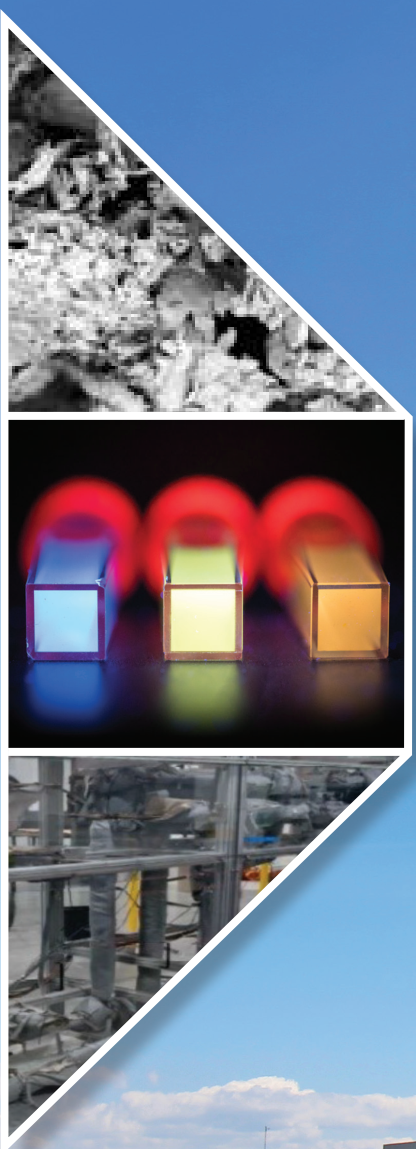
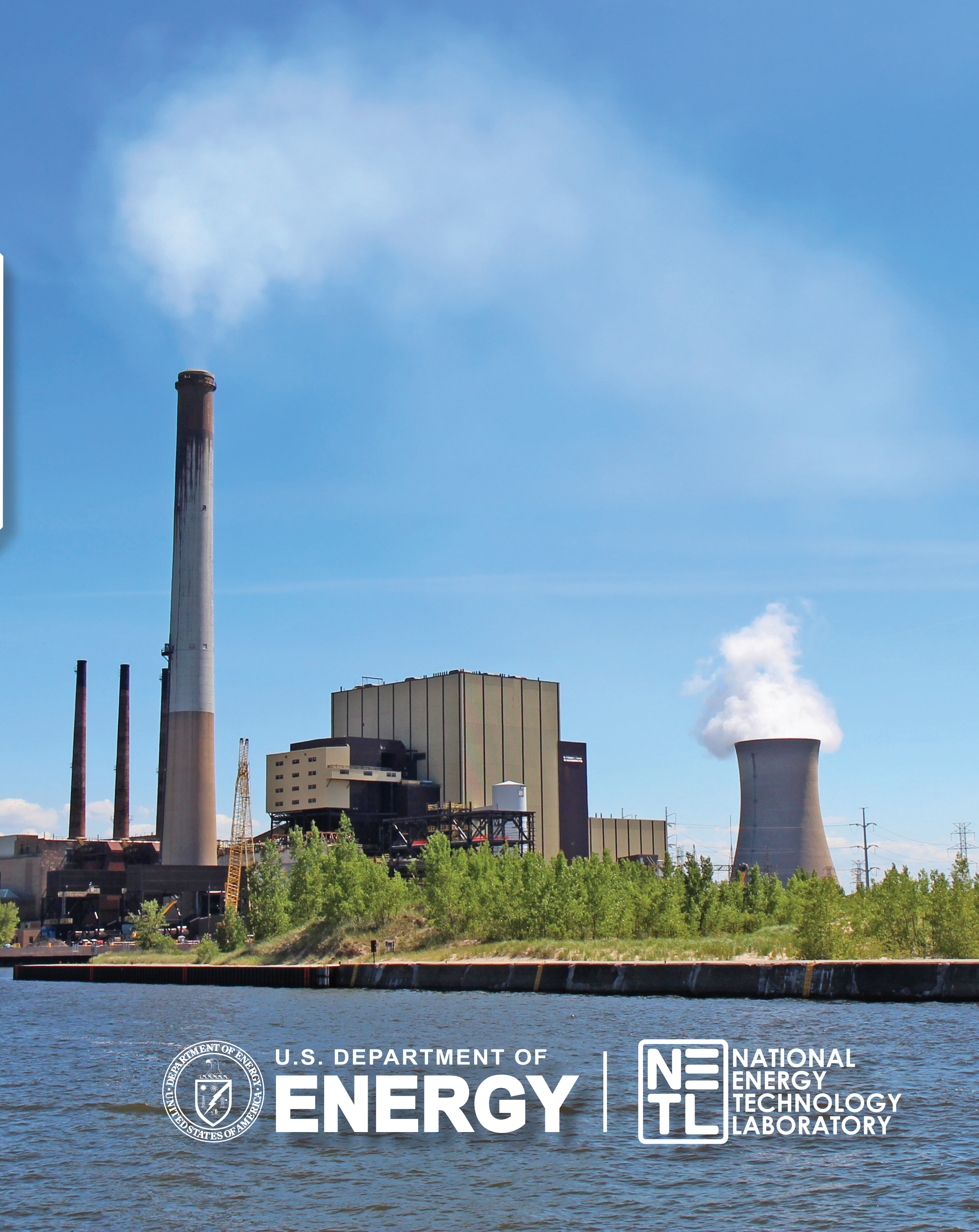
CROSSCUTTING RESEARCH

CARBON ORE TO PRODUCTS PROJECT PORTFOLIO 2021





U.S. DEPARTMENT OF ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY

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CONTENTS

INTRODUCTION

The Carbon Ore to Products Program focuses on both enhancing the value of coal as a feedstock and developing new high-value products derived from coal. Research includes testing of laboratory- and pilot-scale technologies to produce upgraded coal feedstocks and additional revenue-producing products. Expanding existing coal property databases assists research efforts and informs potential consumers in domestic global markets.

Carbon Ore to Products technologies will extract the full economic value from the United States' coal resources by:

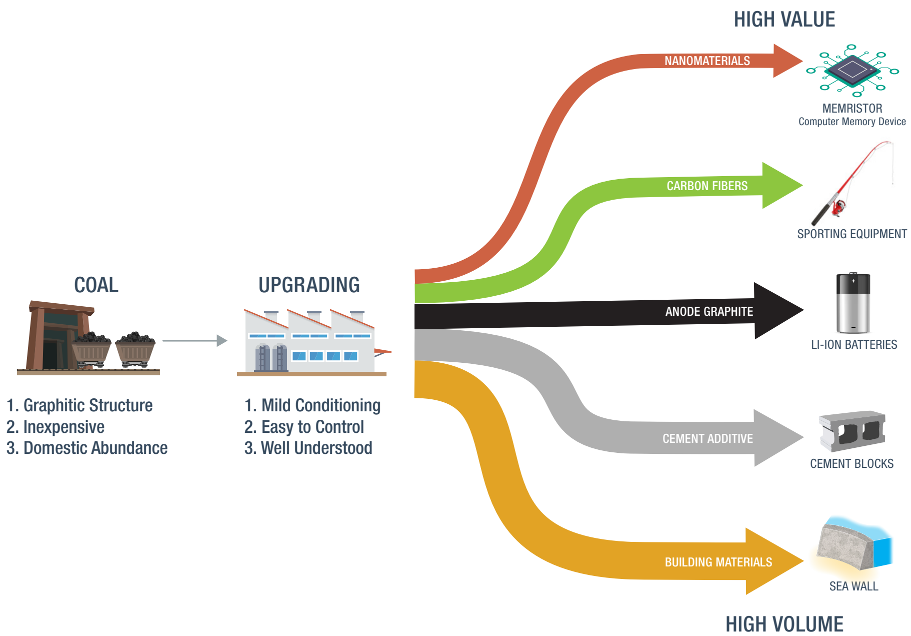
- Developing process options for broadening the slate of products produced from a coal mine
- Enhancing the value of domestic coals as fuel for power generation and steelmaking
- Making U.S. coals more attractive for export

The U.S. coal value chain can be extended by manufacturing carbon products directly from coal instead of using petrochemical or biomass feedstocks or by expanding markets for existing coal products. Coal can be used to manufacture high-value carbon products including carbon fiber, carbon additives for cements and structural composites, battery and electrode materials, carbon nanomaterials and composites, plastic composites, critical materials, coking process by-products, and 3D printing materials.

Markets for coal as a fuel for power generation or steelmaking can be expanded by upgrading the properties of raw coal using new approaches including coal dewatering, fine coal cleaning, dry-cleaning processes to upgrade lower-rank reserves, chemical treatment, and biological processing technologies.

Carbon Ore to Products Technology area has three primary technology focuses:

- **Coal to Carbon Products** enables production of cost-competitive, high-value carbon fibers and nanomaterials for use in non-traditional products such as structural materials, 3D printing materials, energy storage and electrode materials, and carbon composites.
- **Feedstock Upgrading** enhances coal's value and expands markets for power generation and steelmaking with new coal cleaning, treatment, and processing technologies.
- **Coal Properties Database** enables coal suppliers and power plant operators to estimate the economic impacts of coal properties and compositions on the efficiency, reliability, and emissions of both existing and new power generation facilities.



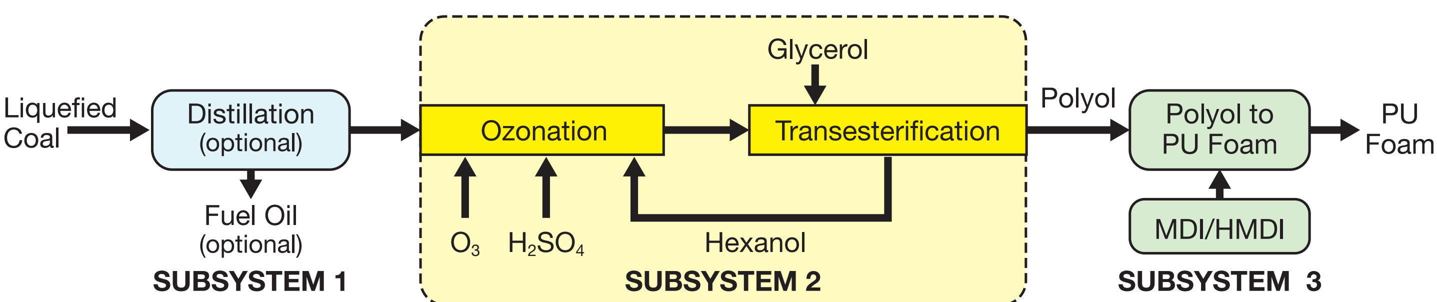
COAL TO CARBON PRODUCTS

A Novel Process for Converting Coal to High-Value Polyurethane Products

Performer	**Battelle Memorial Institute**
Award Number	FE0031795
Project Duration	10/01/2019 – 12/31/2021
Total Project Value	$ 937,108

The goal is to advance Battelle's breakthrough technology for making high-value polyurethane (PU) foam from coal, which involves three subsystems: preparing liquefied coal via direct liquefaction, converting liquefied coal to polyols via ozonation, and converting coal-derived polyols to PU foam. The objectives are to (1) demonstrate the proposed novel coal-to-PU foam process at bench scale and establish a straightforward path to near-term commercial production, (2) confirm a high rate of return compared to petroleum-based, solid PU foam products, (3) determine the PU foam properties to establish a market value for these high-value solid products, and (4) develop a process scale-up and commercialization plan.

Potential benefits include a breakthrough in innovative utilization of U.S. coals without the need for advanced preparation of coal. Target products, which could be up to $81 billion/year, could lead to coatings and adhesives manufacturing. The process developed could also help reduce petroleum imports and improve the economics of PU foam production.



Coal to polyurethane foam process.

Light, High Performance and Scalable Coal-Derived Composites for Construction: Precast and Cast-In-Place Applications

Performer	**C-Crete Technologies, LLC**
Award Number	FE0031980
Project Duration	03/01/2021 – 09/30/2022
Total Project Value	$ 625,000

C-Crete Technologies' overall objective is to produce coal-based construction material that has up to ~95 percent-by-weight coal with physical, chemical, and thermal properties exceeding ordinary Portland cement (OPC)-based construction material. The first goal is to minimize external binders by implementing novel mixing techniques while exceeding the performance/cost ratio of OPC. The second is to demonstrate a semi-continuous production process of precast products through design and fabrication of a bench-scale semi-continuous process.

C-Crete Technologies will couple a combination of advanced synthesis, fabrication, characterization, and engineering to create novel coal-based construction materials. The strategy is to apply and further develop current data on binders, activators, and modular industrial design through a bottom-up approach. A set of systems-scale analyses will be performed to understand the technoeconomics and determine the economic viability of the proposed technology and the market penetration possibilities. Candidates from a wide (coarse) Taguchi design of experiments on different recipes will be shortlisted using performance/cost ratio index (figure of merit) as the downselection criterion. The top candidates will be optimized by fine tuning the composition and curing parameters (a second refined Taguchi design) to achieve properties that exceed those of OPC. Refined recipes that surpass a comprehensive performance/cost index of OPC will be demonstrated, leading to the design and fabrication of a small bench-scale semi-continuous process.

Carbon materials and carbon composites have mechanical, thermal, and electrical properties that can produce new types of building materials or superior versions of existing building materials. The market value of these products exceeds the fuel value of coal, representing an opportunity to produce products that have superior properties, and in some cases lower cost, offering value to both manufacturers and consumers of coal-derived building materials. This project may provide key technical information needed to optimize coal-derived construction materials with near-term implications for precast applications.

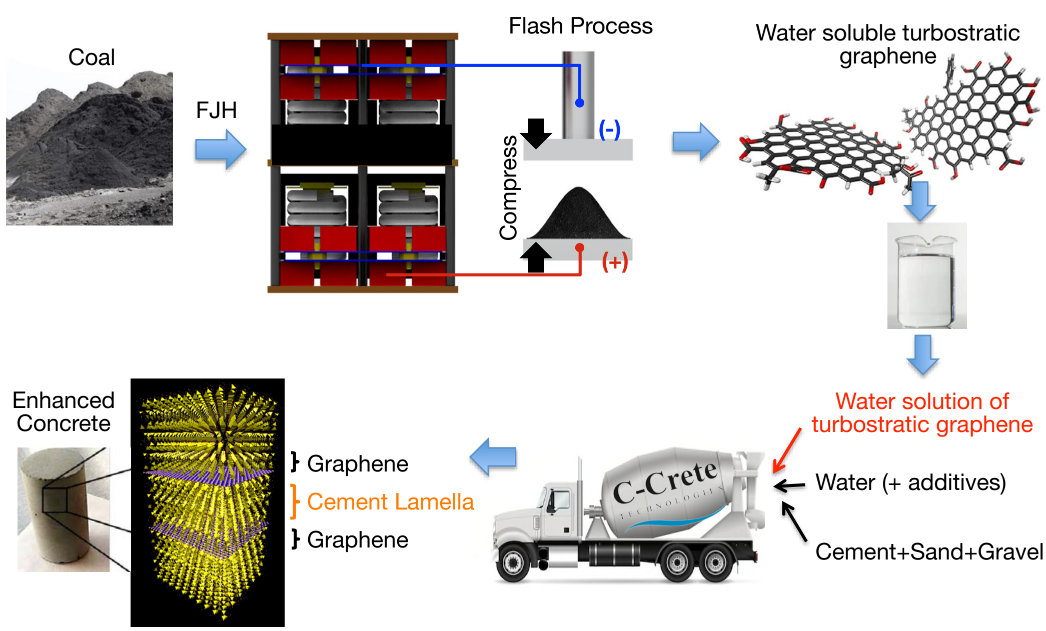
Key unique features of this technology include: High-Strength, Tough and Lightweight Properties; Minimum Binder and maximum coal content; Scalability and Ease of Implementation; and Energy Efficient Processes.

Low Cost Conversion of Coal to Graphene: Bench-Scale Testing, Modeling and Techno-Economical Analysis

Performer	C-Crete Technologies, LLC
Award Number	FE0031999
Project Duration	03/01/2021 – 02/29/2024
Total Project Value	$ 625,000

The overall objective of this project is to demonstrate the techno-economical feasibility of a 250 ton/day manufacturing facility to convert coal to high quality graphene. The first objective (tasks 1–3) is bench-scale testing of FJH and parametric study of FJH processes on various coal ranks. The second objective (tasks 4–5) is to accelerate process optimization in real time via machine learning (ML) and in-line characterizations, followed by small-scale demonstration of an optimized graphene/concrete composite as end product. The third objective (Task 6) is to use the collected performance data and design criteria in objectives 1–2 to perform process modeling, a techno-economic analysis and a technology gap analysis for a 250 ton/day manufacturing facility. The core technology is based on flash joule heating (FJH) to convert various coals to high-quality graphene. The advantage of FJH is that it requires no reactive gases or furnace, is exceedingly fast, works with various coal compositions, is self-purifying and is tolerant to ashes/moisture.

This project could provide key technical information on scaled-up FJH process and bench-scale dynamic data to turn various coals to value-added graphene to be used in concrete. The high-value graphene, along with the demonstrated high potential for large markets such as concrete, could increase demand for domestic coals, increasing the value chain across the entire coal industry. This technology is scalable and could convert all coal ranks to graphene for <$40/ton in FJH cost, with a high yield up to >90% and purity of >99%.



Manufacturing concrete composites reinforced with graphene.

Continuous Processing of Carbon Foam Products Made from Coal at Atmospheric Pressure

Performer	CFOAM, LLC
Award Number	FE0031992
Project Duration	01/01/2021 – 12/31/2022
Total Project Value	$ 2,421,802

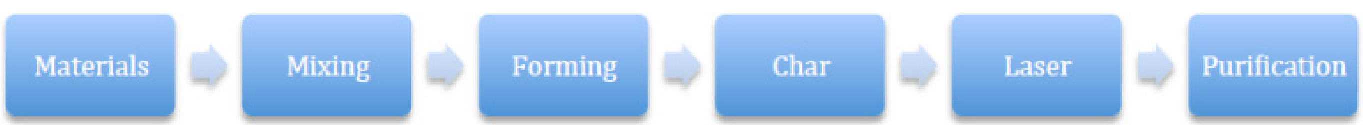
The objective is to develop methods for continuous production of carbon foam panels and lightweight aggregates from coal at atmospheric pressure. Coal-derived carbon foams are currently produced commercially via a batch process at elevated pressure, primarily for use in composite tooling applications for the aerospace industry. This method of production limits carbon foam to high-value, small-volume markets; the goal of this project is to reduce the cost of carbon foam manufacture by over 90% to open up much larger market opportunities in the construction, infrastructure, and other industries, creating meaningful demand for U.S. coal. The technology could enable carbon foam to enter much larger markets and create meaningful demand for U.S. coal. Several markets have been identified that could collectively result in the use of hundreds of millions of tons of coal and tens of billions of dollars of revenue generation per year, creating substantial coal demand with much greater value uplift and reduced emissions versus current combustion uses of coal.

Carbon foam panel (left, 2x18x38 inches) and lightweight carbon foam aggregates - coarse and fine sizes.

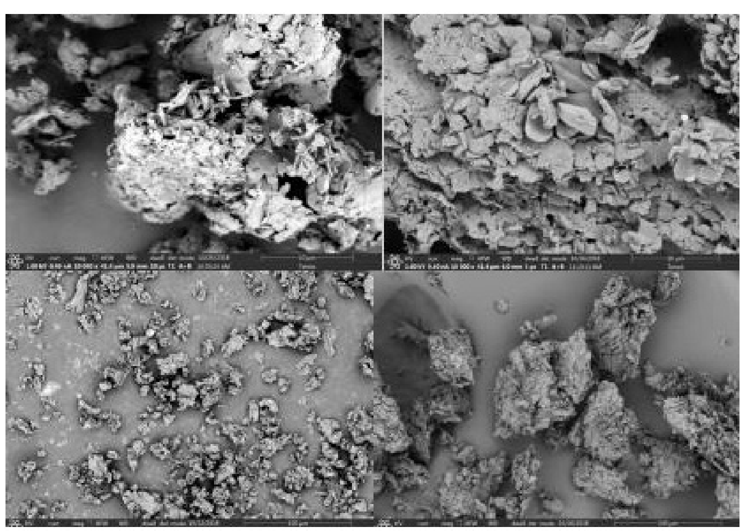
Conversion of Coal to Li-Ion Battery Grade (Potato) Graphite

Performer	**George Washington University**
Award Number	FE0031797
Project Duration	09/01/2019 – 08/31/2022
Total Project Value	$ 949,030

The main objective is to further develop George Washington University's recently discovered process to efficiently transform low-cost coal (lignite) into high-performance, high-value lithium-ion (Li-ion) battery-grade "potato" graphite, so called because potato-shaped agglomerates result from the process. This transformation represents an approximately 1000-fold increase in the coal's value. The initial phase of the project will be devoted to improving the graphite yield by optimizing reaction conditions and improving first-cycle coulombic efficiency to greater than 90 percent by optimizing potato size and porosity and increasing the purity level. Efforts to transition the process from batch to continuous production will run concurrently and synergistically, with results from one effort informing the others. In addition, electrochemical testing of the graphite produced will be conducted with the ultimate goal of demonstrating long-term (500-plus) cycle performance that meets or exceeds commercial graphite. At the end of the project, solutions that valorize domestic coal will have been found, and conversion of domestic lignite coal to Li-ion battery-grade graphite will have been demonstrated.



Graphite production from lignite process



Graphite from small (left) and large (right) grain sawdust.

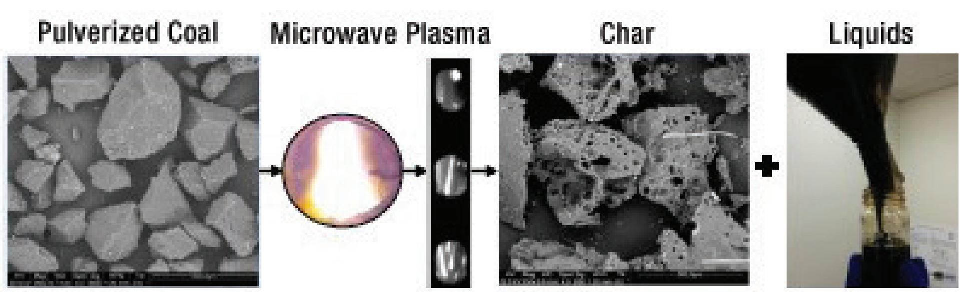
Efficient Ultra-Rapid Microwave Plasma Process for Generation of High Value Industrial Carbons and 3D Printable Composites from Domestic Coal

Performer	**H Quest Vanguard, Inc.**	**Oak Ridge National Laboratory (ORNL)**
Award Number	FE0031793	FWP-FEAA365
Project Duration	10/01/2019 – 12/30/22	10/01/2019 – 12/30/22
Total Project Value	$ 803,048	$ 150,000
Collaborators	Pennsylvania State University; Ramaco Carbon; Research Triangle Institute; Schobert International LLC; Two Point Solutions; West Virginia University	

The main objective of this project is to establish the technical and economic feasibility of using coals from the major domestic coal basins—Powder River, North Appalachia, and Central Appalachia, which together account for 68% of the current coal production—as feedstocks for production of value-added solid products. The project also aims to close (to the extent possible) technology gaps and identify additional research and development needed to commercialize the technology. Technical feasibility will be established through demonstration of rapid, efficient, high-yield conversion of commercially sourced domestic coals using a low-temperature microwave plasma coal pyrolysis technology (Wave Liquefaction™; WL), with subsequent conversion of liquid intermediaries into solid products. Economic feasibility will be established through a techno-economic assessment using the experimental process data and targeted market studies for the solid products.

The two high-value solid product targeted categories are carbon and graphitic materials for industrial electrode applications and advanced 3D-printable carbon polymer composites. The first category represents an established industrial use case with a large and growing market, while the second represents an advanced manufacturing use case with potential for wide industrial adoption in a rapidly growing market. To address conversion by-products, solid char will be transformed into activated carbon feedstock, while the purity and composition of the aromatic platform chemicals (BTEX—benzene, benzene, toluene, ethylbenzene and xylenes; naphthalene; and anthracene oil) will be evaluated for their potential use as feedstock to the petrochemical (i.e., plastics) industry.

Expected outcomes include (1) advancing the understanding of low-temperature microwave plasma as a means of converting domestic coal into high-performance carbon materials such as polymer composites, graphitic materials, and activated carbon, and (2) integration of coal into the value chain of the advanced composites and 3D printing industries, neither of which have used coal in their typical manufacturing processes. High-performance advanced polymer composites are used in many industries where both strength and weight are of critical importance, such as the aerospace and defense industries.



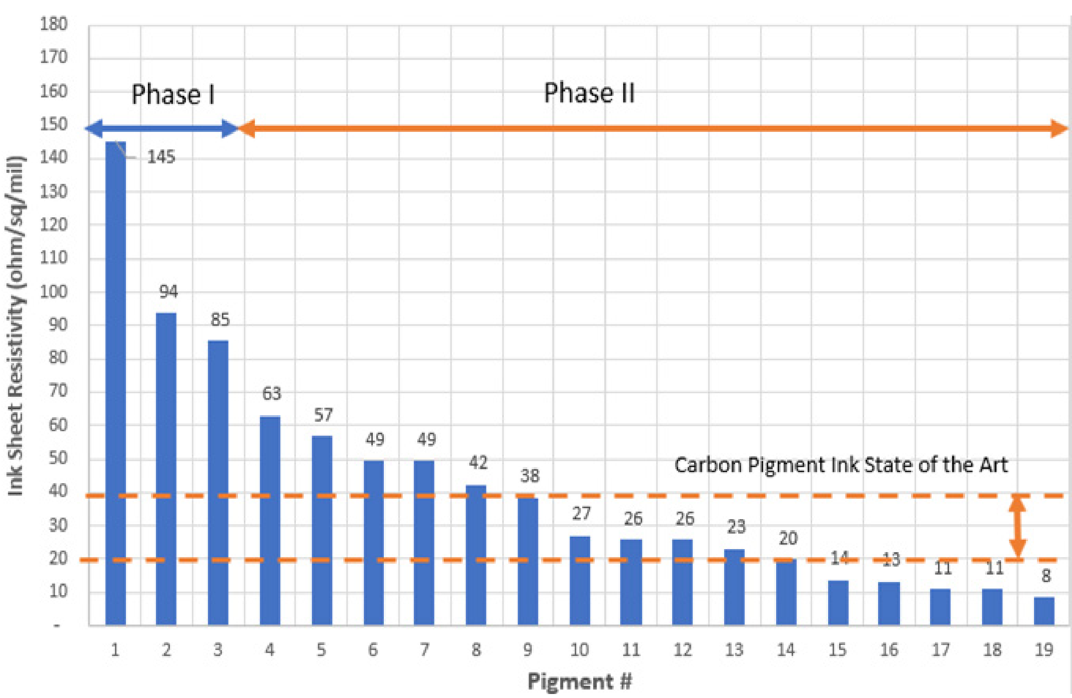
Direct microwave heating and plasma discharges drive rapid pyrolysis reactions within the hydrogen-rich media, affording control over liquid compositional profile (e.g., aromatic vs. naphthenic) and physical properties and low gas yields.

U.S. Coal to Conductive Inks

Performer	**Minus 100, LLC**
Award Number	SC0018694
Project Duration	07/02/2018 – 08/18/2021
Total Project Value	$ 1,774,489

This project is developing new or improved methods of manufacturing conductive ink pigments using coal as a primary feedstock. The conductive inks under development 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 graphite as a precursor material for graphene production. Minus 100 is collaborating 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 are being 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 is being performed to validate the economics of the new and improved conductive pigment manufacturing process using coal as the primary feedstock.

A significant portion of the current conductive inks use elemental silver or silver compounds to achieve 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% less than silver-based conductive inks.



Coal-based ink sheet resistivity (ohm/sq/mil) vs pigment #.

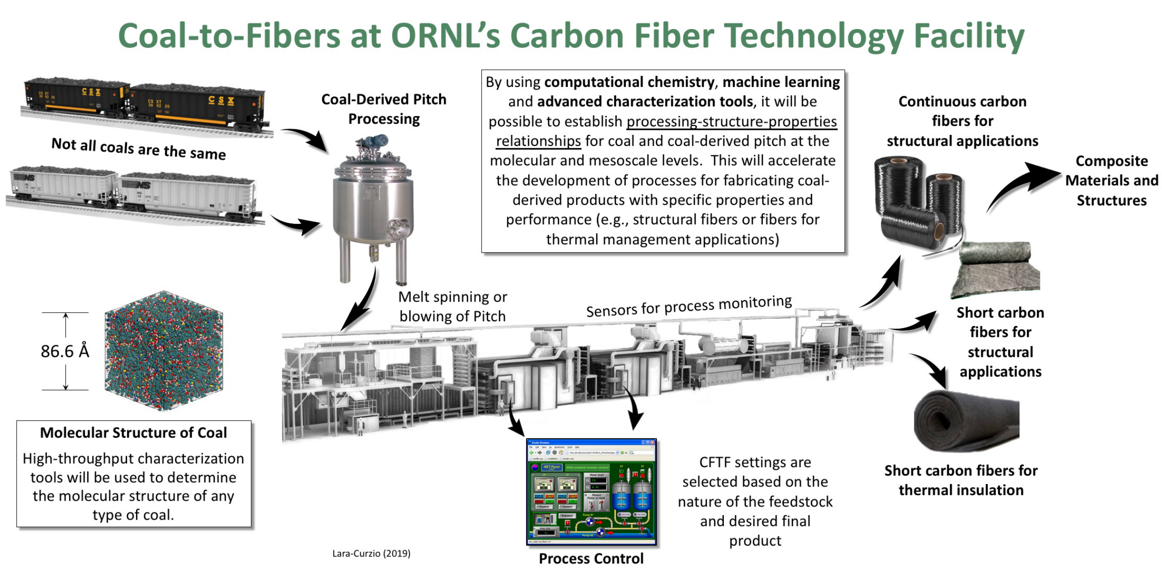
C4WARD: Coal Conversion for Carbon Fibers and Composites

Performer	**Oak Ridge National Laboratory**
Award Number	FWP-FEAA155
Project Duration	06/01/2020 – 09/30/2022
Total Project Value	$ 10,000,000
Collaborator	University of Kentucky Center for Applied Energy Research (UK-CAER)

The purpose of the ORNL C4WARD Field Work Proposal is to develop the underlying and translational science to establish processing-structure-properties relationships for coal-derived fibers, thus enabling the development of energy-efficient and cost-effective processes for manufacturing carbon fibers with tunable properties. This project will address challenges associated with coal processing, variability in feedstocks, and scaling up carbon fiber manufacturing from the laboratory bench scale to semi-production scale at ORNL's Carbon Fiber Technology Facility.

The scope of this project includes classification of coals based on their molecular makeup rather than on their rank; identification of the best coals for obtaining precursors for manufacturing carbon fibers; carbon fiber manufacturing; and manufacturing of carbon fiber-reinforced composite prototypes. The molecular representation of coal will inform computational chemistry models to identify the most energy-efficient and cost-effective pathways for processing coal into precursors that have molecular structures best suited for manufacturing carbon fibers. At the end of this project, ORNL will demonstrate a clear path for competitive industrialization of coal-derived carbon fibers and composites for a wide range of applications.

By identifying alternative pathways for processing carbon fiber precursors not from coal tar, but directly from coal, ORNL will mitigate the risk associated with potential disruptions in the availability of coal tar pitch in the United States. Another key element of this project will be the successful demonstration of manufacturing coal-derived carbon fibers with tunable properties at semi-production scale. This effort is a major step towards providing a low-cost carbon fiber product from coal for potential use in automotive and other important markets and will also lead to new economic development opportunities for communities with coal- based economies.



Schematic illustrating key elements of this field work proposal.

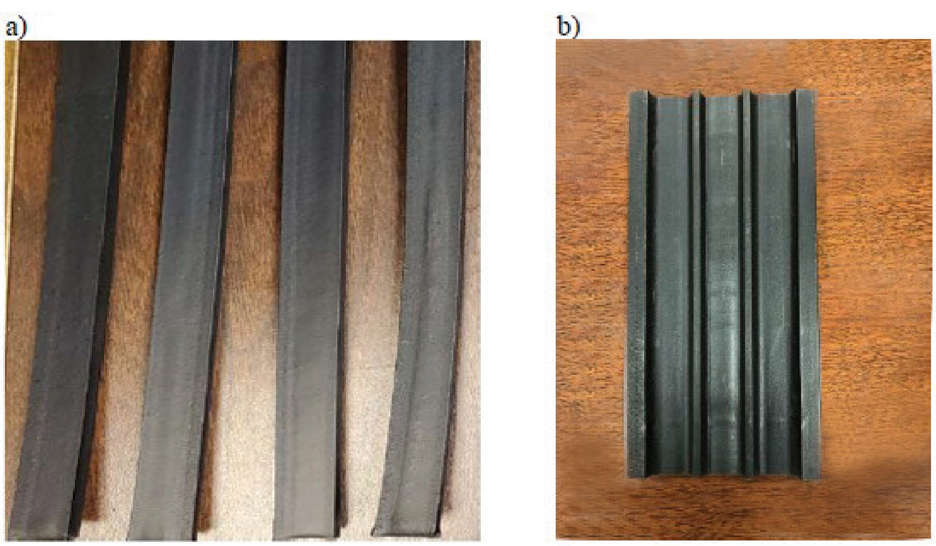
Direct Utilization of U.S. Coal as Feedstock for the Manufacture of High-Value Coal Plastic Composites

Performer	**Ohio University**	**Pacific Northwest National Laboratory**
Award Number	FE0031809	FWP-74294
Project Duration	10/01/2019 – 09/30/2021	10/01/2019 – 09/30/20121
Total Project Value	$ 1,875,710	$ 130,968
Collaborators	Clear Skies Consulting; CONSOL Energy; Engineered Profiles	

The objective of this project is to develop coal plastic composite (CPC) decking boards which possess lower manufacturing costs than current commercial wood plastic composite (WPC) decking boards and meet all applicable ASTM and International Building Code (IBC) performance specifications. Bench-scale screening trials will be completed to assess coal/polymer interface chemistry and impacts of formulation additives on composite properties. Commercial continuous-manufacturing equipment will be used to produce CPC decking boards, which will undergo ASTM testing to determine important application properties and be installed in outdoor applications. Process simulations will be developed and validated using continuous-manufacturing information to support techno-economic studies. Further, CPC marketing studies will be completed along with the identification of additional promising applications for CPC materials.

The project will contribute to the goal of creating new or existing coal processing plants that can increase the domestic and international marketability of U.S. coals through new products and create or maintain coal industry jobs in the U.S. In addition, the carbon products developed could create new industries that will increase the value of U.S. coal resources.

Utilizing coal to produce carbon materials will create new business opportunities by integrating coal into the value-chain of industries that typically do not use coal in their manufacturing processes. Coal-based carbon fiber and carbon fiber-reinforced polymers offer opportunities for producing new forms of lightweight structural materials and composites which have utility in automotive and aerospace applications.

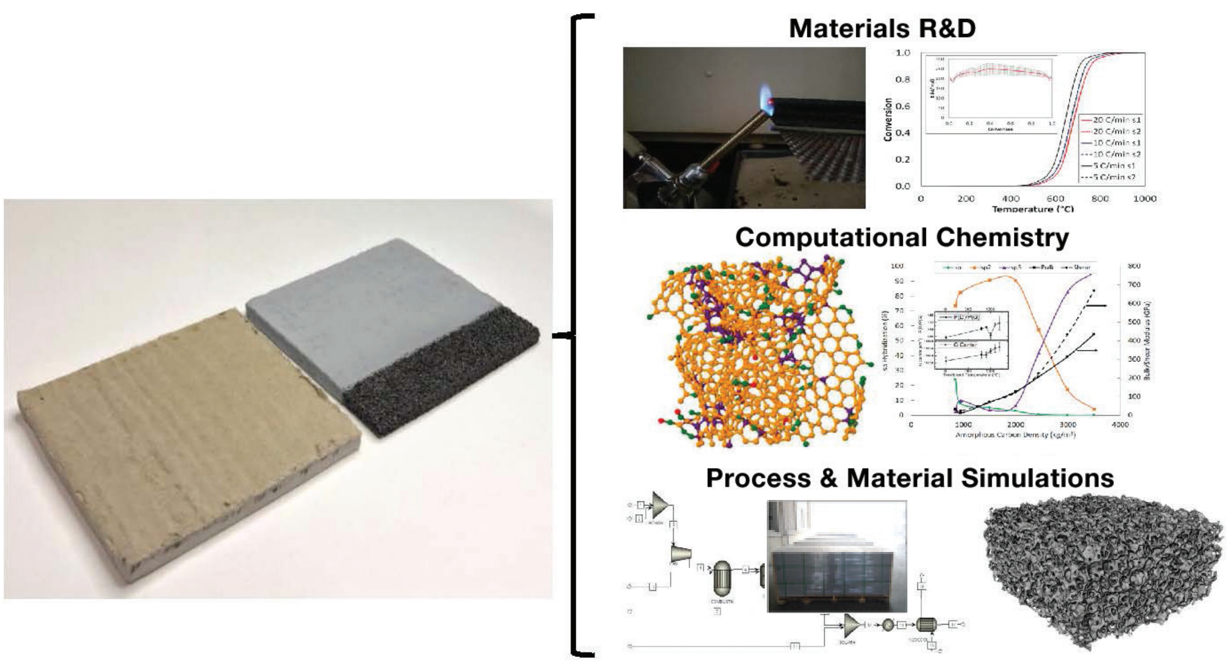


a) CPC formulation extrusion results and b) scaled composite profile manufactured using industrial extruder.

Coal-Derived Alternatives to Fiber-Cementitious Building Materials

Performer	**Ohio University**
Award Number	FE0031981
Project Duration	01/01/2021 – 09/30/2022
Total Project Value	$ 625,000

The objective of this project is to develop coal-based siding materials used for cladding of residential and commercial buildings. The coal-based alternatives will consist of at least 70% carbon (by weight), and at least 51% of the carbon (by weight) must be coal derived and offer performance, cost, and environmental benefits in comparison to commercially available fiber-cementitious (FC) siding materials. The project team will assess the ability to design a continuous thermal process to directly convert coal into siding material to supplant and meet all applicable ASTM performance specifications for fiber-cementitious building materials. Bench-scale manufacturing trials will be conducted to assess coal-derived material properties and technical feasibility for siding and related applications. In addition, molecular dynamic simulations will be experimentally validated and utilized to predict properties of coal siding materials. Techno-economic and technology gap analyses will be conducted to assess coal siding manufacturing costs and identify best suited initial market applications and resources necessary to scale and commercialize the product. Coal siding potentially offers consumers and the construction industry significant advantages over fiber-cementitious siding materials including lower cost, better manufacturing life cycle, and minimal silica content. The global fiber cementitious siding market is undergoing tremendous growth and expected to reach $20.3 billion by the end of 2025. If proven successful, coal siding manufacturing would establish a new high-value market and increase market demand for U.S. coal by 0.5-1.0 million tons annually along with creating new manufacturing jobs.



Cross-sectional views of (left) commercial FC siding and (right) prototype coal siding product.

Coal Plastic Composite Piping Infrastructure Components

Performer	**Ohio University**
Award Number	FE0031982
Project Duration	01/01/2021 – 09/30/2022
Total Project Value	$ 625,000

The objective of this project is to develop coal plastic composite (CPC) formulation(s) containing at least 70 wt% carbon and 51 wt% coal that offer cost, performance, and environmental benefits in comparison to existing plastic pipe infrastructure materials. Phase I objectives include conducting bench-scale formulation and pipe manufacturing trials to generate data to validate CPC pipe technical feasibility, identifying and analyzing existing market applications for CPC piping, and conducting techno-economic and technology gap analyses to identify required selling prices and resources necessary to scale-up and commercialize CPC-based piping materials. If successful, a Phase II program will be proposed with the objective of conducting commercial-scale manufacturing trials to generate sufficient CPC piping to undergo testing and use in field applications to demonstrate the materials comply with ASTM plastic piping specifications and assess CPC formulations for plastic pipe fitting applications.

CPC piping offers significant advantages including minimal coal processing yielding low capital/operating costs, generates nearly zero carbon emissions, utilizes existing commercial manufacturing equipment, and produces a CPC piping product with lower manufacturing costs and properties equivalent or superior to existing plastic piping. The global plastic piping market is undergoing tremendous growth and is expected to reach $106.5 billion by 2022, therefore CPC piping could increase the domestic coal value-chain establishing a new demand for U.S. coal. If successful, CPC manufacturing could generate new U.S. coal demand of over 3 million tons annually along with new manufacturing jobs.

a)

b)

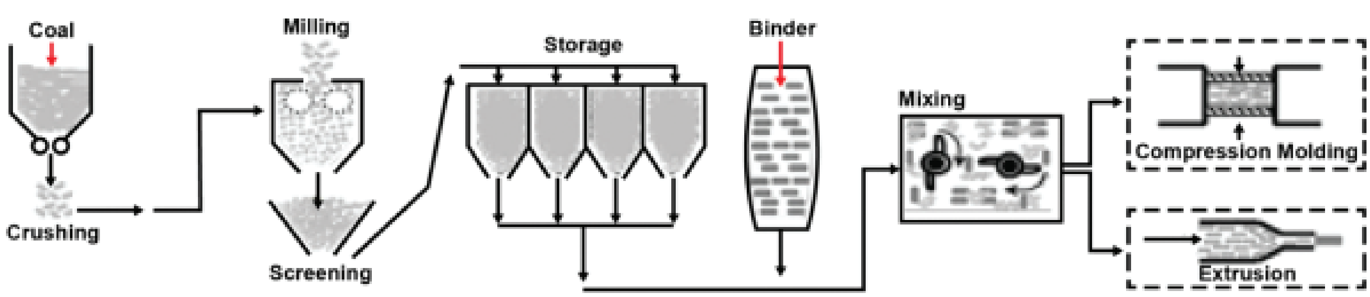
a) EP EDM system and b) semi-continuous CPC extrusion manufacturing line.

Coal-Based Bricks & Blocks (CBBS): Process Development to Prototype Fabrication Coupled with Techno-Economic Analysis and Market Survey

Performer	**Pennsylvania State University**
Award Number	FE0031987
Project Duration	01/01/2021 – 09/30/2022
Total Project Value	$ 624,773

Pennsylvania State University, with assistance from Schobert International LLC, ADI Analytics LLC, and Bolashak Coal Corporation, will evaluate the ability of coal-based bricks to compete on price and quality, identifying competitive strengths and limitations. Market attractiveness will be assessed based on market size, market growth rate, required attributes, and competitive strengths of the coal-based bricks and blocks (CBBs). The research plan will gather data via testing for an assessment of the technical feasibility of the concept, provide an analysis of the target market for the coal-derived products and all by-products created from the process, including a discussion of the required selling price, and complete a technology gap analysis showing additional research and development necessary to scale-up or commercialize the technology. To assess the readiness of the proposed technology a techno-economic analysis will be conducted at the end of the project.

Potentially advancing new markets for coal could enhance U.S. national defense security, the nation's energy and mineral security, nation's environmental objectives, and contribute to America's economic prosperity. The economic growth potential of coal-to-products may provide social benefits in the form of new mining and manufacturing job creation. Locating coal-based brick manufacturing on-site should reduce coal transportation costs within mining communities. This could lead to increased coal demand for the local manufacturing industry.



Process Flow Model.

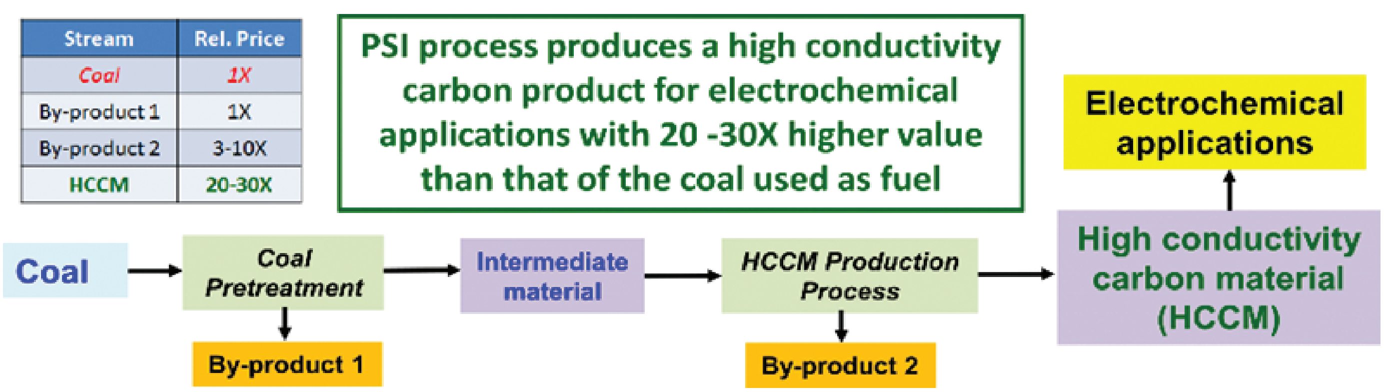
Efficient Process for the Production of High Conductivity, Carbon-Rich Materials from Coal

Performer	**Physical Sciences, Inc.**
Award Number	SC0018837
Project Duration	07/02/2018 – 08/18/2021
Total Project Value	$ 1,724,983

The overall goal of this project is to demonstrate the feasibility and economic viability of producing high-value carbon-based products from coal feedstocks for the manufacturing of high-conductivity materials for electrochemical applications. The proposed technology builds upon pre-existing coal structures to create high- conductivity features under mild conditions. The innovation is a two-step process that generates carbonaceous materials with key structural attributes for high conductivity. The process provides for minimal reagent usage, efficient recycling (greater than 90%), and produces a carbon product for electrochemical applications with 20 to 30 times higher value than coal used as fuel. In addition, the process generates valuable byproducts such as minerals and low-emission gaseous fuels.

The research team will (a) screen and select coal sources suitable as feedstocks; (b) demonstrate scalable processes to produce the high-conductivity material; (c) demonstrate performance in battery electrode formulations and one potential electrochemical application; and (d) perform techno-economic analysis to outline pathways for scale-up and further development and optimization.

The high-conductivity materials developed in this project could provide much higher market value than the fuel value of coal. In addition, the production process will generate valuable co-products that can be integrated with other commercial operations, such as the recovery of trace elements and low-emission energy production.



PSI's innovative process.

Coal to Carbon Fiber Novel Supercritical Carbon Dioxide (sCO_2) Solvated Process

Performer	Ramaco Carbon, LLC
Award Number	FE0031800
Project Duration	10/01/2019 – 09/30/2021
Total Project Value	$ 1,056,799

The objective of the project is to assess the technical feasibility for generation of quality carbon fiber precursor materials using a supercritical carbon dioxide (sCO_2) solvation process. This includes the generation and recovery of coal tar pitches from Powder River Basin (PRB) coal, removal of low-molecular-weight (MW) compounds from pyrolysis coal tar, evaluation of the efficacy of sCO_2 systems for increasing coal tar average MW, and carbon fiber creation from high-MW coal tar pitch fractions. PRB coal-derived pitch needed for sCO_2 solvation testing will be generated using an sCO_2 pyrolysis test loop. Pyrolysis tar will be tested with sCO_2 and co-solvents to solvate light-MW compounds and increase the average MW of the resulting pitch. Methods used will determine the rate of solvation and condition severity (temperature and pressure) for optimum recovery of high-MW pitch fractions. High-MW coal tar will be heat treated within an sCO_2 solvated system (neat CO_2 and solvent solutions) to build MW, and heat-treated samples will be analyzed to determine if aromatic condensation occurs. The conversion of the high-MW coal pitch to carbon fiber will be tested. Techno-economic evaluation of sCO_2 solvation and the carbon fiber forming process will be performed based on experimental results and analysis.

Coal-based carbon fiber and carbon fiber reinforced polymers offer opportunities for producing new forms of lightweight structural materials and composites which will be beneficially used in both automotive and aerospace applications. Using coal as the basis for carbon nanomaterials such as graphene and carbon quantum dots can bring down the costs of these materials for use in electronic display screens, pigments/dyes/coatings, enhanced textiles, and structural composites. Inexpensive carbon nanomaterials can also be used in 3D printing fluids/plastics to enhance the electrical/thermal/optical properties of the final printed material. Also, coal-based coke, pitch, and carbon nanomaterials can be used to produce electrode materials for aluminum production, batteries and related energy storage, and supercapacitors.

Supercritical CO_2 test loop for generating coal pyrolysis tar.

Experimental Validation and Continuous Testing of an On-Purpose High-Yield Pitch Synthesis Process for Producing Carbon Fiber from US Domestic Coal

Performer	Ramaco Carbon, LLC
Award Number	FE0031801
Project Duration	10/01/2019 – 09/30/2021
Total Project Value	$ 1,104,207
Collaborators	Axens North America; Headwaters Technology Innovation

This project aims to develop technology that converts domestic United States (US) raw coal to high quality, high-value and marketable carbon fiber. More specifically, the project aims to significantly improve the selectivity and yield of carbon fiber produced per ton of coal over conventional coal pitch-based production by using low-severity direct coal conversion technology to maximize the yield of pitch from coal, suitable for production of carbon fiber. The proposed scope of work involves testing of a low-severity direct coal liquefaction (LSDCL) process approach and includes the following sequential activities:

- Coal/Conversion Screening
- Feedstock Production
- Carbon Fiber Production
- Commercialization Plan

Project personnel will develop a process of creating high-quality carbon fiber precursor material from U.S. domestic coal, using low severity direct coal liquefaction (LSDCL) techniques in the synthesis of coal tar pitch. These techniques can dramatically increase coal tar pitch yields, especially from low-cost western U.S. coals which have not historically yielded high amounts of suitable coal tar pitch by other conventional means. The objective of the project is the development of a high-quality carbon fiber precursor material from U.S. domestic coal, accomplished through pilot-scale processing and characterization to develop a scheme(s) that can be evaluated for technical and economic feasibility prior to future scale-up. To achieve this goal, the project aims to: 1) Investigate the effectiveness of using a low-severity direct coal liquefaction technique as a continuous process to synthesize coal-tar-derived pitch; 2) Qualitatively evaluate the use of this mesophase pitch to produce carbon fibers; 3) Determine any modifications to the coal-to-tar processes that aid in the production of mesophase pitch optimized for carbon fiber production and further reduce the overall cost of such; and 4) Assess the engineering and economic impact of using LSDCL and associated processes to produce carbon fibers from coal.

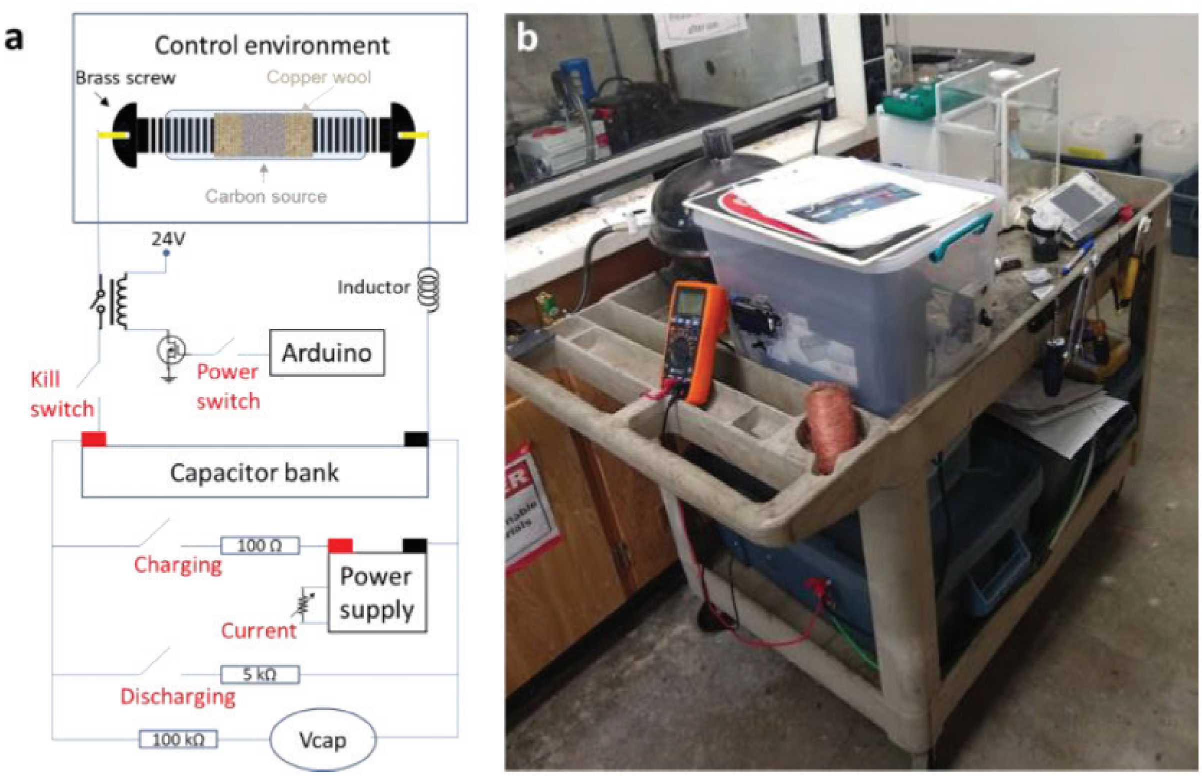
Example of micro-autoclave rig for coal reactivity and liquefaction severity testing.

Conversion of Domestic US Coal into Exceedingly High-Quality Graphene

Performer	**Rice University**
Award Number	FE0031794
Project Duration	10/01/2019 – 09/30/2021
Total Project Value	$ 937,500

Rice University is studying how flash Joule heating (FJH) can produce high-value graphene from anthracite coal at gram scales in less than 1 second per conversion step. The graphene is termed flash graphene (FG). During the first year, reaction equipment was built, the reaction profiles were studied, and data was gathered and analyzed. Iterations will be made to produce the best FG for the several applications proposed. Throughout the first and second years, scale-up equipment will be refined and built that will be designed to meet the target of 1 kg of FG per day from anthracite.

The process uses no furnace and no solvent or reactive gases, and the yields from anthracite coal are 85–95% with a purity greater than 99%. FG might provide the long-sought method to make graphene in bulk with industrially acceptable economics: inexpensive coal, furnace-free, solvent-free, and chemical-free processing, and low energy input to render the process suitable for bulk plastic, metal, and even concrete composites.



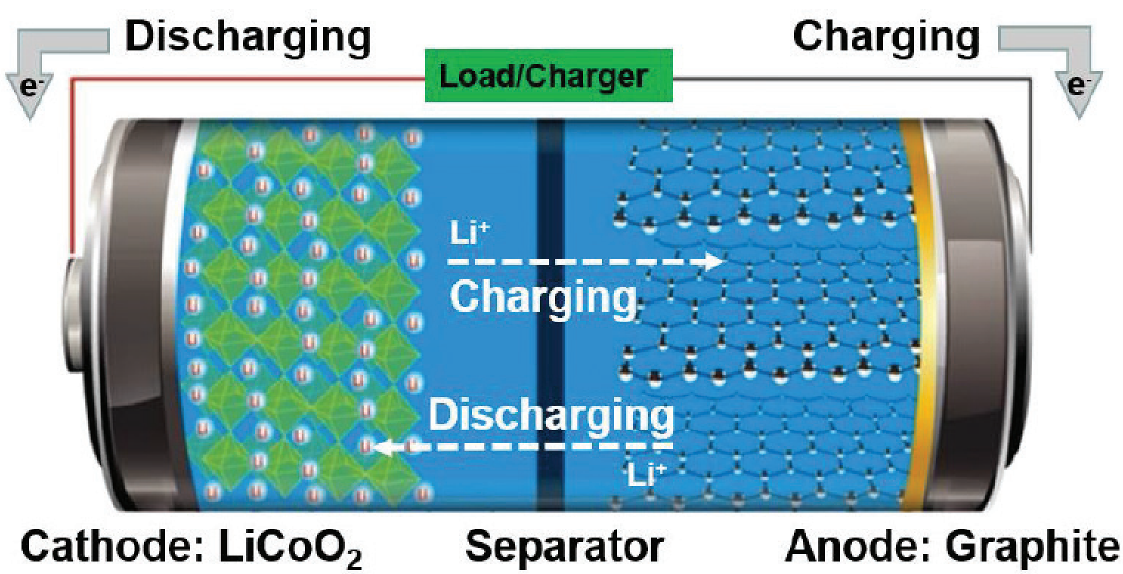
a) Circuit diagram of the FJH station. b) Image of the system on a cart.

Coal as Value Added for Lithium Battery Anodes

Performer	**Semplastics EHC LLC**
Award Number	FE0031879
Project Duration	05/15/2020 - 05/14/2023
Total Project Value	$ 937,442

Semplastics will complete development and begin commercialization of a novel composite material specifically targeted for use in lithium ion (Li-ion) battery anodes. The goal is to find the best formulation for technical performance and economic viability, thereby preparing this material for insertion into the coal value chain. Specifically, this project will (1) produce several new battery anode materials comprised of filled, conductive silicon oxide carbide or silicon oxycarbide (SiOC) ceramics based on Semplastics' X-MAT technology, targeting a specific capacity at least three times that of current graphite anodes as well as improved specific power; (2) provide the best six formulations (highest specific capacity and/or highest specific power) to a commercial Li-ion battery manufacturer as fine powders or of the form they request; and (3) fund the battery manufacturer to produce prototype single-cell industrial batteries and test the batteries under standard test conditions.

At the end of the project, the X-MAT anode material will be ready for implementation into existing battery manufacturing processes and will have a significant impact on the utilization of coal, with positive effects for the mining sector and the mitigation of carbon dioxide emissions.



LIB operating mechanism.

Coal Core Composites for Low Cost, Light Weight, Fire Resistant Panels and Roofing Materials

Performer	**Semplastics EHC LLC**
Award Number	SC0018794
Project Duration	07/02/2018 – 08/18/2021
Total Project Value	$ 1,768,724

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.

Successful commercialization of and market penetration by these roofing tiles will positively impact 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 will offer a viable high-volume, high-growth end market for mined coal.

Cut samples of the tile materials tested.

High-Performance Coal-Based Commercial Facade Panels and Architectural Components

Performer	**Semplastics EHC, LLC**
Award Number	FE0031990
Project Duration	01/01/2021 – 09/30/2022
Total Project Value	$ 624,042

Semplastics will develop, test, and prove the viability for commercialization of a new class of composite architectural panel materials that use coal as the primary constituent. Semplastics will produce sample panels using these novel materials that comprise 55% coal by mass (71% carbon by mass) and are comparable in dimensions to commercially available materials, but that display far superior mechanical strength (three to five times stronger), significant weight savings (30% to 50% lower density), and better insulating ability at a competitive cost.

These new materials require less energy to produce than comparable commercial products and could be manufactured on existing conventional plastic resin processing equipment in commercial quantities. The coal particles are completely encapsulated in ceramic from a polymer-derived ceramic (PDC) precursor, then bonded together by another inorganic resin. The material can be molded and cured to produce fireproof components such as ceiling panels, facades, and extruded underlayment, blocking, and backer boards, as well as other architectural design components such as moldings.

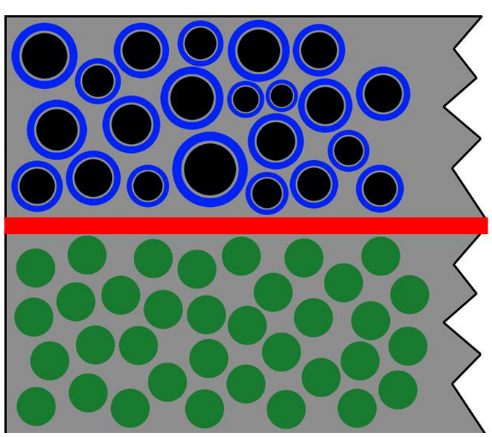
Phase I will move this coal-based composite materials technology from a current technology readiness level (TRL) of 3 to TRL 5.

The proposed work could result in a secure and consistent channel for the use of significant amounts of coal in building materials across North America. Because the X-MAT Panels will be fire-resistant, lightweight, and less bulky, a major impact can be made on the building materials industry.

Benefits include:

1. Higher percentage of non-toxic fire-resistant materials in residential and commercial homes
2. Faster installation time because of lighter materials
3. Greater design flexibility because of thinner panels with paintable surfaces
4. Lower total cost and schedule because panels can fill both interior and exterior needs

Expected beneficiaries of this work include coal producers, who will be able to leverage a new use for their product, and the construction industry, who will have access to new high-strength, lightweight alternative material.



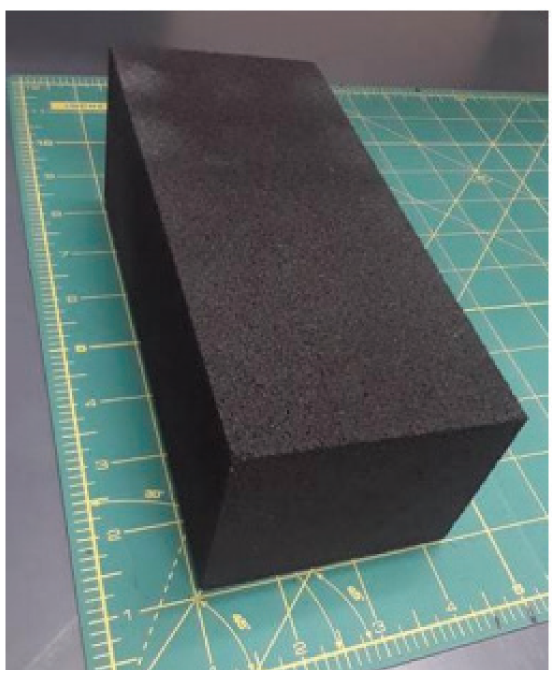
Sketch of 2-layer insulating panel.

Set of 10 coal-based ceramic roof tiles containing 70% coal.

Low Weight, High Strength Coal-Based Building Materials for Infrastructure Products

Performer	**Semplastics EHC, LLC**
Award Number	FE0031991
Project Duration	01/01/2021 – 09/30/2022
Total Project Value	$ 623,688
Collaborators	The Center for Applied Research and Technology; University of North Dakota Energy and Environmental Research Center

This project will develop and demonstrate the viability of a new class of composite infrastructure components that use coal as the primary component. Coal particles are completely encapsulated and bonded using a specially formulated polymer-derived ceramic (PDC) that is cured to form an aggregate of coal and PDC resin. This aggregate can be further processed and pressed to produce a brick. The project team aims to produce brick and block components, called X-BRIX and X-BLOX, with dimensions comparable to commercially available bricks and concrete blocks, but with superior mechanical strength, lower weight, greater hardness, improved toughness, greater abrasion resistance, and greater chemical resistance than concrete. Sufficient quantities of full-size X-BLOX and X-BRIX will be fabricated to demonstrate the technology and to support the development of mortar or joining techniques. The work could result in a secure and consistent channel for the use of coal in infrastructure and commercial building materials. X-BRIX and X-BLOX are lightweight for low-cost transportation and easy assembly, have high design flexibility because of their high strength-to-weight ratio, and have a low total cost. Expected beneficiaries of this work include owners of mines, coal processors, coal-based power plants, and the infrastructure and construction industries.



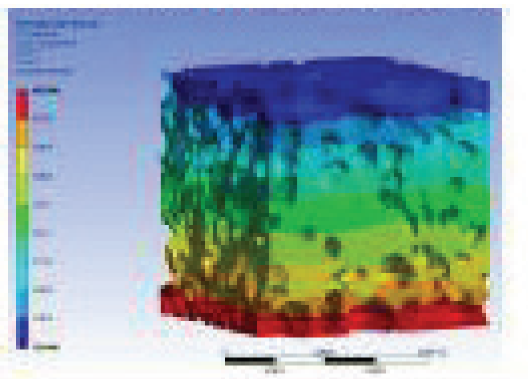
Sample of full-size X-BRIX - Coal-derived building block of the future.

Silicon Carbide (SIC) Foam for Molten Salt Containment in CSP-GEN3 Systems

Performer	**Touchstone Research Laboratory, Ltd.**
Award Number	SC0018678
Project Duration	07/02/2018 – 08/18/2021
Total Project Value	$ 1,747,540

Molten salt thermal energy storage is the lowest capital cost energy storage system. Solar thermal power plants with integrated energy storage are cost-competitive with any new-build coal, natural gas, or nuclear technology. Storage allows the facility to produce more than twice as much net annual output (megawatt hours) than any other solar technology. Firm output ensures a more stable and secure transmission system. Porous silicon carbide (SiC) foam was synthesized directly from coal feedstock in Phase I. The foam's high porosity and open cellular structure make it ideal for containment of molten salt phase-change material (PCM). Silicon carbide foam's inherent high-temperature oxidation and corrosion resistance make it ideal for molten salt applications where melting temperatures exceed 750 °Celsius. The Phase II objective is to scale up the process, demonstrate manufacturability, and validate silicon carbide foam produced from coal for successful commercial implementation in Phase III.

Based on the investigations on the full-scale system, the SiC foam could significantly improve the heat transfer performance of the thermal energy storage (TES) system. For example, the SiC foam can accelerate the melting and solidification processes for efficient thermal energy storage and release, respectively. Hence, use of SiC foam can reduce the number of required high-temperature furnace tubes compared to a phase-change material-only system and lead to cost reduction in the concentrated solar power plant. Furthermore, the SiC foam/PCM composite could achieve the round-trip exergy efficiency to meet the storage target for the TES system.



ANSYS thermal analysis.

3D CT scan.

Developing a Facile Technology for Converting Domestic United States Coal into High-Value Graphene

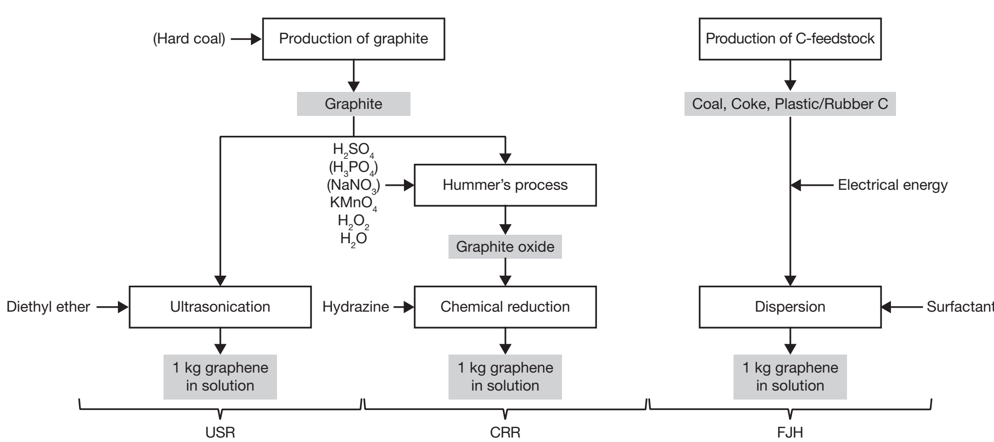
Performer	Universal Matter Ltd
Award Number	FE0031988
Project Duration	03/1/2021 – 02/28/2023
Total Project Value	$ 625,000

Universal Matter Ltd., in partnership with the University of Missouri, will scale up and attempt to commercialize a breakthrough process, flash joule heating (FJH), to transform different coal grades into high-quality graphene. The main objective of this project is to optimize the process by using artificial intelligence techniques (AI) and to validate the technical and economic benefits of producing graphene by using different grades of coal as the feedstock for the FJH process. The graphene products developed from different feedstocks will be analyzed for application development in different strategic markets to further validate the cost and performance advantages and the environmental benefits that can be realized by the incorporation of graphene-based modifiers into different end-use applications.

This graphene is made using a high-voltage electric discharge that brings the carbon source to temperatures higher than 3,000 K in less than 10 milliseconds. The short burst of electricity breaks all chemical bonds and reorders the carbon atoms into thin layers of a special type of graphene.

This project plans to advance the FJH technology from its current technology readiness level (TRL) of 4 to TRL 5. To achieve this goal, Universal Matter Ltd will focus on application of AI methods to develop the process-structure-property relationship required for process optimization and quality control of graphene produced in a controlled industrial environment using the FJH process.

Information garnered from the FJH process can be utilized to set a guideline for application development of coal-derived graphene in different strategic markets. The exceedingly high quality of flash graphene (FG), with yields of 70–90% and conversion cost of $100 per metric ton, presents an opportunity for the U.S. coal industry as well as the electronics, steel, aluminum, concrete, and plastics industries to become potential bulk users of the high-quality and cost-effective FG product to enhance their respective products. Once scaled up, this process can convert large quantities of different grades of coal into high-quality graphene in a most economical and environmentally friendly manner. The 1–5 layers thick, high-quality graphene (with less than 0.05% defects and purity greater than 99%) will have potential utility across several market segments including energy storage, sensors, hyper-lubricants, reinforced plastics, and building materials such as concrete.



Different production pathways for manufacturing graphene.
(USR-ultrasonic route; CRR-chemical reduction route; FJH-flash joule heating)

Production of Carbon Nanomaterials and Sorbents from Domestic U.S. Coal

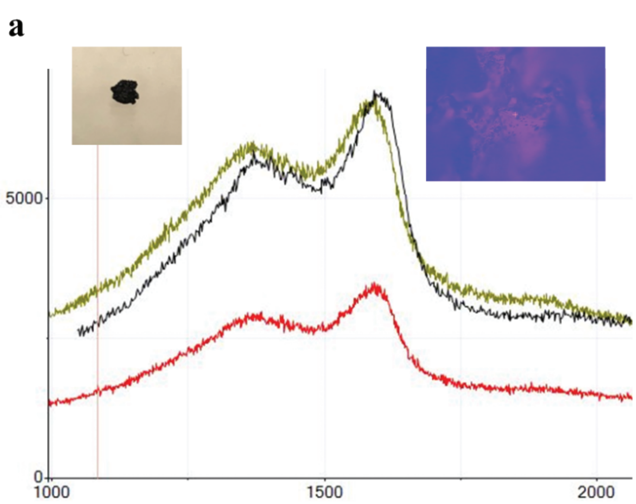
Performer	**University of Illinois**
Award Number	FE0031798
Project Duration	11/01/2019 – 10/31/2022
Total Project Value	$ 988,431

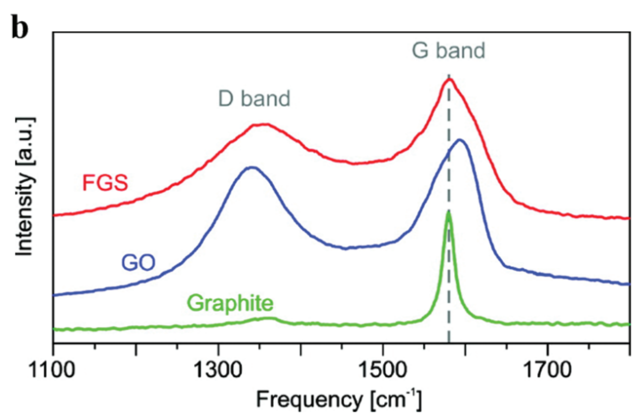
The main goal of this project is to produce high-value carbon nanomaterials and carbon sorbents from domestic coal resources in a cost-effective manner. Specific objectives of this project include (1) converting domestic coal samples to graphene oxide (GO), reduced graphene oxide (RGO), and activated carbon (AC) products at a laboratory scale by using an integrated approach with oxidation, reduction, and activation stages; and (2) performing a technoeconomic analysis, market evaluation, and technology gap assessment for the proposed technology.

Different domestic coal samples will be processed using the proposed process, to produce GO, RGO, and AC products. Materials developed will be extensively characterized, and the impact of the coal feedstock type on the yield and quality of each product will be determined.

A technoeconomic analysis for process simulation and conceptual cost estimation for a production facility, a market evaluation for graphene materials, and a technology gap analysis will be performed. The feasibility of producing coal-based graphene materials at a cost 10–50 times lower than the current cost of graphene will be evaluated.

With further development, the proposed technology could provide low-cost graphene materials for numerous applications such as composites, functional coatings, and electronics that could lead to a new market for domestic coal.





Raman spectra of FGS (functionalized graphene sheets), GO (graphene oxide), and graphite. G band is indicated with a dashed line (Source: K.N Kudin et al., *Nano Lett.*, 2008, 36-41).

Characterization by Raman spectroscopy of a graphene oxide sample produced from PRB coal and comparison with the literature data. (a) Replicate analyses of a laboratory-prepared sample from PRB coal, along with a sample photograph. (b) Raman spectra of graphene oxide materials or graphite from the literature.

Coal to Carbon Fiber (C2CF) Continuous Processing for High Value Composites

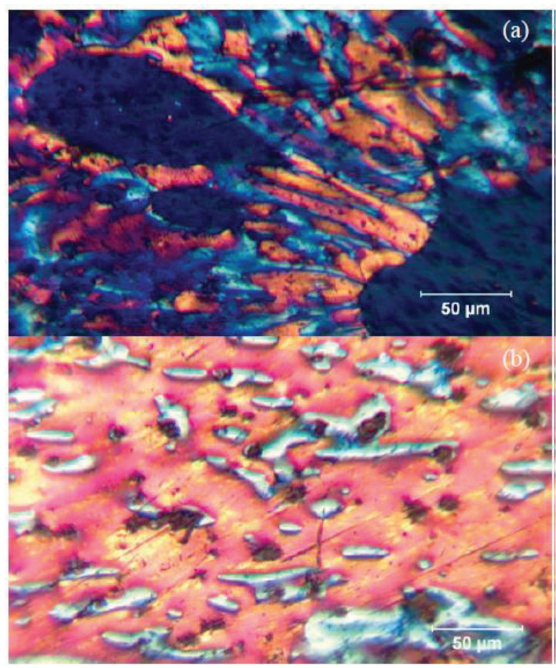
Performer	**University of Kentucky**
Award Number	FE0031796
Project Duration	10/01/2019 – 09/30/2022
Total Project Value	$ 1,847,971

The University of Kentucky (UK) Center for Applied Energy Research will develop and demonstrate the technologies, from precursor to continuous spinning and processing, to produce carbon fiber with an estimated value-add of up to 55 times the value of the coal tar pitch.

UK will partner with Koppers Inc., which buys tens of kilotons per year (kt/yr)of recovered domestic coal tar, to generate isotropic coal-tar pitch (CTP) that has ultra-low levels of quinoline insolubles (QI) and a high softening point for carbon fiber precursor. Koppers will efficiently convert the CTP to mesophase pitch. UK will develop the processing of continuous multifilament fiber to generate high-quality carbon fiber from this new mesophase precursor. Collaborating with Materials Sciences LLC, UK will develop unique green fiber weaving and subsequent thermal processing for high-volume efficient throughput of coal-derived carbon-fiber woven preforms. In the end, the project aims to develop novel low-QI CTP and subsequent mesophase pitch in a process easily scaled to tens of kt/yr, ready for scale-up, and to demonstrate end composites that will lead to new markets.

The project is expected to increase domestic and international marketability of U.S. coals through new products, creating new or maintaining existing U.S. coal industry jobs. The carbon products thus developed could lead to the creation of new complementary industries that will increase the value of U.S. coal resources.

Utilizing coal for carbon materials production creates new business opportunities by integrating coal into industries that typically do not use it in their manufacturing processes to add value. Coal-based carbon fiber and carbon-fiber reinforced polymers offer opportunities for producing new forms of lightweight structural materials and composites which have utility in automotive and aerospace applications.



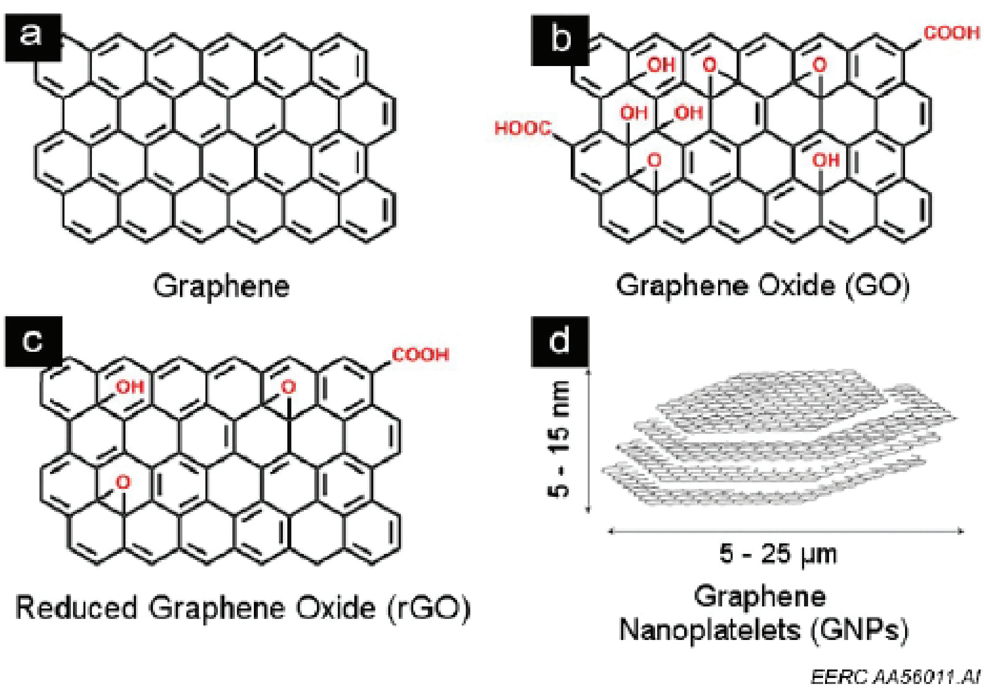
Polarized reflected light microscopy imaging of the Koppers coal tar mesophase. (a) Sample C2CF-20-0002, 72–76% mesophase. (b) Sample C2CF-20-0012, 96–100% mesophase.

Laboratory-Scale Coal-Derived Graphene Process

Performer	**University of North Dakota Energy and Environmental Research Center (UNDEERC)**
Award Number	FE0031881
Project Duration	05/01/2020 – 04/30/2023
Total Project Value	$ 930,080

University of North Dakota Energy and Environmental Research Center (UNDEERC) will demonstrate a laboratory-scale coal-derived graphene process to produce graphene oxide, reduced graphene oxide, and graphene quantum dots starting from domestic U.S. coals. The steps to meet the proposed objective include (1) coal pretreatment with EERC-developed methods, (2) graphitization of treated coal products, (3) exfoliation of graphite to graphene, (4) an economic feasibility analysis, and (5) analysis of product target markets and technology gaps. These processes will be applied to anthracite, bituminous, subbituminous, and lignite coals to advance the current state of technology as well as maximize the coal value chain. EERC-developed techniques will be employed to pretreat the coal, which will then be further improved via chemical hydrogenation and reduction reactions. The resultant residue will be carbonized at 1000 °C and graphitized at 2800 °C. The modified Hummer's method will be used to exfoliate graphite to graphene oxide, which will then be chemically reduced to graphene derivatives.

Potential benefits include economic growth stemming from an increased use of coal in nonenergy sectors as well as in potential new industries and markets. In addition, the results of the economic feasibility analysis will be useful for evaluating the commercialization prospects of this technology.



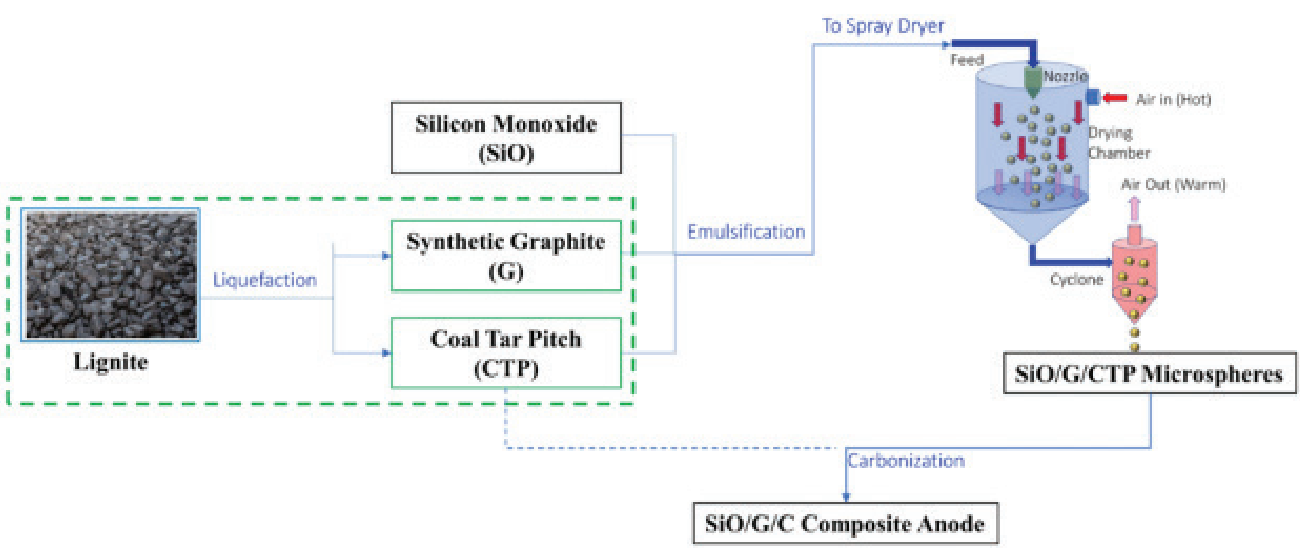
Structural models of graphene products.

Lignite-Derived Carbon Materials for Lithium-Ion Battery Anodes

Performer	**University of North Dakota Energy and Environmental Research Center (UNDEERC)**
Award Number	FE0031984
Project Duration	01/20/2021 – 01/19/2023
Total Project Value	$ 667,465

The overall goal of this project is to develop advanced anode materials for lithium ion batteries (LIBs) from lignite-derived carbon feedstock. Specific objectives include (1) prepare silicon carbon (Si-C) composite anode materials for LIBs using lignite-derived pitch and synthetic graphite (SG) as the main feedstock; (2) identify the optimal pitch and SG for LIB anode applications from a variety of sources produced by a co-sponsor; (3) develop a low-cost and scalable process to make porous and spherical Si-C composite anode materials; (4) evaluate the battery performance of the new Si-C composite anodes and compare with a similar commercial anode as the benchmark; (5) investigate the feasibility of making the Si-C composite anodes at pilot scale; and (6) evaluate the economic and commercial potential of the technology.

The anticipated benefits of this project are (1) the unique high-quality lignite-derived pitch and synthetic graphite will be suitable feedstocks for high-value carbon-based LIB anode materials such as Si–C composite anodes; (2) the current technology of preparing Si–C anode materials will be advanced toward a low-cost and high-performance product; (3) the project will accelerate the commercialization of production of high-quality lignite-derived pitch and SG through opening a high-value LIB market; and (4) the domestic and international marketability of U.S. coals and of domestic production of LIBs will be increased.



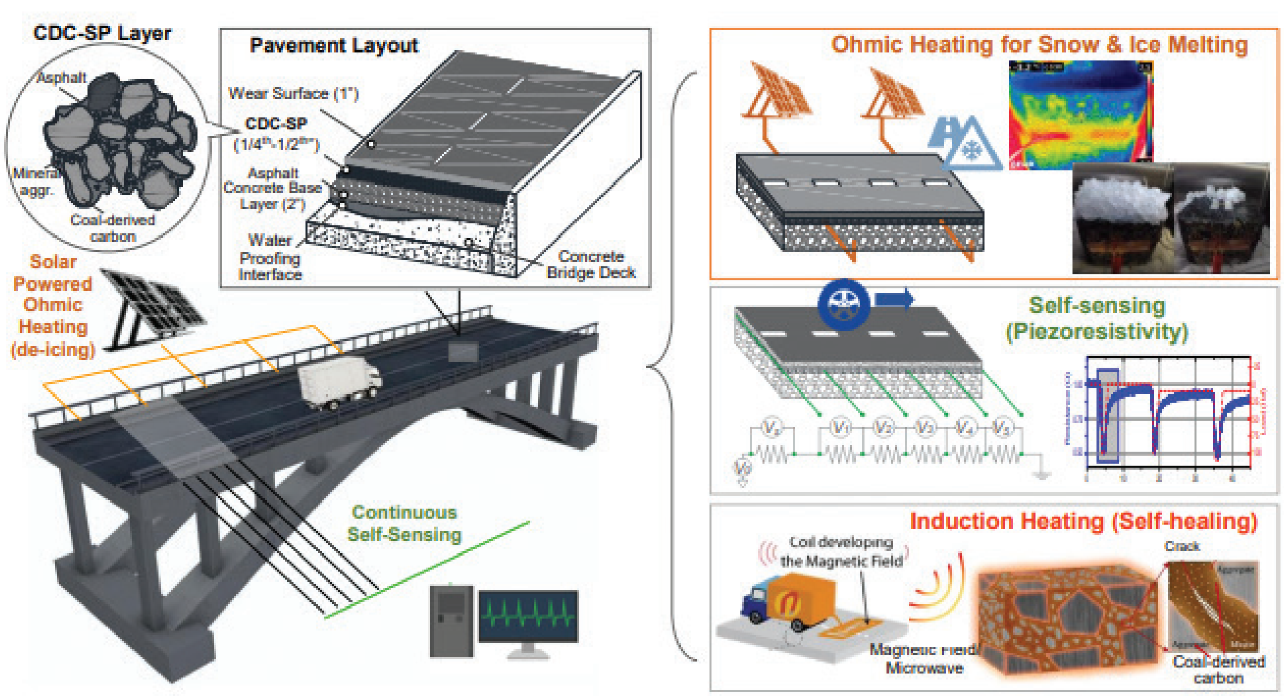
Simplified schematic of the proposed technology for producing LIB anodes from lignite.
The process in the green dashed frame was completed by NAC through its proprietary technology.

Utilizing Coal-Derived Solid Carbon Materials Towards Next-Generation Smart and Multifunction Pavements

Performer	University of Tennessee
Award Number	FE0031983
Project Duration	01/5/2021 – 09/30/2022
Total Project Value	$ 537,500

This project is planned to develop and demonstrate a field deployable, multifunctional smart pavement system made from domestic coal-derived solid carbon materials. This research will demonstrate the use of coke-like coal char, a key byproduct of the coal pyrolysis process, in the design and construction of a prototype multifunctional pavement system that could provide roadways with the capability for self-sensing, self-heating (deicing), and self-healing. Specifically, this project will (1) carry out multiscale experimental and numerical studies to establish processing-structure-property relationships, (2) develop a novel coal char-bearing multifunctional pavement system and gather experimental data to evaluate its performance and assess the feasibility for scale up, (3) test a prototype pavement section to evaluate its intended functionalities, and (4) perform a comprehensive techno-economic analysis to identify the potential market size and key technology gaps to field implementation.

The coal-based multifunctional pavement system to be developed in this project could provide a promising pathway to convert U.S. domestic coal resources to a high-value solid carbon product by promoting the integration of domestic coal resources in bridge and roadway construction. Compared to current roadways, potential performance benefits of the multifunctional pavement system include reduced maintenance costs, extended service life, and reduced travel delay costs due to deicing.



The proposed multifunctional pavement made from coal-derived solid carbon (e.g., coal-char, coke).

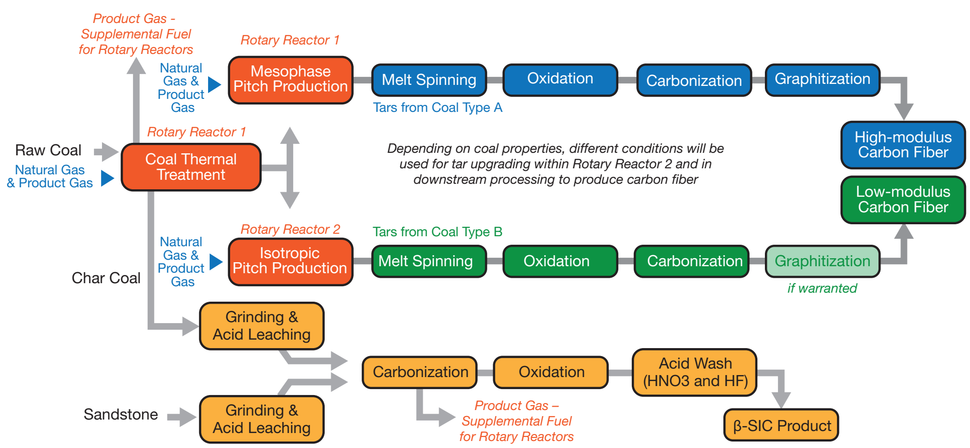
Sub-Pilot-Scale Production of High-Value Products from U.S. Coals

Performer	**University of Utah**
Award Number	FE0031880
Project Duration	06/01/2020 – 05/31/2022
Total Project Value	$ 1,932,495
Collaborators	University of Wyoming; Marshall University

University of Utah will (1) provide sub-pilot-scale verification of lab-scale developments on the production of isotropic and mesophase coal-tar pitch for carbon fiber production, using coals from five U.S. coal-producing regions (Utah, Wyoming, West Virginia, Alaska, and Illinois), (2) investigate the production of a high-value β-SiC byproduct using residual coal char from the tar production process, and (3) develop an extensive database and suite of tools for data analysis and economic modeling to relate process conditions to product quality and assess the economic viability of coals from different regions for producing specific high-value products. An existing 0.5 ton per day rotary reactor will be used to pyrolyze coals to produce tars suitable for upgrading to coal-tar pitch. The same reactor technology will be used in a second stage to perform the tar upgrading to either mesophase or isotropic pitch, depending on the properties of the original coal. The operating parameters used for this effort will be based on scaling up previous lab-scale R&D that identified conditions for primary and secondary pyrolysis reactions leading to desired chemical properties for the tar intermediates.

Additional lab-scale testing will be performed on the new coals included in this study to provide this information. The product pitch will be spun into carbon fiber to assess fiber quality arising from different coals and from different processing conditions. The solid char byproduct from coal pyrolysis will be used to produce a high-value β-SiC byproduct. A novel database, coupled with detailed economic models and analysis tools, will be created to provide a means for understanding correlations between coal properties, process conditions, and product quality to allow for the assessment of the potential economic viability of coals from different regions for producing specific high-value products. Access to some of these computational tools will become available to the public through a web-based community portal.

This effort is a major step toward providing a low-cost carbon fiber product from coal for potential use in automotive and other important markets. It is expected to lead to new opportunities for economic development in communities with coal-based economies.



Process for the production of coal-tar pitch products, carbon fiber products and β-SiC byproduct from raw coal.

Eco-Friendly High-Performance Building Material Development from Coal

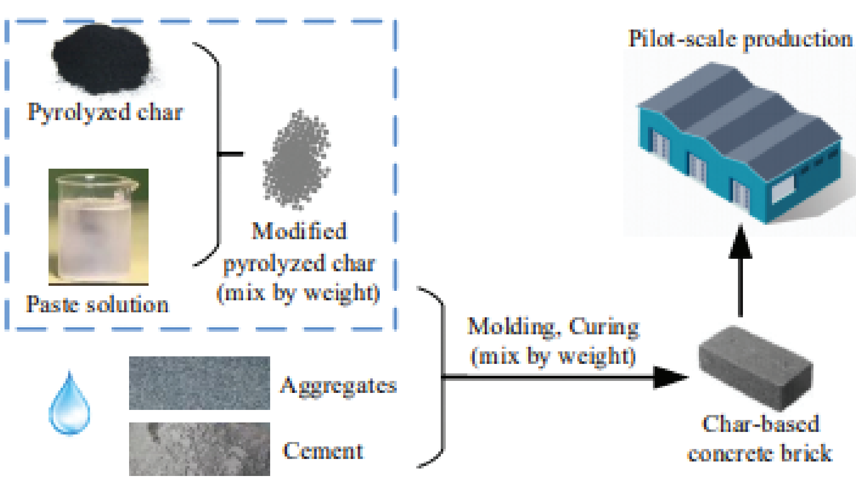
Performer	**University of Wyoming**
Award Number	FE0031996
Project Duration	01/01/2021 – 06/30/2022
Total Project Value	$ 584,499

University of Wyoming researchers will develop coal-derived carbon building materials from Wyoming Powder River Basin (PRB) coal pyrolysis products. Two building components containing more than 70% carbon, most of which is derived from coal itself, are proposed: char-based concrete brick (CCB) and carbon-based structural unit (CSU). These construction products have the potential to be transformational from a cost-benefit perspective and can be scale manufactured for use in residential and commercial buildings.

In this project, the as-mined coal will be converted to functional carbon elements through an integrated solvent extraction and pyrolysis process invented by the University of Wyoming that includes elevated temperature in an inert atmosphere and generation of pyrolyzed char (PC) and coal deposits, extracts, and residuals tar (CDER). The CCB will be developed for building wall applications by adding surface functionality to the PC, providing the modified material with engineered properties to ensure a high degree of interaction/reactivity and bonding with the cement binder. The purity of the PC and CDER intermediates has been shown to comply with the strictest health and environmental requirements for building materials from metals.

Specific goals for the development of the CCB and CSU coal-carbon based building components are: CCB with thermal conductivity greater than 0.40 W/mK, mechanical strength of 14 MPa (compression), and light weight at 1.0–1.5 g/cm^3; and CSU with mechanical strength greater than 30 MPa (compression) and light weight at 1.0–1.3 g/cm^3 with minimal water retention and long-term corrosion resistance and durability in service.

The coal-derived building material products CCB and CSU will result in value-added consumption of domestic coals. Also, these materials can be produced with a minimal carbon footprint and conform to the most stringent health standards for building products. Other advantages and beneficial attributes of these products are that they are manufactured at low cost and, in accord with industry standards, are lightweight with excellent thermal insulation characteristics and robust mechanical properties.



Technical route for the proposed CCB fabrication process.

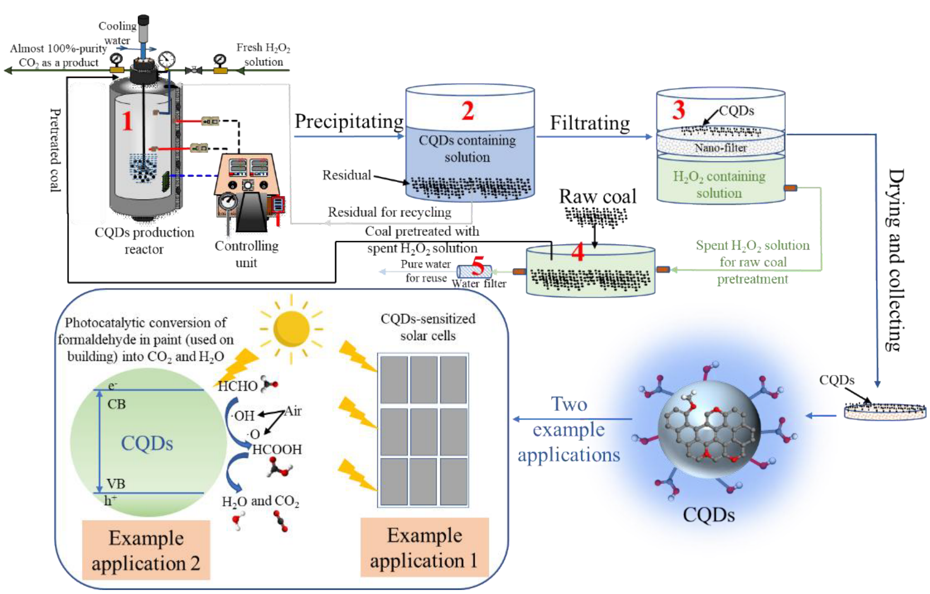
Environmentally Friendly Production of High-Quality and Multifunctional Carbon Quantum Dots from Coal

Performer	**University of Wyoming**
Award Number	FE0031997
Project Duration	01/01/2021 – 12/31/2022
Total Project Value	$ 554,765

The University of Wyoming's overall objective of the proposed project is to develop innovative coal-derived quantum dots (CQDs) as photocatalyst modifiers synthesized from the Fenton reaction of domestic coal as a manufacturing feedstock. The Fenton solution is prepared by a mixture of hydrogen peroxide (H_2O_2) with ferrous iron (typically iron (II)) in Powder River Basin (PRB) coal as a catalyst that is used to oxidize and dissociate the macromolecules in coal into CQDs. The Fenton reagent is desired as a strong oxidizer to increase the product yield of CQDs from coal directly, minimize the consumption of H_2O_2, and convert coal to a high-value product through an environmental-friendly, low-cost and low-emission pathway.

The proposed coal based CQD production is based on a proprietary technology developed at UW. A green solvent is used for directly extracting carbon out of coal with the help of coal itself. Optimal extraction conditions will be obtained via a study on the effects of different factors on the quantity and qualities (size, bandgap, and purity) of the solid carbon from coal. The efficiencies of the photoelectric conversion and photocatalysis (as two example applications) of the synthesized CQDs will be conducted. Also, a techno-economic analysis of the novel coal to CQDs technology will be performed to evaluate the proposed CQD production technology.

If successful, the potential benefits and impacts from this project are a direct and one-step production of high-purity CQDs without the need for heat and chemical separation, a new way for coal utilization, which not only leads to the production of a high-value production from coal but also increases employment and thus the sustainable development of the coal-based economy, and an environmentally friendly CQD production technology that only produces water and pure CO_2 as byproducts, where the pure CO_2 can be directly collected and marketed.



Schematic drawing of the proposed CQDs technology.

Modular, Manufactured Homes from Coal-Based Building Materials

Performer	**X-MAT CCC, LLC**
Award Number	FE0031985
Project Duration	01/01/2021 – 03/31/2022
Total Project Value	$ 624,442

X-MAT CCC, LLC will work with production partner, the Center for Applied Research and Technology, Inc. (CART), to establish the utility of Coal-Derived Building Materials (CDBM). The project will result in a market-worthy design for a CDBM structure and achieve the performance requirements to meet insurance standards (seismic, fire, wind resistance) and those of the International Building Code (IBC). CDBM components contain at least 55% coal by weight. Including the binders within the resin, the components contain at least 71% carbon by weight. In this Phase I effort, X-MAT CCC will perform the development and testing needed to improve the maturity of the technology.

The project will examine the feasibility of utilizing CDBM for manufactured building components for lower-cost public housing and for higher-performance modular construction. The outcome of the project will not only reduce the cost of building construction for the targeted markets, it will also maintain employment in the existing coal supply value chain including mining and preparation, and additionally provide employment opportunity in the CDBM industry.

Conceptual use of coal-derived building materials.

COAL TO CARBON PRODUCTS & COAL PROPERTIES DATABASE

National Energy Technology Laboratory (NETL):

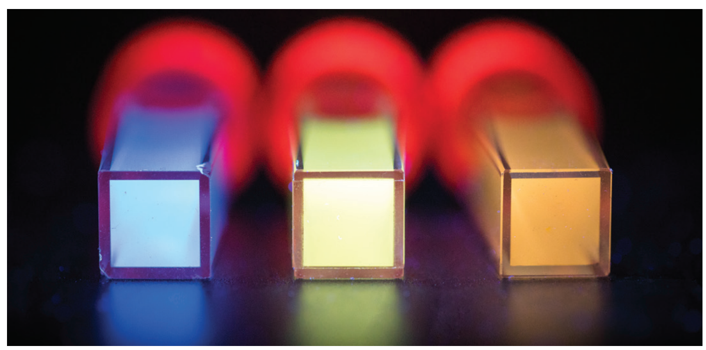
Coal Beneficiation

Performer	**National Energy Technology Laboratory (NETL)**
Award Number	FWP-1022432
Project Duration	08/15/2018 – 03/31/2020
Total Project Value	$ 3,052,075

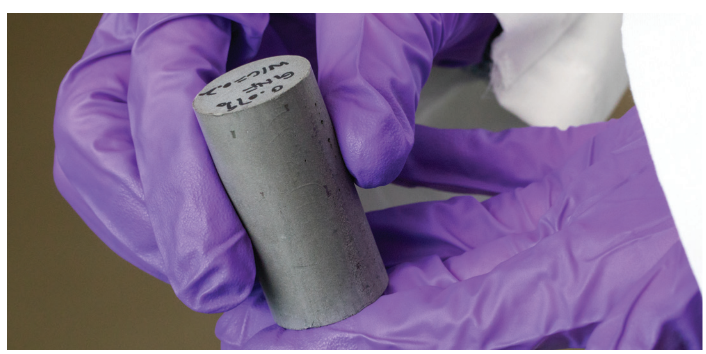
The Office of Fossil Energy (FE) Carbon Ore to Products Program is enhancing the value of coal as a feedstock and developing new, high-value products from coal. This Field Work Proposal (FWP) supports the program by performing research and development (R&D) aimed at developing high-value products from coal feedstocks and evaluating how these products impact coal and manufacturing markets. Specifically, the FWP will develop early-stage technologies in three primary areas: (1) manufacturing high-technology carbon additives such as carbon nanomaterials; (2) incorporating these carbon additives into composites and devices to assess performance enhancements; and (3) providing engineering analysis and techno-economic characterization of the manufacturing processes, supply-chain logistics, and markets associated with integrating coal-derived materials into the global value chain. Research focuses on developing laboratory- and pilot-scale technologies to upgrade coal feedstocks for power and heat markets, and on use of coal and coal-byproducts for manufacturing high-value carbon products such as carbon fiber, carbon foam, and their composites; low-cost carbon nanomaterials; and cement and polymer composites for structural and construction applications.

Projected impacts include (1) identification of the technology gaps and research needs associated with using beneficiated coal as a manufacturing feedstock for high-value carbon materials and products and (2) development of early-stage R&D that indicates how domestic coal can be used for manufacturing high-value products such as carbon nanomaterials, structural composites, and carbon fiber.

A memristor computer memory chip that contains a coal-derived carbon nanomaterial.



Light-emitting carbon nanomaterials made from coal under evaluation as advanced sensing materials used to detect disease in humans.



Cement material enhanced with engineered carbon made from coal is stronger and more durable than conventional cement without increasing the cost significantly.

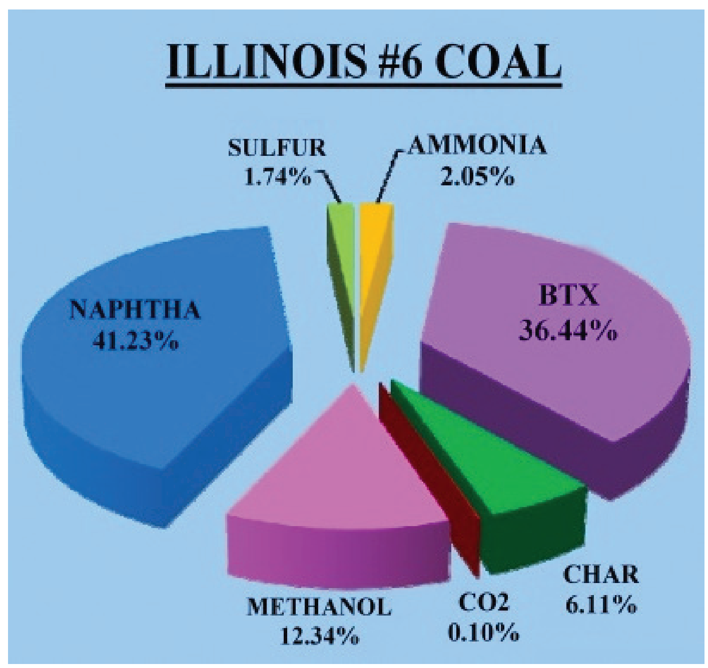
FEEDSTOCK UPGRADING

The Novel Charfuel Coal Refining Process 18 Tpd Pilot Plant Project for Co-Producing an Upgraded Coal Product and Commercially Valuable Co-Products

Performer	**Carbon Fuels LLC**
Award Number	FE0031708
Project Duration	02/01/2019 – 01/31/2022
Total Project Value	$ 3,166,443
Collaborator	Hazen Research

Carbon Fuels, LLC will operate the integrated 18 ton- per-day pilot plant using two coal ranks. Other objectives of this work include demonstrating process flexibility by producing different products (gas, liquid, and char) as well as determining operating parameters for identifying scale-up criteria for the two coal ranks; generating engineering and design information for use in designing a commercial scale plant; determining the environmental issues surrounding the process and the products by analysis of effluent streams; producing sufficient quantities of product to allow reliable commercial economic evaluation of both the refined coal product and the co-products; and assessing longer-term reliability of unit operations. To achieve these objectives, Carbon Fuels, LLC will reconfigure, as well as add specific utilities to, the current process to accommodate a large amount of coal and corresponding product storage in order to meet the technical and economic performance targets required to commercialize the technology; perform computer analysis of the critical process parameters against produced products to optimize a particular slate of products produced from a specific rank of coal; analyze the data generated from the pilot plant for each rank of coal to assess economic feasibility and viability; conduct a market penetration analysis of the upgraded coal product and all coproducts for each coal rank; and conduct a complete environmental assessment of a commercial facility for each rank of coal, including pollutants reporting to the upgraded coal product, as well as external process water consumption and the environmental emissions impact of the process associated with each coal rank.

Project benefits would include improved quality of coal as a fuel and production of high-value products from coal. Data obtained from the project could subsequently be used to increase the capacity of the process to commercial-scale modules that could potentially be integrated with existing power plants to supplement current revenue.



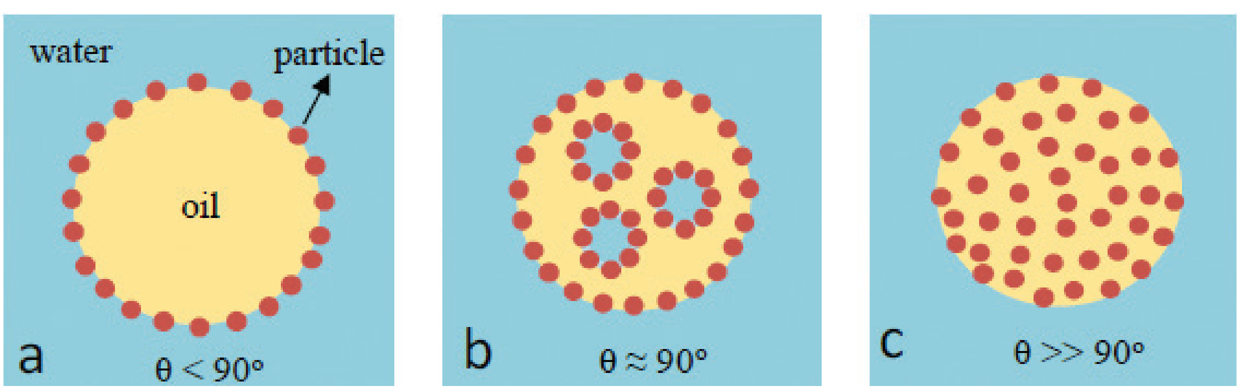
Main products produced from the Charfuel® process for Illinois #6 coal

Pilot-Scale Testing of the Hydrophobic-Hydrophilic Separation Process to Produce Value-Added Products from Waste Coals

Performer	**Minerals Refining Company, LLC**
Award Number	FE0031711
Project Duration	02/13/2019 – 09/30/2021
Total Project Value	$ 1,806,857
Collaborator	Virginia Polytechnic Institute and State University

In a typical coal preparation process, coal particles are separated from earthen matter using mechanical separation techniques. These techniques are only economically capable of separating coal particles greater than 40 microns in particle size. As a result, the particles less than 40 microns in size are not efficiently recovered and are subsequently lost to impoundment ponds. The hydrophobic-hydrophilic separation (HHS) novel process is a physicochemical process that was developed to capture coal particles of less than 40 microns; its technical feasibility has been successfully demonstrated using bituminous coal in batch laboratory experiments, in a small proof-of-concept process, and most recently in a larger pilot-scale process with a coal recovery rate of 500 to 750 pounds per hour. To be economically viable, the process equipment, energy consumption, and chemical consumption must be optimized. The objectives of this project are to utilize the one-skid HHS process to demonstrate that (1) the HHS process is an economical method for recovering fine coal particles for use in coal-fired power plants, (2) the HHS process is an economical method for recovering high-purity coal particles containing less than 1.5% ash for high-value specialty market applications, and (3) the HHS process can be used to recover fine coal particles from an anthracite rank of coal, and to evaluate several process improvements to reduce the capital investment and operating costs associated with the HHS process.

Completed market penetration analysis will define the demand/price structure for the proposed sales of the coal and carbon products generated by the pilot-scale HHS facility and will include potential customers' evaluation of the super-clean and ultra-clean coal for use in new market applications.



Effect of contact angle on the recovery of fine particles during two-liquid flotation.

ABBREVIATIONS

°C....degrees Celsius
3D....three-dimensional
AC....activated carbon
ASTM....ASTM International (formerly American Society for Testing and Materials)
β-SiC....beta form of silicon carbide
BTEX....benzene, toluene, ethylbenzene, and xylene
C2CF....coal to carbon fiber
CBBs....coal-based bricks and blocks
CCB....char-based concrete brick
CCC....coal-core composite
CDBM....Coal-derived building materials
CDER....coal deposits, extracts, and residuals tar
CO_2....carbon dioxide
CPC....coal plastic composite
CQD....coal-derived quantum dot
CSU....carbon-based structural unit
CTP....coal-tar pitch
DOE....Department of Energy (U.S.)
FE....Office of Fossil Energy (DOE)
EERC....Energy and Environmental Research Center (University of North Dakota)
FJH....flash joule heating
FG....flash graphene
FWP....Field Work Proposal (DOE)
GO....graphene oxide
H_2O_2....hydrogen peroxide
HCCM....high conductivity carbon material
HHS....hydrophobic-hydrophilic separation
IBC....International Building Code
kt/yr....kilotons per year
LIB....lithium-ion battery
Li-ion....lithium-ion
LSDCL....low-severity direct coal liquefaction
ML....machine learning
MPa....megapascal
MW....molecular weight
NETL....National Energy Technology Laboratory (DOE)
OPC....ordinary Portland cement
PC....pyrolyzed char
PCM....phase-change material
PDC....polymer-derived ceramic
PSC....porous silicon carbide
PU....polyurethane
PRB....Powder River Basin
QI....quinoline insoluble
RGO....reduced graphene oxide
sCO_2....supercritical carbon dioxide
SG....synthetic graphite
Si-C....silicon-carbon
SiC....silicon carbide
TES....thermal energy storage
TPD....tons per day
TRL....technology readiness level
UK....University of Kentucky
UNDEERC....University of North Dakota Energy and Environmental Research Center
U. S....United States
UW....University of Wyoming
W/mK....watts per meter-kelvin
WL....Wave Liquefaction™
WPC....wood plastic composite

NOTES

NOTES

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