Future of coal

Solutions for Today | Options for Tomorrow

Chris Nichols
Analyst, Systems Engineering and Analysis

Associated Governments of NW Colorado
Board Meeting
July 17, 2019
Presentation overview

• Who am I and what is NETL?
• Trends in US energy production and use – historic and projected
• The future of coal – power, beneficiation and exports
• How to work with NETL
• Q&A
National Energy Technology Laboratory (NETL)

Mission
Discover, integrate and mature technology solutions to enhance the Nation's energy foundation and protect the environment for future generations

Vision
Be the Nation’s renowned fossil-energy science and engineering resource, delivering world-class technology solutions today and tomorrow

- Effective Resource Development
- Efficient Energy Conversion
- Environmental Sustainability
- Technology Convener
- Knowledge and Technology Generation Center
- Responsible Steward
**NETL Snapshot**

**NETL** is...

900+ R&D projects/50 states

3 labs across U.S.

$1.03B FY19 budget

**NETL** possesses an array of authorities to manage & implement complex R&D programs

- Program planning, development, and execution
- Legal, Financial, Procurement and Head of Contracting Authority (HCA)
- Project Management Expertise

**Workforce**

1,234 Full Time Equivalent Employees (FTEs)

78 Joint Faculty

124 Postdoctoral Researchers

101 Graduate Students

43 Undergraduate Students

460 Federal

774 Contractor

FTE WORKFORCE
### Core Competencies & Technology Thrusts

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<td>Carbon Storage</td>
<td>Carbon Capture</td>
<td>Sensors &amp; Controls</td>
<td>Advanced Materials</td>
<td>Advanced Computing</td>
<td>Water Management</td>
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<td>Coal</td>
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<td>Rare Earth Elements</td>
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<td>Enhanced Resource Production</td>
<td>Environmentally Prudent Development</td>
<td>Methane Hydrates</td>
<td>Offshore</td>
<td>Natural Gas Infrastructure</td>
<td>Unconventional</td>
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<td>Oil &amp; Gas</td>
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<td>Cybersecurity</td>
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<td>Support to Other DOE Offices</td>
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Technology Development Pathway

An Active Portfolio from Concept to Market Readiness

COMMERCIALIZATION
- Technology available for wide-scale market use

DEMONSTRATION
- System demonstrated in operational environment

SYSTEM TESTING
- System performance confirmed at pilot-scale

DEVELOPMENT
- Technology component validated/integrated

DISCOVERY
- Concept identified/proven at laboratory-scale

 TECHNOLOGY MATURATION

- Fundamental Studies

- Scale
- Technology Confidence
- Investment
- Private Sector Cost Share

KNOWLEDGE-BASED DECISION MAKING
- Systems Engineering and Integration
  - Engineering analysis
  - Pre-FEED/FEED studies
  - NEPA
- Decision Science and Analysis
  - Screening studies
  - Techno-economic analysis
  - Technology Readiness Assessments
From Discovery to Commercialization

Petra Nova CO2 EOR CCS Plant

Technology Maturation

Government – Industry Partnership to Commercialization

Industry Leading the Effort

Scale Technology Confidence Investment

TRL 1 - 3

DISCOVERY

Concept identified/proven at laboratory-scale

TRL 4 - 5

DEVELOPMENT

Technology component validated/integrated

TRL 6 - 7

SYSTEM TESTING

System performance confirmed at pilot-scale

TRL 8

DEMONSTRATION

System demonstrated in operational environment

TRL 9

COMMERCIALIZATION

Technology available for wide-scale market use

2016

Full Scale Commercialization

2011

First-of-a-kind Integrated Coal CCS Small Commercial Scale Plant

2008

Pre-Commercial Prototype Validated in Relevant Environment

1994 & 1999

Component/Subsystem Validated – KM CDR Process and Improved Process Validated

Early 1990s

Proof-of-Concept Developed – Initial Carbon Capture Development

TRL 2 - 3

MHI/KEPCO Pilot Plant – 2 tons/day

TRL 4 - 5

KM CDR Process® Developed

TRL 6 - 7

First Commercial Plant - w/ Improved KM CDR Process® - 400 tons/day

TRL 7 - 8

First fully Integrated Coal CCS Plant – 500 tons/day Alabama Power

TRL 9

Petra Nova – NRG W.A. Parish Power Plant
Thompsons, TX – 4,766 tons/day est.

NRG W.A. Parish Power Plant – Full Scale Integrated CCS

Government – Industry Partnership to Commercialization
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100 years of energy and the economy

Growth or stagnation?

U.S. Energy Consumption by Source and Annual GDP Growth Rate, historical and projected by Annual Energy Outlook 2017

Energy consumption (Quadrillion BTUs)

GDP annual growth rate (%)

**U.S. Fossil Energy Production and Trade 2018**

### Imports

- **Petroleum**
  - 21 QBtu
  - 3.6 Billion Barrels

- **Coal**
  - 0.1 QBtu
  - 6.0 Million Tons

- **Natural Gas**
  - 3.0 QBtu
  - 2.9 TCF

### Production

- **Petroleum**
  - 31 QBtu
  - 30 TCF

- **Coal**
  - 15 QBtu
  - 754 Million Tons

- **Natural Gas (dry)**
  - 29 QBtu
  - 5.8 Billion Barrels

### Exports

- **Petroleum**
  - 15 QBtu
  - 2.8 Billion Barrels

- **Coal**
  - 2.8 QBtu
  - 116 Million Tons

- **Natural Gas**
  - 3.6 QBtu
  - 3.6 TCF

### Approximate Heat Content

<table>
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<th>Imports</th>
<th>Production</th>
<th>Exports</th>
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<td>mmBtu/Barrel</td>
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<td>5.3</td>
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<tr>
<td>NGL</td>
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<td>3.7</td>
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<tr>
<td>Natural Gas</td>
<td>1.025</td>
<td>1.036</td>
<td>1.009</td>
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**Legend**

- **Eastern Coal**
- **Interior Coal**
- **Western Coal**
- **Major Shale Play**
- **Oil/Gas Field**
- **Shale-Coal Overlap**
- **Shale-Oil/Gas Overlap**

**Data Source:**
- EIA Monthly Energy Review (March 2019)
- EIA Annual Energy Outlook 2019

**Gross Heating Values**

- LNG: 22,300 Btu/lb
- Gasoline: 20,500 Btu/lb
- Crude Oil: 18,300-19,500 Btu/lb
- Coal (Bituminous): 10,200 – 14,600 Btu/lb
- Ethanol: 11,600 Btu/lb

**Shale = Coal Overlap**

**Crude Oil = 77%**

**Gasoline = 20,500 Btu/lb**

**Coal (Bituminous) = 10,200 – 14,600 Btu/lb**

**LNG = 22,300 Btu/lb**

**Ethanol = 11,600 Btu/lb**

**All percent values are based off of specific fuel units (not QBtu)**

1 ton LNG ~ 44,192 ft³ ~ 47 million Btu
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Projected electricity generation by fuel

Source: U.S. Energy Information Administration
Electricity generation capacity
An existing and new fleet of NGCC will drive gas growth

Electricity Generation Capacity Additions and Retirements by Fuel, Historical and Projected from AEO'17

## US Coal Units shown by size and operational status

<table>
<thead>
<tr>
<th>Year</th>
<th>Nameplate capacity (MW)</th>
<th>Total</th>
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<tbody>
<tr>
<td>2010</td>
<td>2,086</td>
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</tr>
<tr>
<td>2011</td>
<td>3,265</td>
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</tr>
<tr>
<td>2012</td>
<td>9,811</td>
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</tr>
<tr>
<td>2013</td>
<td>6,384</td>
<td></td>
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<tr>
<td>2014</td>
<td>5,349</td>
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<tr>
<td>2015</td>
<td>16,002</td>
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<tr>
<td>2016</td>
<td>9,250</td>
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</tr>
<tr>
<td>2017</td>
<td>8,529</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>13,723</td>
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</tr>
<tr>
<td>2019</td>
<td>2,232</td>
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</tr>
<tr>
<td>2020</td>
<td>7,785</td>
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<tr>
<td>2021</td>
<td>2,571</td>
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<td>2022</td>
<td>9,387</td>
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<td>2023</td>
<td>4,270</td>
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<tr>
<td>2024</td>
<td>1,295</td>
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<tr>
<td>2025-2030</td>
<td>7,515</td>
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</table>

### Announced Retirement
- 2010: 2,086
- 2011: 3,265
- 2012: 9,811
- 2013: 6,384
- 2014: 5,349
- 2015: 16,002
- 2016: 9,250
- 2017: 8,529
- 2018: 13,723
- 2019: 2,232
- 2020: 7,785
- 2021: 2,571
- 2022: 9,387
- 2023: 4,270
- 2024: 1,295
- 2025-2030: 7,515

### Retired since 2010
- Total: 76,632

### NERC Subregions
- Announced Retirements thru 2030
- Continued Operation
- Retired since 2010

### Legend
- All coal units
  - Size By Nameplate Capacity (MW)
    - 500 to 1300
    - 250 to 500
    - 0.4 to 250
- All coal units
  - Color By Status
    - Announced Retirement
    - Operating
    - Retired
    - NERC_Regions
Natural gas price projections

Future coal use for electricity generation will be tied to natural gas price


The “Furthering Carbon Capture, Utilization, Technology, Underground Storage, and Reduced Emissions Act” or “FUTURE Act” was passed as part of the Bipartisan Budget Act of 2018 in February. The Act expands and extends the existing Section 45Q CO₂ sequestration tax credit.

- The 45Q tax credit provides a 12-year, permanent sequestration tax credit for qualified facilities that capture and permanently store CO₂.
- The tax credit is available to both power and industrial sources of CO₂.
  - The tax credit for CO₂ used for enhanced oil recovery (EOR) ramps in starting at $12.83 per metric ton in 2017 and rising linearly to $35 per metric ton by 2026. After 2026, credits rise with inflation.
  - The tax credit for CO₂ that is permanently stored in saline aquifers ramps in starting at $22.66 per metric ton in 2017 and rising linearly to $50 per ton by 2026. After 2026, credits rise with inflation.
- Facilities must start construction by January 1, 2024 to be eligible for the tax credit.
Carbon Capture Utilization and Storage

• CO2 emissions are captured from sources such as fossil power generation or industrial processes, and further either reused or stored. While initial development of CCUS technology primarily focused on decarbonizing the power sector, the technology has evolved to include energy-intensive industries.

• In 2018, there were 37 large-scale integrated CCS or CCUS facilities all over the world (17 projects are operating, 5 are under construction, and 15 projects are at the development stage). Those project are located at different countries, but majority are in the US (12) and Canada (5). *

The general model for CO2-EOR in a reservoir may be described as follows:

➢ Initially the reservoir is flushed with significant amounts of CO2 and rule-of-thumb is that it may take between 18 to 24 months from initial injection of CO2 until production starts.

➢ The more CO2 added to the reservoir, the more oil may be expected to be produced. The objective is to have as large an amount of CO2 injected as economically possible to achieve optimum production.

➢ After CO2 injection, the produced oil will contain CO2. The CO2 in this oil is separated and re-injected back into the oil field. The result is that the field’s need to purchase “fresh” CO2 is gradually reduced as more and more of the CO2 injected is actually produced with the oil itself, and then the CO2 is recycled and re-injected.

* https://www.sciencedirect.com/science/article/pii/S0306261918317252
CO2-EOR Project

Can 45Q help coal make a comeback?

Tax Credit and R&D Impact Cases

Sensitivities using the NETL CTUS-NEMS model to analyze the impact of sequestration tax credits and R&D

- AEO2016 No CPP case (Reference)
- High Growth case: AEO2016 No CPP case with
  - higher gas prices, higher GDP growth, higher load growth (~ 2 percent per year);
  - lower EOR O&M costs; low cost heat rate improvements
  - planned coal retirements (14 GW) from 2017 onward removed (High Growth)
- High Growth Case plus
  - 12-year sequestration tax credits 12 years providing $35/ton CO₂ for EOR and $50/ton CO₂ sent to geologic storage
  - new coal CCS capacity with 90% capture, state of the art technology (Tax Credit)
- Tax Credit Case with CCS power plant program goals included (R&D Success)
Coal Capacity, Generation, and Consumption

**Reference:** No new coal;  **High Growth:** 13 GW

**Tax Credit:** 35 GW;  **R&D Success:** 80 GW
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What is coal?

Hundreds of millions of years of compressed solar energy

Representative chemical structure of bituminous coal
(adapted from Christian-Albrechts-Universität zu Kiel “History of Carbon”)

Representative only – “coal” does not have a defined chemical formula

Important highlights:
• Energy is stored in chemical bonds and can be released by combustion
• Coal assay properties (volatility, heat content, sulfur, ash, etc) are determined by the configuration and amount of molecules in the structure
• The hexagons (with a Carbon atom at each intersection) are strongly bonded – if they are separated from the rest of the structure, they are graphite which has many useful properties:
  • Lubricant
  • Strong and light materials
  • High temp and pressure conductor
Coal utilization
The U.S. Department of Energy’s (DOE) Office of Fossil Energy (FE) and NETL have awarded 4 projects and selected 2 more for total funding of up to $9.5 million in federal funding for cost-shared research and development (R&D) under the funding opportunity announcement (FOA) DE-FOA-0001992, *Maximizing the Coal Value Chain*. This FOA seeks to develop innovative uses of domestic coal for upgraded coal-based feedstocks used to produce power, make steel, and make high-value products—ultimately creating new market opportunities for coal.
U.S. Coal to Conductive Inks

Project Information

Prime Performer: Minus 100, LLC  
Project Duration: 07/02/2018 – 04/01/2019  
Technology Area: Coal Beneficiation  
Key Technology:  

Location: Clarks Summit, Pennsylvania  
Agreement Number: SC0018594  
Total Award Value: $224,813  
DOE Share: $224,813  
Performer Share: $0

Project Description

This project will develop new or improved methods of manufacturing conductive ink pigments using coal as a primary feedstock. The conductive inks to be developed will use calcined coal pigments obtained from proprietary thermal treatment processes and combinations of the coal-derived conductive pigments with other conductive materials such as graphite/graphene platelets and carbon black. The commercial manufacturing of graphene is in its infancy and currently top-down (subtractive) scalable manufacturing processes use graphene as a precursor material for graphene production. Minus 100 will collaborate with existing graphite and ink manufacturers to convert domestic coal sources to conductive pigments that, in turn, can be used to produce highly conductive inks. Process flow diagrams will be developed for individual process steps that are intended to lead to practical scale-up to commercial- or demonstration-scale operations. A bottom-up cost analysis will be performed to validate the economics of the new/improved conductive pigment manufacturing process using coal as the primary feedstock.

Project Benefits

A significant portion of the current conductive inks use elemental silver or silver compounds as a means of achieving high levels of conductivity. This expensive base material will be replaced, where appropriate, with electrically conducting coal-based materials that are significantly lower in cost. It is estimated that the unit cost of these coal-based materials will be at least 50 percent less than silver-based conductive inks, thus providing a significant advantage to penetrate these markets.
Coal Core Composites for Low Cost, Light Weight, Fire Resistant Panels and Roofing Materials

Project Information

Prime Performer: Semplastics EHC LLC
Project Duration: 07/02/2018 – 07/01/2019
Technology Area: Coal Beneficiation
Key Technology:

Location: Oviedo, Florida
Agreement Number: SC0018794
Total Award Value: $220,359
DOE Share: $220,359
Performer Share: $0

Project Description

In this project, prototypes of a coal-core composite- (CCC) based roofing tile will be produced. This work will include optimization of the blending process to ensure scalability and to position the product for commercial production. The prototypes will be subjected to testing in laboratory facilities near Semplastics in Florida to characterize the material properties, as well as testing by commercial laboratories to show compliance with roofing industry standards.

Project Benefits

The successful commercialization and market penetration of these roofing tiles will lead to an immediate positive impact on the coal industry ecosystem, contribute to diversification in the use of coal through value added products across the United States, and produce domestic manufacturing jobs. The CCC-based roofing tiles offer a viable high-volume, high-growth end market for mined coal.

Cut samples of the tile materials tested.
Additional beneficiation projects

1. The Novel Charfuel® Coal Refining Process 18 TPD Pilot Plant Project for Co-Producing an Upgraded Coal Product and Commercially Valuable Co-Products – CarbonFuels LLC (Denver, CO) aims to employ the novel Charfuel® Coal Refining Process at its existing, permitted pilot plant to produce an upgraded coal product and a number of organic and inorganic coproducts in order to produce engineering and product data that will then be used to design a commercial-scale integrated facility.

DOE Funding: $2,000,000; Non-DOE Funding: $1,180,519; Total Value: $3,180,519

2. Pilot-Scale Testing of the Hydrophobic-Hydrophilic Separation Process to Produce Value-Added Products from Waste Coal – The Minerals Refining Company (Richmond, VA) plans to demonstrate the technical, economic, and environmental benefits of the hydrophobic-hydrophilic separation process for producing high-purity, value-added clean coal and specialty carbon products from discarded coal wastes. The project will provide thorough analyses to identify pathways for promoting commercial acceptance.

DOE Funding: $2,000,000; Non-DOE Funding: $500,000; Total Value: $2,500,000
Rare earth elements

The critical REEs (CREEs) deemed as potential supply risk and are highly important to United States national security and clean energy technologies.

- essential materials in a broad range of technologies that are significant to domestic and national security, energy, and daily consumer products.
- typically occur at low concentrations throughout the earth’s crust not found in an isolated form readily available for extraction, but are distributed throughout a variety of minerals, and are also found in coal-based resources.
- REE-bearing mineral deposits are relatively rich in either light rare earth elements (LREEs) or heavy rare earth elements (HREEs), with LREEs being more abundant.
REE are ubiquitous in today’s technology

…but are almost completely produced by China
Certain coal and coal by-products have elevated concentrations of HREEs.

In 2015, NETL performed an initial assessment of the amount of REEs that is likely to be found in coal deposits and associated mineral matter:

- Approximately 6 million MTs of REEs from known coal reserves in select western state coal basins in MT, WY, CO, UT, NM and AZ.
- 5 million MTs among the coal deposits found in PA, WV, KY and VA.
- Several million MT available in coal ash and coal mine refuse.

Current global production is around 200 MT per year.
In FY14, Congress began funding of a REE Recovery from Coal Program

NETL RIC (September 2018)
- Production of 40wt% REE-Y (400,000 ppm) Pre-Concentrates - CaMg/Fly Ash, 2.7wt% (27,000 ppm) CaC03/Mn-AMD (Co-Enriched) (Lab-Scale Facility)

Feasibility Assessment

2014 2015 2016 2017 2018

West Virginia University (July 2018)
- Commissioning of the Rare Earth Extraction (REEF)
- Bench/Pilot-Scale Facility
- Acid Mine Drainage Feedstock

2019 2020 2021 2022

University of Kentucky (November 2018)
- Pilot-Scale Facility Currently Producing a Few Grams/Day of a Rare Earth Oxide Concentrate Containing Greater than 90% (900,000 ppm) Total RE Oxide (Dry Basis)
- Products Were a Result of Processing Leachate Collected from the Coarse Refuse Area at Dotiki

Physical Sciences Inc., (July 2018)
- Micro-Pilot Facility Produced >15 wt% (150,000 ppm) Concentrate of Mixed Rare Earths from Post-Combustion Ash Resulting from Burning East Kentucky Fire Clay Coal in a Power Plant Boiler
- Pilot Facility (Sharon, PA) to be Operational June/July 2019

Three domestic bench/pilot-scale operating facilities will domestically be producing REEs from coal and coal-based resources in the July-August 2019 timeframe

West Virginia University (February 2019)
- Bench/Pilot-Scale Facility Production of 69% TREE (80% TREO) from Acid Mine Drainage
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US Coal trade

Coal exports are typically 5-10% of US Production

2017 Coal exports from 10 largest exit outlets

Bubble Size Represents Tonnage & % of Coal Exported

US western coal export terminal plans are in various court actions in CA and WA

China’s coal generation capacity is expected to reach 1,300 GW by 2020 (US coal capacity will be around 250 GW by 2020)

- Over 200 GW of new capacity is planned worldwide

Low sulfur steam coal is well positioned for Asian markets

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Working with NETL

The toolbox
# Mechanisms to work with NETL (1)

## CRADA
Cooperative Research and Development Agreements

- Joint R&D performed by NETL and participant researchers
- CRADA-developed IP and data are addressed
- Participants offered the right of first refusal to an exclusive license for NETL or jointly developed IP
- Cost sharing between NETL and CRADA participant is essential
- Small businesses are given preferential consideration

## CFA
Contributed Funds Agreements

- 100% funded by the participant
- For a specific scope of work to be completed by NETL
- DOE owns any resulting IP

## MOU/MOA
Memorandums of Understanding/Agreement

- State the areas of cooperation or the terms of a partnering relationship
- Not considered binding contracts
- Cannot be used to obligate, commit, or transfer funds
- Implementation of specific tasks/projects must be accomplished through a legally binding instrument such as a CRADA, contract, or other appropriate agreement
FOA
Funding Opportunity Announcements

• A notice of a federal grant funding opportunity
• NETL uses FedConnect and or Grants.gov and FedBizOpps to post announcements related to the energy sector, receive proposals and applications, and disseminate award information
• Proposals will be accepted only through FedConnect or Grants.gov

SBIR & STTR Programs
Small Business Innovation Research & Small Business Technology Transfer

• Gov’t programs that award funding
• Competitions among small businesses only
• Small businesses keep the rights to any technology developed
• Encouraged to commercialize the technology

• Phase I - feasibility of innovative concepts - $150,000 for about 9 months
• Phase II - the principal R&D effort - up to $1,000,000 over a two-year period
• Phase III - non-Federal capital used to pursue commercial applications
Working with NETL

https://netl.doe.gov/
Coal will continue as a major contributor to the Nation’s electricity mix for decades to come, but a rebound is not currently projected. Coal could increase its share from rising natural gas prices, utilization of tax credits and CO2 mitigation incentives, economic growth, intermittent renewable saturation.

Other options for coal utilization are available:
- Beneficiation
- Coal to liquids
- Rare earth elements
- Exports

DOE cost-shared projects are currently researching processes to improve the cost/performance profile for new coal utilization technologies.
"An economist is an expert who will know tomorrow why the things he predicted yesterday didn't happen today."

--Evan Esar