A large yellow crane is positioned on a pile of dark, rocky material, likely lignite. The crane's long boom extends towards the left, silhouetted against a bright sunset sky with orange and yellow clouds. The sun is low on the horizon, creating a strong lens flare effect. The foreground is filled with the dark, textured material of the mine. A large, stylized blue 'Y' shape is overlaid on the left side of the image.

VALUE-ADDED OPPORTUNITIES FOR NORTH DAKOTA LIGNITE




HELPING DEVELOP AFFORDABLE, RELIABLE, AND CLEAN LIGNITE-GENERATED ELECTRICITY FOR YOU



Value-Added Opportunities for North Dakota Lignite

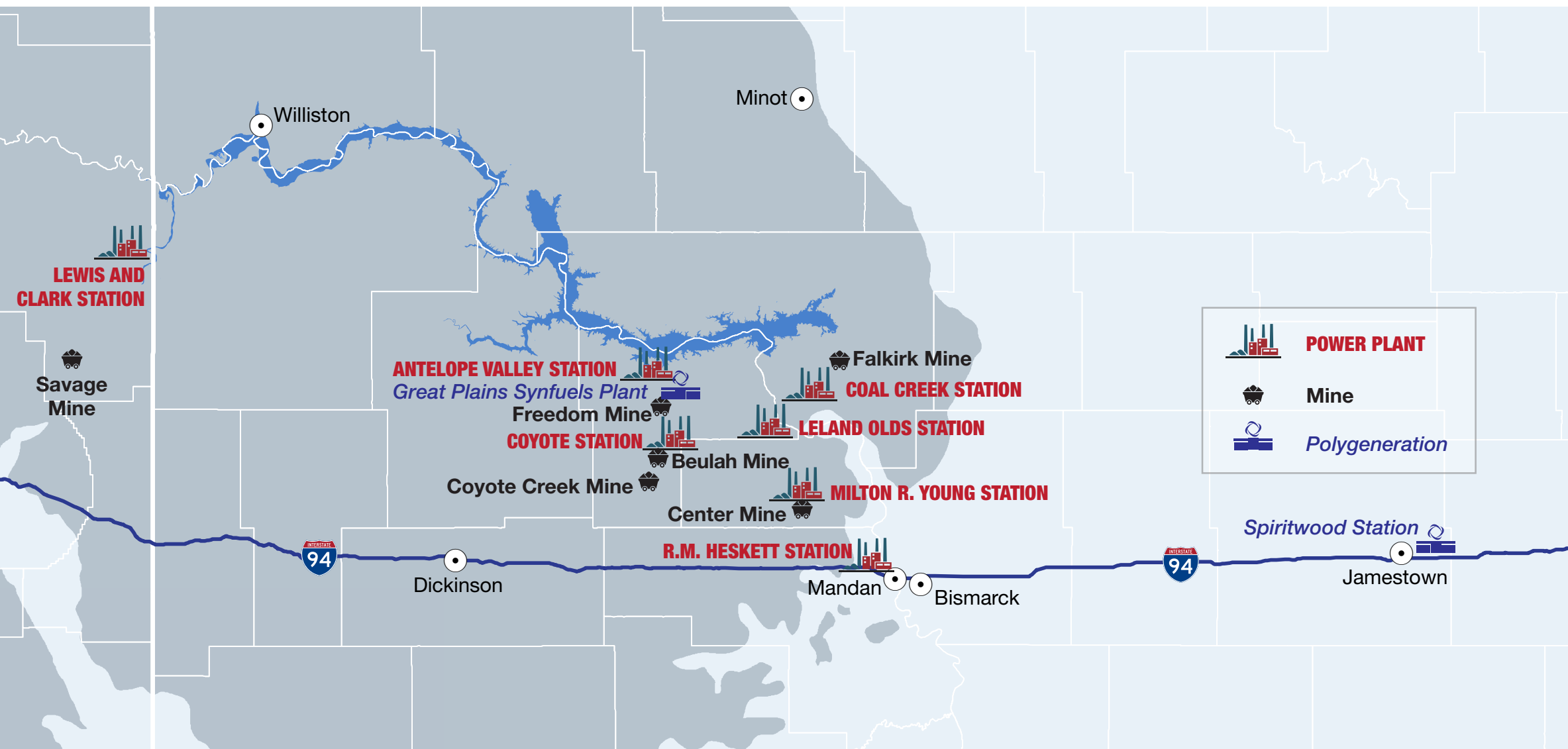
INTRODUCTION

Lignite is a dark brown combustible material formed over millions of years by the partial decomposition of plant matter. Lignite is, essentially, an immature form of the same coal materials found in Wyoming, Kentucky, Pennsylvania, and other places.



The lignite reserves in North Dakota were deposited by enormous amounts of decaying plants in a swampy region that existed here

50 million–70 million
years ago.

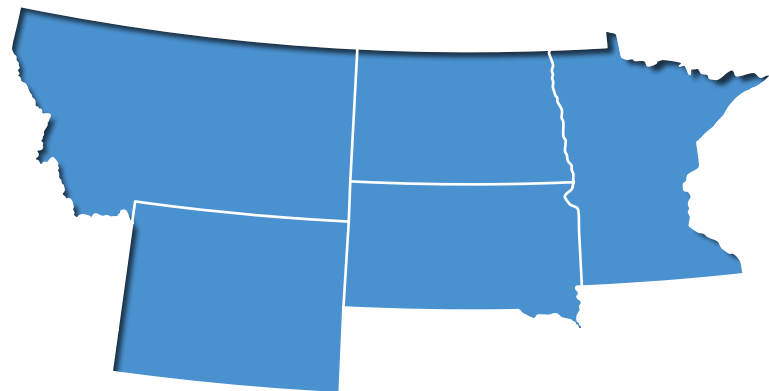


In recent years, coal-based electrical generation has decreased nationally because of a combination of economic and regulatory factors. The North Dakota Industrial Commission and the Lignite Energy Council foster continual innovation to maintain markets for this valuable state and national resource. Indeed, lignite will continue to be critical to the nation's economy and its energy security.

This document summarizes a sampling of value-added uses of lignite that can be pursued further to enhance utilization of this valuable and strategically important natural resource.

North Dakota is one of the country's top ten coal-producing states. Approximately 30 million tons of lignite is mined regionally each year. Our lignite reserves contain an 800-year supply of economically recoverable coal at current usage. This coal is primarily used to generate steam at seven coal-fired power generation stations and two polygeneration plants. Lignite-generated energy serves over 2,000,000 consumers and businesses in the upper Midwest region of the United States.

The lignite industry accounted for \$5.7 billion of the state's economy in 2017, directly employs 3820 people in North Dakota, and indirectly employs 10,200 people. As evident, this resource is vital to the health of North Dakota and its people.



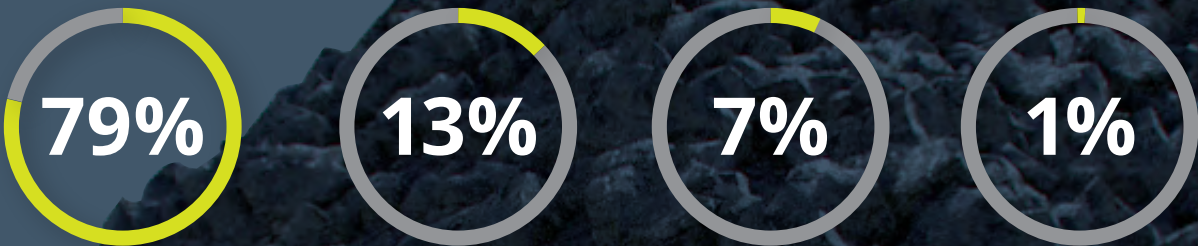
Reach of North Dakota's lignite-produced electricity.



Nearly 80%

of lignite mined in North Dakota is used in generating electricity. However, lignite is a raw material that is also used in many other products, and research is under way to expand this suite of value-added products from lignite.

Percentages of How Lignite Is Used



Electricity Generation Synthetic Natural Gas Generation Fertilizer Products Home Heating and Oil Well Drilling Mud



2 million

Consumers and Businesses in the Upper Midwest Use Lignite-Generated Energy



400,000

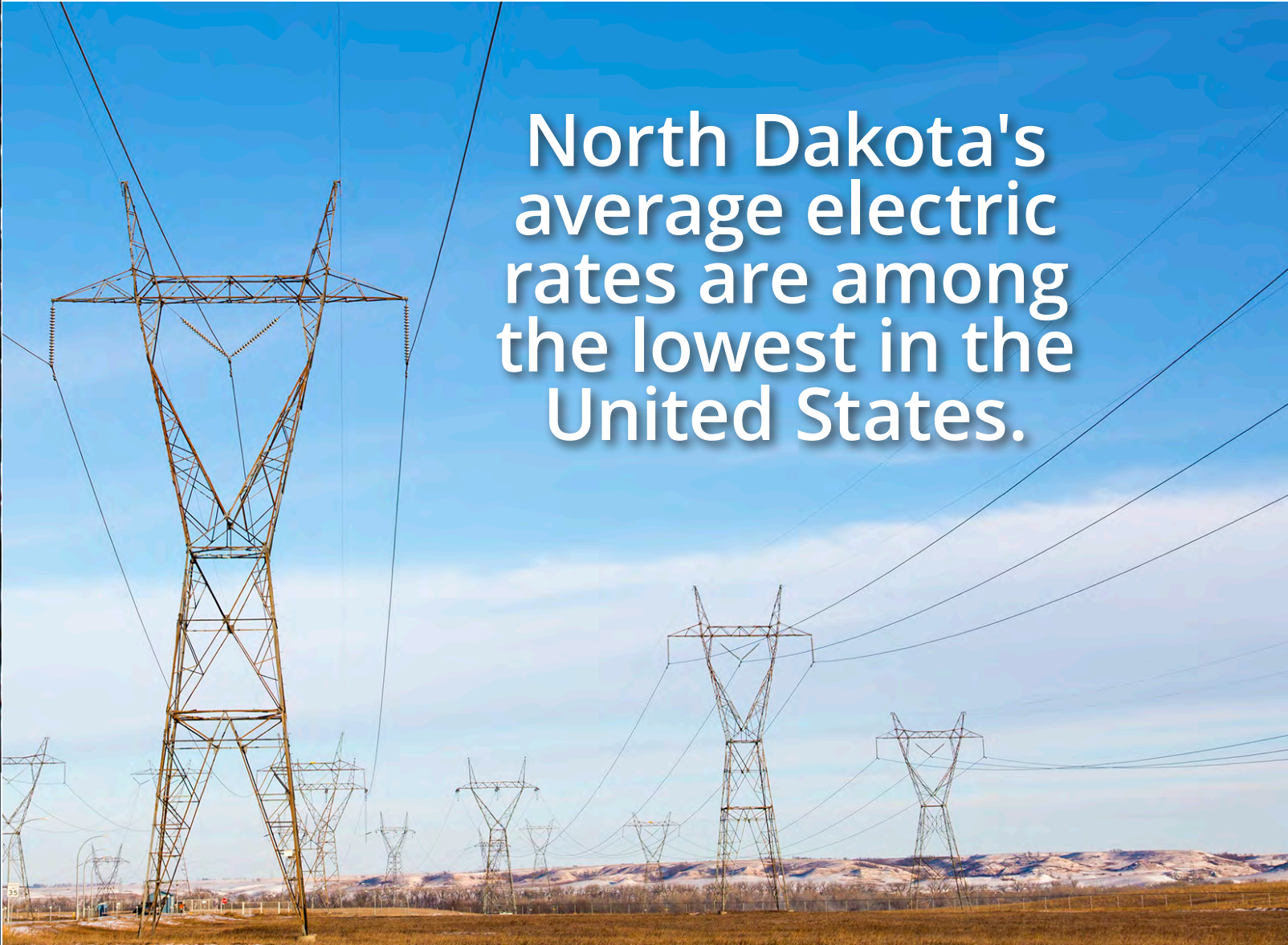
Homes and Businesses in the East Use Electricity from the Great Plains Synfuels Plant

Many valuable minerals can be extracted from raw lignite or from the ash recovered after combustion of lignite. A few examples include lithium, various rare-earth elements (REEs) critical to industry and national defense, and pure carbon, one of the building blocks of countless products.



North Dakotans benefit in multiple ways from affordable and reliable power generated at the state’s lignite-based power plants.

- ◆ Low-cost electricity helps agricultural, manufacturing, and petroleum industries lower their operating expenses and allows them to be competitive on an international level. It also promotes industrial and economic development, since low electricity costs attract new business and help retain existing companies.
- ◆ North Dakota’s average electric rates are among the lowest in the United States, and about 15,000 jobs in the state are due to the lignite industry. In addition, people working for the coal industry in North Dakota enjoy some of the state’s highest wages. North Dakota’s economy receives about \$3 billion in total business activity because of coal and about \$100 million in state tax revenue annually.
- ◆ Low-cost electricity is particularly beneficial to our region. Even though we consume high amounts of energy because of our weather extremes, we enjoy some of the lowest electric rates in the nation.



North Dakota's average electric rates are among the lowest in the United States.

Value-Added Products from Existing Lignite Power Plants

FLY ASH CONCRETE

Fly ash is a particulate by-product of coal combustion. When used instead of cement, the ash enhances the quality of the finished concrete product by making it stronger, more durable, and easier to finish. Some producers are now replacing 30% or more of their cement with fly ash. Cement production is an energy-intensive process, and more than a ton of carbon dioxide is emitted for each ton of cement produced. However, each ton of fly ash used in place of cement reduces greenhouse gases by at least a ton.

Fly Ash

Bottom Ash

BOTTOM ASH

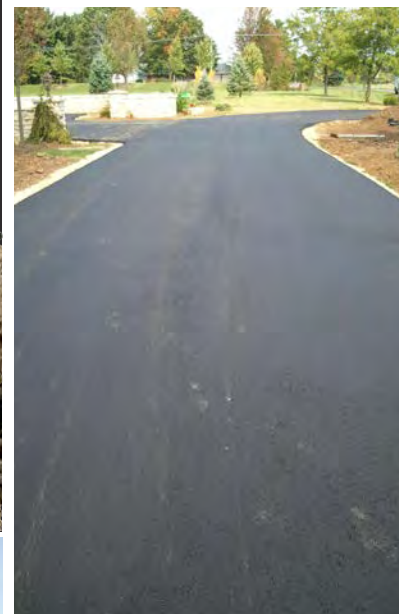
Another by-product of coal combustion consists of the heavier particles remaining after pulverized coal is combusted in a furnace. These particles collect on the bottom of the furnace, resulting in the name "bottom ash." Bottom ash can be used as an aggregate in road bases, pavement, and cement. It also serves as a good alternative to sand for roads in the winter.



HEAT FOR ETHANOL PRODUCTION

As coal is combusted to produce electricity, a large amount of heat is generated that typically goes unused. Coal-fired power plants can utilize this heat. An example of this is the Dakota Spirit ethanol plant at Spiritwood Station. An expensive component of ethanol production is the fuel and boiler used to heat the process. Eliminating the need for a boiler by using a coal plant's process heat saves millions of dollars and only requires that the ethanol plant be built next to a coal-based power plant.

Other uses of this heat resource include space heating, greenhouse agriculture, and other industrial heating needs.



DRYFINE™ BENEFICIATED COAL

DryFining™ is a patented technology for utilizing process heat and mechanical separation to dry and refine lignite coal. Developed by Great River Energy with support from the U.S. Department of Energy, the technology has been in operation at Coal Creek Station in Underwood, North Dakota, since 2009 and improves the efficiency of power production while also reducing emissions. DryFine lignite produced at Coal Creek Station is also transported to Spiritwood Station in Jamestown, North Dakota, by railcar and provides the fuel for power production and process heat for the Dakota Spirit ethanol plant.



Coal Gasification to Fuels, Chemicals, and Hydrogen

In simplest terms, coal gasification is essentially coal combustion with insufficient oxygen to sustain a flame. While combustion produces primarily carbon dioxide and water, gasification produces “syngas” (short for synthesis gas, a coal-derived gas that was used for municipal lighting and heating before large-scale production of natural gas became popular). Syngas is a mixture comprising carbon monoxide, hydrogen, carbon dioxide, methane, and water.

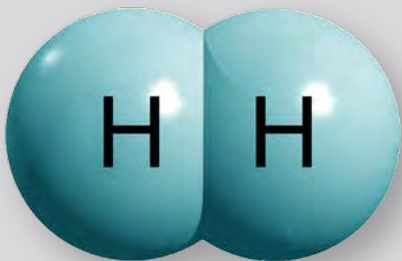
NORTH DAKOTA GASIFICATION: GREAT PLAINS SYNFUELS PLANT

The Great Plains Synfuels Plant is the only commercial-scale coal gasification plant in the United States that manufactures natural gas. Great Plains delivers approximately one-half of the carbon dioxide it makes to Saskatchewan via pipeline for use in enhanced oil recovery and associated CO₂ storage.

Despite recent technological advances, large capital investment is required for gasification plants. This financial risk presents a barrier to market penetration. New gasification systems may provide cost savings, but another economic driver could come from the dramatic decrease of coal in electrical generation. Geopolitical pressures and environmental concerns could incentivize U.S. gasification efforts in new ways.



Because syngas has a large quantity of hydrogen and methane, its chemistry is supportive of subsequent production of purified hydrogen, synthetic natural gas (SNG), or chemical feedstocks for a wide variety of products, including ammonia, methanol, diesel, gasoline, tar, creosote and, even, plastics.



The process of coal gasification produces syngas. From this syngas, many valuable by-products can be made:

- **DEPHENOLIZED CRESYLIC ACID**
Industrial solvents, industrial resins, antioxidants, pesticides, disinfectants, perfumes, preserving agents
- **CATECHOLS**
Pharmaceuticals, food flavoring, insecticides
- **NAPHTHA**
Gasoline, cleaning fluid, shoe polish, oil paints
- **PHENOLS**
Plywood
- **CARBON DIOXIDE**
Enhanced oil recovery, greenhouse agriculture
- **FERTILIZER**
Urea, ammonia, ammonium sulfate

Dakota Gasification Company currently produces nitrogen-based fertilizer from syngas (carbon monoxide and hydrogen) generated by gasification of coal and nitrogen extracted from the air. This technology is commercially deployed and is satisfying regional fertilizer demands today in the form of anhydrous ammonia, urea, and ammonium sulfate.





EMERGING VALUE-ADDED PRODUCTS

In addition to its current uses, North Dakota lignite has a variety of value-added opportunities.

Synthetic Graphite

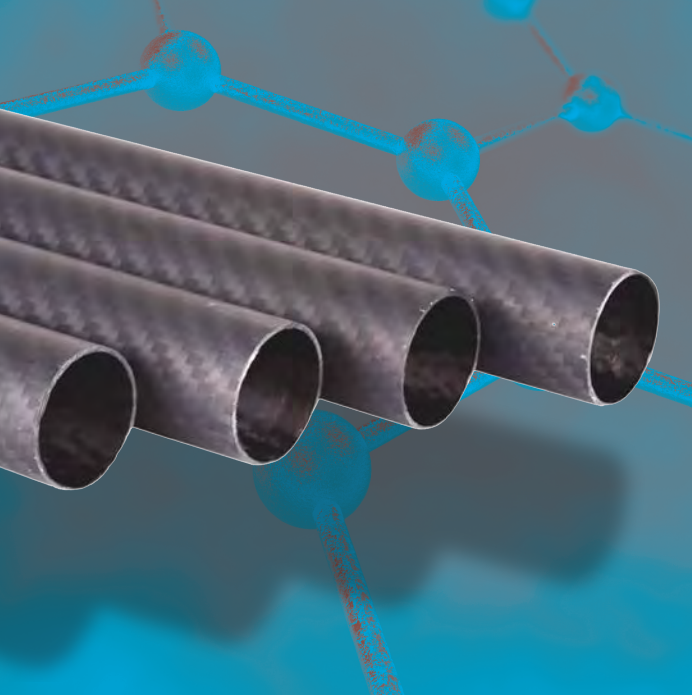
Graphite is a crystalline form of carbon with a layered, planar structure. Think of it as tightly packed sheets of carbon atoms. Graphite is produced either synthetically or mined in its natural form and used in a wide range of industrial applications, including electrodes, brake linings, foundry operations, lubricants, refractory agents, and steel manufacture.

Synthetic graphite is manufactured in a process that involves heating of petroleum coke, coal tar pitch, or even lignite. Heat treatment is in the range of 2500° to 3000°C. At these temperatures, any impurities are driven off, leaving a high-purity graphite product. A vast majority of synthetic graphite is currently produced from petcoke feedstocks, but researchers have proven that lignite is a viable alternative source of synthetic graphite.

Synthetic graphite is dominant in the manufacture of anodes for batteries. The high cost of production tends to result in a high sales price. The increasing demand for graphite because of a rapidly expanding market for lithium-ion batteries may present a unique opportunity for graphite derived from lignite.



Some other carbon-based products that could be manufactured from lignite include activated carbon, carbon fibers for lightweight materials, and carbon nanotubes which are being studied for their unique properties and use in nano technology.



NATIONAL AND GLOBAL DEMAND

Current annual global consumption of graphite for Li-ion batteries is approximately 80,000 tonnes, with 100% of current production controlled by China. Synthetic graphite (preferred in Li-ion battery manufacturing) currently sells for approximately \$20,000 per tonne which equates to a potential global market of \$1.6B. Battery manufacturers are faced with growing pressure from shareholders to source graphite from environmentally responsible and sustainable producers.

If North Dakota's current annual lignite production was applied to production of synthetic graphite, it could conceivably supply three times the global demand for synthetic graphite in Li-ion batteries. Such a market shift would require substantial advancements in the processing of lignite to high-purity spherical graphite.

As technological advances make electric vehicles and economical grid-scale power storage with batteries possible and attractive, North Dakota's lignite resource could provide this industry with ample source material, adding potentially tens of millions of dollars to North Dakota's economy and, possibly, enabling the creation of a battery-manufacturing industry in North Dakota.

Leonardite

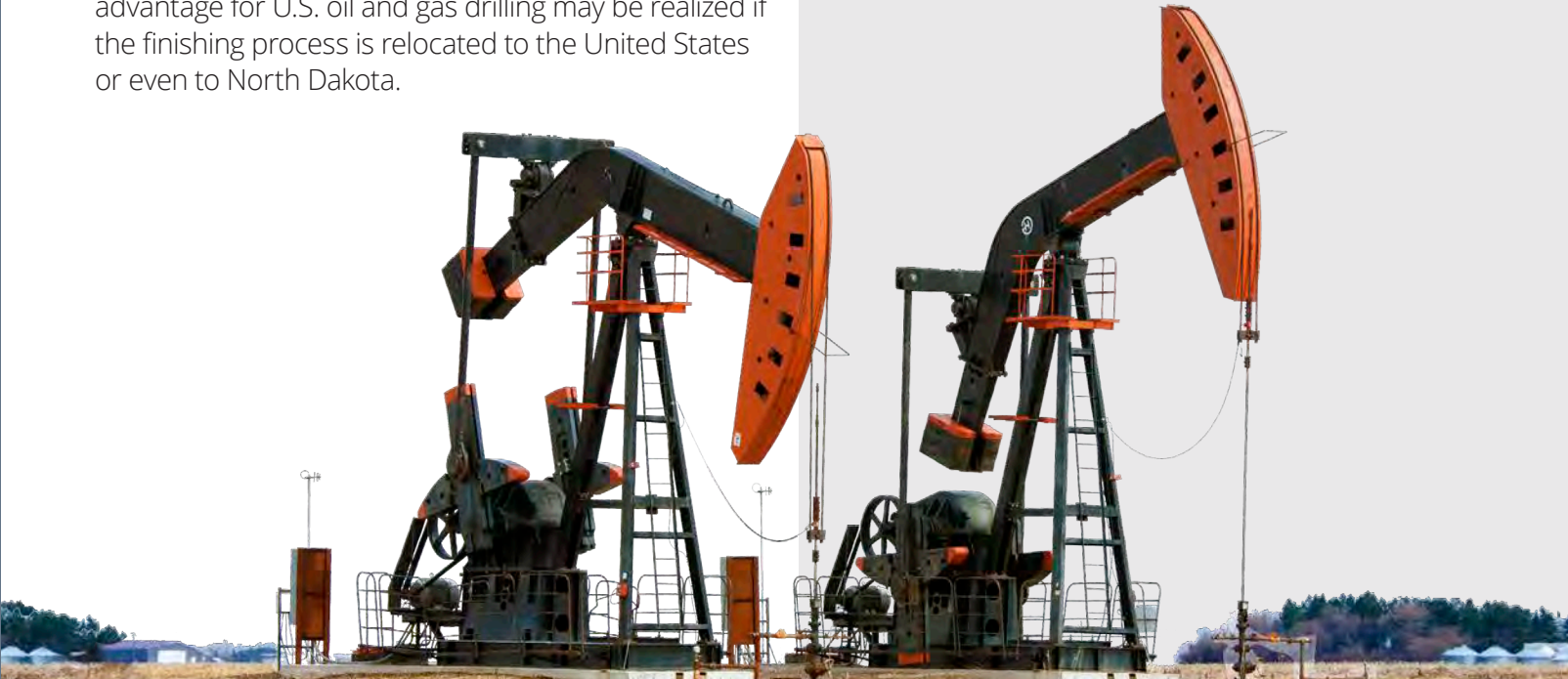
Leonardite is naturally oxidized lignite that is rich in humic acid and is associated with near-surface mining. It is used as a soil conditioner in agriculture, as a stabilizer for ion-exchange resins in water treatment, in the remediation of polluted environments, and as an additive in drilling fluids in the oil and gas industry. The oil and gas sector is showing signs of increased demand for leonardite as drilling increases owing to the shale revolution.



Leonardite

Globally, more than 1 million tonnes of leonardite is produced annually, with an approximate value of \$1400 per tonne (thus a \$1.5 billion global market). A majority of global production of finished product is done in India. Lignite source material is shipped there, where it is subjected to a finishing process, then sent back to the United States. A significant economic advantage for U.S. oil and gas drilling may be realized if the finishing process is relocated to the United States or even to North Dakota.

It is unclear how much leonardite is currently purchased by the oil and gas sector, but the growing market is one worth considering and could be substantial. If 5000 tonnes were used annually for drilling activity support, the annual market would be \$7 million.



Rare-Earth Elements

REEs are critical components in a vast array of consumer goods, energy system components, and military defense applications. They include 17 elements: cerium (Ce), dysprosium (Dy), erbium (Er), europium (Eu), gadolinium (Gd), holmium (Ho), lanthanum (La), lutetium (Lu), neodymium (Nd), praseodymium (Pr), promethium (Pm), samarium (Sm), scandium (Sc), terbium (Tb), thulium (Tm), ytterbium (Yb), and yttrium (Y). Because of their geochemical properties, REEs are typically dispersed and not often found concentrated in economically exploitable ore deposits.



Global production (70,000 tonnes) and the entire value chain are dominated by China, with the United States currently importing 100% of these materials. Traditional mineral ores, including previously mined

deposits in the United States, have several challenges. Chief among these is that the content of valuable REEs is deficient, making mining uneconomical. However, China's supply of these REEs is projected to last only another 10 to 20 years. The United States currently considers the REE market an issue of national security.

According to the North Dakota Geological Survey, new evidence indicates that North Dakota lignite may have some of the highest concentrations of certain REEs in coal seams in the nation. Of 352 coal samples analyzed from the state, 277 averaged 120 parts per million total REEs: twice the published average for U.S. coal. Many samples contained concentrations in excess of 500 ppm. At these concentrations, as much as 3600 tonnes of total REE annually, or 5% of the current global annual market, could come from North Dakota lignite.

Adding to the potential economics, the elements contained in the samples tended toward the heavier, more valuable ones, such as scandium. Three ongoing studies funded by the U.S. Department of Energy and the North Dakota Industrial Commission are exploring the economics of REE extraction from coal, such as extraction of concentrated REEs from ash residue after the coal is burned.

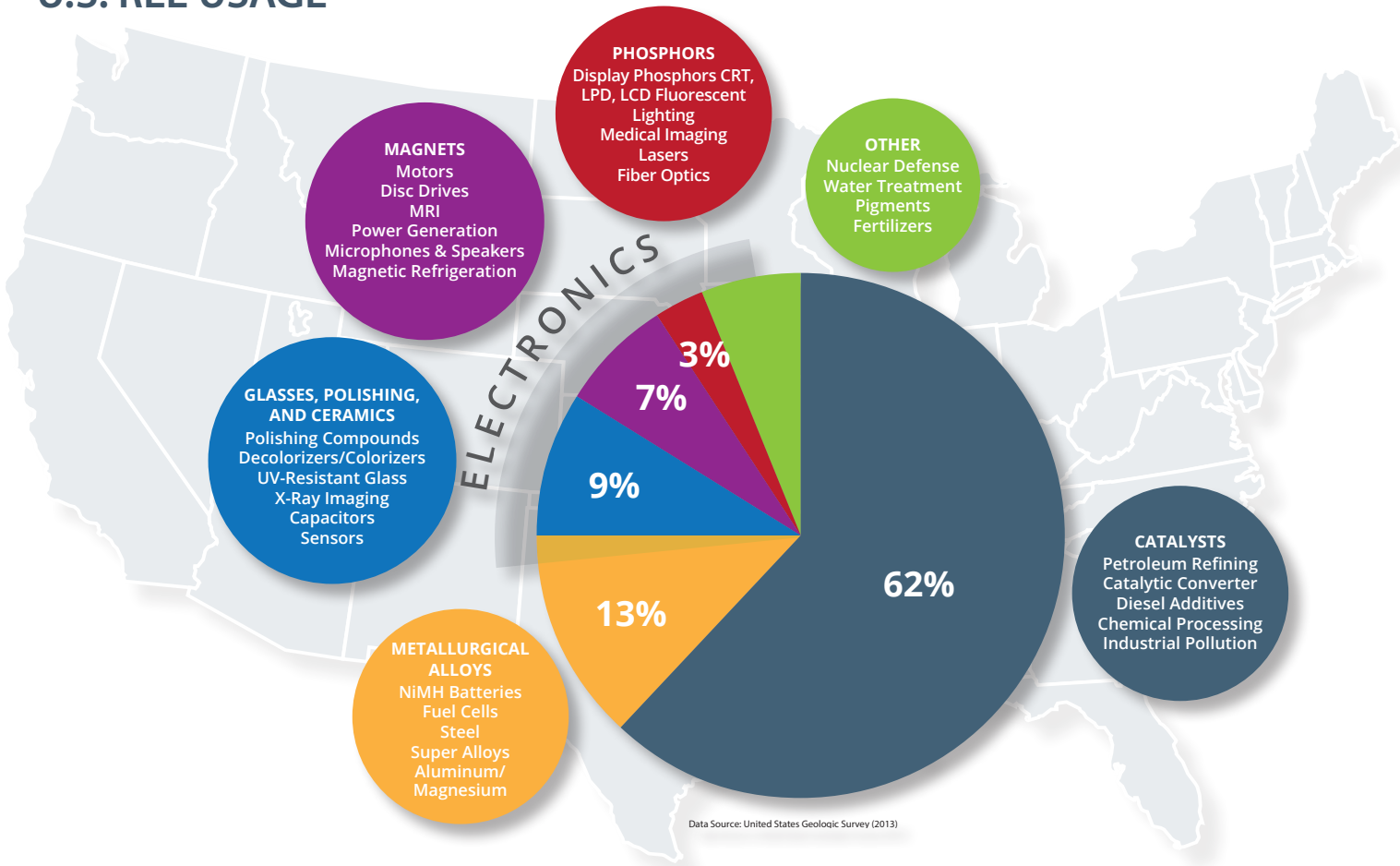


Rare-Earth Elements

REE ECONOMICS

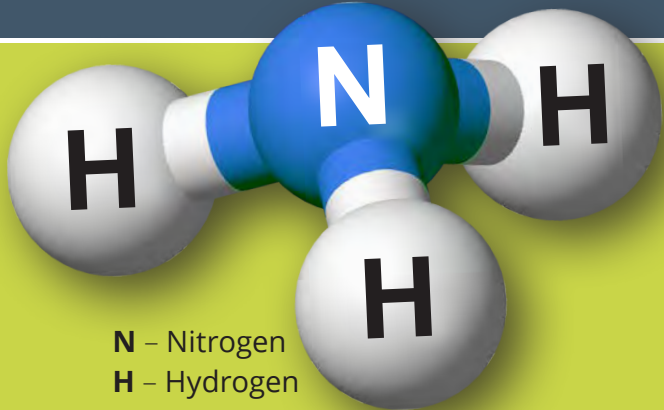
- Intermediate products delivered **\$39.2 billion in revenue**, creating **101,800 jobs** and **generating \$6.1 billion in payroll** (magnets, catalysts, metallurgical additives, polishing powders, glass additives, ceramics, and batteries).
- End market technologies **delivered \$259.6 billion in revenue**, creating **433,500 jobs** and **generating \$27.3 billion in payroll** (health care, hybrid electric vehicles, lighting, communication systems, audio equipment, defense systems, optics, oil refining, and wind power).
- In 2017, estimated prices for pure forms of **REEs ranged from \$14,000 per tonne** (Ce, La, and Sm) **to \$340,000,000 per tonne** (Tm).

U.S. REE USAGE



Fertilizer from Coal

Ammonia, which comprises one nitrogen atom and three hydrogen atoms (NH₃), is a colorless gas with a characteristically pungent odor. It is widely used as a fertilizer, and its derivatives can be applied to crops as a salt, solution, or anhydrously to provide the nitrogen nutrient plants need to grow. Globally, the vast majority of ammonia is used in nitrogen-based fertilizers. Nearly all nitrogen-based compounds are derived from ammonia, including urea, ammonium sulfate, and urea-ammonium nitrate (UAN).



POTENTIAL SUPPLY

- ▶ North Dakota’s annual consumption of nitrogen-based fertilizer is about 750,000 tons.
- ▶ Dakota Gasification Company in Beulah, North Dakota, produces about 400,000 tons/year.
- ▶ One ton of ammonia requires approximately 1.5 tons of coal.

Annual U.S. consumption of ammonia from 2012 to 2016 was about 13.7 million metric tons, of which 87% was consumed as fertilizer. The average U.S. ammonia price for 2016 was \$270/ton. From 2017 through 2020, it is expected that 3 million tons of annual production capacity (from natural gas) will be added in the United States and that this additional capacity will reduce, but likely not eliminate, ammonia imports.

TECHNOLOGY READINESS

Traditionally, ammonia is produced using the Haber-Bosch process which reacts hydrogen and atmospheric nitrogen at high temperature and pressure. The hydrogen reactant can be derived from a variety of sources, including the gasification of coal, reforming of natural gas, or electrolysis of water.

Developmental technologies are being pursued to reduce the cost and improve the energy efficiency of fertilizer production. With electrochemical (electricity-driven) processes, it may be possible to produce ammonia at lower temperature and pressure than the traditional Haber-Bosch process. These technologies are currently being developed at the bench and pilot scale.



Potential Economic and Employment Impact

COMPETING FACTORS

Regardless of how nitrogen fertilizers are produced, hydrogen is a critical component. Growing domestic natural gas production represents the greatest competition to coal as the hydrogen source for fertilizer production. Advancements in technology to extract hydrogen from coal represent an opportunity to increase coal-based fertilizer production.



PROCESS HEAT AND CO₂ USE IN AGRICULTURE

According to recent studies, greenhouse agriculture may be one of the most promising technologies to reduce carbon dioxide in the atmosphere. An under way project, funded by the North Dakota Industrial Commission, is examining the benefits of utilizing low-grade heat and CO₂ from a lignite-fired power plant and an ethanol production facility to support locally grown, fresh produce year-round.

Greenhouse agriculture has potential in North Dakota because of the high market value of its products. Productivity of such greenhouses is several times higher than traditional farming, so the extra cost could be recovered through the sale of the additional product produced. Potential benefits include economically viable and scalable agricultural production, creation of marketable CO₂ or flue gas products to the agricultural sector, job creation, and increased power plant efficiency. The goal is to create a model that can be duplicated at other lignite power plants and ethanol facilities in the state, providing a value-added boost that may result in tens of millions of additional revenue to the North Dakota economy.



Take-Home Message

U.S. lignite reserves are enormous, providing the United States with an 800-year supply at current utilization rates. Lignite is a critical component of the nation's inventory of strategic natural resources. Although nearly 80% of lignite is currently used to generate inexpensive electricity powering our nation's productivity and economy, a number of value-added products can also be derived from lignite. With ongoing research, this suite of value-added products will grow substantially in the near future.


WANT TO KNOW MORE?

The Lignite Energy Council is a leading promoter of national and international utilization of this valuable U.S. resource. The Lignite Energy Council is responsible for a great deal of public and corporate outreach on the topic of lignite utilization. Additional information can be found on our website at <https://lignite.com/>.

The value-added products described here represent only some of the opportunities that exist for the lignite industry in North Dakota. Research and development work is ongoing in a variety of areas to explore the production of other carbon-based materials from lignite. These materials include carbon fiber for manufacturing lightweight materials as well as activated carbon and carbon nanotubes.

Lastly, certain approaches and applications enhance lignite-fired electrical generation in North Dakota. Some of these approaches, which warrant additional study and evaluation by the North Dakota Industrial Commission and the Lignite Energy Council, include:

- Commercial-scale data center operations that take advantage of North Dakota's low cost of electricity and efficient cooling from winter temperatures and geothermal cooling resources.
- Plug-in electric vehicles that can provide a valuable demand-side management tool for power plant and grid stability while providing a reliable alternative to internal combustion engines.



JASON BOHRER
President & CEO

Jason Bohrer's background as an attorney, a communications director for the Idaho Republican Party, and chief of staff to U.S. Representative Raul Labrador (R-Idaho) provide a diverse skill set in his role as President and Chief Executive Officer of the Lignite Energy Council. He is a graduate of North Dakota State University and earned his law degree from George Mason University. Prior to joining the Lignite Energy Council in 2013, Bohrer worked 9 years in Washington, D.C.



MIKE HOLMES
Vice President of Research
and Development

Mike Holmes is Vice President of Research and Development for the Lignite Energy Council. Prior to joining the Lignite Energy Council, he served as Director of Energy Systems Development at the Energy & Environmental Research Center in Grand Forks, where he oversaw fossil energy research areas. His principal areas of interest and expertise include CO₂ capture; fuel processing; gasification systems for coproduction of hydrogen, fuels, and chemicals with electricity; process development and economics for advanced energy systems; and emission control technologies.

