Critical and Strategic Minerals

Can Colorado Play a Role?

Colorado has long been known for its mineral resources. The discovery of gold by prospectors headed for California spurred the settlement of the territory. The state’s mining history has been glorious. Beginning with the most alluring of metals – gold – Colorado has been preeminent in the U.S., and the world, in the production of that precious metal, plus silver, lead and zinc, tungsten, uranium and, more recently, molybdenum.

As technology advanced, the demand for these traditional metals increased. At the same time, other mineral commodities gained in importance. The world economy developed a surging demand for lesser-known minerals unknown to the old prospectors. These metals were never recovered in the mills because they had no known use. **Indium, gallium, germanium, tantalum** – these are just a few of the names. They are considered “critical and strategic” minerals because of the key roles they play in modern technology. The U.S. is dependent on imports for most of our supply. Fortunately, these materials have begun to capture the attention of policy-makers and the media.

Critical and strategic minerals are necessary across the spectrum of modern technology, from electronics and electrical systems applications, aerospace and defense, and the conventional energy industry. Many of the uses overlap and converge in the field of alternative or “green” energy.

**Indium, gallium, germanium, selenium, tellurium, neodymium, lanthanum, tantalum**: these mineral materials are relatively new to most people, even within the mining profession. They join others we’ve known such as vanadium, lithium, silicon, platinum, cobalt, nickel, arsenic and silver as key players for producing hardware and infrastructure for the various alternative energy technologies. Solar photovoltaic, thermal solar, wind power, electric and hybrid vehicles all depend on one or more of these mined materials. Many are also in demand in the broader area of electronics. On the positive side, many of these may be found in Colorado, although no comprehensive inventory has been done of their occurrence.

Within the defense and aerospace industries many lesser-known mineral commodities are important. A number of metals are needed for military equipment, both aircraft and ground-based equipment. **Vanadium, rhenium, cobalt, nickel and niobium** are all important for special alloys. Various electronic devices for air-traffic control, satellite communications, and lasers require neodymium, samarium, cobalt, yttrium, terbium, europium, erbium and others. Because of the need for sophisticated electronics in military applications, all of the materials needed for electronics are also aerospace/defense needs.

In the traditional energy fields, many critical and strategic minerals are needed. **Lanthanum** and **tantalum** are used in capacitors. **Cerium** is used as an additive in diesel fuel to lower emissions. **Praseodymium, samarium and scandium** are all used in forms of high-intensity lighting. **Europium, gallium and indium** are used for light-emitting diodes (LEDs). **Dysprosium, erbium, europium, holmium, samarium and molybdenum** are used in nuclear plants. **Molybdenum also performs valuable functions in the oil and gas and coal power industries.**
Alternative Energy

The promise of “green energy” as an alternative to the traditional fossil fuel sources has raised awareness of wind and solar sources for energy generation. Many automobile manufacturers are adding hybrid vehicles to their fleets – cars that can switch between battery and fossil fuel power. Vehicles propelled by fuel cells are under development to take a share of the personal transportation market. Much of the impetus for these efforts is a desire to eliminate dependence on foreign imports for our energy. While sun and wind energy can be utilized in the U.S., many of the key materials needed for these technologies must be imported. And, they must be mined.

Solar Power
The most common photovoltaic material is silicon. Used in several different forms in photovoltaic applications, silicon is the most abundant metal in the earth’s crust. Silicon with few impurities is sought because the process of purifying it to the grade required for electronics and photovoltaics is expensive and energy-intensive. Producers seek high-purity quartz (the principle silicon mineral) to minimize the amount of purification needed. The two leading thin-film photovoltaic materials are Cd-Te (cadmium-tellurium) and CIGS (copper-indium-gallium-selenium). The best reflective coating for mirrors used in thermal solar generation is silver.

Hybrid Vehicles
Another area of alternative energy in the spotlight is hybrid vehicles. These vehicles can run part-time on batteries, thus saving gasoline. At the present time, only two technologies exist in the hybrid vehicle battery market – Nickel-Metal hydride batteries are used in the Honda Accord, the Civic, and Ford Escape and the Toyota Prius. The batteries require lanthanum, cerium, neodymium and praseodymium, (called Rare Earth Elements), nickel, cobalt and manganese. The other battery option is the lithium-ion battery. They use the metal lithium, along with others, usually cobalt. Hybrid vehicles use twice as much copper as standard vehicles. The U.S. is dependent on imports for nearly all these metals except copper. Much research is directed at the development of various fuel cell vehicles, using hydrogen as a fuel. At present, fuel cell technology is dependent on metals in the platinum family, which also includes palladium and rhodium. Neodymium magnets are used in the electric generators and motors, as they are in the new generation of wind turbines.

Is There Potential In Colorado?
Among the minerals needed for alternative energy technologies, some have been identified in Colorado and more show promise for successful exploration. Pegmatite deposits are the best place to look for high-purity quartz. Pegmatites occur around the state, mostly along the Front Range, from Larimer south to Teller County and also in Park and Chaffee Counties. Tellurium combined with gold to form the famous telluride deposits of Colorado. Gold is mined from Telluride deposits in the state now, including the famous Cripple Creek district in Teller County. Selenium occurs in numerous places in western Colorado, commonly occurring with uranium deposits. Perhaps the most promising are the metals used for photovoltaics – gallium, germanium, and indium. These three elements often occur in the mineral sphalerite, the primary ore mineral of zinc. Colorado has many zinc deposits and the possibility is strong that one or more of these can be found in the zinc ore. Germanium is commonly found in coal deposits, so the abundant coals of Colorado, including those under the eastern Plains, are a potential source of this valuable material. Lithium is found in oil shale deposits, including Colorado’s oil shale, as well as in geothermal waters. Rare earth elements have been found in Moffat and Gunnison Counties and in the Wet Mountains of Custer County.
Electronics and Traditional Energy

The world runs on energy. Per capital electricity consumption increased worldwide by 25 percent from 1997 to 2007. Overall energy consumption increased at an even greater rate. The personal incomes in popular countries like India and China are rising and, with that, the demand for electrical appliances and lighting, personal vehicles – the trappings of modern industrial society. Energy providers are under pressure to make more energy available, preferably at a low cost.

Lighting
Critical and strategic minerals are used in both traditional energy technologies and in emerging technologies. Energy conservation and technologies that enable lower energy use, are dependent on critical minerals. Two rare earth elements – praseodymium and samarium, along with scandium, are used in forms of high-intensity lighting. Light-emitting diodes or LED’s, represent a promising new technology for saving energy. LED’s provide light using only a fraction of the electricity used by conventional lights. A wide variety of metals are used, depending on the color and application, and include europium, gallium, indium, germanium, tin, cerium, lanthanum, zinc and selenium.

Oil and Gas Industry
At the front end of oil and gas production, molybdenum is used in drill steel for wells and barium is used in drilling mud. Petroleum refining – converting crude oil to its many usable products – is a complex process. Among catalysts used in refining are zeolite minerals and the platinum group metals platinum, palladium and rhodium and the rare earth element Lanthanum. Petroleum and its products are transported using molybdenum alloys because of that metal’s resistance to corrosion. New generation double-hulled tankers and oil and gas pipelines use molybdenum alloys. Cerium is used as an additive in diesel fuel to reduce emissions.

Nuclear Industry
Molybdenum is used in alloys in the piping and tubing of nuclear plants. Other metals used in nuclear plant structures include manganese, nickel, chromium, zirconium, titanium and niobium in addition to iron. Rare earth elements dysprosium, erbium, holmium and samarium are used for control rods.

Electronics and Miscellaneous
Capacitors are a vital component in electrical systems, including electric motors. Lanthanum and tantalum are both used for capacitors and promising research shows that tantalum supercapacitors may possibly replace batteries in electric vehicles. Gallium is a necessary component of cellular telephones. Germanium is used in computers. Indium and tin are used in flat panel displays and liquid crystal displays.

Is There Potential in Colorado?
A potential exists for economic deposits of the minerals used in electronics and energy within Colorado. Germanium, gallium, and indium often occur with zinc, present in many places in the State. The family of rare earth elements, including lanthanum, cerium, praseodymium, samarium, europium, erbium, and holmium, have been identified in promising concentrations in several places in Colorado, including Moffat and Gunnison Counties and the Wet Mountains. In a 1993 report, the U.S. Bureau of Mines identified several locations in Colorado where further work is warranted in the search for tantalum. Platinum group metals platinum, rhodium, and palladium don’t show great promise in Colorado, but there are several locations where these have been identified. Molybdenum is a Colorado success story. With four identified world-class deposits, there are other locations within the state that show promise for further discoveries.
Aerospace and Defense

Modern aerospace and defense technologies increasingly depend on critical and strategic minerals. Breaking new frontiers of speed and altitude requires materials that withstand greater ranges of conditions than ever before. The materials must operate effectively and efficiently. Aircraft, including rockets, must perform at near perfection in extremes of temperature and gravity. Ever more sophisticated equipment, especially electronics, provide communication and safety for U.S. troops in hostile conditions. Researchers are constantly devising new materials to meet these challenges. The materials often require critical and strategic minerals for their optimum performance.

Aircraft

Airplanes and rockets must perform under extreme conditions. Structural elements of these craft use a variety of mineral materials, including vanadium, nickel, niobium and hafnium. Engine components in particular require alloys and ceramic materials able to withstand extreme temperatures. Alloys and superalloys using rhenium, cobalt, nickel, niobium, hafnium and titanium play important roles. Samarium and cobalt are used in flight controls and yttrium in high-temperature ceramics.

Defense Applications

Many of the same minerals used in electronics and power applications are also important in the defense realm. Of particular note, though, is the group known as the rare earth elements. These seventeen minerals are used in many different areas of defense. Below is a list of some defense applications and the mineral materials used. Note that many other critical and strategic minerals are needed in addition to these rare earth elements.

- Protective coatings against neutron radiation (gadolinium)
- Precision guided munitions, such as “smart bombs” (samarium, neodymium, cobalt)
- Lasers in rangefinders, target designators (dysprosium, erbium, europium, gadolinium, holmium, terbium, ytterbium, yttrium along with non-rare earths vanadium and cobalt)
- Mine detection technology (neodymium and yttrium)
- Line-of-sight communications (erbium)
- Radar systems (yttrium, samarium, gadolinium, as well as cobalt)
- Specialized optical equipment (gadolinium, lanthanum, cerium)
- Sonar technology (dysprosium)
- Electronic countermeasures (gadolinium, yttrium, samarium)
- Nuclear marine propulsion (gadolinium)
- Travelling wave tubes and klystrons (samarium, neodymium, non-rare earth cobalt)
- Stealth technology (neodymium, samarium + non-rare earths cobalt, nickel, titanium)
- Audio devices for psychological warfare (neodymium, dysprosium, samarium + non-rare earth cobalt)
- Electronic displays (europium, yttrium, cerium, terbium, gadolinium, lanthanum)
- Sonic and ultrasonic transducers (dysprosium)

Is There Potential in Colorado?

Promising concentrations of rare earth elements are known in Gunnison and Custer Counties along with paleo-placer deposits in Moffat County. The Pikes Peak granite has been described as one of the richest known in rare earth content. Zirconium and hafnium are obtained from zircons in placer deposits. None are known in Colorado, but occurrences are possible, most likely in old beach deposits. Gunnison County contains what has been described as the world’s largest reserve of titanium; titanium-rich placers are known in eastern Colorado, notably in Elbert County. Vanadium occurs abundantly in the uranium ores of southwest Colorado. Rhenium occurs as a by-product of molybdenum where that occurs with copper. It is not known in primary molybdenum deposits, but Colorado’s wealth of molybdenum makes it a possible source worth investigating.