VALUE-ADDED OPPORTUNITIES FOR NORTH DAKOTA LIGNITE

Lignite Energy Council

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, a younger form of the same coal materials found in Wyoming, Kentucky, Pennsylvania, and other areas.

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

50–70 million years ago.

VALUE-ADDED PRODUCTS FROM LIGNITE

Nearly 80% of lignite mined in North Dakota is used in generating electricity.

However, lignite as a raw material is also used in many other products, and research will expand the suite of value-added products from lignite.

How Lignite is Used

- **79%** Electricity Generation
- **13%** Synthetic Natural Gas Generation
- **7%** Fertilizer Products
- **1%** Home Heating and Oil Well Drilling Mud

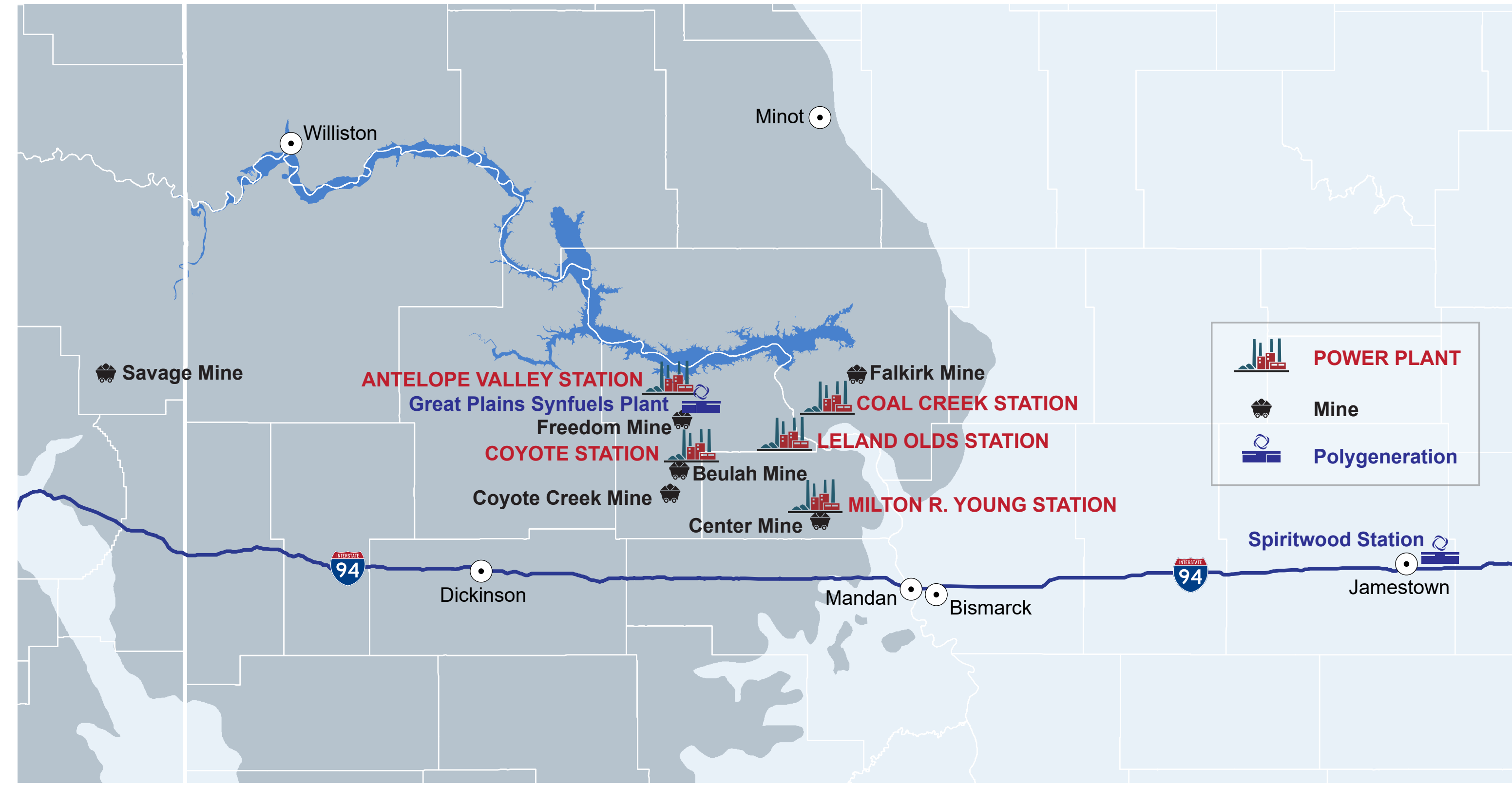
2 MILLION
Consumers and Businesses in the Upper Midwest Use Lignite-Generated Energy

400,000
Homes and Businesses in the East Use Coal-Derived (synthetic) Natural Gas

Rare-Earth Elements

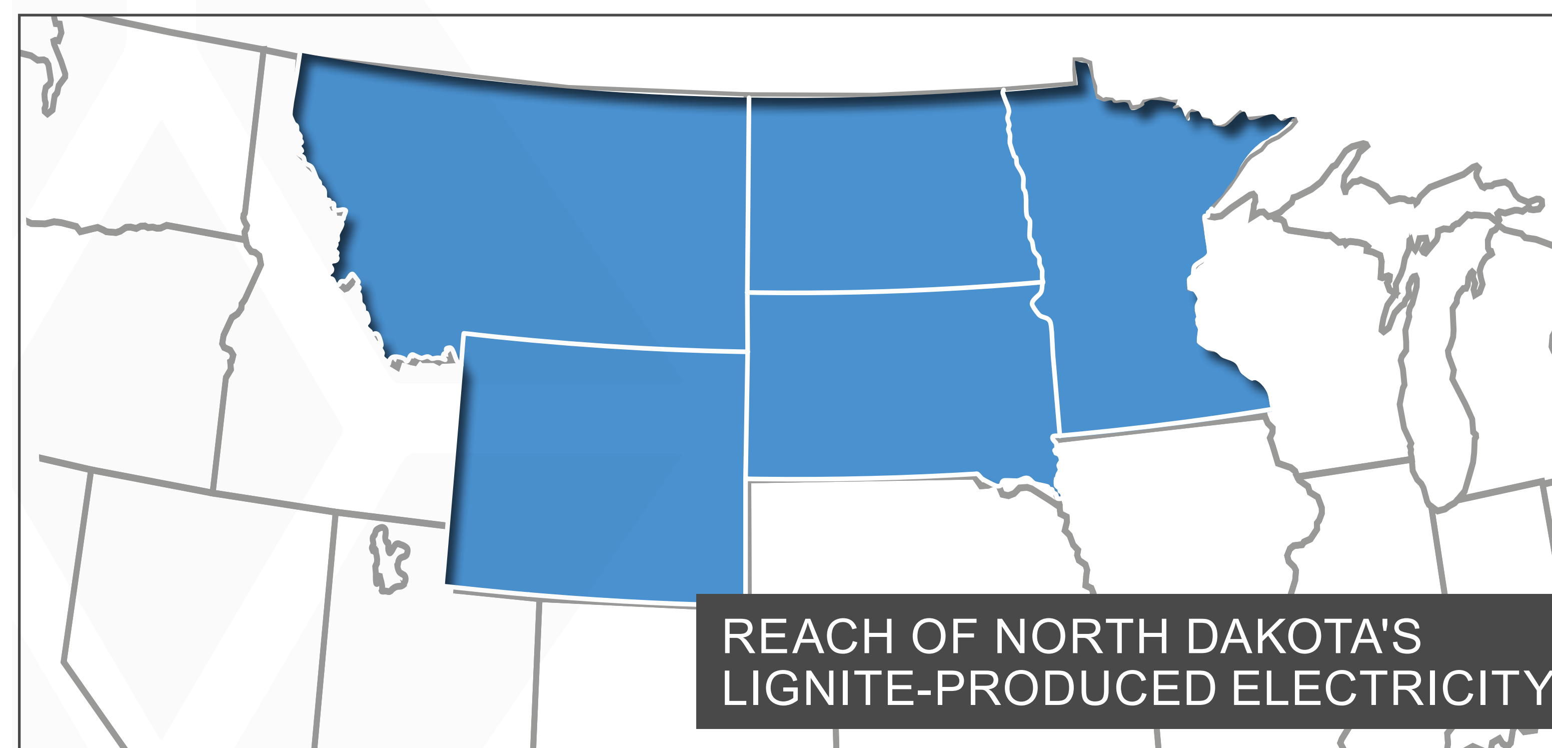
Pr Nd Gd Tb Dy Sc Y

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.



At about 30 million tons of lignite mined annually, North Dakota is a top coal-producing state. At current usage, our economically recoverable lignite reserves constitute an 800-year energy supply. Lignite 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.

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.



REACH OF NORTH DAKOTA'S LIGNITE-PRODUCED ELECTRICITY

ELECTRICITY

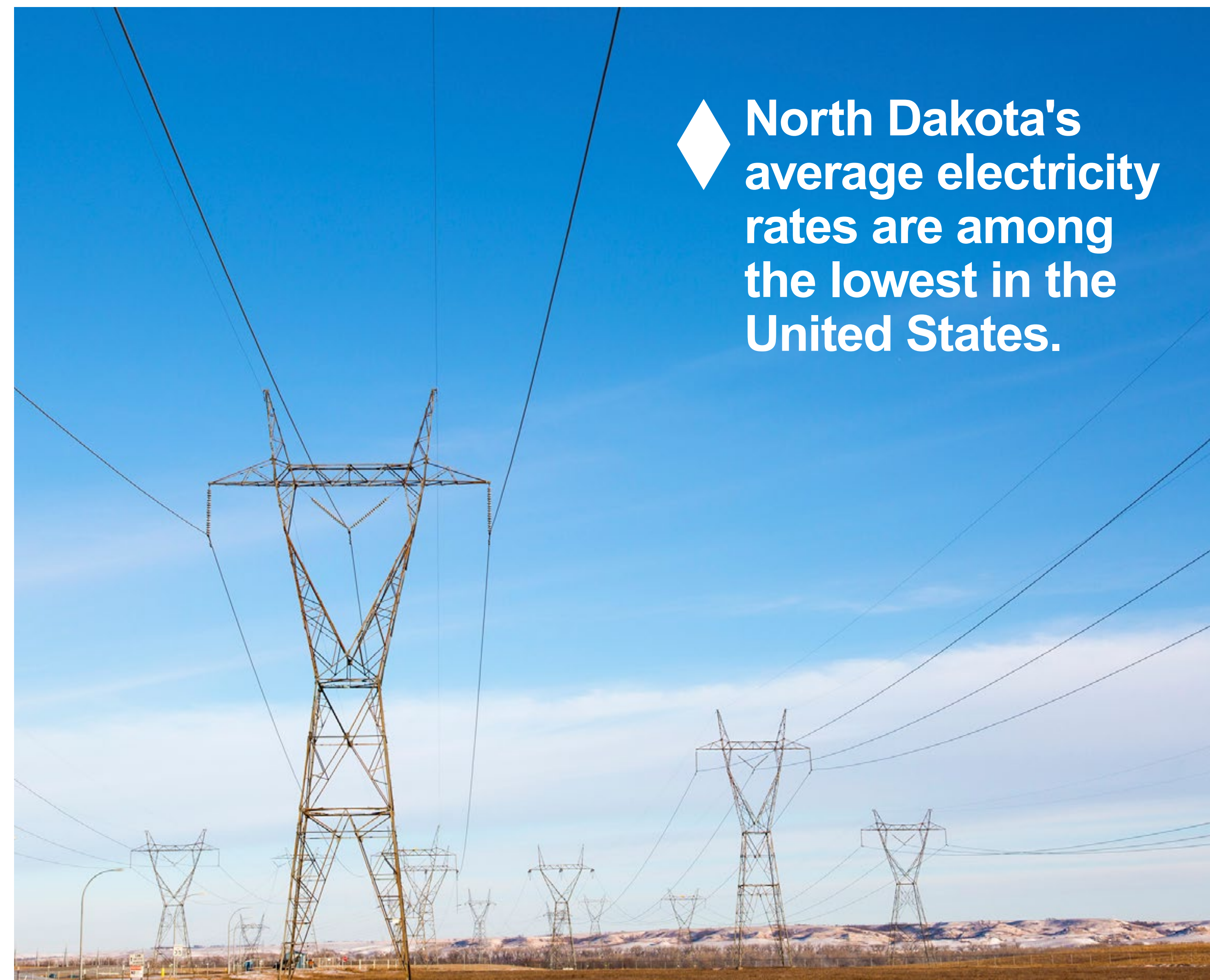
In recent years, coal-based electrical generation has decreased nationally because of economic and regulatory factors. To maintain and expand lignite markets, the North Dakota Industrial Commission and Lignite Energy Council are supporting the efforts to develop and commercially deploy new lignite-based technologies that leverage the unique chemistry of lignite and existing lignite industry infrastructure, partnerships, and agreements.

This document summarizes several current and new lignite value-added scenarios.

Antelope Valley Station near Beulah, North Dakota

NORTH DAKOTANS BENEFIT IN MULTIPLE WAYS FROM AFFORDABLE AND RELIABLE POWER GENERATED AT THE STATE'S LIGNITE-BASED POWER PLANTS.

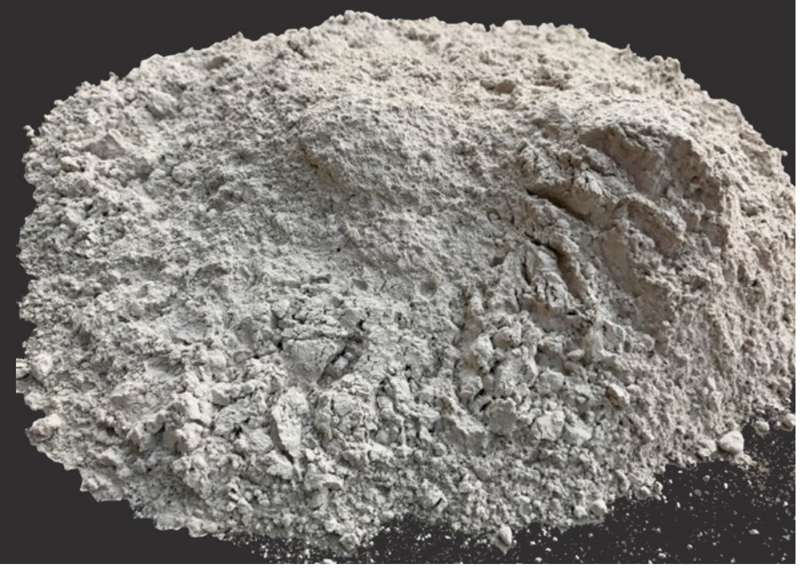
- Low-cost electricity translates to lower operating expenses for agricultural, manufacturing, and petroleum industries, enabling their commercial competitiveness on an international level. This low cost also attracts new business and helps retain existing companies.
- Low-cost electricity is particularly beneficial to our region. Even though we consume high amounts of energy because of our weather extremes, we enjoy some of the lowest electricity rates in the nation.



VALUE-ADDED PRODUCTS FROM LIGNITE POWER PLANTS

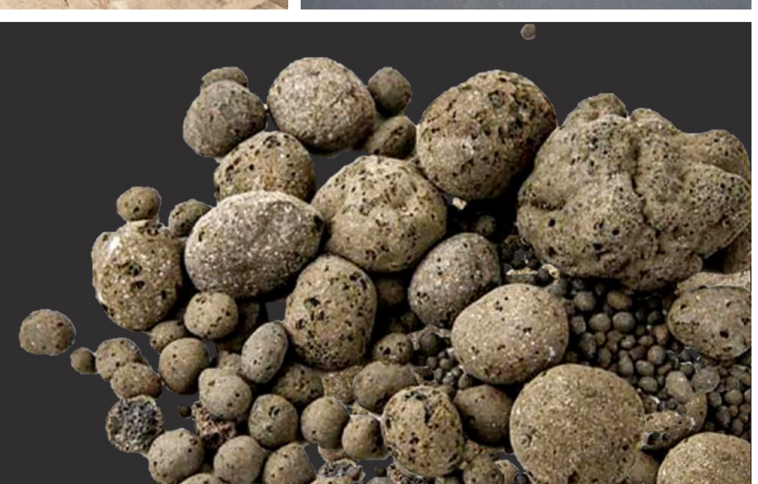
FLY ASH CONCRETE

Fly ash is a particulate by-product of coal combustion. When used instead of cement, fly 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.



BOTTOM ASH

Another by-product of coal combustion is “bottom ash.” These heavier particles collect on the bottom of the furnace. Bottom ash can be used as aggregate in road bases, pavement, and cement. It serves as a good alternative to sand for roads in the winter and is also sold for use in roofing materials.



HEAT FOR ETHANOL PRODUCTION

As coal is combusted to generate electricity, a portion of the heat produced is often unused. New innovative means of using/monetizing this heat are being explored and deployed. One example is the Dakota Spirit ethanol plant at Spiritwood Station. By strategically integrating the power plant excess heat resource with the ethanol plant process heat requirements, the need for an expensive ethanol plant boiler system was eliminated, translating to decreased capital cost, annual multimillion-dollar fuel cost savings, and reduced emissions.

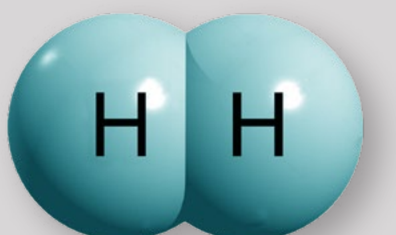
DRYFINE™ BENEFICIATED COAL

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.

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 plastics.



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 (EOR) and associated CO_2 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.

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.

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

EOR, greenhouse agriculture

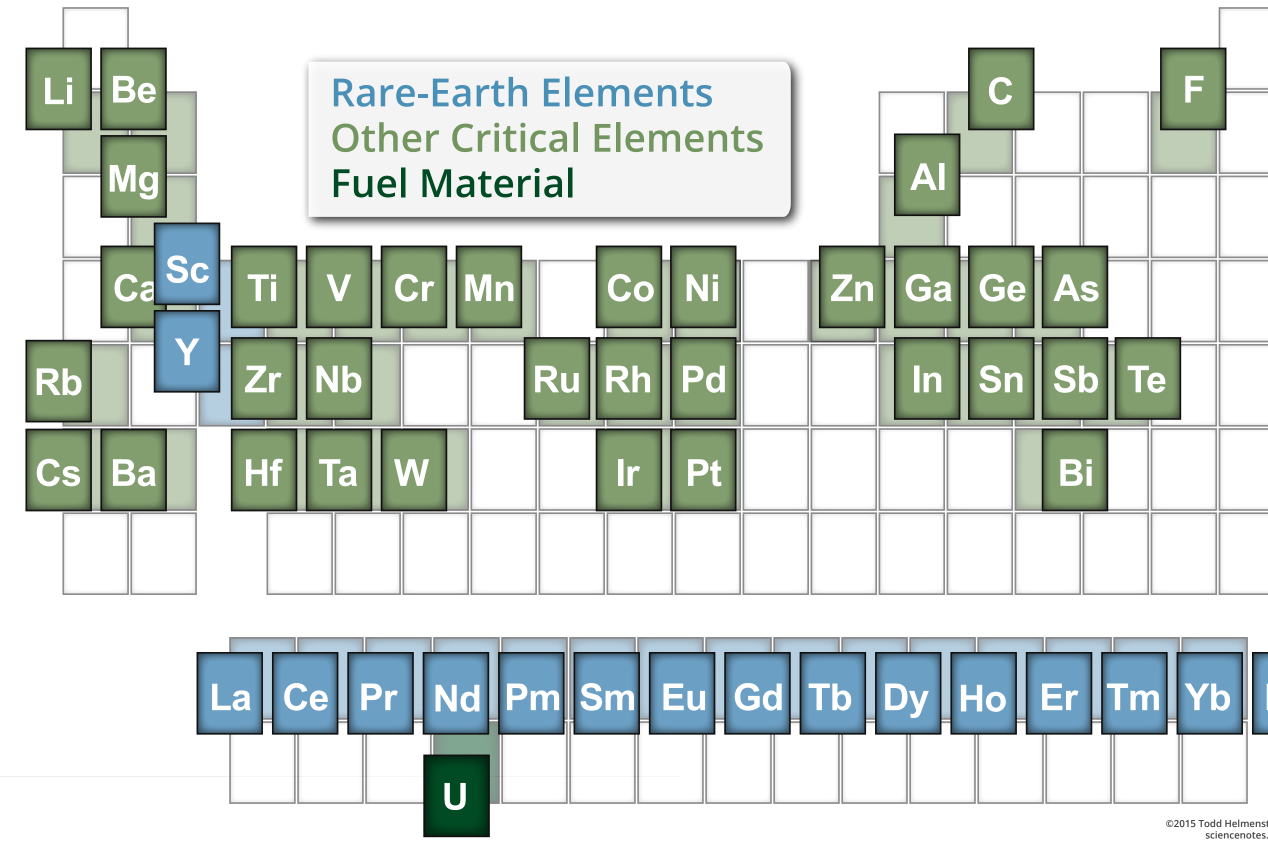
♦ FERTILIZER

Urea, ammonia, ammonium sulfate

EMERGING VALUE-ADDED PRODUCTS

In addition to its current uses, North Dakota lignite offers numerous additional value-added opportunities.

As demand for REEs and other critical metals increases, the North Dakota lignite industry is uniquely positioned to fuel the drive to U.S. self-sufficiency in these economic/national security critical materials. By strategically leveraging permitted and paid-for lignite mining and processing infrastructure, technologies, and expertise, the North Dakota lignite industry could lead development of a new high-value, sustainable, and expandable economy based on lignite as carbon ore.



Rare-Earth Elements	$/pound (2017)	Conc., ppm, ND Lignite*	Import Reliance, %
Scandium – Sc	900	41	100
Yttrium – Y	4	213	100
Lanthanum – La	1	163	100
Cerium – Ce	1	314	100
Praseodymium – Pr	25	37	100
Neodymium – Nd	18	145	100
Samarium – Sm	1	32	100
Europium – Eu	93	7	100
Gadolinium – Gd	9	40	100
Terbium – Tb	204	6	100
Dysprosium – Dy	103	39	100
Holmium – Ho	25	7	100
Erbium – Er	32	22	100
Thulium – Tm	454	3	100
Ytterbium – Yb	23	18	100
Lutetium – Lu	499	3	100
		Total – 1089**	

Other Critical/Valuable Metals in ND Lignite	$/pound (2017)	Conc., ppm, ND Lignite*	Import Reliance, %
Cobalt – Co	14	18	76
Gallium – Ga	89	17	100
Germanium – Ge	798	18	50
Vanadium – V	8	137	96
Thorium – Th	115	16	?
Nickel – Ni	5	36	?
Molybdenum – Mo	5	19	?
Copper – Cu	3	67	?
For Comparison: Silver – Ag	204		80

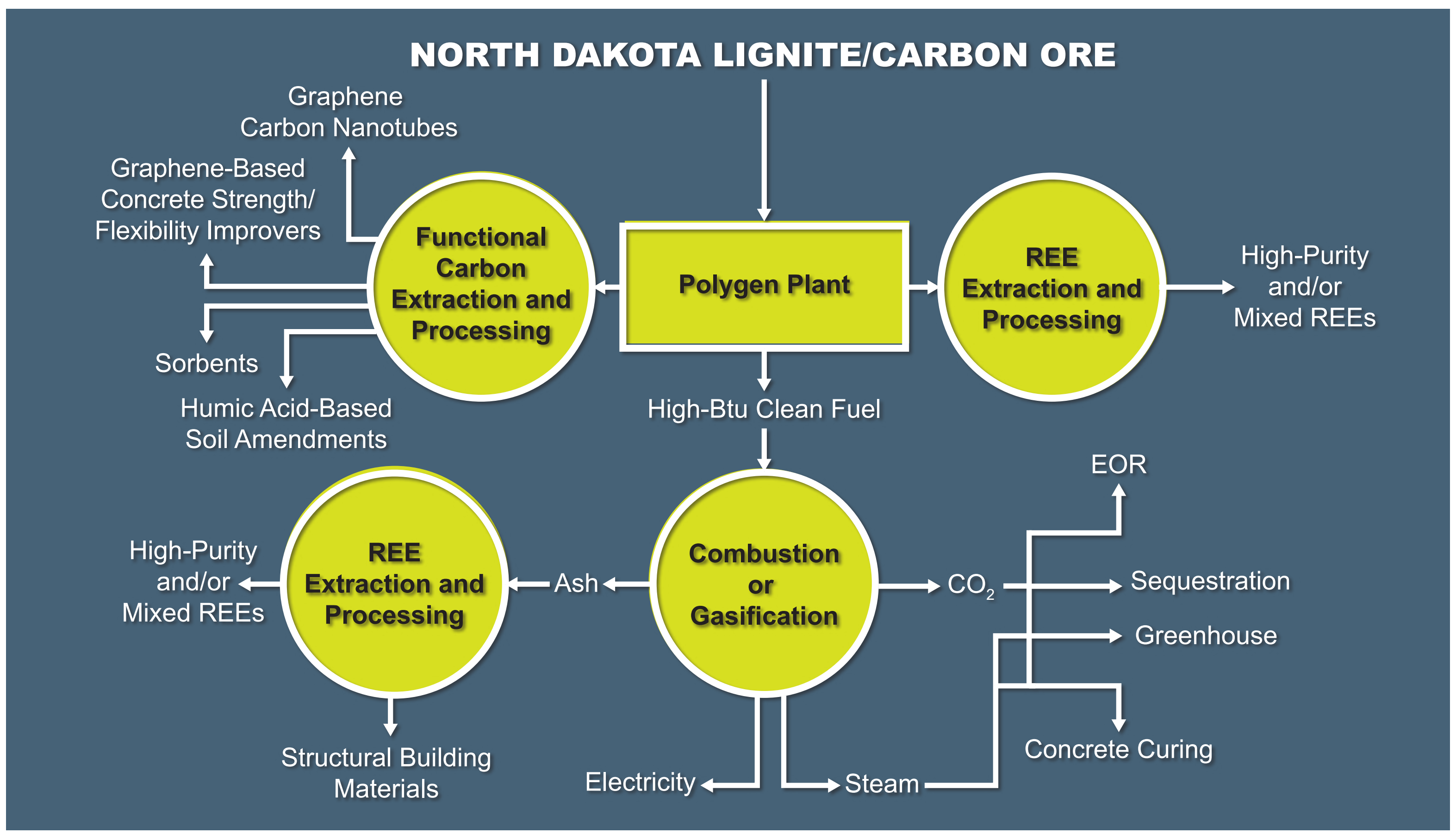
* Harmon–Hanson coal combustion ash.

** According to the U.S. Geological Survey (USGS), total rare-earth concentration of at least 300 ppm is economically significant.

LIGNITE/CARBON ORE POLYGEN PLANT

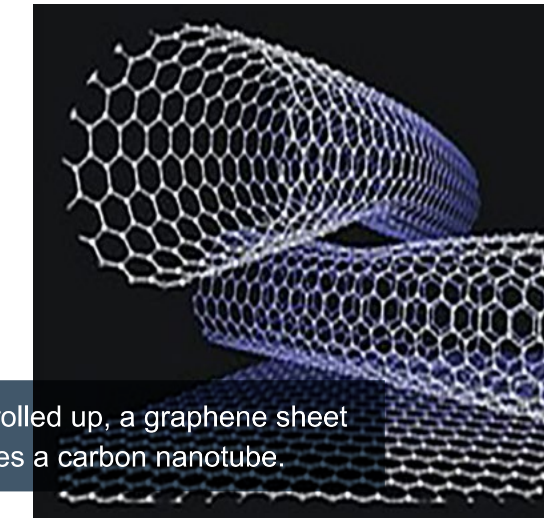
The Oxford Dictionary defines ore as "a naturally occurring solid material containing a precious or useful metal in such quantity and chemical combination as to make its extraction profitable." Unlike traditional ore mining/refining operations that yield small quantities of high-value metals and lots of negative-value waste, lignite carbon ore polygeneration (polygen) plants will yield:

- High-value REEs and other critical metals identified by the U.S. Interior Department as *"…vital to the Nation's security and economic prosperity."* Many of these critical metals are present in North Dakota lignite in economically significant concentrations.
- Graphene, carbon nanotubes, and other highly structured "functional carbons" with valuable properties that enable emerging energy, electrical, biotechnology, imaging, laser, and fiber optic technologies.
  - Use of less structured graphene materials to improve concrete strength, flexibility, and durability is increasingly being demonstrated and offers potential as a major market for lignite-derived graphene.
- High-performance carbon-based sorbents and water-conserving soil amendments.
- Electricity from combustion or gasification of high-Btu clean fuel.
- CO_2 for concrete curing, EOR, greenhouses for year-round produce and other ag products, and subsurface sequestration.
- Concrete and composite building materials from coal ash.
- Minimal waste.

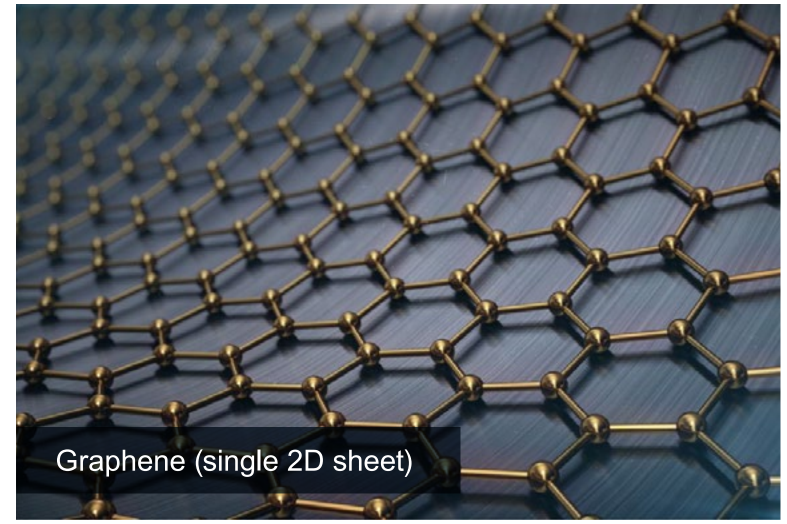


WHAT IS GRAPHENE?

Another value-added product from coal, graphene could open new markets in nonenergy sectors such as electronics, optical devices, lightweight farming tools, military equipment, etc.



When rolled up, a graphene sheet becomes a carbon nanotube.

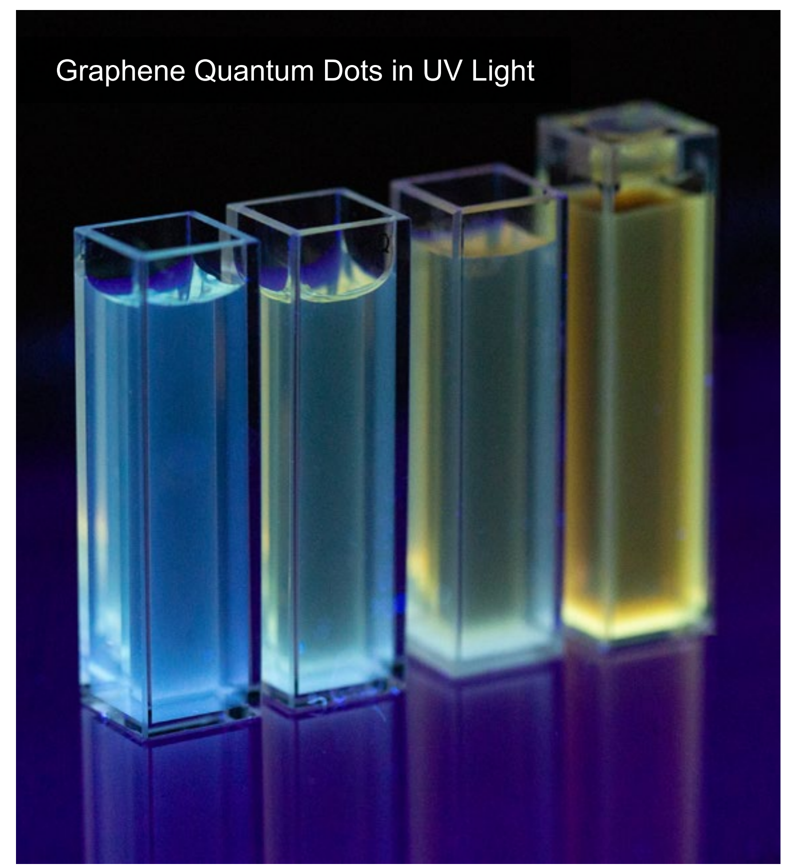


Graphene (single 2D sheet)

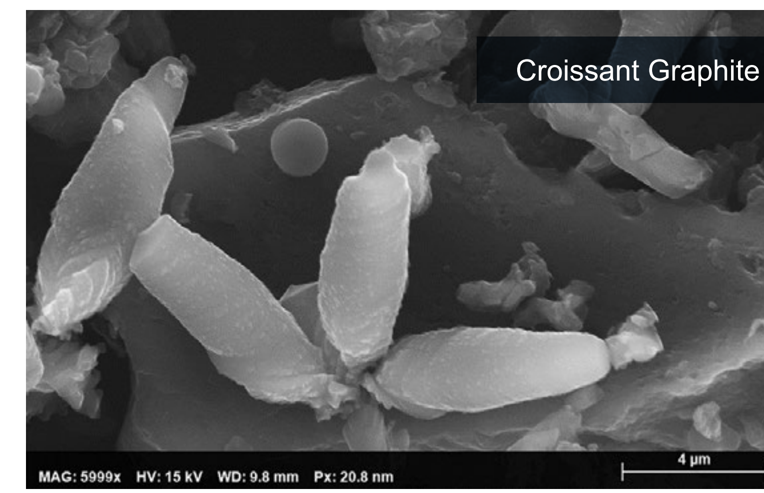
GRAPHENE IS A CARBON-BASED 2D MATERIAL WITH A THICKNESS OF ONE ATOM.

Reduced Graphene Oxide

Graphene Oxide



Graphene Quantum Dots in UV Light



Croissant Graphite

Graphene Quantum Dots in White Light

AUTOMOTIVE HYBRID TECHNOLOGY IS TOTALLY DEPENDENT ON PHOSPHORESCENT REEs

The REEs comprise a group of 17 metals with structural–electronic commonalities that translate to valuable magnetic, phosphorescent (light emission without heat emission), and catalytic properties. In November 2020, the U.S. Department of Defense announced contracts and agreements with REE producers to support and strengthen the domestic REE supply chain.

REEs – Key Applications

MAGNETICS

Nd Tb Dy Pr

Computer Hard Drives
Disk Drive Motors
Anti-Lock Brakes
Frictionless Bearings
Microwave Power Tubes
Power Generation
Communication Systems
MRIs (magnetic resonance imaging)

METAL ALLOYS

Nd Y La Ce Pr Sc

NiMH Batteries
Fuel Cells
Super Alloys
High-Power-Density Rechargeable Batteries

DEFENSE

Nd Eu Tb Dy Y Lu Sm Pr La Sc

Satellite Communications
Guidance Systems
Aircraft Structures
Fly-by-Wire
Smart Missiles

PHOSPHORS

Nd Eu Tb Y Er Gd Ce Pr Sc

Display phosphors – CRT, LPD, LCD
Fluorescent Lighting
Medical Imaging
Lasers
Fiber Optics

According to the USGS 2021 Mineral Commodity Summary report, the United States is 100% import-reliant on REEs and other critical metals, with the bulk of imports coming from China. Chinese dominance in the REE market is due, in large part, to possession of a unique minable clay resource that contains high concentrations of REEs in the form of adsorbed ions, making their extraction and refining simple and cheap versus most other REE resources. Because these REE-rich clay reserves are projected to run out in about 15 years, building a domestic REE mining, concentration, and refining industry is critically important to U.S. technology leadership, manufacturing industries, and defense.

Numerous North Dakota lignite seams contain REEs in concentrations exceeding 300 parts per million (ppm), the USGS-established threshold for an economically significant REE resource. North Dakota lignites also contain economically significant concentrations of other critical minerals, including Ga, Ge, Nb and In. Many lignite-containing REEs and other metals are chemically bound in ways that make their extraction simpler and cheaper than extraction from traditional U.S. ore resources.

REEs from North Dakota Carbon Ore Polygen Plant vs. Traditional Hard Rock Mining Operation

	Carbon Ore Polygen Plant	Hard Rock Mine
Mine Permitting, Regulatory Approvals, Financing	Done	About 8 years $ millions (studies, legal filings) No guarantee of success
Mining Infrastructure	In place, paid for	Design/construction – 2 years
Ore Processing for REE Extraction/Purification – Techno-Economics	Accessible, weaker REE–lignite bonding chemistry translates to simpler/cheaper processing	Complex, stronger REE–ore bonding chemistry means more complex/expensive processing
Mining/Processing Environmental Economics	Lignite chemistry translates to reduced strong acid use, less toxic waste generation, risk, cost	Ore chemistry requires high consumption of strong acids, more toxic waste, risk, cost
Coproduct(s)	Diverse coproduct slate means high economic resiliency	No coproducts means limited responsiveness to market swings
REE Concentration in Ore	1000 ppm[1]	5000–25,000 ppm[2]

[1] Measured in Slope County lignite seam; with possible exception of single Appalachian coal seam, highest measured REE concentration in U.S. coal resource to date.

[2] Reported REE concentrations in operating or under-consideration hard rock mining projects around the world.

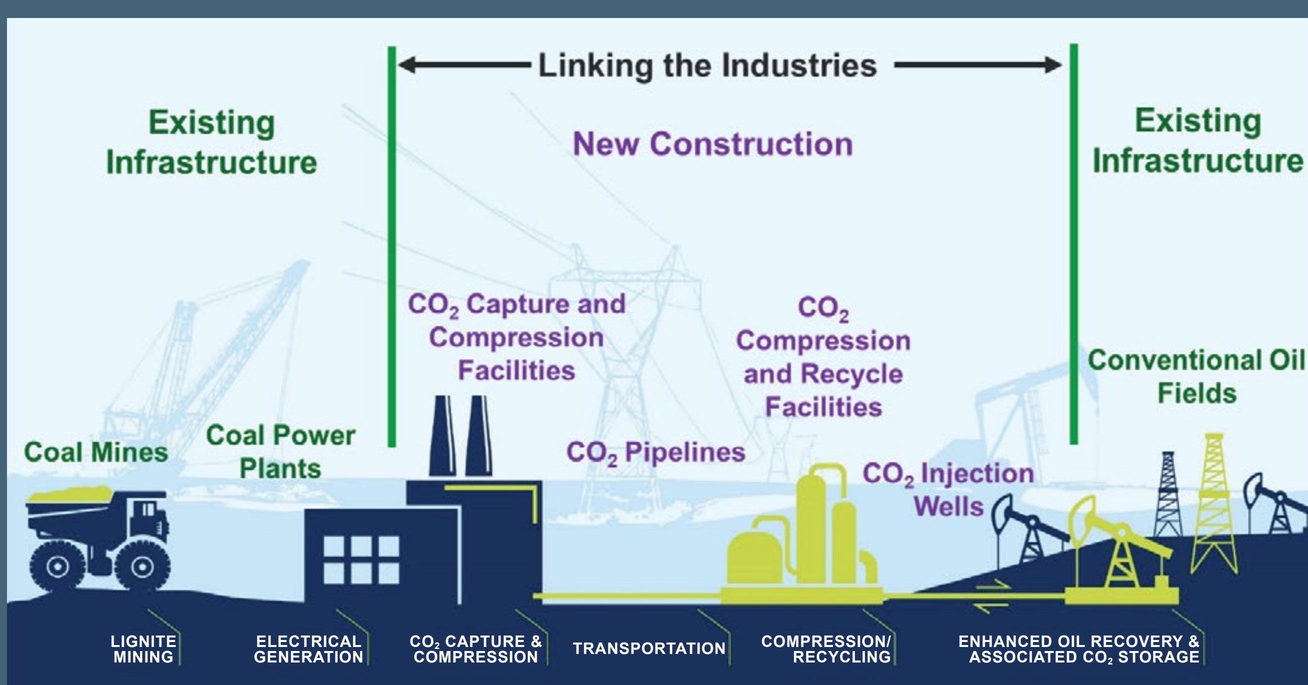
PROJECT TUNDRA

The objective of Project Tundra is to build the world's largest carbon capture facility at the Milton R. Young Power Plant, Center, North Dakota, and permanently store 4 million metric tons of CO_2/year in mile-deep geologic formations. Storage at this rate would be equivalent to taking 800,000 gasoline-fueled vehicles off the road every year. North Dakota geology is ideal for safe and permanent geologic storage of carbon dioxide.

The world's largest CO_2 capture facility is in North Dakota.

Currently, Project Tundra is completing front-end engineering and design (FEED) to establish CO_2 capture technology performance, capacity, and integration requirements and estimate capital and operating costs. Operational parameters for CO_2 injection and underground storage were studied to ensure safe injection of pressurized CO_2, protection of groundwater resources, and accurate monitoring of injected CO_2 to ensure it remains in the storage zone. As a result, the North Dakota Industrial Commission granted underground injection control Class VI permits to store the CO_2.

Carbon capture, utilization, and storage (CCUS) is a critical component of maintaining, diversifying, and expanding the North Dakota lignite industry. CCUS deployment would link and strengthen two major North Dakota economic drivers: power generation and oil production and enable new industry development.



POWER GENERATION + ENHANCED OIL PRODUCTION

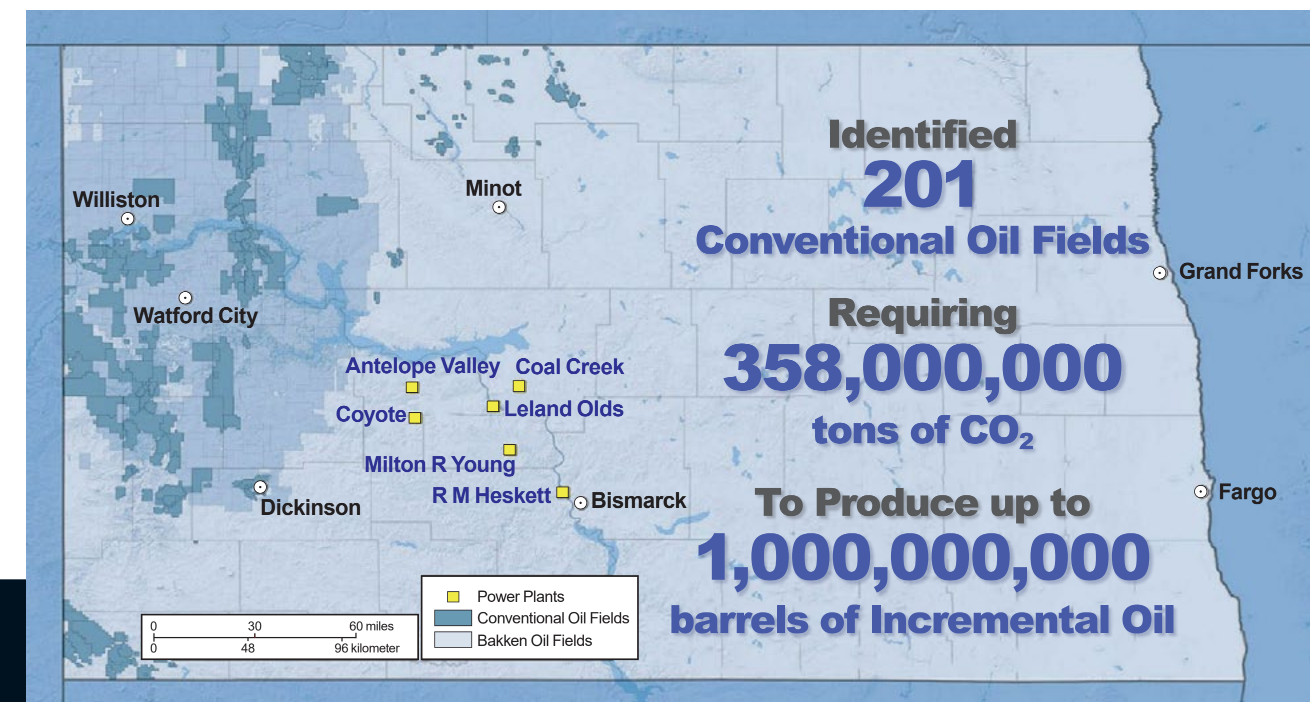
Linking two major North Dakota industries boosts oil production, increases state revenues, and creates jobs.

Under U.S. Internal Revenue Code Section 45Q, captured CO_2 used for EOR or other profit-making purpose is worth a tax credit of \$35/metric ton (1000 kilograms or 2200 pounds), while the credit for CO_2 sequestered (permanently stored) in appropriate subsurface geologic formations is \$50/metric ton. These federal tax credits are available to CO_2 capture projects that start construction prior to 2026. The fact that Congress passed 45Q with overwhelming bipartisan support indicates good prospects for its extension.

Economic modeling conducted by the EERC and North Dakota State University in 2019 projected that linking the North Dakota power and oil industries through CO_2 capture and conventional oil field EOR could:

- Generate economic activity of \$2.5 billion – \$3 billion/year.
- Provide \$160 million/year in state revenue.
- Create/sustain 8000 jobs.

In terms of CO_2-based EOR, this is just the beginning. Research is under way on how to most efficiently deploy EOR technologies to increase reservoir yields from the unconventional "tight" Bakken formation currently being tapped via fracking.



Access to high-volume, dependable-supply, affordable CO_2 opens up possibilities for new industries, including concrete curing and greenhouse agriculture.

CURING CONCRETE WITH CO_2

Concrete comprises three primary components:

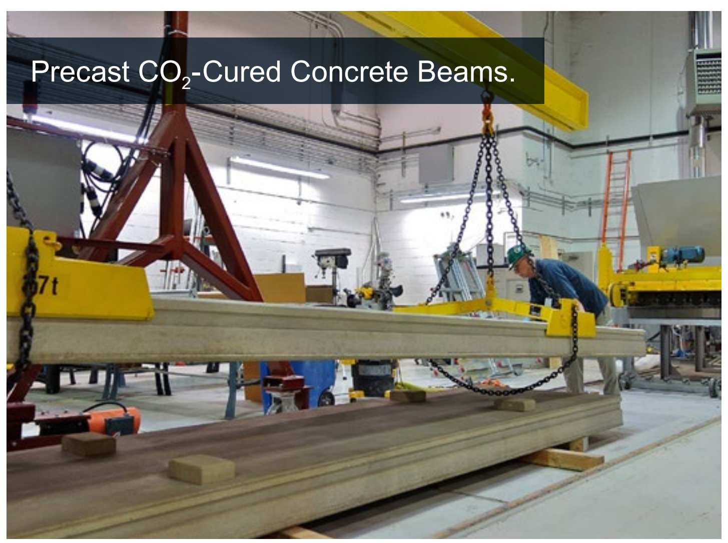
- Cement—powder that chemically reacts with water in hydration/curing reactions to yield a paste that hardens and holds concrete together.
- Aggregate—sand, gravel, and/or other hard solids that are bound in a hardened cement matrix.
- Fresh/pure water—required to ensure proper hydration/curing, since impurities (even at low concentrations) can interfere with curing reactions, yielding weaker concrete.

The concrete industry accounts for 6%–8% of total global CO_2 emissions. In addition to high CO_2 intensity, the concrete industry accounts for about 2% of total global freshwater use. While much of this total is used in the manufacture of cement, about 13% is consumed in concrete-curing reactions.

Curing concrete with CO_2 rather than water would eliminate a significant portion of annual CO_2 emissions to the atmosphere (by permanently sequestering CO_2 in concrete) and save a significant amount of fresh water.

CO_2 curing techniques have been demonstrated to yield concrete blocks and other structural building materials with higher compressive strength and fire resistance than water-cured concrete, at faster curing rates.

CO_2-cured concrete products can contain up to 18 weight percent CO_2. In 2019, global concrete production was about 4.4 billion tons. Curing half of this concrete with CO_2 would translate to permanent sequestration of 800 million tons of CO_2 per year.


Precast CO_2-Cured Concrete Beams.


CO_2-Cured Concrete Blocks


Precast CO_2-Cured Concrete Railroad Ties


Firetruck on CO_2-Cured Concrete Pavers

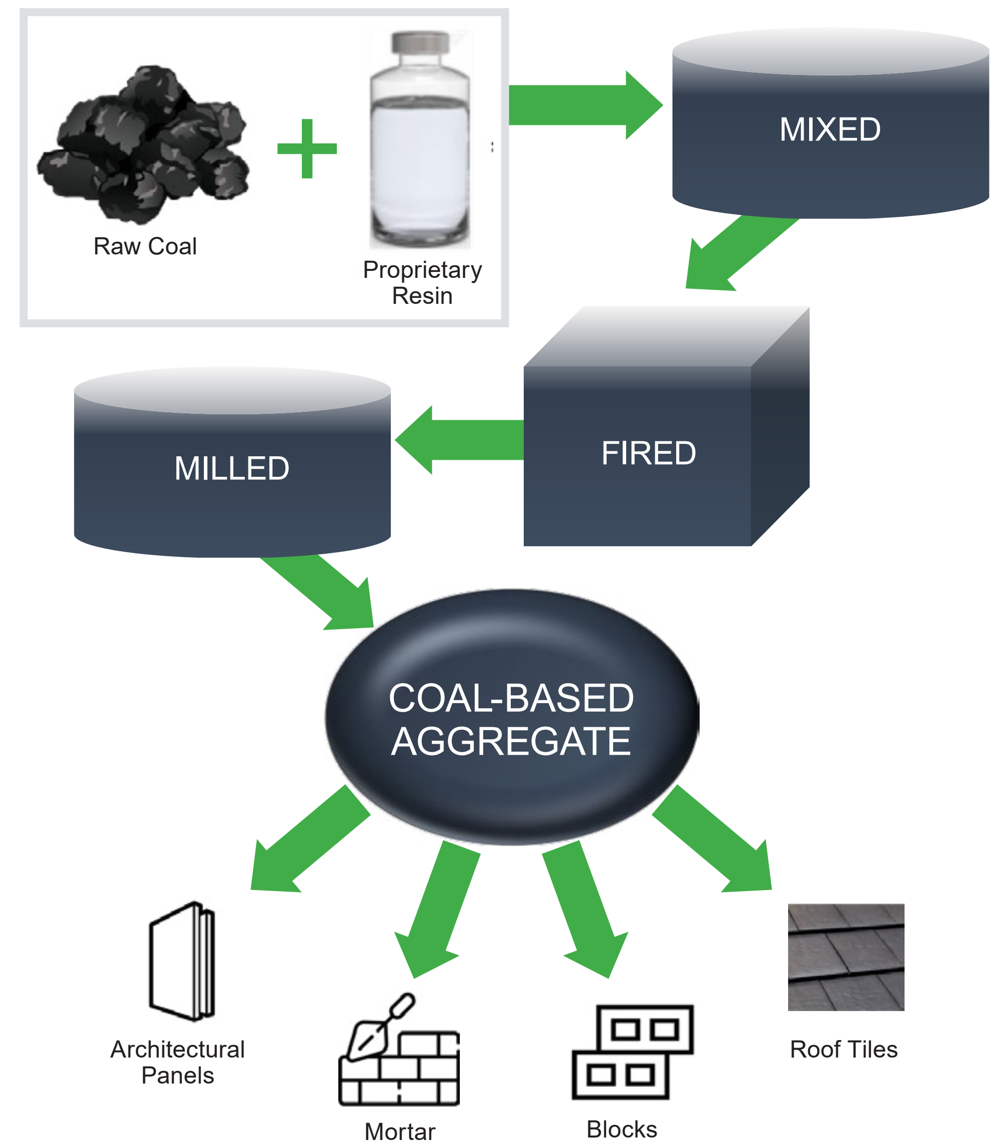
COAL-BASED ENGINEERED AGGREGATE

Coal-based engineered aggregate is coal powder or coal waste mixed with proprietary inorganic polymers.

Products made with coal-based engineered aggregate are comparable to the commercially available products they compete with, such as bricks, concrete blocks, roofing tiles, and architectural panels. However, these coal-based products produce less CO_2 during manufacture while producing a product that has:

- Superior mechanical strength and lower weight.
- Greater hardness and improved toughness.
- Greater chemical and abrasion resistance compared to standard concrete products.

Any type of coal from lignite to anthracite has been shown to work.



ND-GROWN FRESH PRODUCE ALL WINTER?

In 2017, about 50 miles north of the U.S.–Canada border in the small town of Coaldale, Alberta, a company called Whole Leaf built a 6-acre greenhouse and initiated commercial production and distribution of multiple varieties of lettuce. The weather in Coaldale is similar to the weather in western North Dakota. Today, the company operates over 11 acres of northland greenhouses, providing lettuce and other vegetables to regional and North American markets year-round.

Rather than using native Alberta soil, the greenhouses grow produce in mined Canadian peat, enabling water consumption reduction by 70%–90% versus field-grown produce. Weathered/oxidized North Dakota lignite (leonardite) is similar to Canadian peat.

North Dakota leonardite coals contain high levels of easily extractable humic and fulvic acids. Because of their carboxylic acid-based chemistry, when added to agricultural soils, humic/fulvic acids effect beneficial chemical changes that result in:

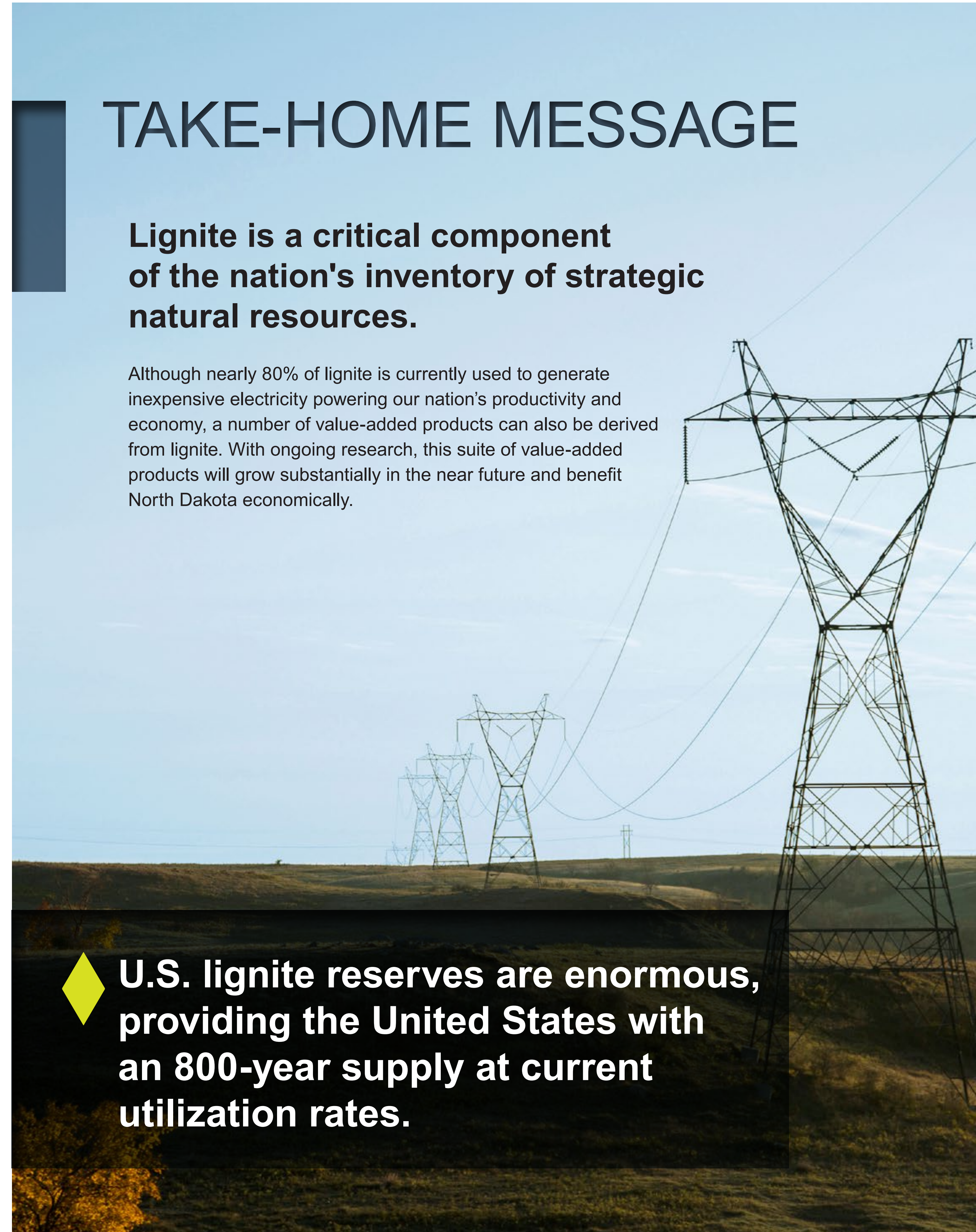
- Improved soil structure, which translates to increased water-holding capacity.
- Enhanced soil cation exchange capacity (CEC) for increased nutrient availability.
- Increased growth of beneficial microorganisms.
- Reduced nutrient leaching (removal).
- Enhanced pH buffering capacity, preventing salinization of soil.

Whole Leaf greenhouses and associated processing facilities created about 130 new full-time jobs, and the company recently secured a contract with Wendy's to provide greens for Canadian Wendy's locations. Other viable high-value greenhouse outputs are fruits, trees, natural supplements/herbs, and cannabis.

A major energy company recently conducted a detailed economic assessment of building and operating a 40-acre greenhouse integrated with a small power plant in Saskatchewan. Power plant inputs to the greenhouse included electricity, heat/steam, humidity, and CO_2. Outcomes of the assessment are:

- Cost of building a 40-acre greenhouse with insulated walls and clear roof – $55 million.
- Depending on produce type, about 85,000 gallons/day irrigation-quality water required.
- 4–6 MW of power needed for high-intensity LED lighting: more in winter, less in summer.

Imagine locally grown fresh tomatoes, peppers, cucumbers, greens, berries, and grapes available in North Dakota in January. By strategically integrating steam/heat, water, and CO_2 streams from North Dakota power plants with colocated greenhouses, produce can be grown year-round.



TAKE-HOME MESSAGE

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 and benefit North Dakota economically.

U.S. lignite reserves are enormous, providing the United States with an 800-year supply at current utilization rates.

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.

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 **www.lignite.com**.

Lignite Energy Council

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 CO_2 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.

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