CORE-CM
WILLISTON BASIN

CARBON ORE, RARE EARTH, AND CRITICAL MINERALS

EERC
UND UNIVERSITY OF NORTH DAKOTA

MORE THAN ENERGY:
COAL AS A MINERAL RESOURCE

CRITICAL CHALLENGES | **PRACTICAL SOLUTIONS**

THE BUILDING BLOCKS OF MODERN LIFE

Three hundred years ago, the world largely ran on the same elements known to antiquity, which included carbon (charcoal), iron, lead, copper, tin, precious metals, and a few others. In the year 1700, only 15 chemical elements were known, and it would be almost another century before the term element was even defined. As science progressed, more elements became known and then essential to the new inventions that took advantage of their unique properties. These new elements enabled not only the advancement of technology but also its miniaturization, leading to miniaturized computers and mobile phones. Today, these elements are considered **critical minerals (CMs)**; they play a vital role in our modern economy and national security but are not produced domestically.

Many essential elements are considered CMs because no alternative exists. One example is manganese, an essential component in the production of steel that, according to the U.S. Geological Survey's Mineral Commodity Summaries 2021, has "no satisfactory substitute." However, importance to daily life is only half the equation. CMs, including many rare-earth elements (REEs), are also vulnerable to supply chain disruptions. The United States imports roughly 80% of its REE needs from China and is completely dependent on imports for 14 CMs. These imports include both raw materials and finished products.

CRITICAL MINERALS ARE BOTH **ESSENTIAL TO MODERN LIFE** AND VULNERABLE TO SUPPLY CHAIN DISRUPTIONS.

RETHINKING THE COAL ECONOMY

A domestic supply of CMs is essential to the nation's future, especially health care, high technology, national security, and clean energy. Research has shown that Williston Basin lignite coal and its by-products are promising potential sources of REEs and CMs. This is where the Williston Basin Carbon Ore, Rare Earth, and Critical Minerals (CORE-CM) Initiative comes into play. The CORE-CM Initiative is setting the stage for future expansion and transformation of coal use within the Williston Basin for the production of REEs, nonfuel carbon-based products, and other CMs, which may catalyze economic growth and job creation.

The starting point of this project's research and development is cataloging which CMs can be found in Williston Basin lignite and its by-products and in what quantity, a process called characterization. However, the CORE-CM Initiative does not stop at analyzing the region's mines and waste streams; a separate task group is exploring new technologies for extracting these components for use.

At the same time, others are evaluating the region's industrial potential. Finding and extracting raw materials are important aspects of the CORE-CM Initiative, and while this first phase of the project concerns identification, characterization, and goal setting, some of the program's longer-term goals include developing a supply chain that leads to domestic manufacture of finished products and training a skilled workforce.

The Williston Basin contains extensive infrastructure for mining, transportation, and resource processing, meaning that the building blocks for a future industry developing a domestic supply chain of CMs are already here—but can the Williston Basin really do all this?

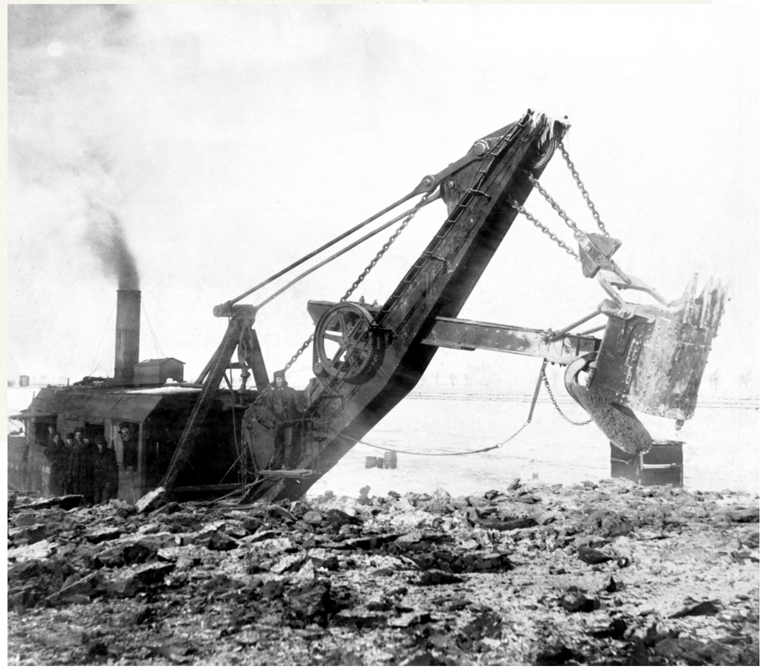
CAN THE WILLISTON BASIN REALLY DO ALL THIS?

MORE THAN A TRADITIONAL ENERGY SOURCE, COAL CONTAINS CMs THAT COULD BE EXTRACTED FROM THIS CARBON ORE, ENERGY PRODUCTION BY-PRODUCTS, AND WASTE STREAMS.

PROVEN VALUE:
THE WILLISTON BASIN HAS DONE IT BEFORE

"THERE IS AN ABUNDANCE OF COAL, AND IT IS GOOD COAL."

—The editor of the Grand Forks Plaindealer on December 18, 1890, as part of an editorial encouraging the continued development of a mining industry in North Dakota.



Man operating coal-mining shovel. Photo from 1920. Image credit: State Historical Society of North Dakota (Photo No. 00081-00005).

Lignite coal mining in the Williston Basin predates the statehood of the Dakotas and Montana. Early settlement in the region led to the discovery of the Williston Basin's vast lignite deposits—now known to be the largest in North America. Lignite was promoted as an abundant and low-cost source of heat, and with settlement in the region came commercial mining ventures, the first of which dates back to the early 1870s.

LIGNITE COAL POWERS THE REGION

As the coal industry grew over the next 50 years, a power industry appeared along with it, with electricity coming to Bismarck in 1887 and a 24-hour, lignite-fueled power plant opening in 1896. Although most urban homes had electricity by the 1930s, electricity was a rarity in rural areas. The Rural Electrification Act, passed in 1936, made it economically feasible for rural electricity cooperatives to form, and the Williston Basin played a substantial part in powering the region's farms. Crop failures during the Great Depression led many area farmers to switch to mining lignite, and production increased. By 1941, 30% of lignite mined in the United States was used in electricity generation. North Dakota, South Dakota, and Montana produced 88% of American lignite that year.

Coal mining in western North Dakota. Photo taken between 1900 and 1920. Image credit: State Historical Society of North Dakota (Photo No. A0925-00001).

THE RISE OF OIL AND GAS

Discovery of the first natural gas deposits dates to the beginning of the 20th century. In 1925, North Dakota State Geologist Dr. Arthur G. Leonard reported on the state's increasing number of natural gas wells. By the 1920s, the Montana side of the Williston Basin also confirmed oil production. However, the Basin's first substantial oil deposits were discovered in 1951 near Williston, North Dakota. A little later that year, significant oil was also found on the Montana side of the Williston Basin. That first North Dakota well, called Clarence Iverson No. 1, produced more than 585,000 barrels of oil from 1951 to 1980. An oil boom began in North Dakota in 1970 and was spurred on by rising prices throughout the decade. The boom ended in 1985, when oil prices dropped to $10 a barrel.

Washburn Lignite Coal Mine No. 2, Wilton, North Dakota. Photo taken between 1923 and 1925. Image credit: State Historical Society of North Dakota (Photo No. 00814-00003).

EARLY SEARCHES FOR CRITICAL MINERALS

The dawn of the atomic age sparked widespread searches for domestic uranium deposits. Although the Williston Basin contains only a small amount of uranium—less than 1% of U.S. reserves—the region produced roughly 270 tons of yellowcake (U_3O_8) from 1956 to 1967.

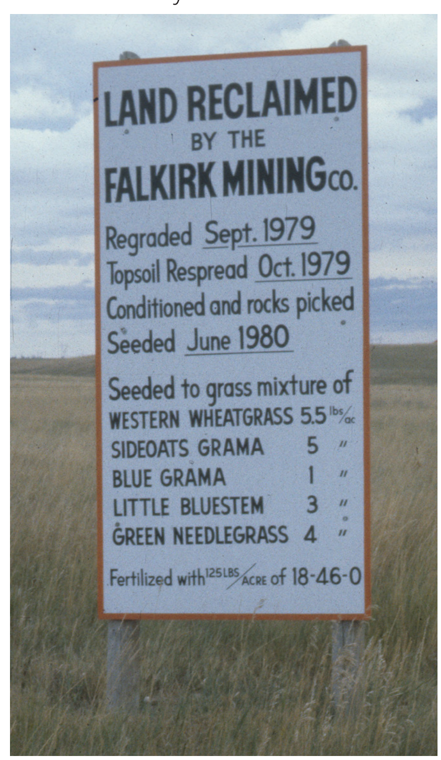
LIGNITE RETURNS TO POWER

Although the demand for coal as a heat source had decreased during the 1950s and 1960s, the oil and gas shortages of the 1970s served as a wake-up call that supplies of these resources were limited and also sparked national concern about energy self-sufficiency. In North Dakota, large-scale power-generating stations fueled by lignite were constructed next to large surface mines, as was the Great Plains Synfuels Plant, the nation's first coal-to-synthetic natural gas conversion facility near Beulah, North Dakota. Along with these developments came the passage of the Surface Mining Control and Reclamation Act of 1977—regulations about reclaiming mine land to premining conditions and monitoring groundwater. The Reclamation Division of the North Dakota Public Service Commission has had a partnership with the U.S. Department of the Interior's Office of Surface Mining Reclamation and Enforcement since 1980.

THE BAKKEN BOOM

Advances in drilling technology—horizontal drilling and hydraulic fracturing—made it feasible to extract oil from the Williston Basin's Bakken and Three Forks Formations. The 2000 discovery of Montana's highly productive Elm Coulee oil field led people to suspect that similarly productive deposits existed on the North Dakota side of the Basin. This was confirmed with the discovery of the Parshall oil field in 2006—a discovery that kicked off a new oil boom, skyrocketing North Dakota from eighth among oil-producing states in 2007 to second in 2012. Williston Basin oil production continues to put North Dakota in the top three oil-producing states.

Band playing at celebration of first railcar leaving Westhope with oil. Photo ca. 1955. Image credit: State Historical Society of North Dakota (Photo No. 2011-P-42-00002).



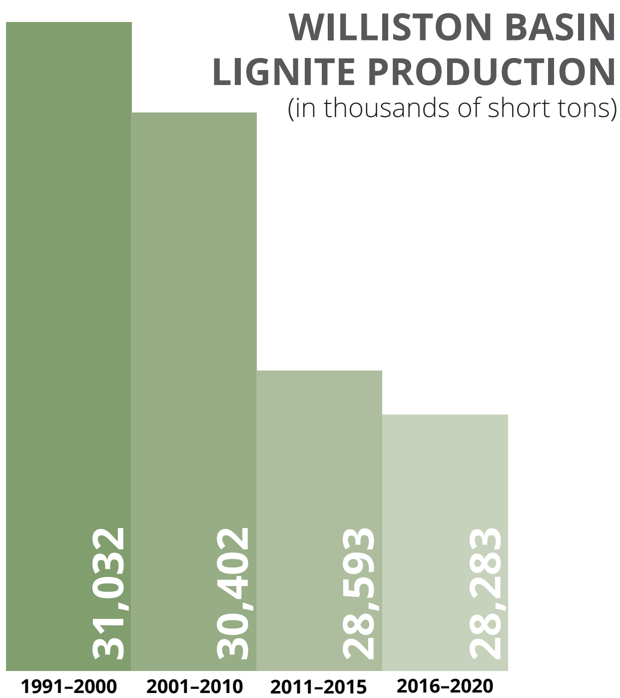
Reclamation site, Falkirk Mine, Underwood, North Dakota. Photo taken September 1982. Image credit: State Historical Society of North Dakota (Photo No. 2013-P-024-00912).

CARBON ORE, RARE EARTHS, AND CRITICAL MINERALS—THE NEXT ADVENTURE

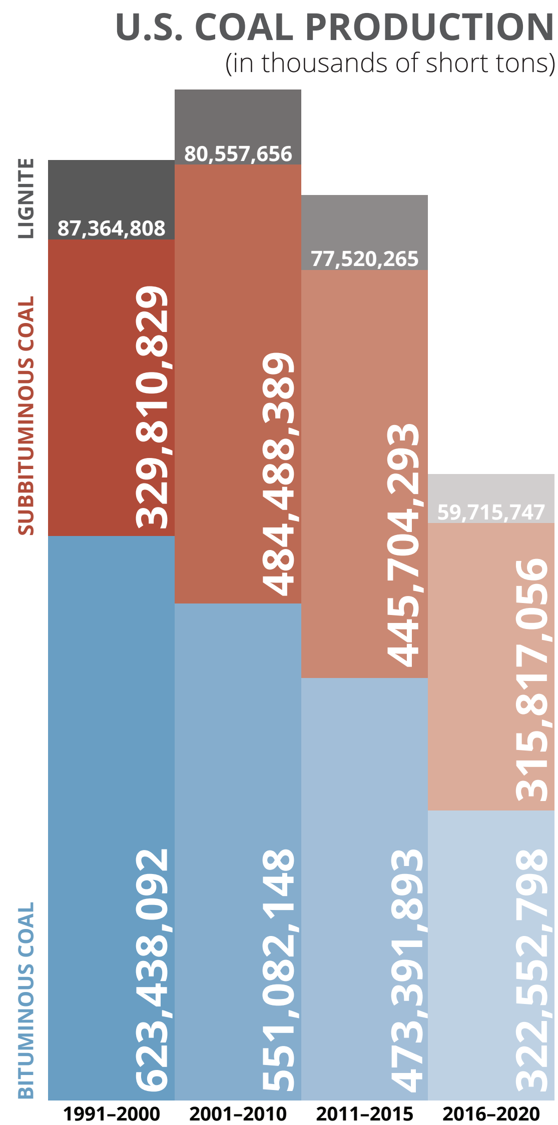
TRENDS IN U.S. COAL PRODUCTION

U.S. coal production peaked in 2008 at 1.171 billion short tons. The period from 2016 to 2020 saw a substantial drop in overall production, with 2020 production being 535 million short tons—a 54% decrease from 2008.

Lignite production, on average, makes up roughly 8% of all U.S. coal production. American lignite production peaked at 90 million short tons in 1992, with the Williston Basin's lignite peak occurring 2 years later in 1994. Lignite production in the Williston Basin remained fairly steady in the 1990s and 2000s but dropped in the 2010s, a trend expected to continue as wind and natural gas production increases.



Anthracite coal makes up less than half a percent of U.S. coal production.

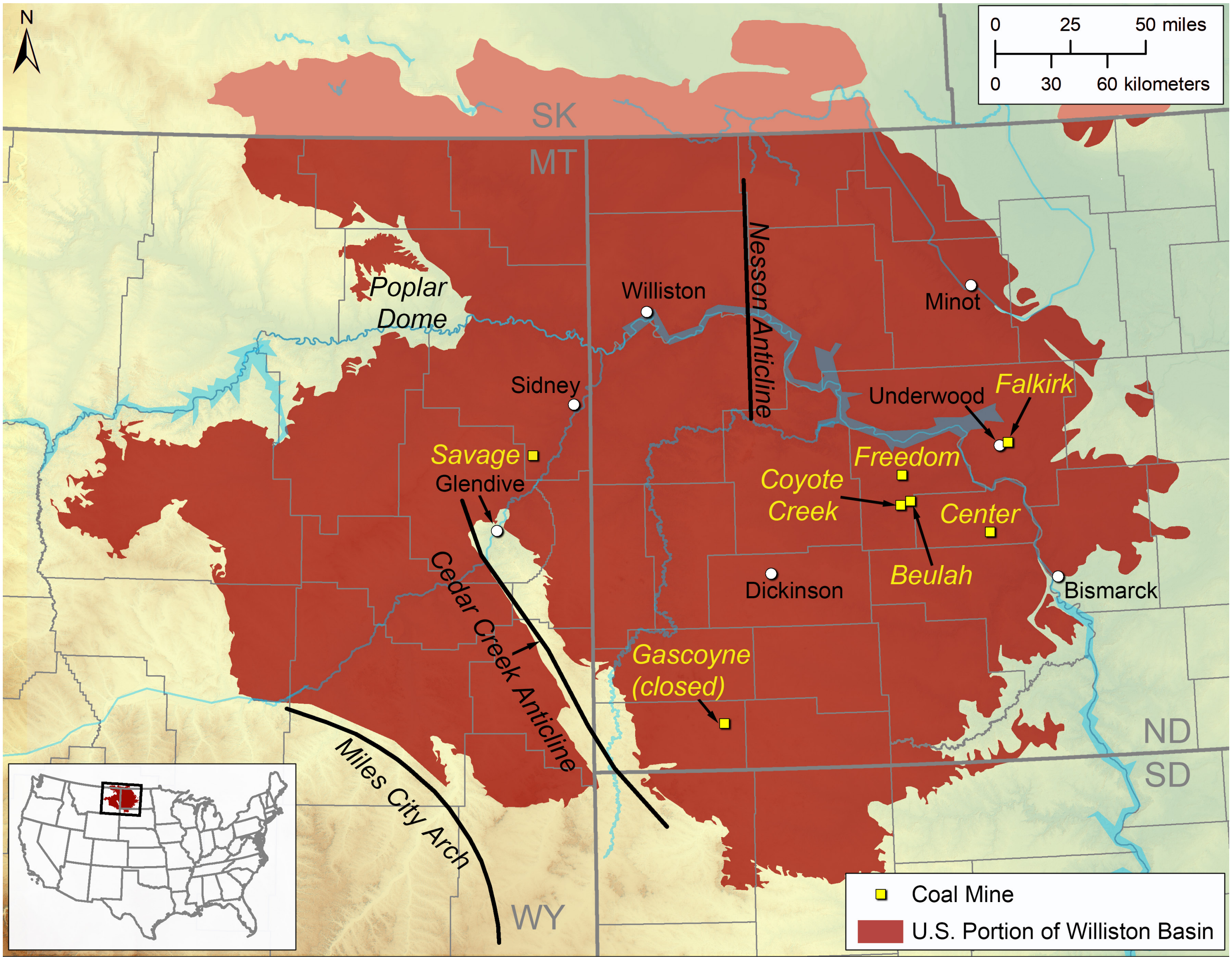


THE WILLISTON BASIN LIGNITE MINES

Six active mines make up U.S. lignite production in the Williston Basin: five in North Dakota and one in Montana. In 2020, these mines produced 54% of U.S. lignite—enough to make up 5% of total U.S. coal production. The largest of these, Freedom Mine, near Beulah, North Dakota, is the largest lignite mine and fourth largest coal mine of any kind in the United States. On its own, it produced 25% of U.S. lignite in 2020: 12,592,297 short tons. Much of Freedom Mine's lignite is delivered to the Great Plains Synfuels Plant, with the remainder going to two different power stations.

The other mines in North Dakota (Beulah, Center, Coyote Creek, and Falkirk) also deliver their coal to power stations. Until recently, this was also true of Montana's Savage Mine, near Sydney. Although it has other customers, Savage Mine delivered most of its output to Lewis & Clark Generating Station, which closed because operating costs made it impossible to compete with natural gas and wind. Natural gas production and wind capacity are projected to increase, but Williston Basin lignite will be available even if the power plants transition to alternative fuel sources.

THE WILLISTON BASIN CONTAINS **MORE THAN 800 YEARS** OF LIGNITE COAL AT CURRENT RATES OF USE.



NEW PLANS FOR COAL

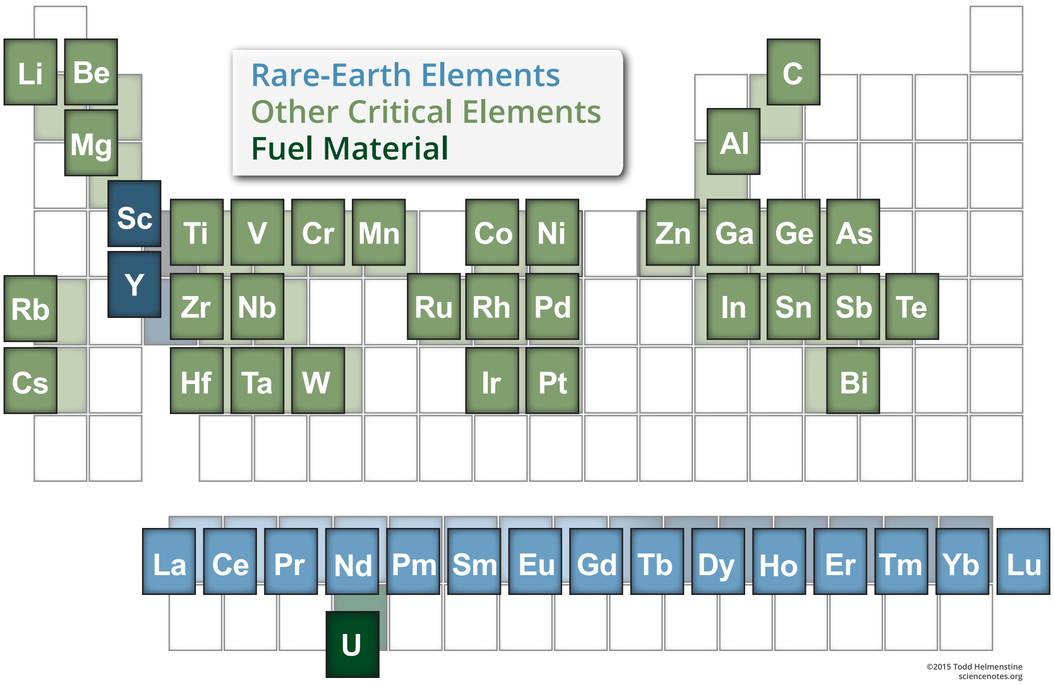
This is why the Williston Basin CORE-CM Initiative is so important: **it is focused on finding new uses for the coal and coal by-products, as well as the existing infrastructure.** The Initiative will also examine creating opportunities in the Williston Basin area for communities in transition as well as the tribal nations that call the Williston Basin region home: the Mandan, Hidatsa, and Arikara Nation, the Standing Rock Sioux, the Cheyenne River Sioux, and the Fort Peck Assiniboine and Sioux Tribes. These opportunities might come in the form of filling existing supply chain gaps, or it might mean new training for the next generation of skilled workers and STEM (science, technology, engineering, and math) professionals. The Williston Basin's history is one of industry, government, and science working together to build a promising future, even as that future evolves with time.

As an example, recent research has focused on the production of graphene, graphite, and carbon-based building materials from lignite coal. Graphite, a crystalline form of pure carbon, and graphene, a one-atom-thick layer of graphite, are critical. Important for more than just pencils, graphite's many uses include heat-resistant materials; batteries; steelmaking; lubricants; vehicle manufacture; nuclear reactors; electrodes; and lightweight, high-strength sports equipment. The United States is currently 100% reliant on imports for graphite, with China currently being the largest producer. Williston Basin graphite would be a great boon to the region and the nation; more than 90 U.S. businesses use graphite in manufacturing.

> DEVELOPING A DOMESTIC SUPPLY CHAIN WOULD BRING ABOUT **SUSTAINABLE OPPORTUNITIES FOR ENERGY COMMUNITIES** AND EXTENDED USEFULNESS FOR EXISTING INFRASTRUCTURE.

CRITICAL MINERALS AND RARE-EARTH ELEMENTS

As material demands ebb and flow, the exact list of which minerals are critical can change. The elements highlighted in the periodic table are currently considered critical by the National Energy Technology Laboratory based on the 2022 U.S. Geological Survey list.



MINERAL VS. ELEMENT

Minerals comprise specific chemical elements in a specific arrangement. The element or the mineral itself may be essential. Examples include aluminum (bauxite) and carbon (graphite). This is why the whole set is referred to as critical minerals rather than critical elements.

HOW ARE CMs USED?

- BATTERIES, FUEL CELLS, ENERGY
- CERAMICS
- DEFENSE APPLICATIONS
- ELECTRONICS
- SPECIALTY GLASS
- HOME USE
- INDUSTRIAL EQUIPMENT
- MAGNETS FOR ELECTRONICS
- MEDICAL INDUSTRY
- SOLAR POWER
- STEEL AND OTHER METALS
- TRANSPORTATION/ AEROSPACE

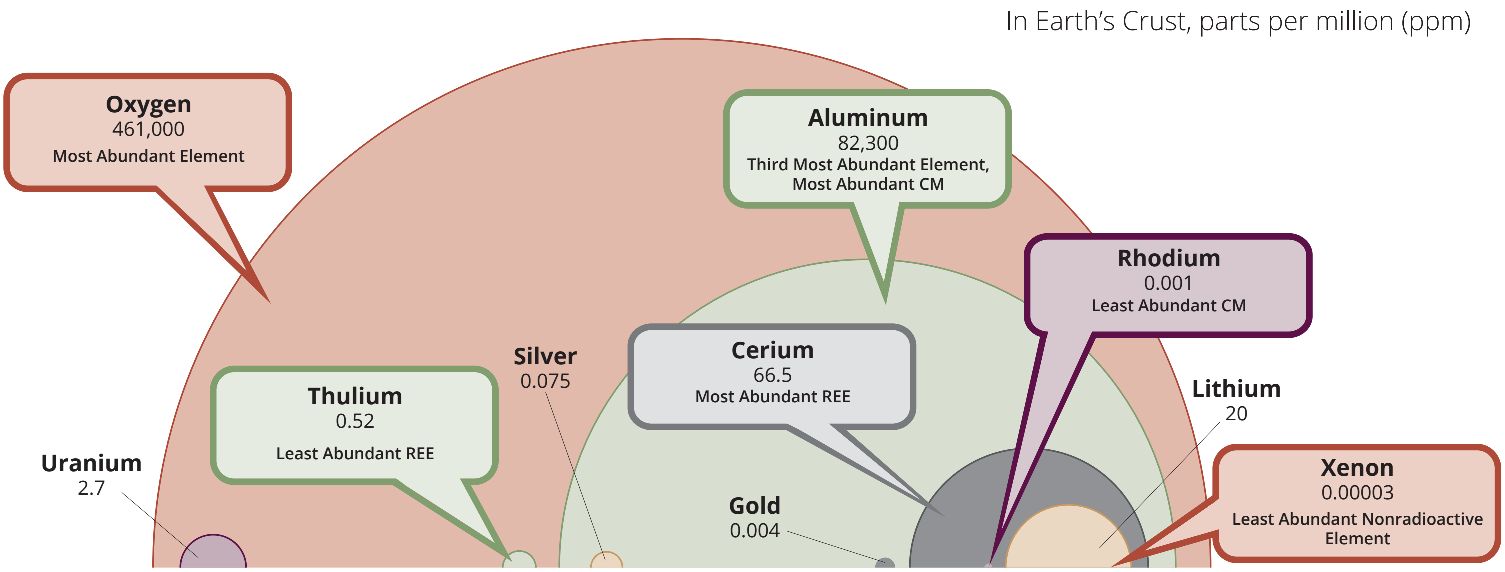
THE U.S. IMPORTS 100% OF

21 Sc | 25 Mn | 31 Ga | 33 As | 37 Rb | 39 Y

41 Nb | 44 Ru | 49 In | 55 Cs | 73 Ta | 77 Ir

Fluorspar | Graphite

THE WILLISTON BASIN'S HISTORY IS ONE OF INDUSTRY, GOVERNMENT, AND SCIENCE **WORKING TOGETHER TO BUILD A PROMISING FUTURE,** EVEN AS THAT FUTURE EVOLVES WITH TIME.



RARE-EARTH RARITY COMPARED TO SELECT OTHER CHEMICAL ELEMENTS

THE RARITY OF RARE EARTHS

Identified and named in the late 1700s, *rare earth* is a misnomer in today's parlance. Even the rarest naturally occurring REEs are 100–200 times more common than gold. The *rare* part of the name comes, in part, from the rarity of minable, concentrated deposits of REEs, while *earth* is an archaic term for something that can be dissolved in acid. These elements are also chemically similar, which makes them difficult, and thus expensive, to separate.

Only a few places on Earth have sufficient quantities of REEs to make mining worthwhile, resulting in supply chains vulnerable to disruption and concern about future demand for these metals. Although China is by far the largest producer of REEs (58% of worldwide supply in 2020), its easily minable resources are being depleted quickly, which will lead to rising costs of the raw materials and, in turn, the products that require them. The United States imports roughly 80% of its REE needs from China.

TAPPING UNUSED RESOURCES: ANNUAL UNINTENDED RARE-EARTH ELEMENT PRODUCTION ASSOCIATED WITH COAL MINING **MIGHT EXCEED THE AMOUNT** THAT THE UNITED STATES USES IN A YEAR.

THREE-STAGE PROGRAM

STAGE I	» Scheduled to last 20 months	COMPRISES SEVERAL TASKS FOCUSED ON:	» Building partnerships » Assessing resources, markets, and infrastructure » Identifying data gaps » Establishing potential technology business development pathways

ASSESSMENT OF CORE-CM RESOURCES

The team handling this task will identify existing data on CORE-CM resources in the Williston Basin, identifying data gaps and developing a plan to fill them. A geographic information system-based model of the Basin will be built, and later teams will integrate their data into it.

STRATEGIES FOR REUSE OF WASTE STREAMS

The EERC will work with federal, state, and local governments and industries to identify potential waste streams available and appropriate for reuse in developing the Williston Basin production of REEs, CMs, and nonfuel carbon-based products, with the goal of formulating a preliminary waste stream reuse plan. This team will construct a database of resources for use in advancing technologies for CMs.

STRATEGIES FOR INFRASTRUCTURE, INDUSTRIES, AND BUSINESS

The business boundary for the CORE-CM Initiative extends beyond the geographic footprint of the Williston Basin. This task includes identifying basinal infrastructure and business and industries within the business boundary, conducting a high-level basinal market assessment, and identifying infrastructure and supply chain gaps.

TECHNOLOGY ASSESSMENT, DEVELOPMENT, AND FIELD TESTING

The task's team will identify the scope of the supply chain from mining and concentration through separation, processing, and manufacturing. This includes technology discovery, identification of technology readiness level, low-fidelity costing and process modeling for promising technologies identified, and field test planning. One of the goals of this task is to inform decisions for future funding efforts into CORE-CM resource recovery demonstrations.

TECHNOLOGY INNOVATION CENTERS

Technology innovation centers will provide a centralized and consistent platform to develop and validate CORE-CM technologies at the laboratory scale, including technologies that use advanced manufacturing techniques. Based on preliminary results from the other tasks, key topics that would benefit from a technology innovation center plan will be identified. These plans include accelerating research; supporting public–private partnerships to advance innovation; and creating opportunities for training the next generation of technicians, skilled workers, and STEM professionals.

BUILDING A NEW INDUSTRY IN THE WILLISTON BASIN WILL CREATE **HIGH-PAYING, HIGHLY SKILLED JOBS.**

STAGE II

- » Completion of Williston Basin assessments
- » Development and initial implementation of strategic plans
- » Anticipated competitive award based on Stage I outcomes

STAGE III

- » Strategic plan implementation

The Williston Basin CORE-CM Initiative is developing a pathway to critical minerals extraction and processing using existing coal-based resources.

Led by the Energy & Environmental Research Center, research partners include the University of North Dakota's Institute of Energy Studies and Nistler College of Business Administration, North Dakota State University, Pacific Northwest National Laboratory, Montana Technological University, and the Critical Materials Institute. Funding partners include the U.S. Department of Energy, the North Dakota Industrial Commission Lignite Research Program, North American Coal, BNI Energy, Minnkota Power Cooperative, and Basin Electric Power Cooperative.

CORE-CM WILLISTON BASIN

CARBON ORE, RARE EARTH, AND CRITICAL MINERALS

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A document citing sources is available at **undeerc.org/wb-corecm**.

CRITICAL MINERALS IN YOUR CAR

Every element and mineral listed is considered critical.

A **BATTERY (nickel-metal hydride)**
antimony, aluminum, arsenic, barium, calcium, cerium, cobalt, chromium, lanthanum, magnesium, manganese, nickel, titanium, vanadium, yttrium, zinc

BATTERY (lithium-ion)
aluminum, cobalt, graphite, lithium, manganese, nickel, tin, titanium, vanadium

BATTERY (lead-acid)
aluminum, antimony, arsenic, calcium, tin, zinc

E **LCD SCREEN**
calcium, cerium, europium, indium, magnesium, yttrium

F **AIR-CONDITIONER**
fluorine

J **BRAKES**
graphite

K **OXYGEN SENSOR**
yttrium

L **ELECTRONIC BRAKES**
dysprosium, neodymium

B **PAINT**
bismuth

C **AUTOMATED MANUAL TRANSMISSION**
dysprosium, neodymium

D **ELECTRONICS**
aluminum, arsenic, beryllium, cobalt, germanium, lithium, samarium, tantalum, tin, yttrium

G **POWER STEERING**
dysprosium, neodymium

H **GLASS/MIRRORS**
calcium, cerium, neodymium

I **CATALYTIC CONVERTER**
cerium, lanthanum, palladium, platinum, zirconium

M **BODY/CHASSIS/ENGINE (exact list will vary depending on type of motor)**
aluminum, cerium, chromium, cobalt, dysprosium, magnesium, manganese, neodymium, nickel, niobium, palladium, praseodymium, tantalum, terbium, titanium, tungsten, vanadium, zinc, zirconium

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