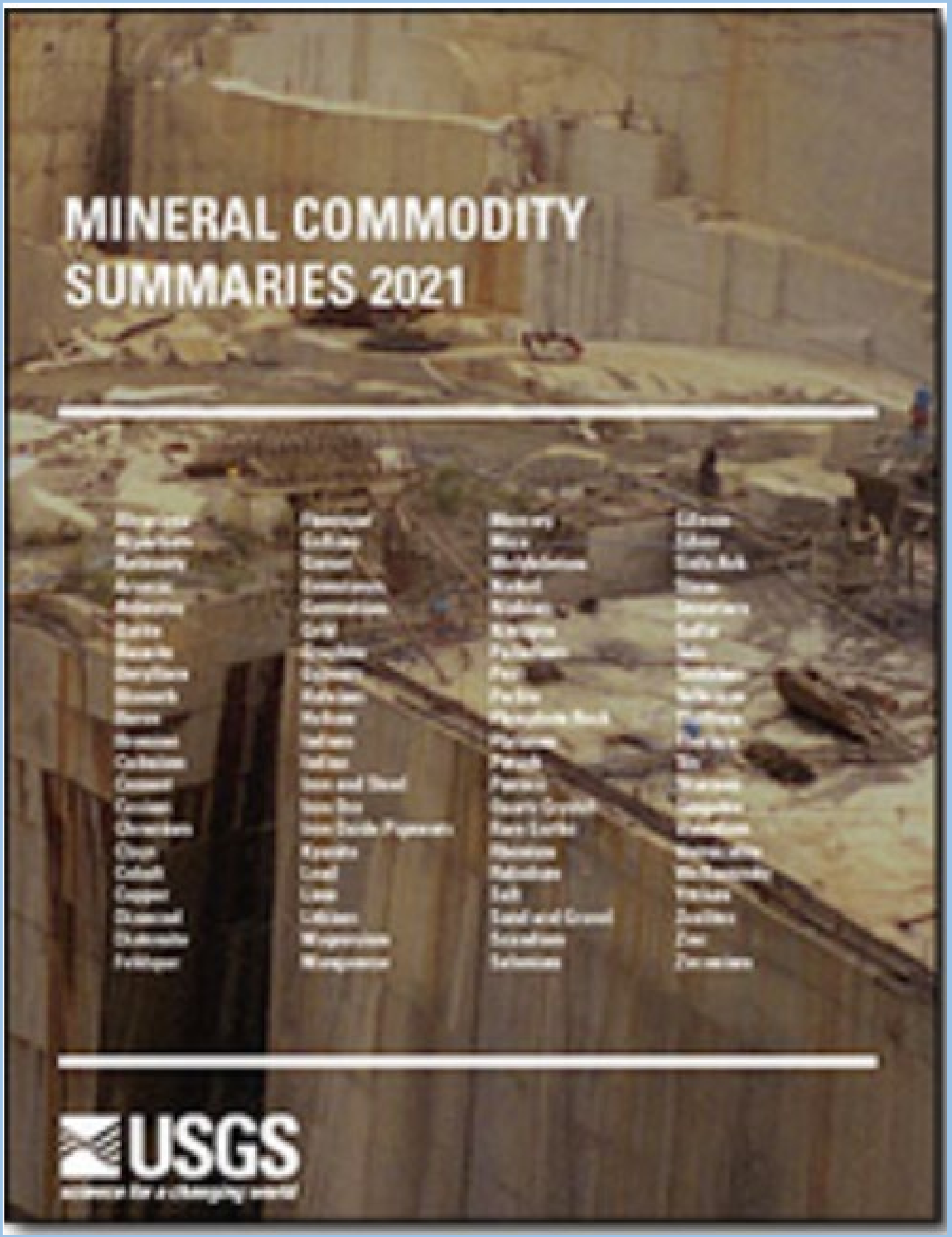
Class

- The class will meet one day per week for 2-3 hrs—Tuesdays
- Remaining time spent on field trips or in occasional extra discussion sessions (other presentations, guest speakers)
- May require extra time for the project presentations

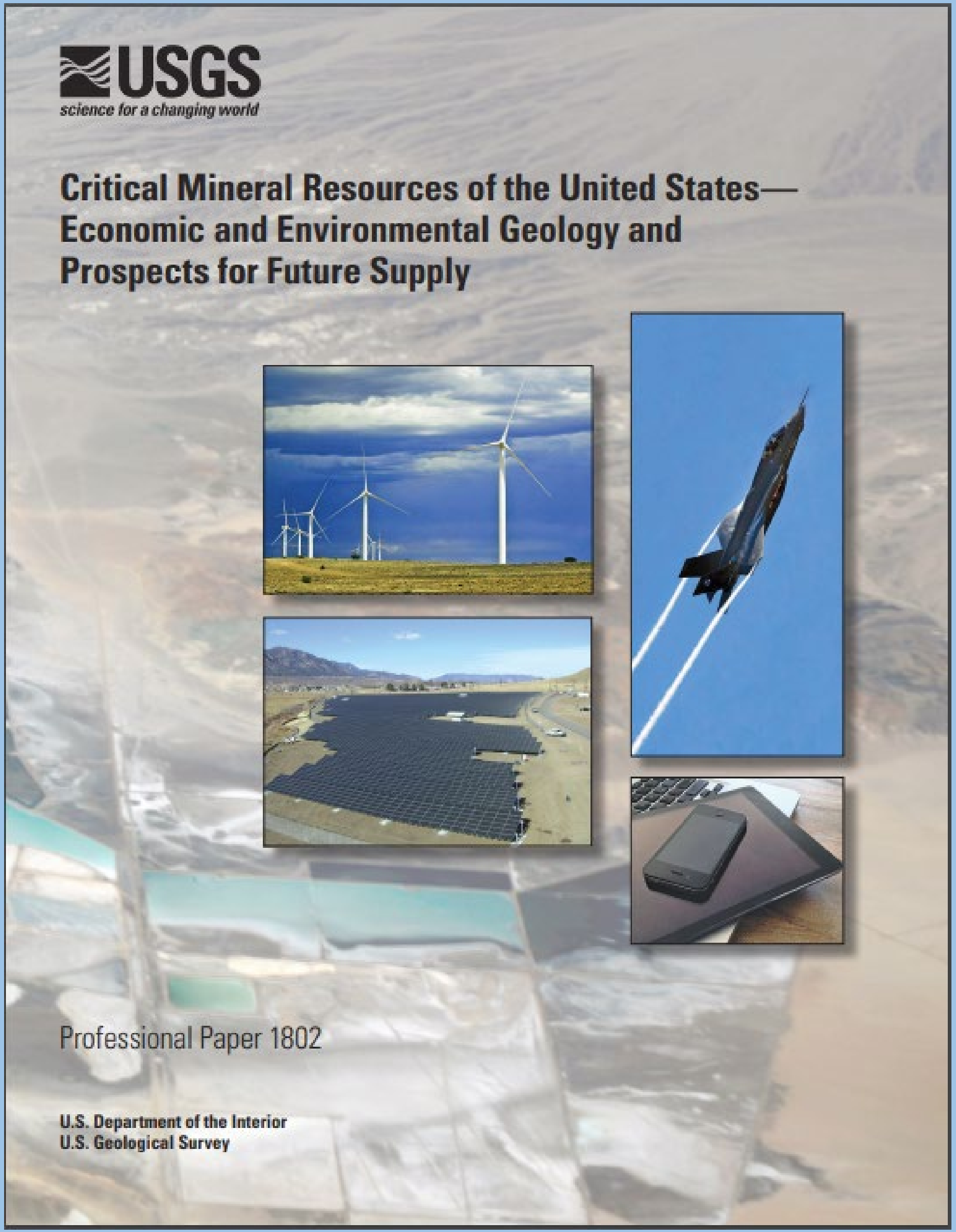
- If you are sick—stay home
- Not going to record lectures unless needed for covid

Textbooks

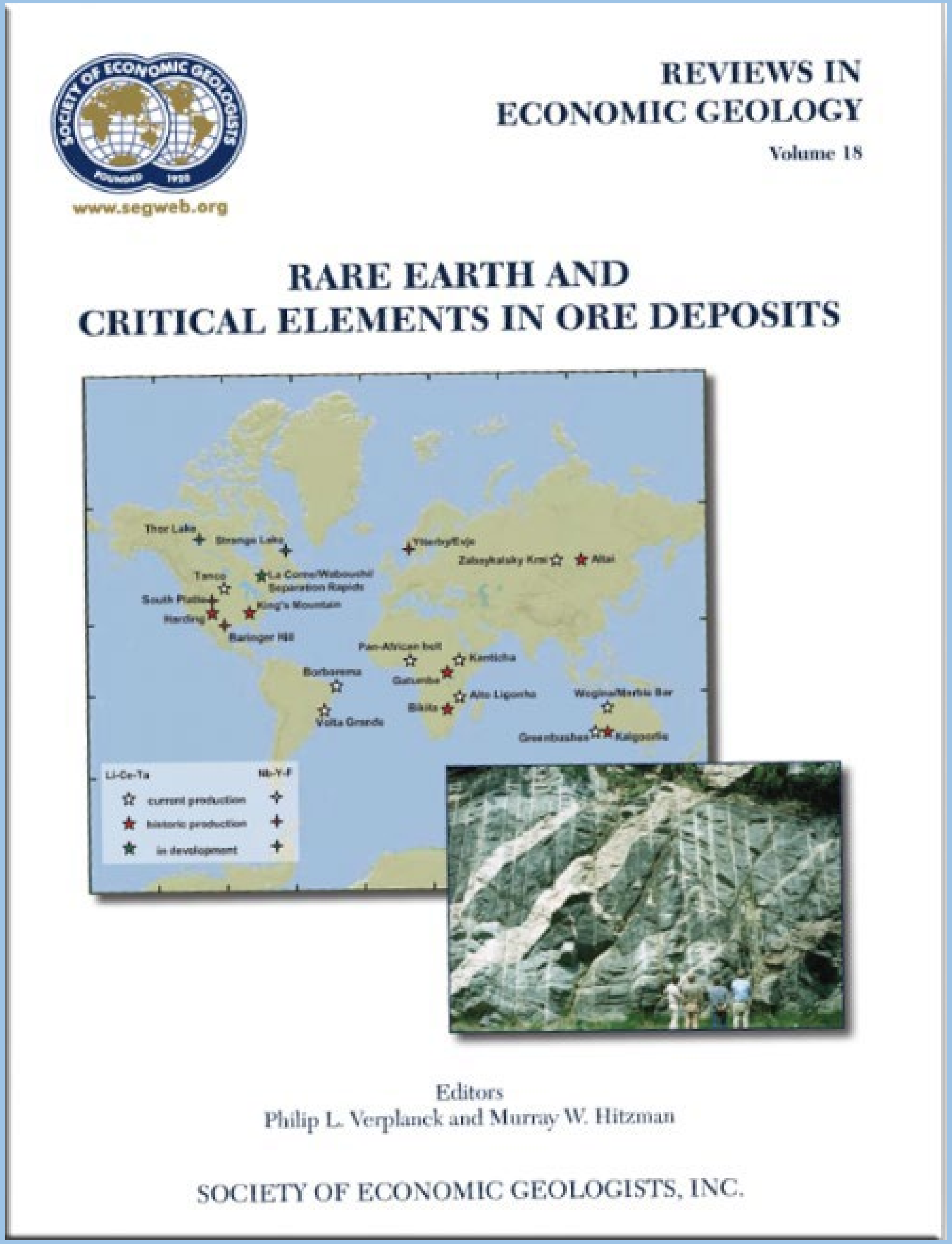
- Hofstra, A.H., and Kreiner, D.C., 2020, Systems-Deposits-Commodities-Critical Minerals Table for the Earth Mapping Resources Initiative (ver. 1.1, May 2021): U.S. Geological Survey Open-File Report 2020–1042, 26 p., https://doi.org/10.3133/ofr20201042.
- Critical mineral resources of the United States—Economic and environmental geology and prospects for future supply: U.S. Geological Survey Professional Paper 1802, Critical mineral resources of the United States—Economic and environmental geology and prospects for future supply (usgs.gov).
- Committee on Critical Mineral Impacts of the U.S. Economy, 2008, Minerals, Critical Minerals, and the U.S. Economy: Committee on Earth Resources, National Research Council, ISBN: 0-309-11283-4, 264 p., download from http://www.nap.edu/catalog.php?record_id=12034#toc
- Papers as assigned



https://www.usgs.gov/centers/nmic/mineral-commodity-summaries



https://pubs.er.usgs.gov/publication/pp1802



https://www.segweb.org/store/detail.aspx?id=REV18-DISC

Class Details

- Exams: Midterm and Final—both are take home exams that will emphasize short answer and essay questions.
- Term project—you are required to do a term/research project that will involve some original work and meetings outside class.
- Field trips—there will be 2 or more field trips and a trip report on each trip will be required.
- Team work and group reports are encouraged, but midterm and final will be on your own.

Class Details

- Lectures from me
- Each week, 1 of you will be assigned or will find an article on REE, Critical Minerals, and will summarize it (powerpoints)
    - Article is due by Sunday before class
- Everyone else will have read it
- We will discuss it in class
- 2 Volunteers to set up a class schedule for the papers and for safety presentations

Term projects

- Lesson plan, poster, and web site on importance of a specific commodity
- Mineral resource potential of specific mineral in a geographic area
- Flow/life cycle of a commodity in our society
- Related to your thesis work
- Sampling and Analytical procedures for a commodity/element
- Detailed analysis of a commodity

Term projects

- Products
  - Powerpoint presentation
  - Summary report (5-10 p.)
  - Periodic updates of progress during class

Grades

Midterm	25%
Final (comprehensive)	25%
Safety share	5%
Lab exercises	5%
Paper Presentations	5%
Term project paper	10%
Term project presentation	10%
Field trip reports	10%
Class Participation	5%

Field Trips

- Depend upon the size of a group allowed by COVID restrictions and how we get everyone there
- We will use some Bureau vehicles, and if you want to travel in your own that is fine
- I am hoping someone will video the trips, then share with those who do not go
- Sometimes we may have small groups on two separate trips to the same site, other times field trips will be limited to a number of students
- We will adjust as necessary
- If you can’t go on field trips, then your field trip reports will be on virtual field trips—we will work it out

Schedule

January	18—Introduction: Critical minerals definition and overview
	25—Basic concepts: Geology, types of deposits, mining, and processing
February	1— Sampling
	8— Rare earth elements
	15—Rare earth elements—cont
	22—Beryllium, **Midterm exam** (Take Home)
March	1— Annual SME meeting in Salt Lake City (27-March 3), **no class**
	8— No class, lab exercise
	12-20— Spring break, no class
	22—Platinum group metals
	29—Tellurium, gallium, indium
April	5—Cobalt, nickel, zinc
	12—REE in coal, other commodities
	19— Sustainable development
	26— Present research results in class (15 mins); **Final exam** (Take Home)
May	03— **Final Exam, research report** due by noon on May 8th

Sources of data

- Internet
- http://minerals.usgs.gov/minerals/pubs/commodity/myb/
- http://www.minerals.com/
- USGS and DOE reports
- Societies (SME, others)
- My web site
- Library
- Bureau GIC records
- Other reports not in electronic form

Wikipedia

- Use sparingly
- Some of the information on Wikipedia is incorrect
- Some of your best data and sources of information are in the library and not in electronic form

- Be aware of using copyrighted material—get permission
- Cite references

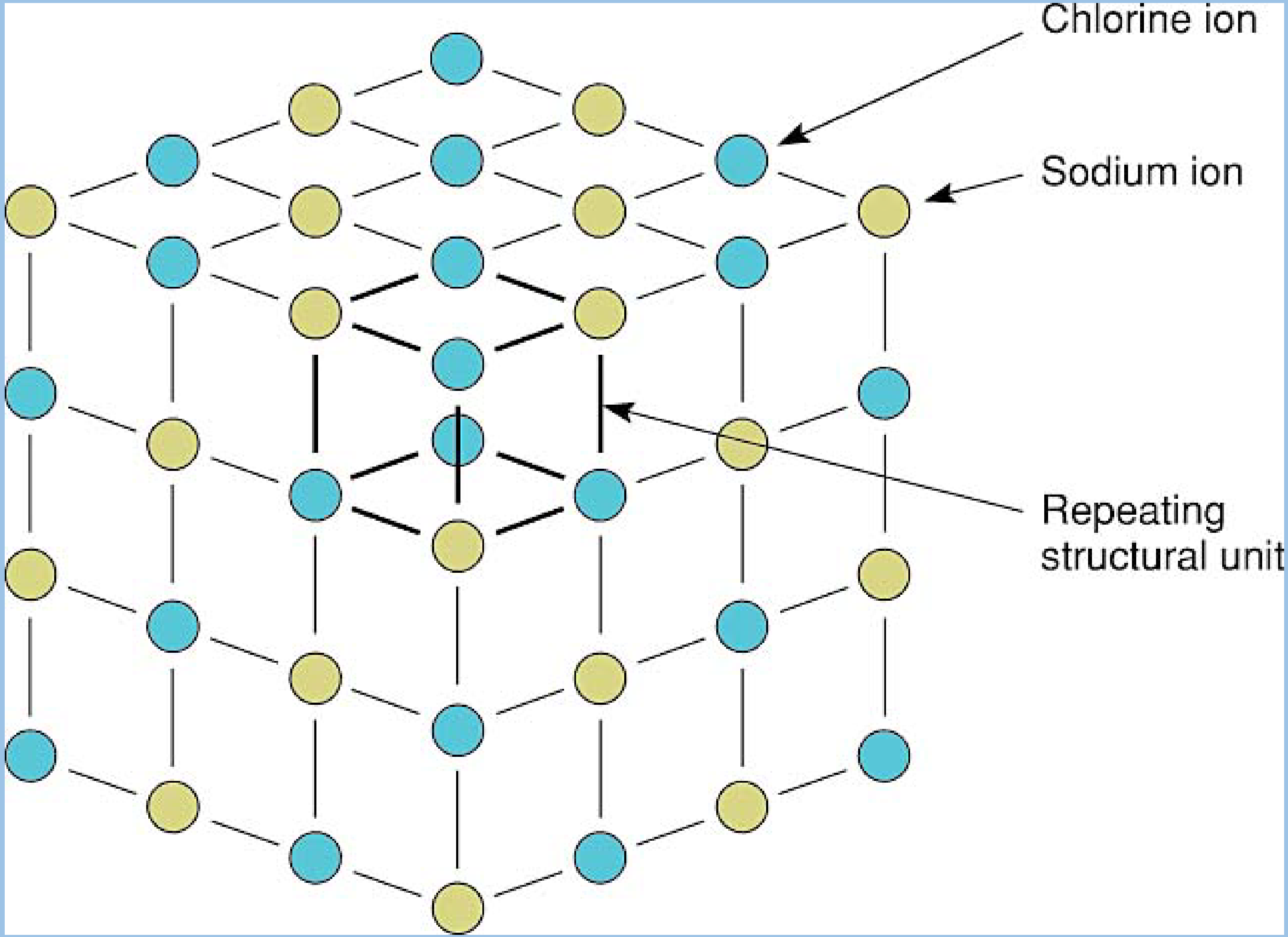
Definitions

- Some of the largest incorrect misperceptions are because of lack of understanding of definitions of terms
- Most reports need a glossary of terms
- Do not assume everyone understands the terms you use

What is a mineral?

What is a mineral?

- Naturally occurring
- Inorganic
- Solid
- Homogeneous
- Crystalline material
- With a unique chemical element or compound with a set chemical formula
- Usually obtained from the ground



A crystal is composed of a structural unit that is repeated in three dimensions. This is the basic structural unit of a crystal of sodium chloride, the mineral halite.

Another definition

Definition of Minerals

In industry, *minerals* refer to any rock, mineral, or other naturally occurring material of economic value, including metals, industrial minerals, energy minerals, gemstones, aggregates, and synthetic materials sold as commodities.

1. Metals - rare, difficult to find, expensive
2. Energy minerals – coal, oil and natural gas
3. Industrial minerals - non-metallic, such as salt, china clay, fluorspar
   - occur in large quantities in a few places
   - require specialised processing and are expensive
4. Construction minerals - sand and gravel, crushed rock, brick clay
   - deposits are extensive and common
   - transportation is economical over short distances only

A **mineral occurrence** is any locality where a useful mineral or material is found.

A **mineral prospect** is any occurrence that has been developed by underground or by above ground techniques, or by subsurface drilling to determine the extent of mineralization.

The terms **mineral occurrence** and **mineral prospect** do not have any resource or economic implications.

A **mineral deposit** is any occurrence of a valuable commodity or mineral that is of sufficient size and grade (concentration) that has potential for economic development under past, present, or future favorable conditions.

An **ore deposit** is a well-defined mineral deposit that has been tested and found to be of sufficient size, grade, and accessibility to be extracted (i.e. mined) and processed at a profit at a specific time. Thus, the size and grade of an ore deposit changes as the economic conditions change. **Ore refers to industrial minerals as well as metals.**

Mineral Deposits versus *Ore Bodies*

mineral deposit	$\neq$	ore body
ore body	=	reserves
mineral deposit	=	± reserves + unmineable + uneconomic + mined

CLASSIFICATION OF MINERAL RESOURCES ON U.S. FEDERAL LAND

Locatable Minerals are whatever is recognized as a valuable mineral by standard authorities, whether metallic or other substance, when found on public land open to mineral entry in quality and quantity sufficient to render a claim valuable on account of the mineral content, under the United States Mining Law of 1872. Specifically excluded from location are the leasable minerals, common varieties, and salable minerals.

Leasable Minerals The passage of the Mineral Leasing Act of 1920, as amended from time to time, places the following minerals under the leasing law: oil, gas, **coal**, oil shale, sodium, potassium, phosphate, native asphalt, solid or semisolid bitumen, bituminous rock, oil-impregnated rock or sand, and sulfur in Louisiana and New Mexico.

Salable Minerals The Materials Act of 1947, as amended, removes petrified wood, common varieties of sand, stone, gravel, pumice, pumicite, cinders, and some clay from location and leasing. These materials may be acquired by purchase only.

It is important to recognize that mineral deposits are controlled by geological processes, not land ownership or classification, and that mineral resources are found in areas where the geology is favorable for the occurrence of mineral deposits, and not just anywhere on earth. Mineral deposits cannot be moved and can only be developed where they are discovered.

Other terms

Canadian Instrument 43-101

- Set of rules and guidelines for reporting information relating to a mineral property in order to present these results to the Canadian stock exchange
  - created after the Bre-X scandal to protect investors from unsubstantiated mineral project disclosures
  - gold reserves at (Bre-X's) Busang were alleged to be 200 million ounces (6,200 t), or up to 8% of the entire world's gold reserves FRAUD
- Similar to JORC (joint ore reserves committee code, Australia)
- South African Code for the Reporting of Mineral Resources and Mineral Reserves (SAMREC)

Other terms

- Adjacent property
  - Company has no interest
  - Boundary close to project
  - Geologic characteristics similar to project
- Advanced property
  - Mineral reserves
  - Minerals resources with a PEA or feasibilty study
- Early stage exploration property

Qualified person (43-101)

- engineer/geoscientist with a university degree, or equivalent accreditation, in an area of geoscience, or engineering, relating to mineral exploration or mining
- has at least five years of experience
- has experience relevant to the subject matter of the mineral project and the technical report
- is in good standing with a professional association

What are critical minerals?

Critical minerals

- Minerals needed for military, industrial or commercial purposes that are essential to renewable energy, national defense equipment, medical devices, electronics, agricultural production and common household items
- Minerals that are essential for use but subject to potential supply disruptions
- Minerals that perform an essential function for which few or no satisfactory substitutes exist
- The absence of which would cause economic or social consequences
- 33-50% minerals are classified as such

Presidential Executive Order No. 13817

"*a mineral (1) identified to be a nonfuel mineral or mineral material essential to the economic and national security of the United States, (2) from a supply chain that is vulnerable to disruption, and (3) that serves an essential function in the manufacturing of a product, the absence of which would have substantial consequences for the U.S. economy or national security*"

List of 35 Critical Mineral Commodities

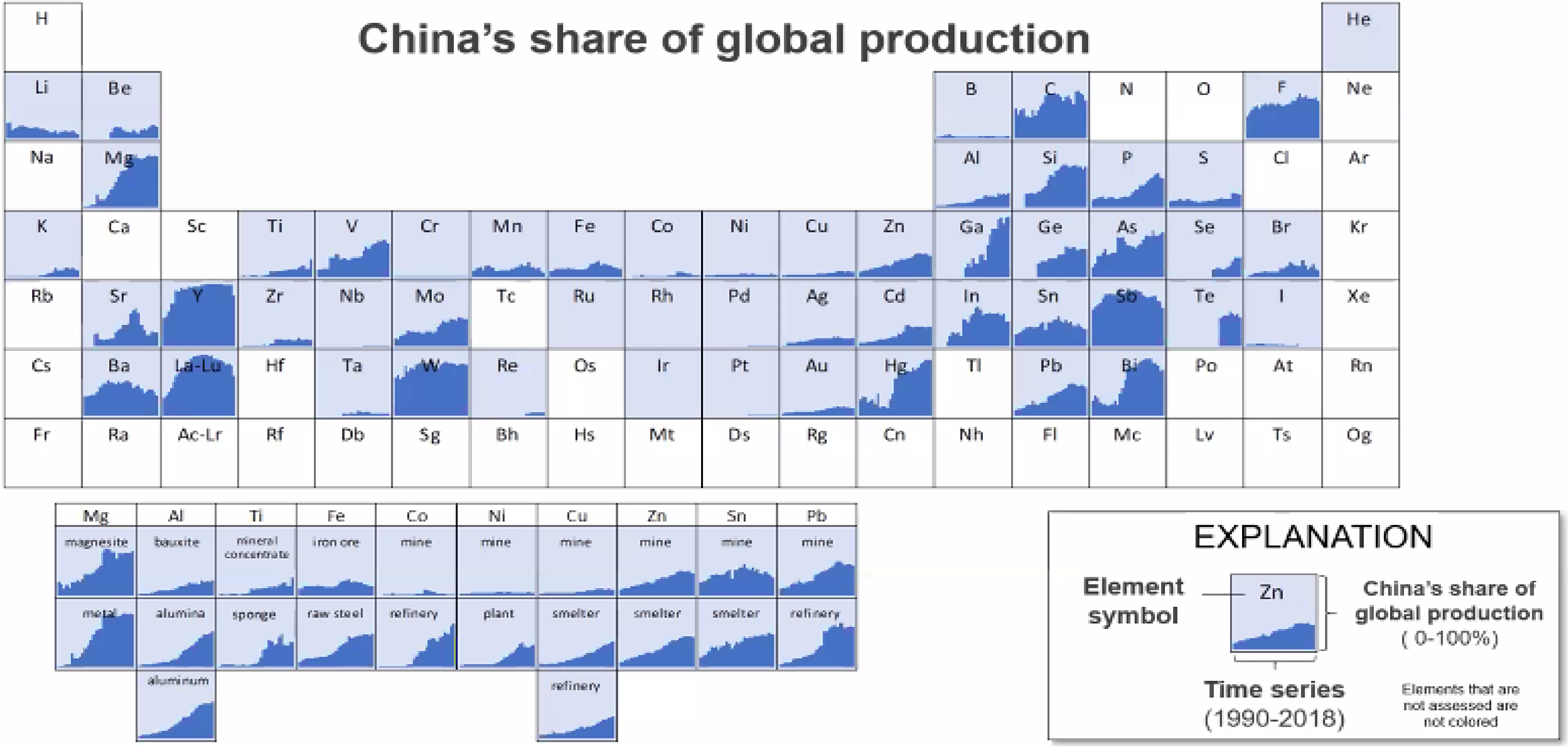
Earth MRI Phases 1 and 2 Critical Minerals (in red)

- Aluminum (bauxite)
- Antimony
- Arsenic
- Barite
- Beryllium
- Bismuth
- Cesium & Rubidium
- Chromium
- Cobalt
- Fluorspar
- Gallium
- Germanium
- Graphite (natural)
- Helium
- Indium
- Lithium
- Magnesium
- Manganese
- Niobium
- Platinum Group Metals
- Potash
- Rare Earth Elements (REEs)
- Rhenium
- Scandium
- Strontium
- Tantalum
- Tellurium
- Tin
- Titanium
- Tungsten
- Uranium
- Vanadium
- Zirconium & Hafnium

Why These?

- US has high net import reliance.
- Usage is increasing beyond foreseeable domestic production.
- Focus first on those commodities that, if discovered, may reduce the Nation's net import reliance.
- Lower priority given to those commodities for which improvements in recovery and marketing of current supplies can satisfy domestic markets.

China's share of global production has increased markedly over the past three decades for many mineral commodities.



Nassar, N.T., Alonso, E., and Brainard, J.L., 2020, Investigation of U.S. Foreign Reliance on Critical Minerals—U.S. Geological Survey Technical Input Document in Response to Executive Order No. 13953 Signed September 30, 2020 (Ver. 1.1, December 7, 2020): U.S. Geological Survey Open-File Report 2020–1127, 37 p., https://doi.org/10.3133/ofr20201127.


How much raw material does a 30GWh NCM Li-ion Megafactory consume?
Graphite anode 33,000 tonnes
Cobalt 6,000 tonnes
Nickel 19,000 tonnes
Lithium 25,000 tonnes
© Benchmark Mineral Intelligence 2021

USGS Earth Mapping Resources Initiative (Earth MRI)

USGS's Response to EO 13817 and SO 3359:

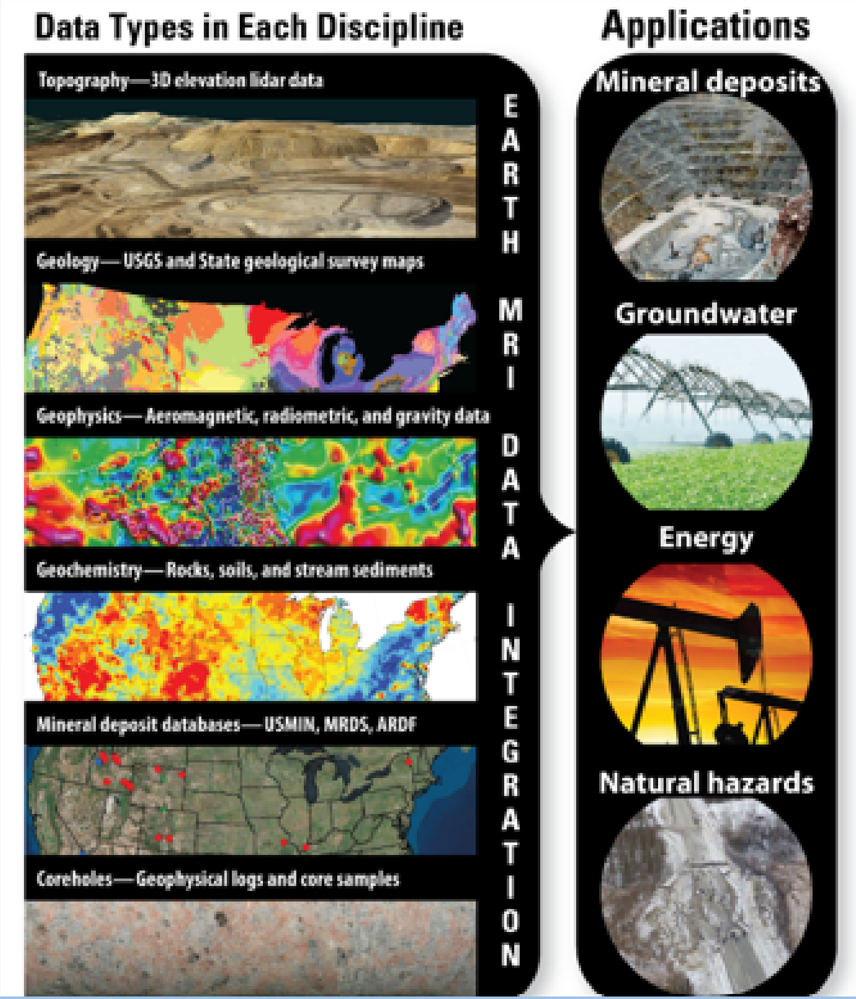
Earth MRI: Partnership between USGS and State Geological Surveys to generate state-of-the-art geologic mapping, geophysical surveys, and lidar data for the Nation in areas with critical mineral potential.

Earth MRI Budget

- **FY 2019**: $9.598M
- **FY 2019 State Matching Funds:** ~$2.9M from 29 States
- **FY 2020:** $10.598M
- **FY 2020 State Matching Funds:** ~$2.2M from 27 States
- Seeking Other Agency Partnerships to leverage funds

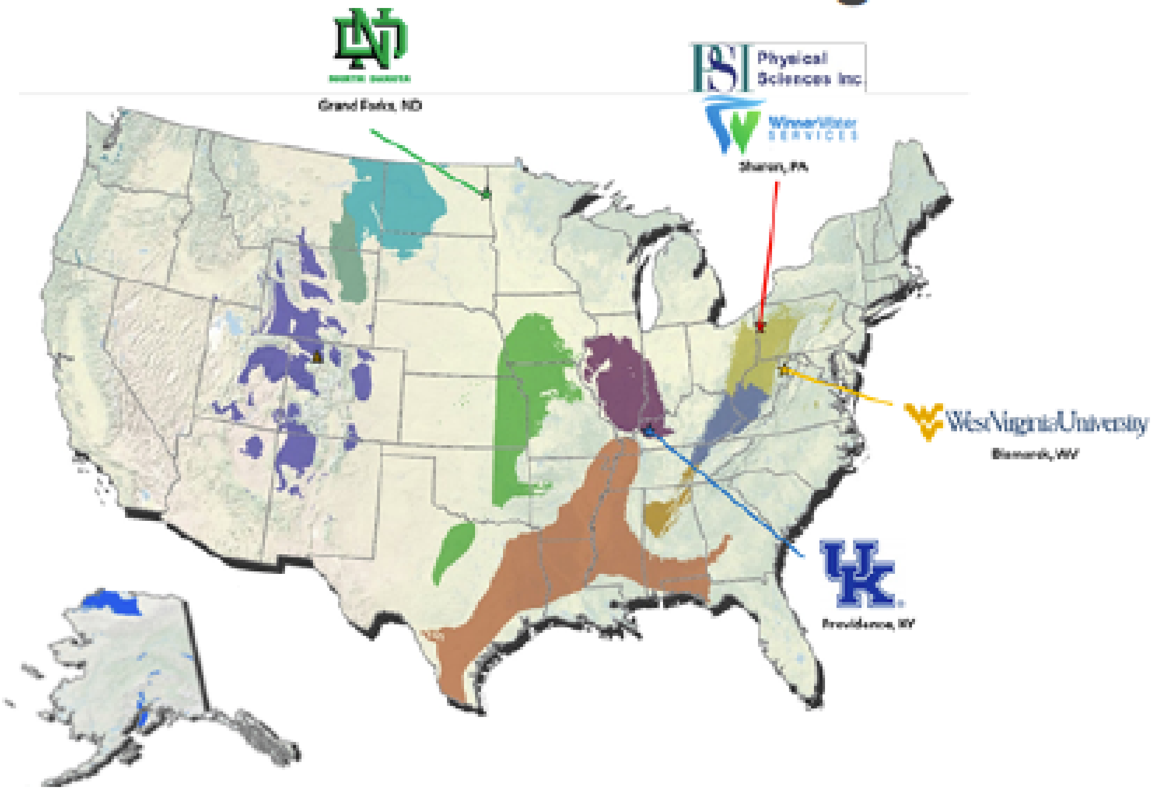
Activities

- **FY 2019:** Focused on rare earth elements
- **FY 2020:** Focused on rare earth elements and 10 more commodities: Al, Co, graphite, Li, Nb, PGEs, Ta, Sn, Ti, and W



Small Scale Pilots: Proving Technical Feasibility

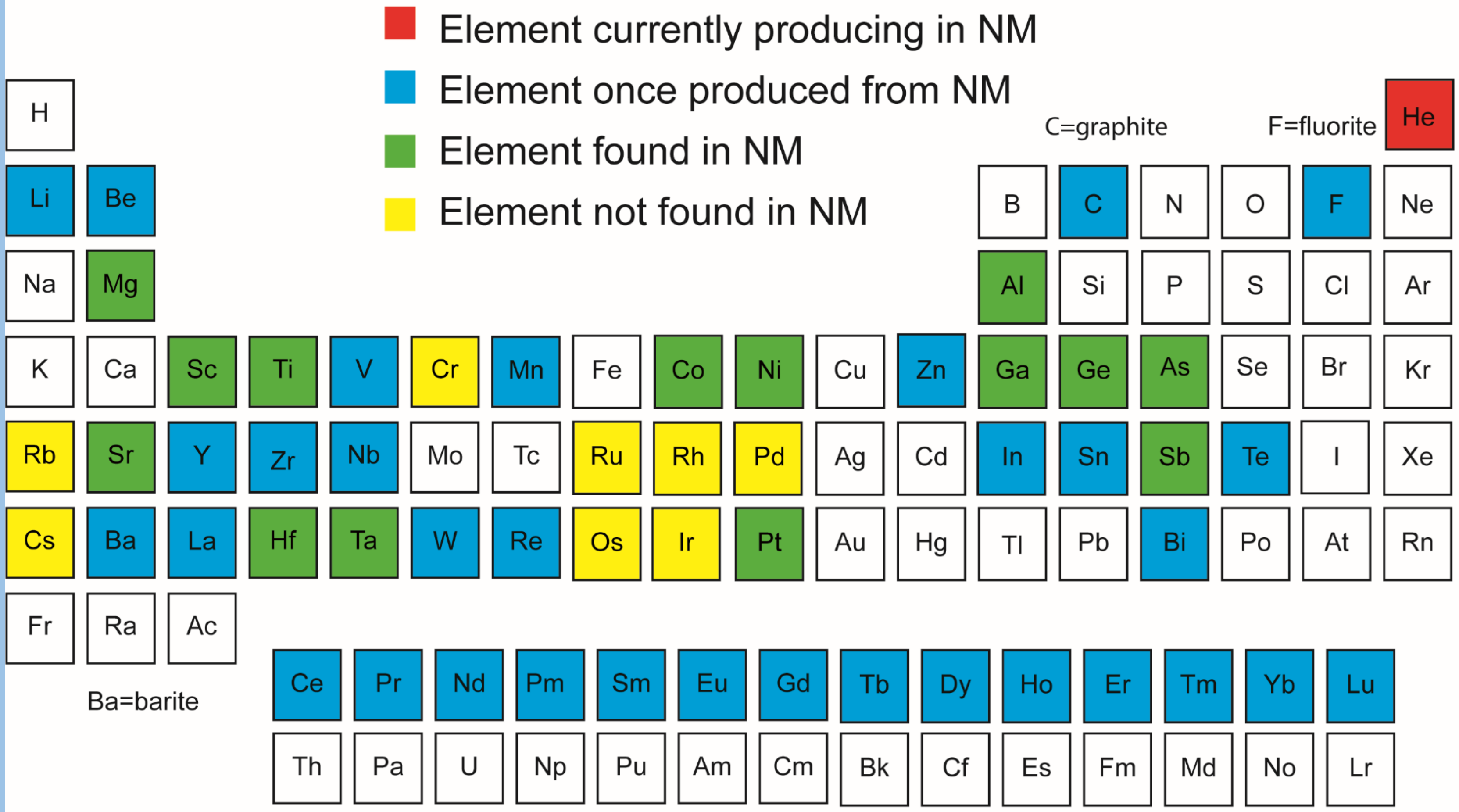
U.S. DEPARTMENT OF ENERGY



Quantity MREO Produced Annually				
	2018	2019	2020	2021
UKY (Refuse)	0.6 kg	1.5 kg	0.5 kg	Processing Begins in Fall
	80% purity	>90% purity	~98% purity	
WVU (AMD)	44 g		Field Pilot Construction (Facility Start Up January 2022	
	95 – 99% purity			
PSI (ASH)	0.01 kg MRES	0.149 kg MRES	1.06 kg MRES	1.76 kg MRES
	≤10% purity	≤14% purity	≤67% purity	≤91% purity
	0.004 kg MREO equivalent	0.057 kg MREO equivalent	0.41 kg MREO equivalent	0.67 kg MREO equivalent
UND (Lignite)	5-10 g	500 g	Pilot Construction (Facility Start – Up October 2021)	
		30 -85% purity		
	5 – 15% purity	4000 g		
		4 – 9 % purity		

Projects increased purity of MREOs being produced up to 99%

Critical Minerals in New Mexico



Note that any element or commodity can be considered critical in the future depending upon use and availability. Coal contains several of these critical elements.

U and K (potash) were removed from the critical minerals list in 2021 and Zn and Ni wee added.

McLemore CM projects

- REE-bearing Cambrian-Ordovician episyenites and carbonatites in southern and central New Mexico, USGS contract completed
  - papers and presentations (abstracts) published and in press
  - Final report in preparation
  - 2 thesis completed, 1 independent study
- Rare earth elements (REE) deposits in the Gallinas Mountains, Lincoln and Torrance Counties, central New Mexico USGS contract No. G19AC00258 (Aug 2019-Nov 2022)
  - 2 M.S. students (thesis pending)
  - 2 undergrad projects (papers in preparation)
  - Presentations (abstracts) given and in press
  - Final report in preparation
- Investigation of rare earth elements (REE) deposits in the Cornudas Mountains area, Trans-Pecos Tertiary Alkaline Rocks, New Mexico and Texas USGS contract No. Grant No. G20AC00170 (Aug 2020-July 2022)
  - 1 M.S. student (thesis pending)
- Preserve Geoscience Data and Materials: Priority II Data Preservation of Critical Minerals in New Mexico: Year 3 USGS contract No. G21AP10434 (Aug 2021-July 2022)
  - Undergrad students projects
- Mineral-Resource Potential of Southwestern New Mexico, including critical minerals BLM contract 140L0321P0009-FE (June 2021-Feb 2022)
  - Undergrad students projects
- CORE-CM project—San Juan River-Raton Basin, New Mexico DOE contract (Oct 2021-Sept 2023)
  - Both graduate and undergrad students will be working on this project

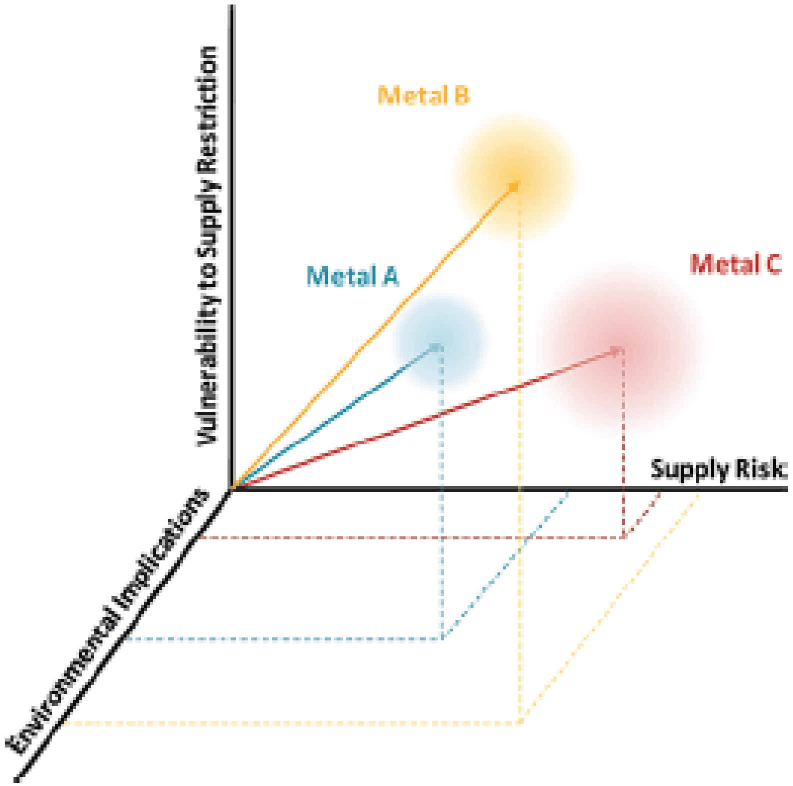
- Demand
  - Material composition increasingly complex
  - Potential rapid growth in demand for some minerals

- Supply
  - Seemingly increasingly fragile
  - More fragmented supply chains, US import dependence, export restrictions on primary raw materials, resource nationalism, increased industry concentration

Criticality is context specific:

- What is critical for a given manufacturer or product may not be critical for another, what is critical for a state may not be critical for a country, and what is critical for national defense may be different than what is necessary to make a television brighter or less expensive.

- Recent studies have expanded the scope of criticality to include environmental and technological factors.



Graedel, T. E.; Barr, R.; Chandler, C.; Chase, T.; Choi, J.; Christoffersen, L.; Friedlander, E.; Henly, C.; Nassar, N. T.;Schechner, D.; Warren, S.; Yang, M.; Zhu, C., 2012, Methodology of metal criticality determination: Environ. Sci. Technol., 46, 1063• 1070.

USGS

2019 U.S. NET IMPORT RELIANCE[1]

Commodity	Percent	Major import sources (2015–18)[2]
ARSENIC (all forms)	100	China, Morocco, Belgium
ASBESTOS	100	Brazil, Russia
CESIUM	100	Canada
FLUORSPAR	100	Mexico, Vietnam, South Africa, China
GALLIUM	100	China, United Kingdom, Germany, Ukraine
GRAPHITE (natural)	100	China, Mexico, Canada, India
INDIUM	100	China, Canada, Republic of Korea, Taiwan
MANGANESE	100	South Africa, Gabon, Australia, Georgia
MICA, sheet (natural)	100	China, Brazil, Belgium, Austria
NEPHELINE SYENITE	100	Canada
NIOBIUM (columbium)	100	Brazil, Canada, Russia, Germany
RARE EARTHS[3] (compounds and metal)	100	China, Estonia, Japan, Malaysia
RUBIDIUM	100	Canada
SCANDIUM	100	Europe, China, Japan, Russia
STRONTIUM	100	Mexico, Germany, China
TANTALUM	100	Rwanda, Brazil, Australia, Congo (Kinshasa)
YTTRIUM	100	China, Estonia, Republic of Korea, Japan
GEMSTONES	99	India, Israel, Belgium, South Africa
BISMUTH	96	China, Belgium, Mexico, Republic of Korea
TELLURIUM	>95	Canada, China, Germany
VANADIUM	94	Austria, Canada, Russia, Republic of Korea
TITANIUM MINERAL CONCENTRATES	93	South Africa, Australia, Canada, Mozambique
POTASH	91	Canada, Russia, Belarus, Israel
DIAMOND (industrial stones)	88	India, South Africa, Botswana, Australia
BARITE	87	China, India, Morocco, Mexico
ZINC (refined)	87	Canada, Mexico, Australia, Peru
TITANIUM (sponge)	86	Japan, Kazakhstan, Ukraine, China, Russia
ANTIMONY (metal and oxide)	84	China, Thailand, Belgium, India
RHENIUM	82	Chile, Germany, Kazakhstan, Canada
STONE (dimension)	81	China, Brazil, Italy, Turkey
COBALT	78	Norway, Japan, China, Canada
TIN (refined)	77	Indonesia, Malaysia, Peru, Bolivia
ABRASIVES, fused Al oxide (crude)	>75	China, Hong Kong, France, Canada
BAUXITE	>75	Jamaica, Brazil, Guinea, Guyana
CHROMIUM	72	South Africa, Kazakhstan, Russia
PEAT	70	Canada
SILVER	68	Mexico, Canada, Peru, Poland

https://www.usgs.gov/centers/nmic/mineral-commodity-summaries

What are the differences between critical and strategic minerals?

Differences between critical and strategic minerals

- Minerals for military uses are strategic
- Minerals for which a threat to supply could involve harm to the economy are critical
- A critical mineral may or may not be strategic, while a strategic mineral will always be critical

History of strategic and critical minerals

- 1918: end of WW1 Harbord List developed
- 1938: Naval Appropriations Act
- 1939: Strategic Minerals Act
- 1940 Reconstruction Finance Corp formed to acquire and transport materials
- 1944: Surplus Property Act authorized strategic materials stockpile
- Became the Defense National Stockpile Center (DNSC)
- 1992: Congress ordered DNSC to sell the bulk of the stockpiles

What are green technologies?

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

REE Mineral Deposits in the Gallinas Mountains, New Mexico

- Thursday EES&Bureau Seminar Thursday at 4 PM

Join Zoom Meeting
https://zoom.us/j/95136410503?pwd=cmxGbDhJTnZPRkZmUkp0Zk94NHJGZz09

Safety Share - Heat Stroke and Heat Exhaustion Safety

Presented by: Megan Badonie

Safety Share Presentation Outline

- Objectives of MSHA and OSHA
- What is heat exhaustion
- What is a heat stroke
- Prevention methods
- Questions and Comments

Objectives of MSHA and OSHA

Severe heat stress may lead to death or serious injury if not treated right away.

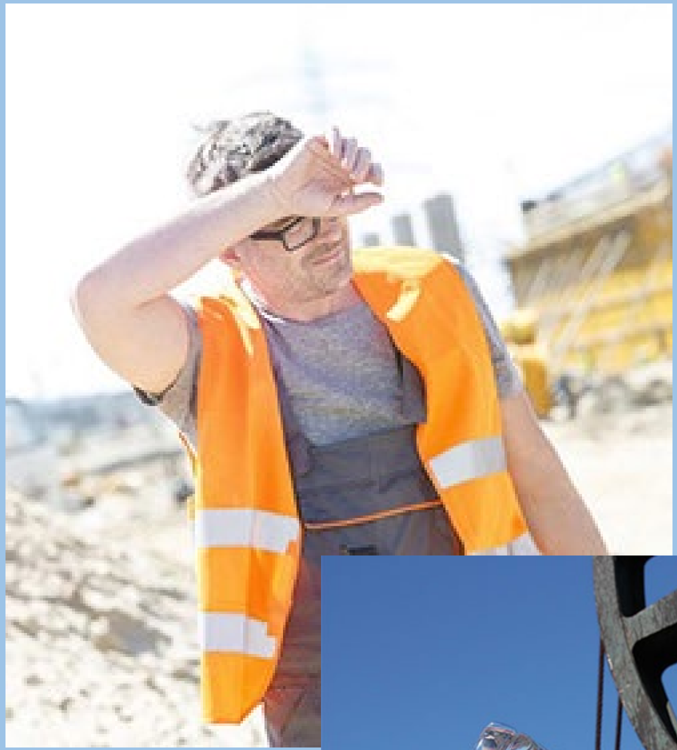
The objective of controls in a hot work site is to keep workers' body core temperature from rising above 100°F (38°C). Excessive heat gained by the human body must be offset by adequate periods of heat loss. The methods of reducing heat fall into these three categories:

- **Engineering Controls**
  - Ventilation and Air Conditioning are key control used to reduce heat stress
- **Administrative Controls and Work Practices**
  - Workplace practices Pace a task, rotate personnel on hot jobs, provide rest areas and water, avoid caffeine, alcohol and sugary drinks.
- **Personal protective clothing and equipment**
  - Water cooled garments, ice vests, heat reflective clothing

What is heat exhaustion?

SIGNS

- "water -deficiency heat exhaustion" Failure to replenish enough fluids and minerals lost during excessive sweating.
- Headache
- Nausea
- vertigo , weakness, dizziness, paleness, muscle cramps
- Thirst, profuse sweating
- Skin is clammy and moist
- Heat exhaustion can lead to a heat stroke.



What is a heat stroke?

SIGNS

- “Sunstroke” Caused by the failure of the body to sweat which results in an accelerating rise in core temperature.
- High body temperature
  - Core body temperature of 104 F of higher.
- Altered mental state or behavior
  - Confusion, slurred speech, irritability, seizures
- Alteration in sweating
  - If you stop sweating, sit down and rest
- Nausea and Vomiting
- Flushed Skin
- Rapid Breathing
- Racing Heart rate
- Headache

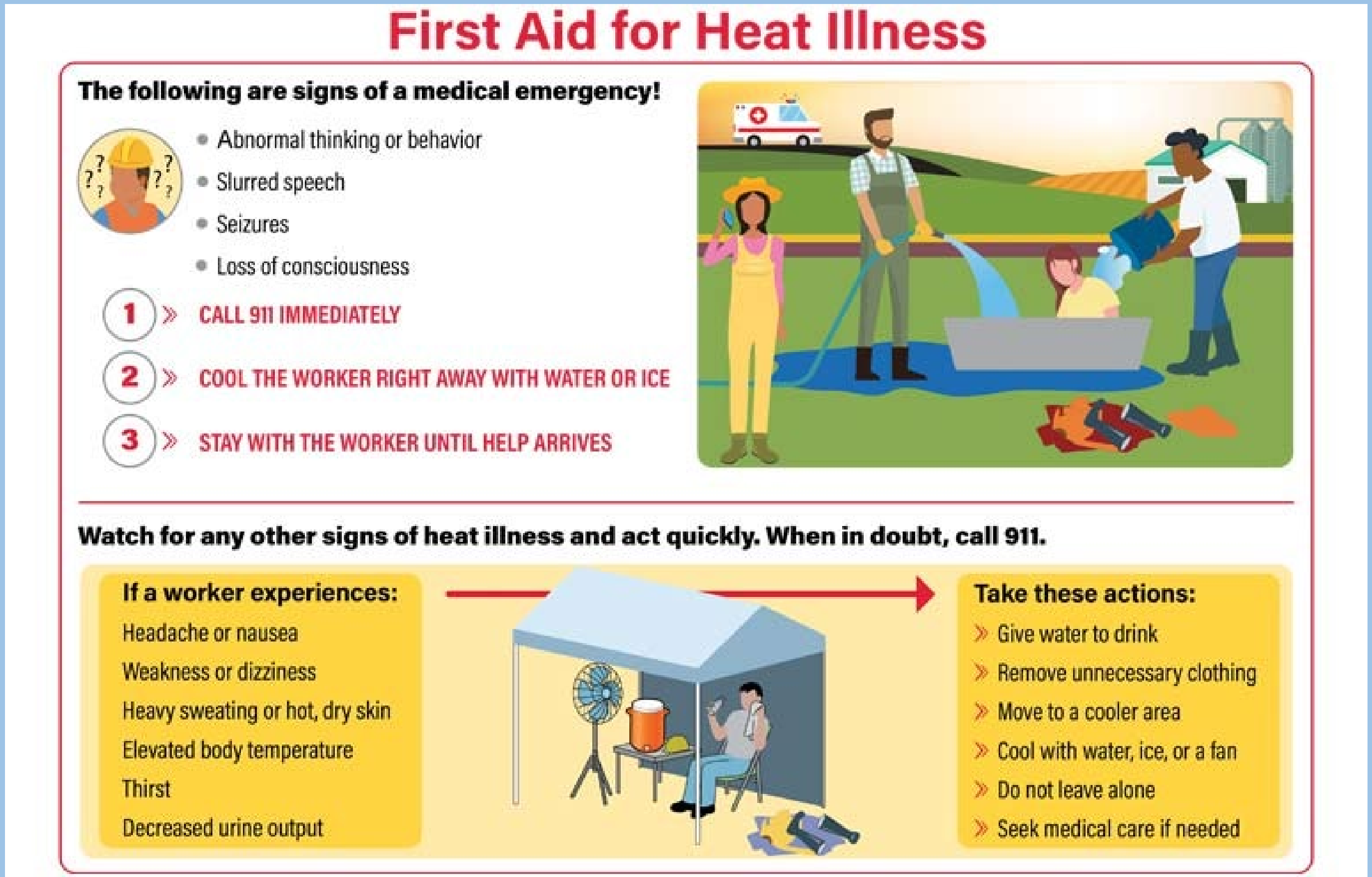
WHAT TO DO

- Call for Help
- Get person into shade or indoors
- Remove excess clothing
- Cool the person down
  - Water on a cloth, ice packs, wet towels on the person’s head, neck, armpits, and groin.

Prevention Methods

MSHA Suggestions

- Drink a cup of water every 20 minutes
- Obtain adequate salt, a sports drink or lightly salted water are examples of desirable fluids
    - Gatorade, Powerade liquid/powder
- Wear loose clothing that allows evaporation of perspiration off of skin
- Take lunch, and rest breaks in cool area after strenuous activity.



Questions or Comments?

References

https://www.msha.gov/sites/default/files/Alerts%20and%20Hazards/Heat%20Stress.pdf

https://www.mayoclinic.org/diseases-conditions/heat-stroke/symptoms-causes/syc-20353581

https://arlweb.msha.gov/s&hinfo/heatstress/heatstress.htm

https://www.safetyandhealthmagazine.com/articles/21320-keep-workers-safe-from-heat-osha-releases-poster

Thank You!

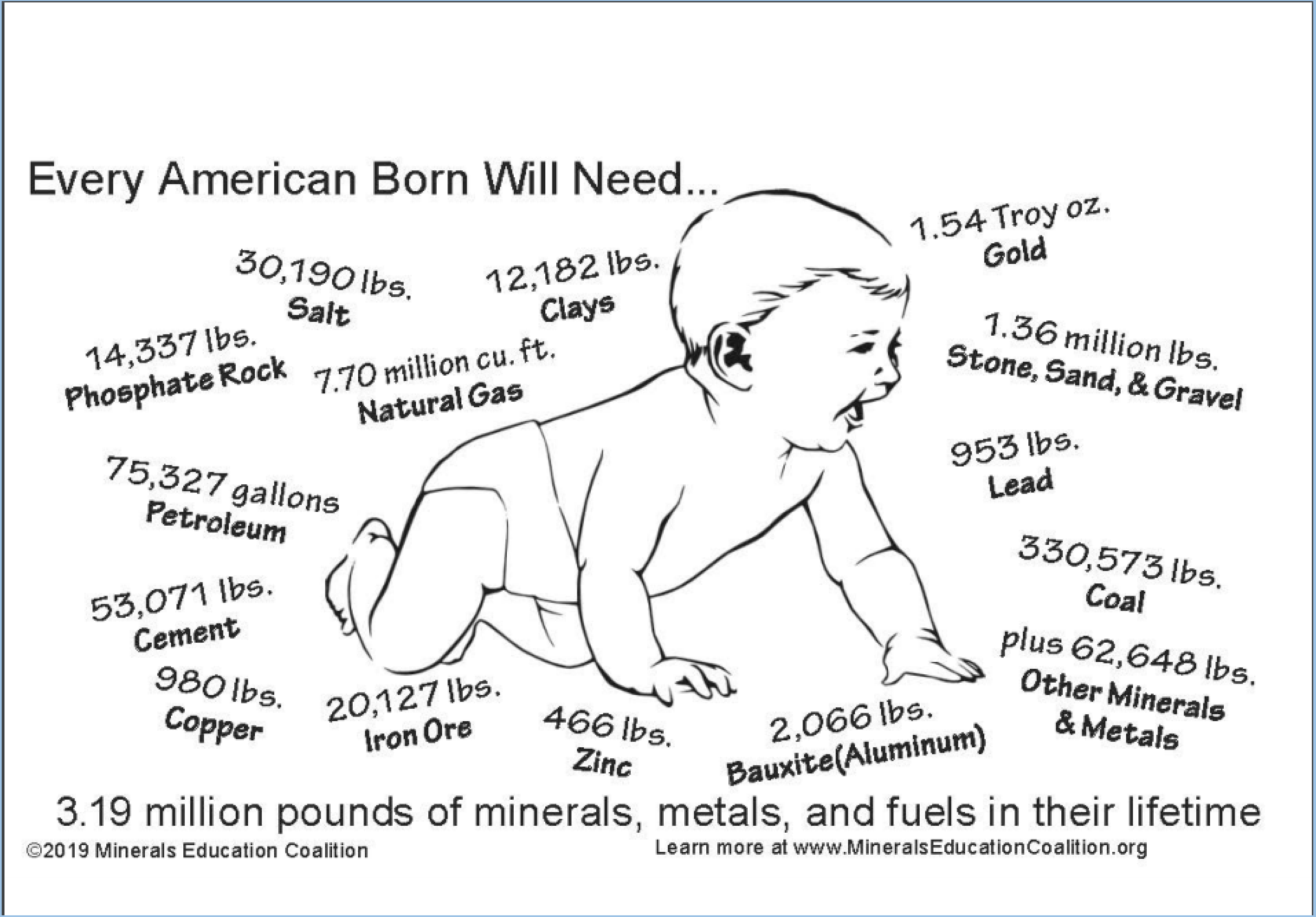
Why are minerals so important?

Why are minerals so important?

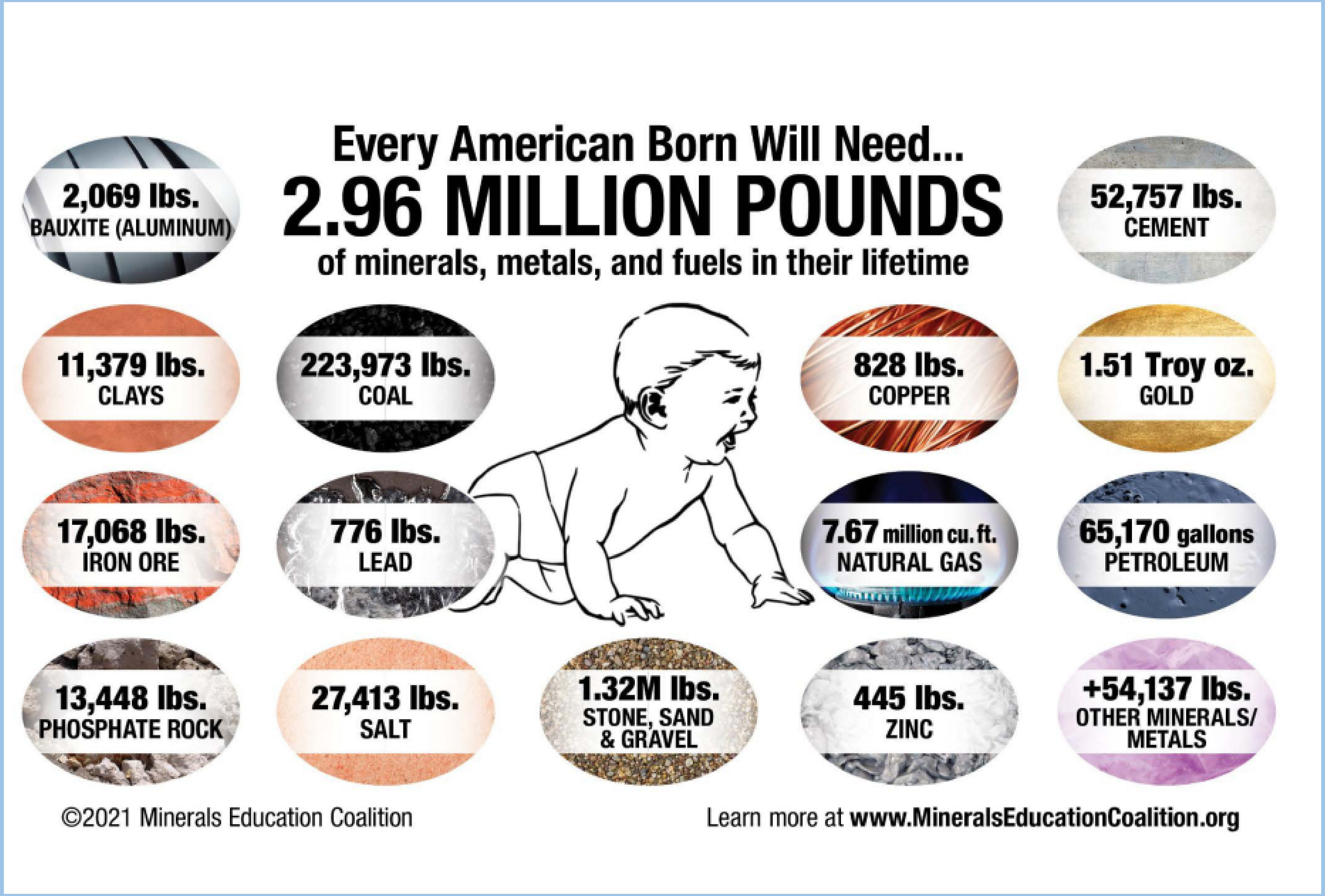
Your world is made of them!

The average American uses about two million pounds of industrial minerals, such as limestone, clay, and aggregate, over the period of a lifetime.

Building blocks of our way of life



https://mineralseducationcoalition.org/mining-mineral-statistics/



https://mineralseducationcoalition.org/mining-mineral-statistics/

Every Year— 38,052 pounds of new minerals must be provided for every person in the United States to make the things we use every day

- 8,509 lbs. **Stone** used to make roads, buildings, bridges, landscaping, and for numerous chemical and construction uses
- 5,599 lbs. **Sand & Gravel** used to make concrete, asphalt, roads, blocks and bricks
- 496 lbs. **Cement** used to make roads, sidewalks, bridges, buildings, schools and houses
- 357 lbs. **Iron Ore** used to make steel— buildings; cars, trucks, planes, trains; other construction; containers
- 421 lbs. **Salt** used in various chemicals; highway deicing; food & agriculture
- 217 lbs. **Phosphate Rock** used to make fertilizers to grow food; and as animal feed supplements
- 164 lbs. **Clays** used to make floor & wall tile; dinnerware; kitty litter; bricks and cement; paper
- 65 lbs. **Aluminum (Bauxite)** used to make buildings, beverage containers, autos, and airplanes
- 12 lbs. **Copper** used in buildings; electrical and electronic parts; plumbing; transportation
- 11 lbs. **Lead** 87% used for batteries for transportation; also used in electrical, communications and TV screens
- 6 lbs. **Zinc** used to make metals rust resistant, various metals and alloys, paint, rubber, skin creams, health care and nutrition
- 36 lbs. **Soda Ash** used to make all kinds of glass; in powdered detergents; medicines; as a food additive; photography; water treatment
- 5 lbs. **Manganese** used to make almost all steels for construction, machinery and transportation
- 332 lbs. **Other Nonmetals** have numerous uses: glass, chemicals, soaps, paper, computers, cell phones
- 24 lbs. **Other Metals** have the same uses as nonmetals but also electronics, TV and video equipment, recreation equipment, and more

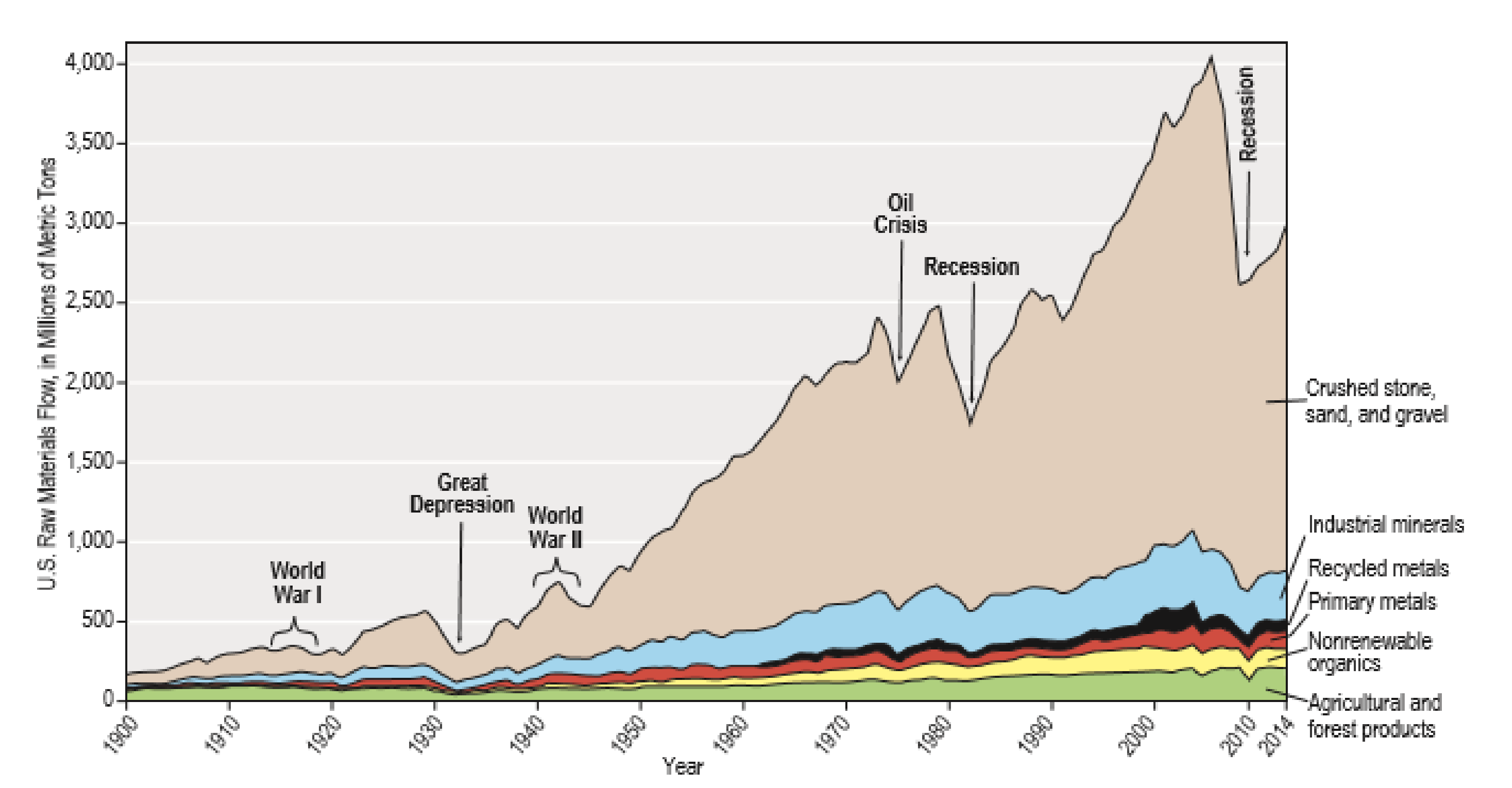
Including These Energy Fuels

• 951 gallons of **Petroleum** • 6,792 lbs. of **Coal** • 80,905 cu. ft. of **Natural Gas** • 1/4 lb. of **Uranium**

To generate the energy each person uses in one year—

http://www.mii.org/pdfs/2011PerCapita.pdf

U.S. flow of raw materials by weight 1900-2014. The use of raw materials in the U.S. increased dramatically during the last 100 years (modified from Wagner, 2002).



https://www.usgs.gov/centers/nmic/mineral-commodity-summaries

Critical minerals

- Many critical elements are produced entirely as by-products of the refining of major metals
  - Tellurium (copper)
  - Indium & germanium (zinc)
  - Gallium (aluminum)
  - Rhenium (molybdenum)
  - Cobalt (copper, nickel)
- Prices are artificially low (economy of scope) until the co-production saturates
- By-product does not drive production of main product, even at high prices
- Price demand inelasticity

Coproduction Issues - Rhenium

- Rhenium is produced as a by-product of molybdenum – there are no primary rhenium producers.

- It is used in producing specialty steels.

Rhenium

- Atomic number 75
- 0.05-1 ppb in crust
- combustion chambers, turbine blades, and exhaust nozzles of jet engines
- US $4,575 per kg (2011)
- By-product of molybdenum and copper production
- Found in molybdenite

Salient Statistics—United States:	**2015**	**2016**	**2017**	**2018**	**2019[e]**
Production[1]	7,900	8,440	8,200	8,220	8,400
Imports for consumption[2]	31,800	31,900	34,500	39,400	39,000
Exports	NA	NA	NA	NA	NA
Consumption, apparent[3]	39,700	40,300	42,700	47,600	47,000
Price, average value, dollars per kilogram, gross weight:[4]					
Metal pellets, 99.99% pure	2,670	2,030	1,550	1,470	1,300
Ammonium perrhenate	2,820	2,510	1,530	1,410	1,300
Employment, number	Small	Small	Small	Small	Small
Net import reliance[5] as a percentage of apparent consumption	80	79	81	83	82

World Mine Production and Reserves:

	Mine production[6]		Reserves[7]
	2018	**2019[e]**	
United States	8,220	8,400	400,000
Armenia	281	280	95,000
Canada	—	—	32,000
Chile[8]	27,000	27,000	1,300,000
China	2,500	2,500	NA
Kazakhstan	1,000	1,000	190,000
Peru	—	—	45,000
Poland	9,090	9,300	NA
Russia	NA	NA	310,000
Uzbekistan	460	400	NA
World total (rounded)	48,600	49,000	2,400,000

https://www.usgs.gov/centers/nmic/mineral-commodity-summaries

- Rhenium changes the phase structure in complex alloys, allowing turbine blades to operate longer at higher temperatures (>1600°C) and pressures without deformation

- General Electric discovered that sufficient Re (by-product of molybdenum production) for mass produced turbines might not be available (or extremely expensive).

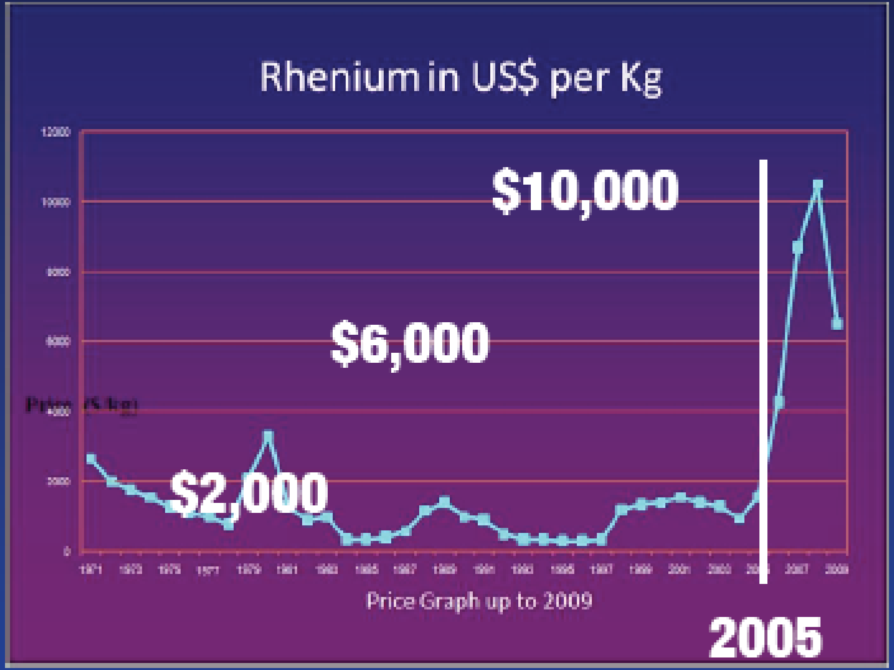
~25 kg Re per
gas turbine

General Electric's Rhenium Story

GE launched a two pronged approach in 2005:

- Recycle pre-consumer scrap to forestall shortage (new supply)
- Develop new alloys with low (zero?) Re (substitution)
- Had success over 5 years*

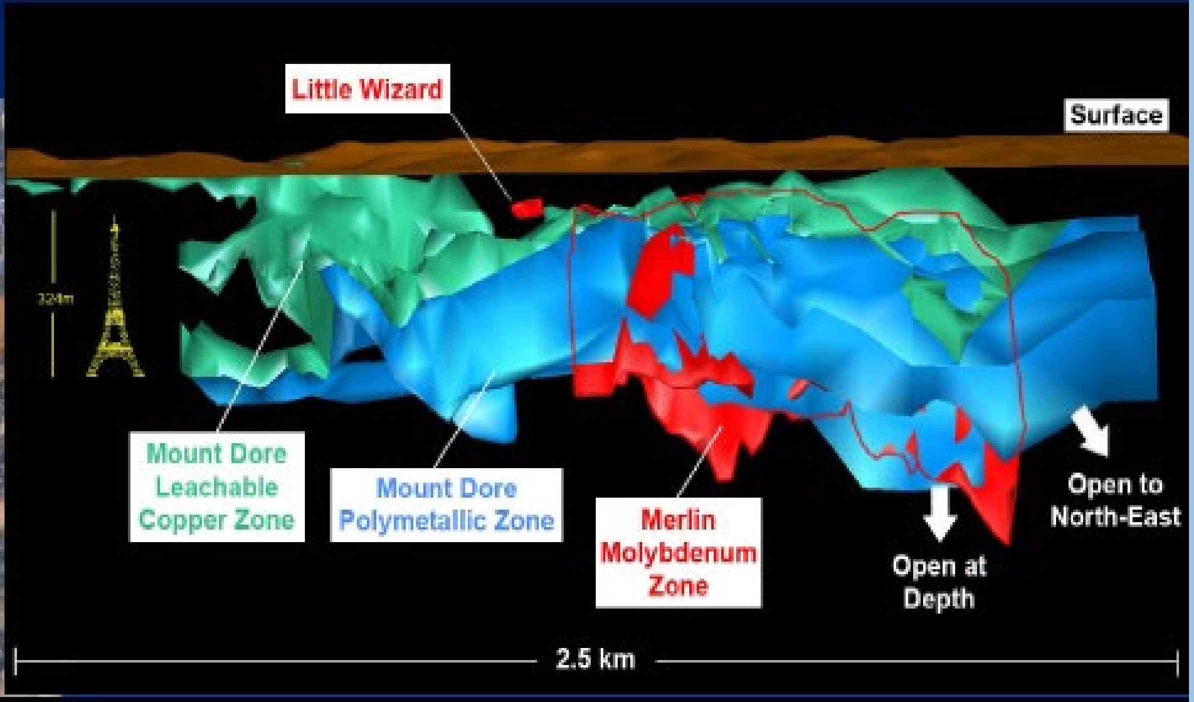
* Fink, P.J., Miller, J.L., and Konitzer, D.G., 2010, J. Minerals Metals Mater. Soc. 62, 57.



Rhenium 10 Years On ©Anthony Lipmann (2009)

Is there really a shortage of Rhenium?

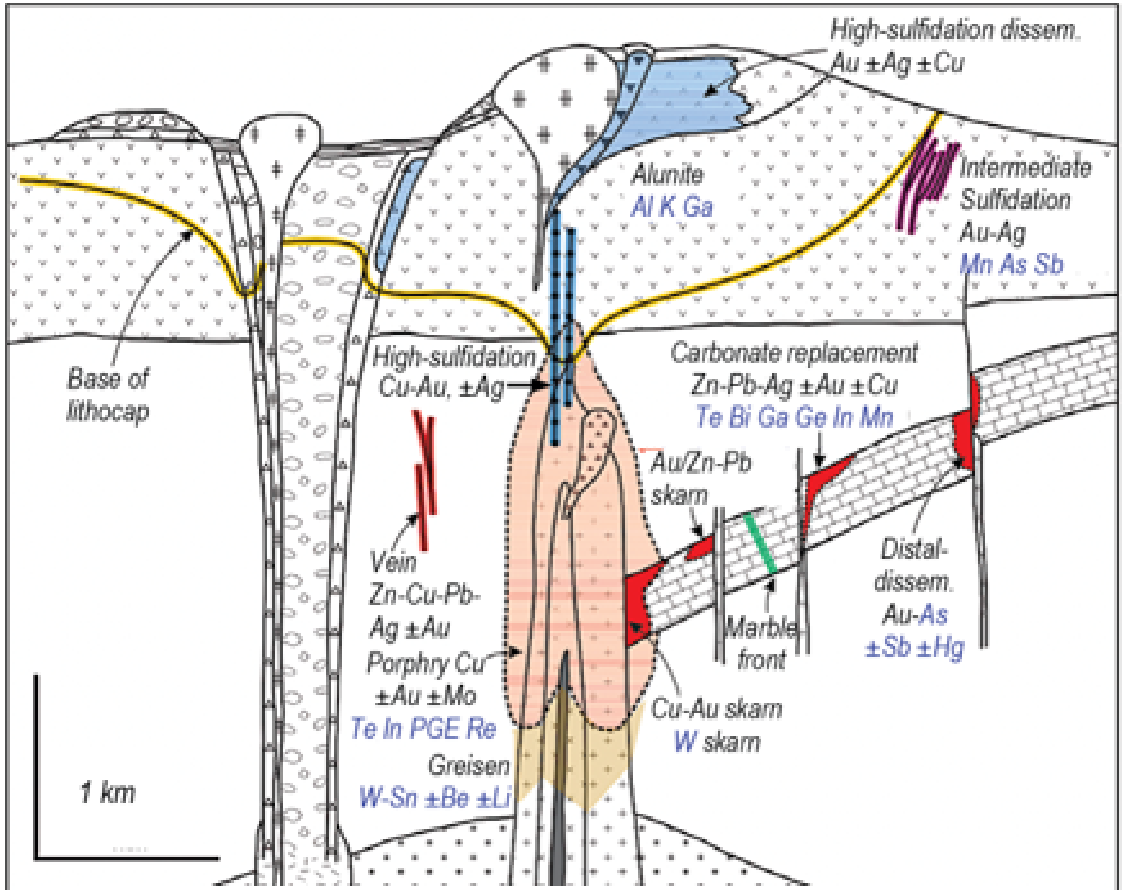
- Serendipity recently resulted in the discovery of a new type of super high grade moly deposit with a high Re content.
- Merlin, Australia (6.7 Mt @1.34% Mo, 23.2 g/t Re)
- Discovery of additional deposits (if we can develop a geological model for the deposits) should ease fears of Re supply.



Where in New Mexico do we have rhenium potential?

Mineral Systems Approach

Example: Porphyry Copper-Molybdenum-Gold System



Hofstra and Kreiner (2020), USGS Open-File Report 2020-1042

System Name	Deposit types	Principal Commodities	Critical minerals
Porphyry Cu-Mo-Au	Pegmatite	Li, Cs, Ta	Li, Cs, Ta, Be
	Greisen	Mo, W, Sn	W, Sn
	S-R-V Tungsten	W	W, Bi, Mn
	Porphyry/Skarn Molybdenum	Mo, W, Sn	W, Re, Bi
	Porphyry/Skarn Copper	Cu, Ag, Au, Mo	PGE, Te, Re, Bi, U
	Polymetallic Sulfide S-R-V-IS	Cu, Zn, Pb, Ag, Au	Mn, Ge, Ga, In, Bi, Sb, As, W, Te
	Distal Disseminated Ag-Au	Ag, Au	Sb, As
	High sulfidation Au-Ag	Cu, Ag, Au	As, Sb, Te, Bi, Sn, Ga
	Lithocap Alunite	$Al2O3$, $K2SO4$, $H2SO4$	$Al2O3$, $K2SO4$, Ga
	Lithocap Kaolinite	Kaolin	Ga

Abbreviations: **S** skarn, **R** replacement, **V** vein, **IS** intermediate sulfidation.

Assignment due next week

- Safety moment
- First paper on coal
- Term project
  - **Title of project due Feb 1**

Assignment

- Safety presentation
- Paper presentation
- Mineral deposit models (Cox and Singer, 1986, http://pubs.usgs.gov/bul/b1693/Tlbc.pdf)
- Principles of a resource/reserve classification for minerals (http://pubs.usgs.gov/circ/1980/0831/report.pdf)
- NATIONAL INSTRUMENT 43-101, *STANDARDS OF DISCLOSURE FOR MINERAL PROJECTS (http://web.cim.org/standards/documents/Block484_Doc111.pdf)*

- **Thursday seminar**