MATERION

Critical Material – The Beryllium Perspective

Keith Smith VP Technology Materion Brush Inc.

History – Charles Brush

Capitalized with $500, Brush Beryllium Company was incorporated on January 9, 1931 in Cleveland, Ohio.

Materion Corporation

A Global Materials Platform

Corporate Office:

Mayfield Heights, Ohio, U.S.A.

2600

Employees

50

Countries served

34

Facilities

12

Countries with our operations

Materion Corporation is a Publicly Traded Company

materion.com

MATERION

Beryllium

- **Beryllium**
  - Be is number 4 on Periodic Table
  - DoD considers Beryllium a “Critical and Strategic” Material
- **Attributes**
  - Lightweight, Stiff, Low CTE, High TC, High Melting Point
  - Transparent to X-Rays, Neutron Moderator, Dampens Vibration
  - Provides enhanced performance when alloyed with Cu, Ni, and Al.
- **Key Markets**
  - Defense, Aerospace, Consumer Electronics, Automotive Electronics, Energy, Medical.

USGS Reports

USGS
science for a changing world

Beryllium—A Critical Mineral Commodity—Resources, Production, and Supply Chain

Beryllium is a lightweight metallic element used in a wide variety of specialty and industrial applications. As a function of its unique chemical and physical properties, such as a high stiffness-to-weight ratio, resistance to temperature extremes, and high thermal conductivity, beryllium cannot be easily replaced by substitute materials in applications where combinations of these properties make it the material of choice. Because the number of beryllium producers is limited and the use of substitute materials in specific defense-related applications that are vital to *national security* is inadequate, several studies have categorized beryllium as a critical and strategic material (National Research Council, 2008, p. 170). This categorization has led to the United States Government recommending that beryllium be stockpiled for use in the event of a national emergency (U.S. Department of Defense, 2015, p. 3). As of December 31, 2015, the National Defense Stockpile inventory of hot-pressed beryllium metal powder, structured beryllium metal powder, and vacuum-cast beryllium metal totaled 78 metric tons (t).

The U.S. Geological Survey (USGS) Mineral Resources Program supports research on the occurrence, quality, quantity, and availability of mineral resources vital to the economy and national security. The USGS, through its National Minerals Information Center (NMIC), collects, analyzes, and disseminates information on more than 90 nonfuel mineral commodities from more than 180 countries. This fact sheet provides information on the production, consumption, supply chain, geology, and resource availability of beryllium in a global context.

Global Beryllium Production

Beryllium is currently produced from two minerals: bertrandite ($Be_4Si_2O_7(OH)_2$) and beryl ($Be_3Al_2Si_6O_{18}$). Bertrandite, which contains about 15 weight percent beryllium, is the principal beryllium mineral mined in the United States. Bertrandite ore mined in the United States contains less than 0.5 weight percent beryllium. Beryl, which can contain up to 5 weight percent beryllium, is the principal beryllium mineral mined in the rest of the world; beryl ore typically contains from 2 to 4 weight percent beryllium. Countries with active industrial beryl mining operations include Brazil, China, Madagascar, Mozambique, Nigeria, Portugal, and Rwanda. From a historical perspective, Argentina, India, and several countries in sub-Saharan Africa were once prominent producers of beryl ore (fig. 1). Other nations that produce gemstone beryl, such as Zambia, may also have produced industrial beryl ore. The United States produced an estimated 90 percent of the world's beryllium in 2015.

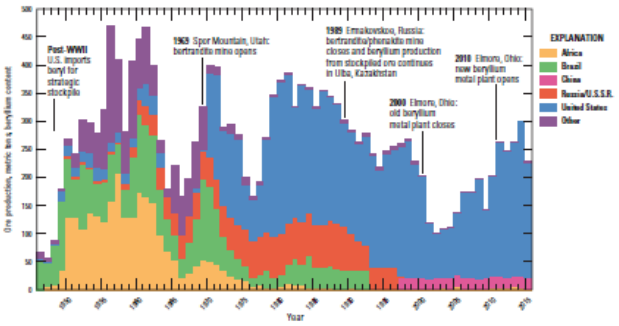

Figure 1. Trends in beryllium mine production from 1946 through 2015 illustrate the dominance of United States production since the opening of the Spor Mountain, Utah, bertrandite mine in 1969. With the exception of Spor Mountain and Ermakovskoe, Russia, beryllium production was derived from beryl mined from pegmatite deposits.

BERYLLIUM

(Data in metric tons of beryllium content unless otherwise noted)

Domestic Production and Use: One company in Utah mined bertrandite ore and converted it, along with imported beryl, into beryllium hydroxide. Some of the beryllium hydroxide was shipped to the company's plant in Ohio, where it was converted into metal, oxide, and downstream beryllium-copper master alloy, and some was sold. Based on the estimated unit value for beryllium in imported beryllium-copper master alloy, beryllium apparent consumption of 200 tons was valued at about $125 million. Based on value-added sales revenues, approximately 21% of beryllium products were used in consumer electronics, 19% in industrial components, 14% in automotive electronics, 11% in defense applications, 9% in telecommunications infrastructure, 6% in energy applications, 2% in medical applications, and 18% in other applications. Beryllium alloy strip and bulk products, the most common forms of processed beryllium, were used in all application areas. The majority of unalloyed beryllium metal and beryllium composite products were used in defense and scientific applications.

Salient Statistics—United States:	2013	2014	2015	2016	2017[e]
Production, mine shipments	235	270	205	155	170
Imports for consumption[1]	57	68	66	68	49
Exports[2]	35	26	29	34	33
Government stockpile releases[3]	10	1	1	3	2
Consumption:					
Apparent[4]	262	318	233	182	200
Reported, ore	250	280	220	160	185
Unit value, annual average, beryllium-copper master alloy, dollars per kilogram contained beryllium					
Stocks, ore, consumer, yearend					
Net import reliance[5] as a percentage of apparent consumption					

Recycling: Beryllium was recovered from new and from old scrap. Detailed data on the quantities recycled were withheld to avoid disclosing company proprietary data. The recycling program for all of its beryllium products included both new beryllium alloy scrap and old beryllium alloy scrap. Beryllium manufacturers recycled about 20% to 25% of total beryllium consumption. The amount of beryllium manufactured from primary sources was estimated to be about 75% to 80% of total beryllium consumption.

Import Sources (2013–16):[1] Kazakhstan, 47%

Tariff: Item

Beryllium ores and concentrates	2
Beryllium oxide and hydroxide	2
Beryllium-copper master alloy	7
Beryllium-copper plates, sheets, and strip:	
Thickness of 5 millimeters (mm) or more	7
Thickness of less than 5 mm:	
Width of 500 mm or more	7
Width of less than 500 mm	7
Beryllium:	
Unwrought, including powders	8
Waste and scrap	8
Other	8

Depletion Allowance: 22% (Domestic), 14%

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USGS Mineral Resources Program

4 Be 9.012

Beryllium—Important for National Defense

As part of a broad mission to conduct research and provide information on nonfuel mineral resources, the U.S. Geological Survey (USGS) supports science to understand

- *How and where beryllium resources form and concentrate in Earth's crust*
- *How beryllium resources interact with the environment to affect human and ecosystem health*
- *Trends in the supply of and demand for beryllium in the domestic and international markets*
- *Where undiscovered beryllium resources might be found*

Why is this information important? Read on to learn about beryllium and the important role it plays in the national economy, in national security, and in the lives of Americans every day.

Beryllium is one of the lightest and stiffest metals, but there was little industrial demand for it until the 1930s and 1940s when the aerospace, defense, and nuclear sectors began using beryllium and its compounds. Beryllium is now classified by the U.S. Department of Defense as a strategic and critical material because it is used in products that are vital to national security. The oxide form of beryllium was identified in 1797, and scientists first isolated metallic beryllium in 1828.

Beryllium and some beryllium compounds are toxic and must be handled carefully. Workplace-related exposures to dusts or fumes of beryllium and beryllium compounds are known to cause serious health problems, such as cancer or chronic beryllium disease, which is an immune system response that can damage the lungs. Proper workplace practices prevent these exposures.

How Do We Use Beryllium?

Beryllium-copper alloys account for approximately 80 percent of the beryllium used in the United States. These alloys are strong, hard, and nonmagnetic; they are good conductors of electricity and heat, and they resist corrosion and fatigue. Beryllium alloys are used in making connectors, springs, switches, and other components of electronic and electrical devices for aerospace, automobile, computer, defense, medical, telecommunications, and other products.

Beryllium metal is very light and very stiff—on a weight-to-weight basis, beryllium is six times stiffer than steel, and it maintains its shape at high and low temperatures. Beryllium metal is used in the aerospace and defense industries to make lightweight precision instruments. The mirrors of the Spitzer Space Telescope and the James Webb Space Telescope (JWST), which is scheduled for launch in 2018, are made of beryllium. The primary mirror of the JWST contains 18 hexagonal segments (each segment is 4.3 feet in diameter) that must maintain their exact shape even at temperatures of −400 degrees Fahrenheit and must be light enough to be carried into orbit; the telescope will operate approximately 1 million miles above Earth. Beryllium is almost transparent to x-rays, and beryllium foil is used as window material in x-ray and other radiation machines. In nuclear reactors, beryllium metal and beryllium oxide are used to control fission reactions. Beryllium has also been used in the trigger mechanisms for nuclear weapons.

View of the back of one of the 18 beryllium mirror segments for the James Webb Space Telescope. The ribs at the back of the mirror help to maintain the mirror's strength and ability to hold its shape under extreme conditions. The front of the mirror is completely smooth and coated in a thin film of gold. Photograph courtesy of the National Aeronautics and Space Administration.

The U.S. Air Force F-35 Lightning II Joint Strike Fighter and many other aerospace vehicles rely on electrical and mechanical components made of beryllium alloys.

Photograph courtesy of the U.S. Air Force

Where Does Beryllium Come From?

Two minerals, bertrandite and beryl, are mined for beryllium, and both are found in association with igneous rocks. All the beryllium currently being mined in the United States comes from the mineral bertrandite. A complex series of events must take place to concentrate beryllium into bertrandite. First, a magma that is rich in fluorine, beryllium, and silica must erupt in an area where there are carbonate rocks (limestone or dolomite). If heat from the magma warms the groundwater in the area and causes the water to move through the surrounding rocks, the water picks up elements, including beryllium, from those rocks; the water may then react with suitable igneous or sedimentary rocks to crystallize minerals, including bertrandite.

The mineral beryl is the main source of beryllium mined outside the United States. Beryl is most often found in veins or pegmatites, which are rocks that contain the last minerals to crystallize from a large igneous intrusion. Pegmatites are distinguished by large interlocking crystals that often include unusual elements and minerals. Pure beryl crystals are colorless, but the inclusion of other elements in beryl creates colorful, valuable gemstones. The green color in emerald is due to traces of chromium and sometimes vanadium in the beryl crystal lattice. The pale blue to blue-green color of aquamarine is caused by iron atoms with an oxidation state of +2 (Fe^{2+}); other elements in beryl crystals produce colors that range from gold to red. America's largest faceted emerald, a 64-carat gemstone, was cut from a 310-carat dark green crystal found at the Adams Emerald Mine in North Carolina in 2009.

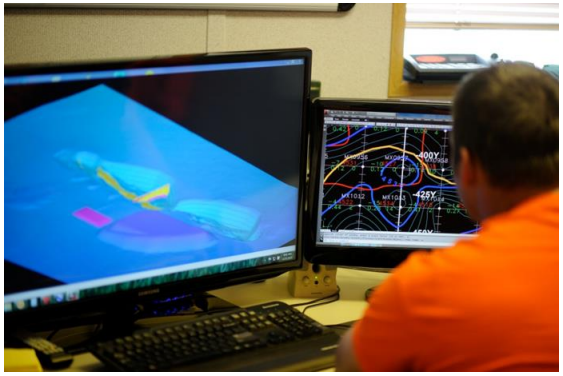
Critical Minerals EO

Table 1: Draft List of critical minerals

Mineral commodity	Sectors							Top Producer	Top Supplier	Notable example application
	Aerospace (non-defense)	Defense	Energy	Communications & electronics	Transportation (non-aerospace)	Other				
Barite								China	China	Oil and gas drilling fluid
Beryllium								United States	Kazakhstan	Satellite communications, beryllium metal for aerospace
Bismuth								China	China	Pharmaceuticals, lead-free solders
Cesium and rubidium								Canada	Canada	Medical applications, global positioning satellites, night-vision devices
Chromium								South Africa	South Africa	Jet engines (superalloys), stainless steels
Cobalt								Congo (Kinshasa)	Norway	Jet engines (superalloys), rechargeable batteries
Fluorspar								China	Mexico	Aluminum and steel production, uranium processing
Gallium								China	China	Radar, light-emitting diodes (LEDs), cellular phones
Germanium								China	China	Infrared devices, fiber optics
Graphite (natural)								China	China	Rechargeable batteries, body armor
Helium								United States	Qatar	Cryogenic [magnetic resonance imaging (MRI)]
Indium								China	Canada	Flat-panel displays (indium-tin-oxide), specialty alloys
Lithium								Australia	Chile	Rechargeable batteries, aluminum-lithium alloys for aerospace
Magnesium								China	China	Incendiary countermeasures for aerospace
Manganese								China	South Africa	Aluminum and steel production, lightweight alloys

Materion Natural Resources – Mining Beryllium

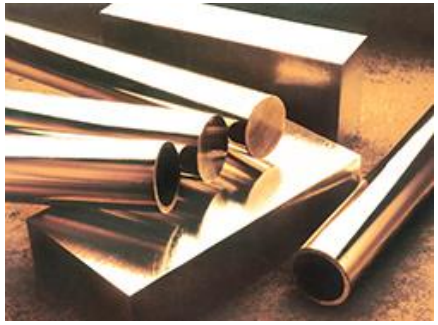
- **Topaz-Spor Mountain** area in western Utah has been a commercial source of uranium and fluorspar.
- Beryllium was discovered in 1959.
- Materion has been actively mining at that site since 1969.
- The mineral is identified as **bertrandite**, a hydrous beryllium silicate ($Be_4Si_2O_7(OH)_2$)



Beryllium Supply Chain

- Materion is the only fully integrated beryllium supplier in the world.
- Materion holds estimated ore reserves for 75 years of production.
- Supplies over 70% of the world's mined beryllium.

- Be production facilities in the US:
  - Delta, UT — Mining
  - Elmore, OH — Extraction, casting, metal fabrication, machining
  - Tucson, AZ — BeO
  - Fremont, CA — Be foil and fabrication
  - Lincoln, RI — Clad products
  - Reading, PA — CuBe strip and wire
  - Warren, MI — CuBe
  - Chicago, IL — CuBe



Challenges

- **Foreign Competition:**
  - Materion produces Beryllium domestically, yet competes internationally.
  - Domestic mining and manufacturing costs much higher.

- **How do we build a domestic capability for Critical Minerals which is viable and competitive?**

Government Involvement - Materion

- **DLA – Strategic Materials Stockpile**
- **Cooperative Research and Development:**
  - LIFT – Manufacturing USA Institute
  - Metals Affordability Initiative
- **DoD Manufacturing and Industrial Base Policy Office**
  - Defense Production Act Title-III Investment

Be Production at Elmore, Ohio Plant

Beryllium Pebble Plant

- The Be Pebble Plant in Ohio is the world's most modern beryllium refining production facility.
- Cost: $110,000,000
- Public-Private partnership with DoD DPA Title-III.
- Initiated 2004.
- First production: April 2011.

Challenges

- Can we obtain sufficient volume to be viable?
- Ability to generate acceptable financial returns.
- Will the stock market reward the effort?
- Skilled Workforce – ability to attract and retain.
- Is there a role for the Government?

BUEHLER

Aluminum beryllium casting, mag. 200x, viewed with Differential Interference Contrast.
– Daniel Slates; Materion Brush Performance Alloys; Elmore, Ohio USA

MATERION

Backup Slides

MATERION

Consumer Electronics

- Advanced chemicals for OLED applications
- Multiple product offerings for smartphones, including connector material and voice coil motor (auto focus lens stabilizer)
- Phosphor wheel and opto-ceramic coatings for laser projectors
- Wafer level optical coatings for electronic devices
- 3D/gesture control optical filter capability
- Semiconductor targets for Tier 1 suppliers

Medical

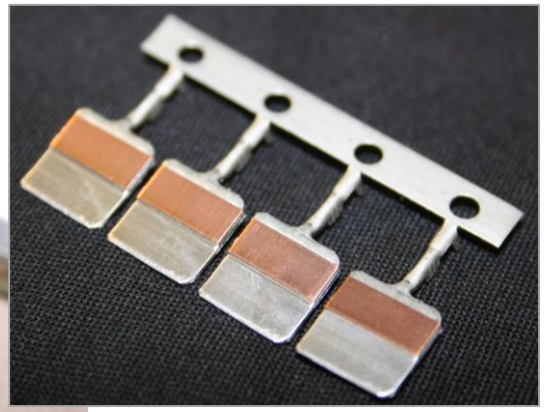
- Precious metal blood glucose test strips for diabetes testing
- Be material for x-ray equipment applications
- Narrow-band optical filters for spectroscopy
- Continuous glucose monitoring (CGM) electrodes for type 2 diabetes

Defense

- Infrared sensors for fighter jet, unmanned aerial vehicle optical targeting
- Optical filters for precision-guided munitions
- Structural components for combat vehicles and aircraft
- Optical, structural, and electronic components for satellites

Automotive Electronics

- Connector material for battery and high temperature applications
- High-performance alloys (i.e., CuBe, ToughMet®) for the powertrain
- Metal matrix composites (i.e., SupremEx®) for chassis, suspension, and braking component applications
- Optical filters: night vision, speed control, sensors, camera applications



Energy

- ToughMet couplings for oil production
- ToughMet components for oil drilling applications
- Connector materials (i.e., Dovetail®) for fuel cell batteries
- Precious metal targets for coatings on construction glass

Materion Business Groups

Advanced Materials Group

Specialty materials for thin film deposition, microelectronic packaging products and inorganic chemicals.

Aerospace Metal Composites

Manufacturer of High Performance Metal Matrix Composites and Alloys.

Precision Optics & Thin Film Coatings

Largest manufacturers of precision thin film coatings and optical filters.

Beryllium & Composites

Global producer of beryllium-based metals and metal matrix composites.

Performance Alloys

One of the world's leading suppliers of high-performance alloys.

Ceramics

Global leader in high-performance engineered ceramics.

Electrofusion

Focused on beryllium x-ray windows, ultra high vacuum (UHV) components and Truextent acoustic solutions.

Large Area Coatings

Specializing in the physical vapor deposition (PVD) of inorganic materials onto flexible polymeric films.

Technical Materials

The world's leading resource for customized, high-performance specialty strip metal products.