# 2018
## Science & Technology
# ACCOMPLISHMENTS

# UNLEASHING AMERICAN ENERGY
## DISCOVERY | INNOVATION | PROSPERITY

> *Americans have long been told that our country is running out of energy, but we now know that is wrong. America's energy revolution has produced affordable, reliable energy for consumers along with stable, high-paying jobs for small businesses—all while dropping carbon emissions to their lowest level in 25 years. American energy policy must balance environmental protection with economic growth in order to encourage innovation, discovery, and prosperity.*

**- President Donald J. Trump**

# WELCOME
## MESSAGE FROM THE DIRECTOR

Welcome and thank you for visiting the National Energy Technology Laboratory. We at NETL, together with our colleagues in the Office of Fossil Energy, are responsible for planning and executing the nation's fossil energy research program.

Our country's long history of economic progress has relied on abundant and secure energy, which is widely available and environmentally responsible. To continue to rely on clean, abundant energy requires a journey of sustained technology development. I am honored to represent NETL and its research partners in sharing the highlights of our recent efforts with you at this 2018 Science and Technology Accomplishments Session — NETL partnerships harness exceptional talent from across America to develop technologies that improve the beneficial role fossil energy plays in our lives.

Today, NETL researchers are advancing the design of structural and functional materials; leveraging the concept of simulation-based engineering with "hands-on" chemical engineering capabilities, to closely integrate laboratory experiments with computational methodologies. This interwoven approach includes predicting physical, chemical, and biological characteristics of extreme environments from the field-scale to the molecular level and over time spans from microseconds to centuries; and applying machine learning-based estimation tools to enable comprehensive evaluation of complex and diversified energy systems.

NETL's unique facilities and core science and engineering capabilities are being applied to solve the nation's most pressing fossil energy challenges:

- *Improving the performance, reliability, and efficiency of the existing coal-fired fleet.*

- *Advancing the next generation of modular, highly efficient, and flexible coal-fired power plants.*

- *Reducing the cost of captured carbon and put it to work for America.*

- *Creating new jobs, products, and markets for coal.*

- *Leveraging big data and machine learning to unlock our nation's vast unconventional oil and gas resources.*

Making progress against these complex challenges is limited only by our creativity in expanding the state of knowledge, innovativeness in applying these advances in the creation of new energy systems, and a willingness to invest both human and financial resources in this endeavor. Investing in these areas supports the Administration's Energy Independence Policy and its Rebuilding Infrastructure in America Initiative, both of which are intended to strengthen our economy, make our country more competitive, reduce the costs of goods and services for American families, and enable Americans to build their lives supported by the best infrastructure in the world.

Our mission is to discover, integrate, and mature technology solutions to enhance the nation's energy foundation and protect the environment for future generations. As you consider the information presented, I hope you are encouraged and inspired by our work and what is being accomplished.

*The journey continues.*

**Sincerely,**

*Brian J. Anderson, Ph.D., Director*
*National Energy Technology Laboratory*

# CONTENTS

# CORE COMPETENCIES

For more than a century, NETL has leveraged its unique core competencies to deliver innovative technology solutions to America's energy challenges. NETL's execution strategy is two-fold, with both internal and external development avenues aligned with DOE's mission-critical strategic initiatives. Through collaborative partnerships with public and private entities, NETL fosters early stage research and development of technologies best positioned to enable American energy independence and domestic job growth in the near- to mid-term, while protecting human health and the environment.
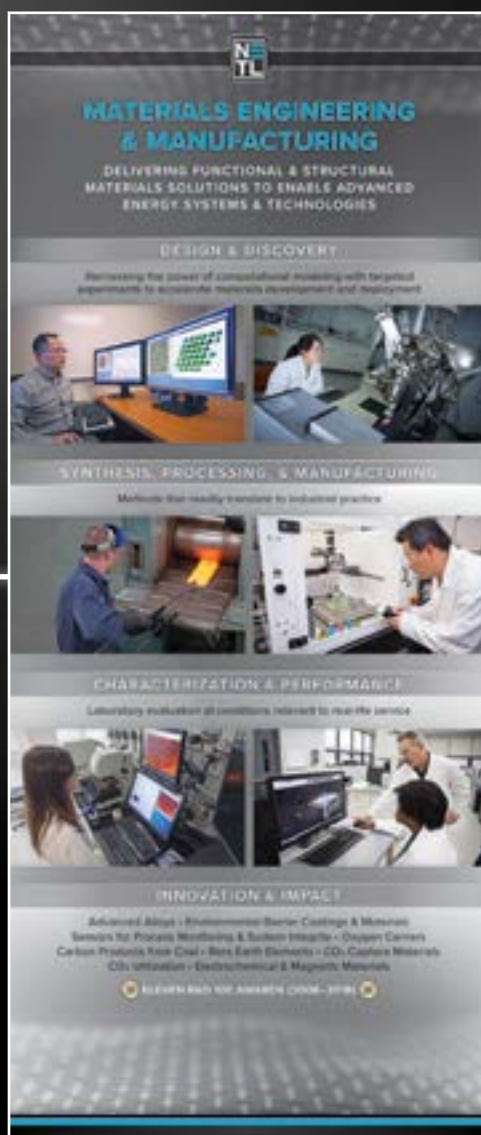
As an applied energy lab, NETL utilizes its six core competencies to address a variety of national challenges, including computational research and scale-up; developing more efficient energy conversion processes; demonstrating novel advanced energy systems; and enabling sustainable, efficient development and production of our domestic fossil energy resources. NETL's world-leading competencies which are relevant to DOE's unique mission are described here as a function of resources (i.e., team, facilities, and/or equipment).

# FE R&D PROGRAM PILLARS

## NETL is focused on solving the nation's most pressing fossil energy challenges, such as:

**IMPROVING THE PERFORMANCE, RELIABILITY, AND EFFICIENCY OF THE EXISTING COAL-FIRED FLEET**

**ADVANCING THE NEXT GENERATION OF MODULAR, HIGHLY EFFICIENT, AND FLEXIBLE COAL-FIRED POWER PLANTS**

# REDUCING THE COST OF CAPTURED CARBON AND PUTTING IT TO WORK FOR AMERICA

# CREATING NEW JOBS, PRODUCTS, AND MARKETS FOR COAL

# LEVERAGING BIG DATA AND MACHINE LEARNING TO UNLOCK OUR NATION'S VAST UNCONVENTIONAL OIL AND GAS RESOURCES

# IMPROVING THE PERFORMANCE, RELIABILITY, AND EFFICIENCY OF THE EXISTING COAL-FIRED FLEET

## ACCOMPLISHMENTS POSTERS:

# ADVANCED OPTICAL FIBER SENSORS FOR NEXT-GEN ENERGY SYSTEMS

Developing sophisticated optical fiber sensors to operate and monitor across the energy production chain

## ENHANCING ENERGY SAFETY, RELIABILITY, & SECURITY

NETL has established research capabilities for the development and optimization of **sensor material and optical fiber sensor devices** suitable for harsh environment applications, such as:

- **Power Generation** — Boilers, Fuel Cells, and Turbines
- **Carbon Storage and Oil and Gas** — Wellbore Integrity
- **Natural Gas Infrastructure** — Pipeline Integrity Monitoring
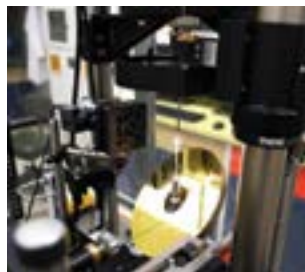

A laser-heated pedestal growth system.

## WORLD-CLASS SENSOR RESEARCH

### PREVENTING NATURAL GAS INFRASTRUCTURE FAILURES
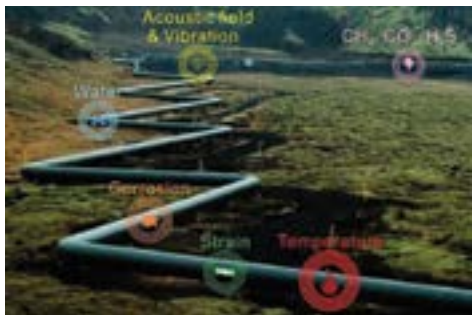


— NETL demonstrated metallic thin-film coated optical fibers can determine corrosion onset and location along the fiber. This **enables distributive monitoring of internal corrosion onset inside natural gas transmission pipelines.**

— NETL demonstrated a multifunctional fiber optic sensor network to monitor water condensation and condensed water chemistry in natural gas transport pipelines for a **highly selective, sensitive, reversible, and fast response.**

### IMPROVED, DISTRIBUTED SENSING IN SOFCs

— NETL developed **new thin-film oxide systems for oxygen sensing in high-temperature conditions for SOFC cathode and combustion gas streams.** These materials will be integrated in the optical fiber platform to test distributed sensing capability.

— NETL **successfully tested 10 optical fiber temperature sensors in an operating fuel cell sample**, which provided the first experimental 2D map of cell performance under operation. **Industrial partners are interested in testing this new technology in their fuel cell stacks.**
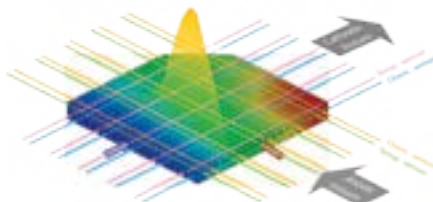

Experimental 2D map of cell performance under operation.

## QUICK FACTS
### BUDGETS & CONTACTS

**FWP-1022424**
TASKS 2.1, 2.5
Award Value $500,000

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**CHRISTOPHER FREITAS**

TECHNOLOGY MANAGER
**JARED CIFERNO**

TECHNICAL PORTFOLIO LEAD
**NATALIE PEKNEY**

---

**FWP-1022427**
TASKS 21, 23, 24, 25, 32, 33
Award Value $903,000

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**BENJAMIN CHORPENING**

---

**FWP-1022411**
TASK 2.2.3
Award Value $223,000

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## PARTNERS

University of Pittsburgh

WATT

VIRGINIA TECH

# ADVANCED OPTICAL FIBER SENSORS FOR NEXT-GEN ENERGY SYSTEMS

Advanced optical fiber sensors for energy systems enhance energy safety, reliability, and security. Optical fibers revolutionize the current sensing methodology by providing real-time and distributed feedback in the harsh operating conditions of thermoelectric power generation. Optical fibers prevent natural gas infrastructure failures and improve sensing in solid oxide fuel cells to ensure reliability for the next generation of energy infrastructure. Through optical sensing improvements, fossil energy continues to produce efficient electricity generation and will do so for decades to come.

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## IMPROVING THE PERFORMANCE, RELIABILITY, AND EFFICIENCY OF THE EXISTING COAL-FIRED FLEET

# AFFORDABLE, DURABLE ALLOYS FOR FOSSIL ENERGY APPLICATIONS

High-performance materials improve efficiencies in the existing coal fleet and enable advanced fossil energy power generation technologies

## MATERIALS ARE AN ENABLING TECHNOLOGY THAT CROSS-CUTS ENERGY SYSTEMS AND PLATFORMS
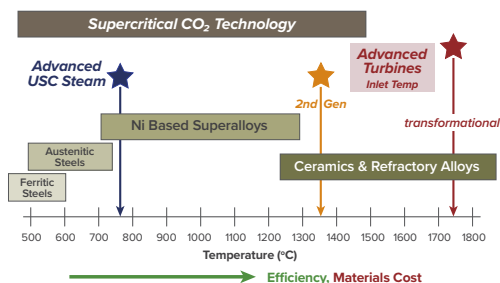


Advanced energy systems: higher operating temperatures and pressures require cost-effective, heat-resistant alloys.

Existing fleet: changing mission profile requires materials that can resist cycling.

## NETL STEEL OUTPERFORMS CONVENTIONAL MATERIALS

Current advanced 9-12Cr steels (alloy Cost-E) can endure about 600 °C in high pressure steam turbines. NETL developed a steel (NETL-JMP) that **may extend service of this work-horse power plant alloy class to 650°C service.** This steel will be more durable in flexible mission profiles and will lower materials costs of advanced energy systems.

Creep behavior of NETL CPJ7 & JMP steels, compared against COST E, COST CB2, and MARBN/SAVE12
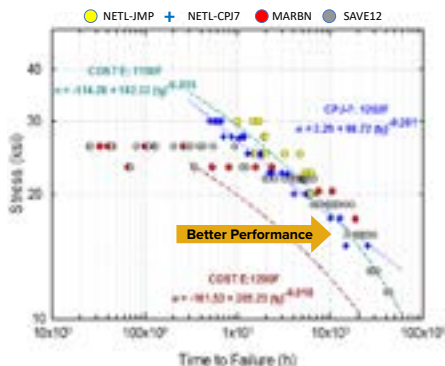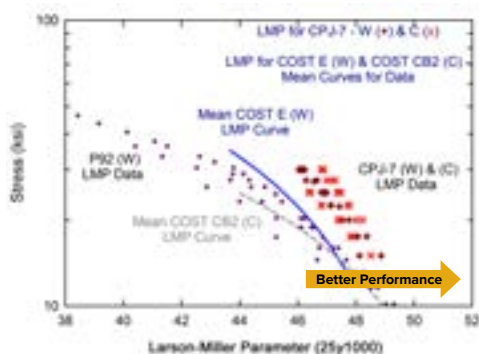


## NETL CAST VERSION OF ALLOY 740: ANOTHER OPTION FOR A-USC CASTINGS

A **modified casting route was developed.** This route leads to more uniform grains throughout the casting and results in **comparable strength to the wrought IN740.**
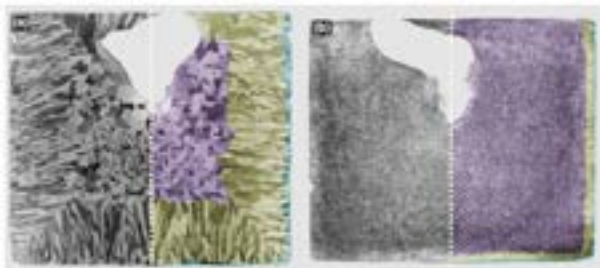


**Conventional Casting:** Non-Uniform Microstructure

**NETL Modified Casting:** Uniform Microstructure

NETL modified casting comparable to wrought alloy
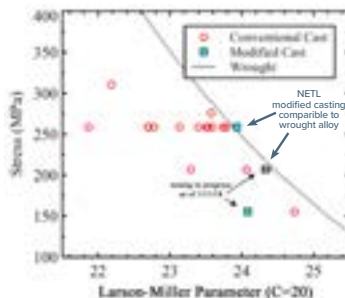
## QUICK FACTS

### AWARD NUMBER
**FWP- 1022406**
**TASKS 5, 6, 7, 8**
RIC ADVANCED ALLOY DEVELOPMENT

## PROJECT BUDGET

**FY18 $1,242,583**
**TASKS 5, 6, 7, 8**

## CONTACTS

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**PAUL JABLONSKI**
**MARTIN DETROIS**
**DAVID ALMAN**

## ASSISTING U.S. INDUSTRY & PROMOTING U.S. ECONOMIC COMPETITIVENESS

**FORT WAYNE METALS**
Turning knowledge into solutions.

Fort Wayne Metals: exploring a **new melt process** method for an aerospace, defense, and medical alloy.

**BioDG, inc.**

Bio-DG: developing **a next-generation bio medical alloy**.

**U.S. DEPARTMENT OF ENERGY** | Energy Efficiency & Renewable Energy
ADVANCED MANUFACTURING OFFICE

Argonne

**De-risking melt processing of Covetic alloy technology.**
NETL demonstrated a consistent process for melt-processing of Covetic Cu and produced the world's first Covetic stainless steel.

# AFFORDABLE, DURABLE ALLOYS FOR FOSSIL ENERGY APPLICATIONS

NETL delivers cost-effective alloy solutions for improving the performance of the existing fossil fleet and enabling next-generation technologies. This research increases the performance of heat-resistant alloys while lowering their manufacturing costs. Using an integrated alloy development approach that combines multi-scale computational modeling with best manufacturing practices and assessment at service conditions, NETL identifies high-performance materials and demonstrates their manufacture at scales that readily translate to industrial practice. NETL's alloy development expertise and manufacturing capability is also leveraged by American industry to develop solutions for other critical technologies and promote U.S. industrial and economic competitiveness around the world.

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**DAVID ALMAN**

## IMPROVING THE PERFORMANCE, RELIABILITY, AND EFFICIENCY OF THE EXISTING COAL-FIRED FLEET

# CYBERSECURITY FOR FOSSIL POWER GENERATION

Guiding solutions to enable a fully automated, reliable, and resilient fossil fleet through intelligent and secure cyber systems

## REDUCING CYBER RISK IN POWER PLANTS

Developing framework to reduce risk and enable industry 4.0 approach

**Industrial Internet of Things**

**Sensing & Monitoring**

Using sensors to continuously monitor process and asset conditions

Integrating cyber intrusion detection functionalities with control and monitoring and diagnostic toolsets

**Software & Systems**

**OT Security**

Eliminating sensor data corruption by assuring sensor data integrity using blockchain

Cyber-secure engineering of sensors and other plant components

**Simulation-Driven Engineering**

**Data Analytics & Data Management**

Recognizing malicious behavior by analyzing sensor data with machine learning

## REDUCING CYBERSECURITY RISKS ACROSS ENERGY INFRASTRUCTURE

### Gap Analyses
- Behavioral analytics — Southern Company
- Cyber-secure sensor networks — Siemens
- Cybersecurity risk reduction — EPRI
- Digital Ghost — GE

### Secure Data Communication
- Blockchain for secure energy — Taekion (GRID7)

### Enhanced Situational Awareness (Machine Learning)
- Metaphortress — Sonalysts
- Fiber-optic sensing — Intelligent Fiber Optic Systems
- Automated situational awareness — Ridgetop Group
- Data ingestion, analysis, and situational awareness — Physical Optics

Secure Data Communication

Risk Mitigation

Gap Analysis

Machine Learning
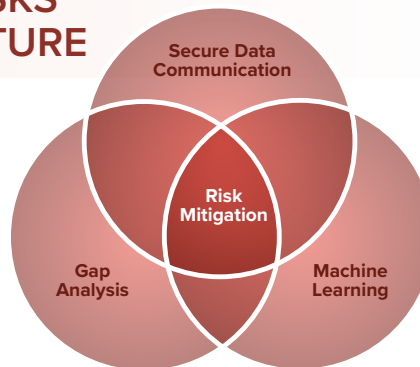
## ADVANCING THE SCIENCE OF CYBER IN ENERGY

- Data-driven control systems and predictive maintenance solutions **to improve reliability using computational tools**
- Decentralized fossil generation **control, monitoring, and diagnostics**
- Managing the proliferation of sensors, especially the communication network for **wireless sensors to enhance infrastructure**

Pressurized air-cooled generator with real-time cyber monitoring of component conditions

## PROJECT BUDGET

TOTAL AWARD VALUE ACROSS ALL PROJECTS

**$3,151,600**

## CONTACTS

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## PARTNERS

ENERGY | OFFICE OF CYBERSECURITY, ENERGY SECURITY, AND EMERGENCY RESPONSE

GE

Southern Company

Taekion

SIEMENS

POC

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

SONALYSTS

IFOS

Ridgetop Group Inc. ENGINEERING INNOVATION

# CYBERSECURITY FOR FOSSIL POWER GENERATION

NETL's cybersecurity program aims to protect the nation's infrastructure from foreign threats and preserve national security through gap analyses, secure data communication, and enhanced situational awareness. By improving cybersecurity for thermoelectric power generation, a baseload source of electricity is protected from weather events or foreign attacks. Cybersecurity enables highly instrumented thermoelectric power plants with advanced controls that may bring about flexibility and reliability benefits through automation, predictive maintenance, and fault detection. Utilizing the latest technology and algorithms, NETL's cybersecurity program will continue to investigate the latest technology solutions to improve reliability, control, monitoring, and diagnostics.

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## IMPROVING THE PERFORMANCE, RELIABILITY, AND EFFICIENCY OF THE EXISTING COAL-FIRED FLEET

# ENABLING RESPONSIBLE WATER USE FOR POWER GENERATION

The 2018 Water Brief raises awareness and guides investment in cost-effective technical solutions on a local, regional, and national scale

## ADDRESSING NATIONAL WATER AVAILABILITY

The 2018 Water Brief documents geographic Areas of Concern for water availability in the continental United States

By identifying these pinch points, regional and national stakeholders can **make informed choices surrounding R&D for thermoelectric power generation and ensure sustainable and reliable generation for decades to come.**



2018 Power Capacity in the Tri-State Area
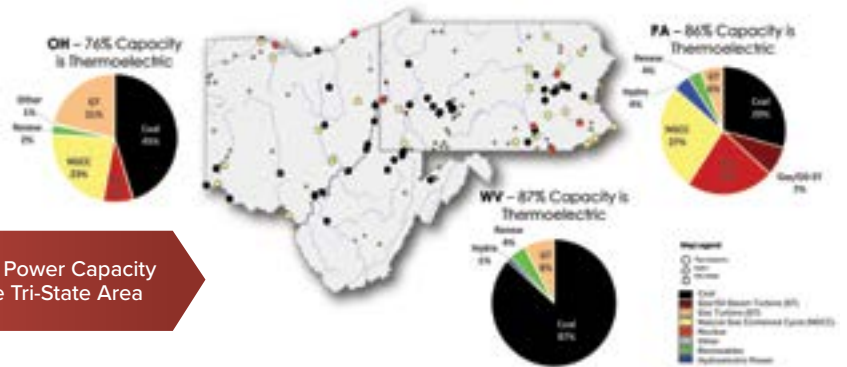
## THE 2018 WATER BRIEF
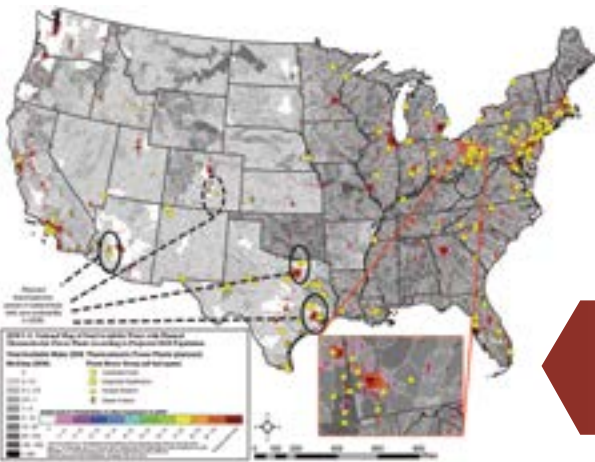


- **Identifies** regions of water scarcity with expected growth in thermoelectric power generation.
- **Recommends** R&D to curb thermoelectric water use in Areas of Concern.
- **Predicts** locations that would benefit from R&D deployment.

Four Hydrologic Unit Code 8 watersheds are projected to have zero water availability in 2030 with expected growth in thermoelectric power generation.

## ADVANCING SOLUTIONS TO LIMITED WATER ACCESS
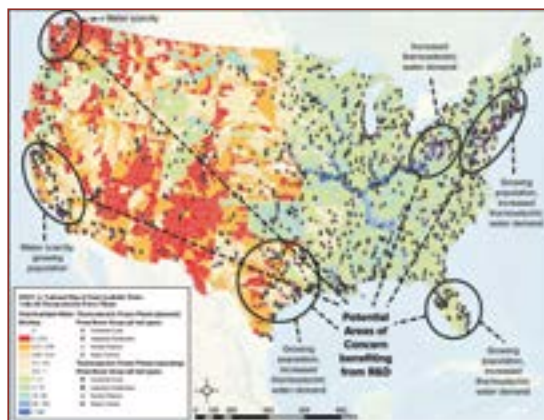


### RECOMMENDATIONS FROM THE 2018 WATER BRIEF:

- Reuse of cooling tower blowdown and effluent water can lower overall water consumption.
- Plant flexibility for load cycling can help plant operators in areas with high renewable penetration.
- Flue gas desulfurization wastewater treatment can affordably enhance effluent water quality, which can then be reused within the plant.

Six potential geographic Areas of Concern that require an R&D plan are shown on a graphic of total available water (2010) overlaid with thermoelectric power generation (2018).

## QUICK FACTS

AWARD NUMBER
**FWP-14-017626**

## PROJECT BUDGET

TOTAL FUNDING
**$1,293,000**

## CONTACTS

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ENGINEER/ENERGY ANALYST
**ERIK SHUSTER**

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Sandia National Laboratories

Carnegie Mellon University

## COMPILERS OF 2018 WATER BRIEF

**JOCELYN KATE MACKAY, KATRINA KRULLA, DALE KEAIRNS, ERIC LOPERT,** AND **MASSOOD RAMEZAN**

# ENABLING RESPONSIBLE WATER USE FOR POWER GENERATION

NETL's 2018 Water Brief raises awareness and guides investment in technical solutions across the national, local, and regional scales. The brief's analysis enables stakeholders to make informed decisions surrounding R&D for thermoelectric power generation to ensure sustainable and reliable generation in water scarce or densely populated geographic locations. The brief identifies locations which may benefit from cooling tower blowdown, effluent water reuse, added flexibility, dry and hybrid cooling, and flue gas desulfurizationD wastewater treatment. Through these recommendations, thermoelectric power generation secures efficient electricity production for years to come.

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## IMPROVING THE PERFORMANCE, RELIABILITY, AND EFFICIENCY OF THE EXISTING COAL-FIRED FLEET

# INSTITUTE FOR THE DESIGN OF ADVANCED ENERGY SYSTEMS

Advanced process systems engineering capabilities to optimize fossil energy systems

## IMPROVING POWER PLANT EFFICIENCY, RELIABILITY, & FLEXIBILITY

The Institute for the Design of Advanced Energy Systems (IDAES) **accelerates cost-effective technology deployment needed to support critical DOE missions.**

IDAES develops and utilizes multi-scale, optimization-based **computational tools** to improve the **design, analysis, and operation** of both the **existing fleet** and innovative, **advanced coal energy systems of the future.**

**IDAES**
Institute for the Design of Advanced Energy Systems

## NEXT-GENERATION COMPUTATIONAL FRAMEWORK

**IDAES builds on fundamental advances in algorithms and computing technology** to address a critical capability gap in process modeling tools, enabling the large-scale optimization of complex dynamic systems.

Transition to glass-box and algebraic modeling and analysis

Advances in continuous nonlinear optimization (dynamics, uncertainty)

Advances in discrete optimization (algorithms and formulation)
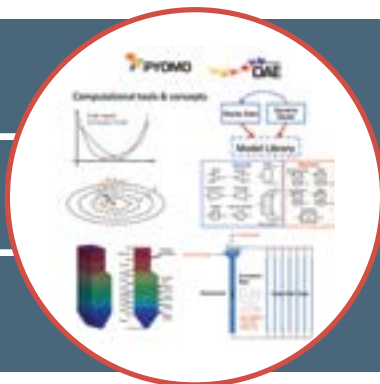
Open-source, extensible algebraic modeling platforms

Emerging computational architectures and high-performance computing

## MEETING POWER INDUSTRY NEEDS

### CONTINUAL DIALOGUE WITH INDUSTRY

**Formalized an advisory board with 15 industrial stakeholders** from diverse industries to provide guidance to the IDAES development team.

**Initiated collaborative agreements** with Tri-State Generation and Transmission Association, Inc., Ohio State University, and GE Power.

### OPTIMIZATION OF EXISTING PLANTS

**Developed a general power plant model suitable for optimization** that incorporates detailed representations of the boiler, steam turbines, and a comprehensive feedwater heater network using rigorous calculations for the water-steam thermodynamic properties.

### OPEN-SOURCE TOOLSET TO PROMOTE WIDE ADOPTION

**Released limited open-source software to existing stakeholders,** including power producers, energy companies, chemical manufacturers, and technology developers.

# INSTITUTE FOR THE DESIGN OF ADVANCED ENERGY SYSTEMS

The Institute for the Design of Advanced Energy Systems (IDAES) revolutionizes industry diagnostic and decision-making capabilities with next-generation process modeling that supports the design, analysis, and operation of fossil energy systems. IDAES enhances the operation, profitability, and efficiency of the existing fleet and empowers sound investment decisions for advanced energy systems. Utilizing the latest technology in algorithms and computing, IDAES' innovative, open-source software enables large-scale optimization and can be applied to several process industries.

PRESENTER:
**DAVID MILLER**
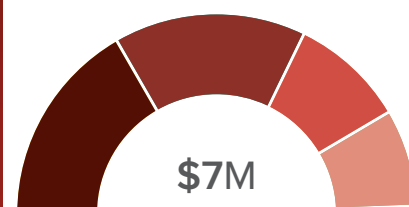
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PRINCIPAL INVESTIGATOR
**DAVID MILLER**

## IMPROVING THE PERFORMANCE, RELIABILITY, AND EFFICIENCY OF THE EXISTING COAL-FIRED FLEET

# MULTIPHASE FLOW SCIENCE: COMPUTATIONAL TOOLS FOR DESIGN AND OPTIMIZATION

World-class expertise, combined with the MFiX Suite of powerful, open-source computational fluid dynamics software tools, enable transformational design and optimization of multiphase flow energy systems.

## DESIGN AND OPTIMIZATION OF EFFICIENT, ROBUST, AND FLEXIBLE ENERGY SYSTEM DEVICES



NETL's MFiX Suite of Multiphase Flow CFD software is a **versatile, open-source toolset,** which significantly **reduces time, costs, and risk inherent to design, optimization, and troubleshooting** of energy conversion devices and reactors at industrial scale.

## COMPUTATIONAL TOOLS FOR TRANSFORMATIONAL DESIGN

**MFiX's tools are built on over three decades of world-class multiphase flow research** to provide validated computational tools and framework for FE reactor design and optimization using high-performance computing systems.
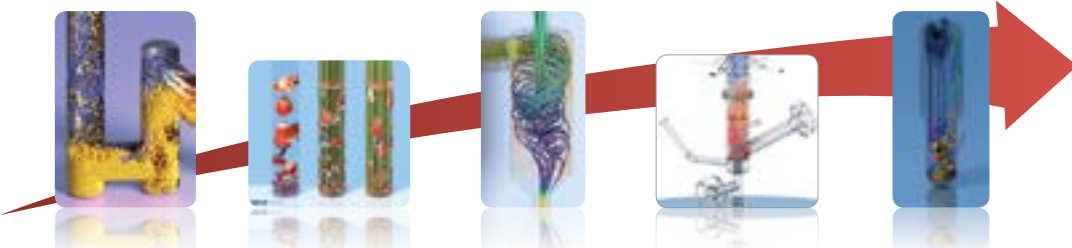


In FY18, MFiX user registration reached an all-time high of 5,000, and its annual software downloads rose to 4,000—a 122% increase from FY17.

## FROM SOUND FUNDAMENTALS TO INDUSTRY RELEVANCE

- **Billion-Particle Simulation Achieved with MFiX:** Utilizing MFiX, collaborators at the University of Colorado, Boulder achieved a breakthrough simulation containing one billion particles, demonstrating capability for high-fidelity multiphase modeling at industrial scale.

- **Computational Tools for the Next Generation:** NETL has released its newest member of the MFiX software suite, MFiX-PIC, which allows for a speed increase of more than 10-fold. NETL and Lawrence Berkeley National Laboratory have teamed under DOE's Exascale Computing Project to develop the MFiX platform for next-generation exascale supercomputers.

- **Relevance in Industry:** NETL and Babcock and Wilcox established a collaborative program using MFiX to address circulating fluid bed boiler performance challenges in today's operating environment.

## QUICK FACTS

### AWARD NUMBER
### DE-FE0026298
### FWP-1022405

## PROJECT BUDGET

DE-FE0026298



**$3.8**M
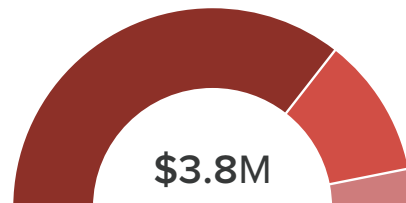
- DOE ·························· $2,857,479
- CU BOULDER ··············· $920,523
- PSRI ·························· $254,812

FWP-1022405

DOE: **$2.3**M

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**NATIONAL ENERGY TECHNOLOGY LABORATORY**

# MULTIPHASE FLOW SCIENCE: COMPUTATIONAL TOOLS FOR DESIGN AND OPTIMIZATION

NETL's Multiphase Flow Science (MFS) R&D enables design, optimization, and troubleshooting of efficient, robust, and flexible energy conversion devices and fossil energy reactors. MFS's MFiX tool suite leverages three decades of world-class multiphase flow research and empowers sophisticated 3D multiphase flow modeling/simulation and computational validation for rapid, cost-saving development of these reactors and systems. Milestones such as a billion-particle simulation, deployment of the MFiX platform in exascale computing platforms, and NETL's industry collaborations demonstrate NETL MFS' relevance in tackling and solving real-world, industrial-scale problems.

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JORDAN MUSSER
WILLIAM ROGERS
CHRISTINE HRENYA**

**IMPROVING THE PERFORMANCE, RELIABILITY, AND EFFICIENCY OF THE EXISTING COAL-FIRED FLEET**

# NEW R&D INITIATIVE FOR EXISTING COAL-FIRED POWER PLANTS

Concentrating on dynamic performance and reliability; materials; sensors, controls, and diagnostics; and power plant component improvements

## IMPROVING THE RELIABILITY, RESILIENCE, AND VIABILITY OF THE EXISTING FOSSIL-BASED FLEET



### NETL RIC IS DEVELOPING NEW TECHNOLOGIES

- R&D program that **focuses on new, early stage concepts** leveraging NETL's and its academic partners' capabilities.

- Using **real-time analysis of existing data streams,** NETL RIC developed a **new concept to identify the maintenance condition** of power plants. The process was demonstrated on a lab-scale turbine at NETL and is **being discussed with coal plant operators for potential use.**

### GE POWER IS ENABLING LOW-LOAD OPERATION AT COAL PLANTS

- **Developed sensor network** to monitor and facilitate low-load operation of the pulverizer and combustor.

- **Completed initial round of low-load pulverizer testing** with promising results.

- The project has been **extended to include field testing** to take place at the Cross Generating Station in Pineville, SC.

### CONTACTS

HQ PROGRAM MANAGERS
**ROBIE LEWIS
MARGARET SCHAUS**

TECHNOLOGY MANAGERS
**JOHN ROCKEY
BRIGGS WHITE**

## EXISTING PLANTS R&D INITIATIVE PARTNERS



**ORGANIZATION CATEGORIES:**
- Utility — Generator (13)
- Service Provider (9)
- Coal Company (1)
- University (13)
- Utility — Power Provider (1)
- Equipment Manufacturer (11)
- Research Institute (4)
- National Laboratory (2)

**INTERNATIONAL PARTNER:**
China University of Mining and Technology

# NEW R&D INITIATIVE FOR EXISTING COAL-FIRED POWER PLANTS

NETL initiated research in 2018 to enhance existing coal plant operation and address the challenges of today's electricity markets. The new initiative—under Transformative Power Generation and Crosscutting Technologies Programs—awarded 28 projects as part of two FOAs. These projects, which fulfill DOE's mission to improve the reliability, resilience, and viability of the existing fossil-based fleet, concentrate on dynamic performance and reliability; materials; sensors, controls, and diagnostics; and power plant component improvements.

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**GEORGE (GEO) RICHARDS**

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## IMPROVING THE PERFORMANCE, RELIABILITY, AND EFFICIENCY OF THE EXISTING COAL-FIRED FLEET

# RAPID MANUFACTURING METHOD FOR HIGH-TEMPERATURE TURBINE COMPONENTS

Providing rapid, low-cost manufacturing for prototype and proof-of-concept gas turbine components

## RESPONDING TO DOMESTIC ENERGY CHALLENGES

**MIKRO Systems, Inc. (Mikro) is producing advanced turbine components for reliable, affordable, and environmentally friendly electric power using its Rapid Manufacturing Method (RMM).**

This project will allow turbine manufacturers to rapidly incorporate design enhancements, **leading to affordable products and lower plant and electricity costs.**
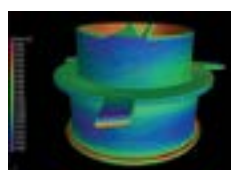


Initial Parts
(Blue & Red represent non-conforming areas)
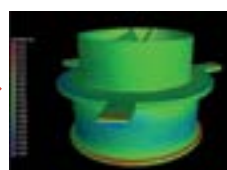
1st Revision
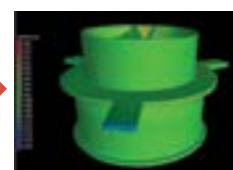
2nd Revision

**MIXER PART**
Developed method for using CT scans to modify production molds

## PRODUCING ADVANCED COMPONENTS AT A REDUCED COST

**Mikro is producing components in higher volumes from industry standard materials, powdered metals, and ceramics.**

- Compressing development time and costs for turbine components
- Established quality controls and inspection protocols for parts made with the Rapid Manufacturing Method

- Expanded material capabilities for turbine alloys by developing materials and binder systems
- Providing a cost-effective manufacturing platform for complex turbine components
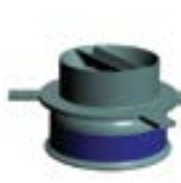


CAD Model

Green Part

Sintered Part

**PRODUCTION OF PRATT & WHITNEY MIXER FROM CAD MODEL**

Mixers produced using Mikro's RMM process were sent to Pratt & Whitney for testing. These parts met acceptance critera.

## TECHNOLOGIES TO IMPROVE EFFICIENCY & PERFORMANCE

**Mikro has demonstrated advantages in component quality and industrialization over competing Layered Manufacturing Techniques while moving technologies into commercialization.**

Other successes are:
- **Advanced the sintering process** with Mikro's in-house hydrogen furnace
- **Investigated hot isostatic pressing** for increasing density of parts
- **Produced green and sintered parts** using a complex Siemens design
- **Explored alternate methods of mold design** for larger scale production
- **Developed a method for producing production molds** without 3D printing
- **Produced three commercially ready turbine components** that meet specifications and acceptance criteria

## QUICK FACTS

AWARD NUMBER
**DE-SC0010175**

## PROJECT BUDGET

TOTAL
**$2,149,180**

## CONTACTS

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**JOHNATHAN MOORE**

## PARTNERS





X-ray image of mixer part produced with RMM

# RAPID MANUFACTURING METHOD FOR HIGH-TEMPERATURE TURBINE COMPONENTS

NETL funded work wherein Mikro Systems (Mikro) used a Tomo-lithographic molding (TOMO) process to rapidly manufacture tooling to make advanced turbine components. The rapid manufacturing method (RMM) of tooling combined with a process to cast and sinter powdered metal dramatically reduced the time and cost to design, prototype, and produce new high temperature turbine components. This method also enables the production of more complex structures with tight-tolerance parts. Mikro successfully produced three commercially ready turbine components from Pratt & Whitney that meet specifications and acceptance criteria. This RMM has significant time and cost advantages and, the TOMO tooling system saves 60% over conventional serial production methods for advanced components, such as investment casting and diffusion bonding. Using a TOMO technology platform, Mikro also commercialized Anti-Scatter Grids for multi-slice CT scanners and licensed technology to Siemens to produce advanced ceramic cores for next-generation Industrial Gas Turbine airfoils.

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## IMPROVING THE PERFORMANCE, RELIABILITY, AND EFFICIENCY OF THE EXISTING COAL-FIRED FLEET

# ADVANCING THE NEXT GENERATION OF MODULAR, HIGHLY EFFICIENT, AND FLEXIBLE COAL-FIRED POWER PLANTS

# ACCOMPLISHMENTS POSTERS:

# ADVANCED ULTRA-SUPERCRITICAL (AUSC) COMPONENT TESTING (COMTEST)

Developing a domestic supply chain for fabricating nickel superalloy and other advanced ultra-supercritical components

## PUSHING BOUNDARIES ON TEMPERATURE AND PRESSURE

By 2021, AUSC materials will be developed to operate at high pressures and temperatures to **meet the global electricity demand, reduce overall emissions, and increase efficiency** in coal-fired power plants.

**The ComTest project will lead to:**

- Lower emissions and higher efficiency
- Minimized risk for AUSC plant development
- Development of a domestic supply chain for AUSC components

## AUSC COMPONENT MANUFACTURING SCALE-UP

**This project will fabricate commercial-scale nickel superalloy components and sub-assemblies that are suitable for use at AUSC temperatures and pressures (760 °C / 4,000 psi).**

**ComTest focuses on building full-scale versions of selected components,** which has been identified as the **final step** necessary **to demonstrate the readiness of AUSC technology for a commercial-scale demonstration** power plant.

**AUSC power plants are 25% more efficient than average power plants, and 10% more efficient than state-of-the-art power plants.**

## AUSC MATERIALS TECHNOLOGY DEVELOPMENT

**1**

AUSC superheater/reheater assembly

**2**

AUSC steam turbine nozzle carrier casting

**PHASE 1: COMPLETE**

Completed front-end engineering design and detailed engineering. Began developing a domestic supply chain for AUSC nickel superalloy components and determined that operational testing of an AUSC steam turbine and AUSC superheater were not required.

**PHASE 2: CURRENT**

Developing a qualified domestic supply chain to manufacture nickel superalloy components for AUSC power plants by fabrication of selected commercial-scale AUSC components and parts.

### QUICK FACTS

**AWARD NUMBER**
**DE-FE0025064**

### PROJECT BUDGET

$6.8M

$20M

**$26.8M**
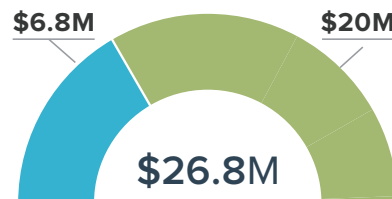
- DOE
- ENERGY INDUSTRIES OF OHIO

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**ROBERT PURGERT**

### PARTNERS

Energy Industries of Ohio

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

ALSTOM

TE

GE

RileyPower

MetalTek

AECOM

SPECIAL METALS

YOUNGSTOWN THERMAL

# ADVANCED ULTRA-SUPERCRITICAL (AUSC) COMPONENT TESTING (COMTEST)

The Advanced Ultra-Supercritical (AUSC) Component Testing project is accelerating the commercial deployment of advanced, coal-based power generation processes that will achieve higher efficiency, lower emissions, and longer life of existing and new power plants. The project is enabling these improvements by manufacturing full-scale, nickel superalloy components needed in advanced coal-fired power plants and developing a domestic supply chain for these components. This is the final step necessary to demonstrate the readiness of AUSC technology for existing power plants to improve their life when operated in severe cycling modes or for a commercial-scale demonstration plant.

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## ADVANCING THE NEXT GENERATION OF MODULAR, HIGHLY EFFICIENT, AND FLEXIBLE COAL-FIRED POWER PLANTS

# ADVANCES IN PRESSURE GAIN COMBUSTION TURBINE SYSTEMS

Collaborating with key energy entities on complementary combined-cycle research

## IMPROVED CYCLES, IMPROVED EFFICIENCY

Pressure Gain Combustion (PGC) systems have the potential to improve combined cycle performance when integrated with combustion gas turbines.

Integrating a rotating detonation engine (RDE) into a PGC system **can achieve a combined cycle efficiency equal to or greater than the DOE target of 65%.**

### RDE would replace the traditional combustion process

RDEs' rapid detonation causes the turbine to react as if the flow were steady. Therefore, RDEs avoid the pressure loss and resulting decrease in efficiency that occurs with conventional gas turbine engines.

## ENCOURAGING NATIONAL COLLABORATION
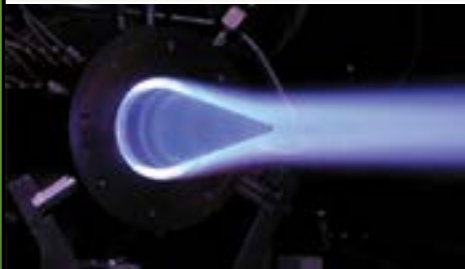

Rotating Detonation Combustor

Groundbreaking research on a potential turbines combustor that **can increase pressure and increase efficiency over traditional methods of improving turbine efficiency** is underway. This research is attracting research partners from some of the nation's leading institutions, including Southwest Research Institute (SwRI), University of Central Florida (UCF), and Purdue.

## COLLABORATIVE ACCOMPLISHMENTS

NETL and Aerojet Rocketdyne brought together major entities working on PGC/RDE. This combined effort utilized existing equipment to run tests that compared data. This approach limited duplication of efforts and ensured complimentary testing.

- RDE testing resulted in hundreds of high-energy tests in support of Aerojet Rocketdyne's RDE for Gas Turbines Project
- SwRI facility set up for efficient RDE hot fire testing
- UCF contributed high-speed, high-resolution imaging and spectroscopy systems
- Purdue research provided unprecedented temporal resolution

### Schematic of system for RDE


Lasers and Beam Splitters
4875nm
2482nm   2551nm
PV Detectors (water)
Diffraction Gratings
PV Detector (reference)
Optical Cables
RDE
Detonation Channel
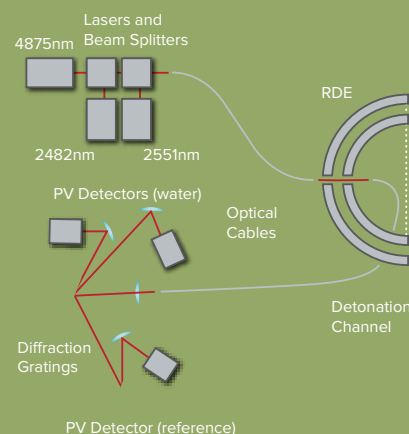
## QUICK FACTS

**AWARD NUMBER**
DE-FE0023983

## PROJECT BUDGET

FY18 FUNDING

$7.6M

- DOE .................... $6,054,678
- PERFORMER ............. $1,515,449

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**GLENN HAVSKJOLD**

## PARTNERS

PURDUE UNIVERSITY

THE UNIVERSITY OF ALABAMA

AEROJET ROCKETDYNE

SwRI

UNIVERSITY OF CENTRAL FLORIDA

# ADVANCES IN PRESSURE GAIN COMBUSTION TURBINE SYSTEMS

Rotating Detonation Combustion (RDC) offers an unconventional approach to greater efficiency in gas turbine engines by increasing the internal pressure through non-mechanical means. This dual-use technology has broad support in the aerospace industry and is the focus of collaborative research efforts between the Energy Department, Defense Department, NASA, and multiple academic partners. A joint program involving NETL and the Air Force Research Laboratory (AFRL) demonstrated negligible impact on turbine efficiency from RDC when installed in a T63 turboshaft engine and reduced NOx emissions. NETL has facilitated collaboration between Aerojet Rocketdyne and UTSR award recipients resulting in hundreds of high-energy tests investigating RDC in gas turbine engines while operating on natural gas and coal syngas.

PRESENTERS:
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## ADVANCING THE NEXT GENERATION OF MODULAR, HIGHLY EFFICIENT, AND FLEXIBLE COAL-FIRED POWER PLANTS

# R&D INITIATIVES LAUNCHED FOR COAL PLANTS OF THE FUTURE

**Modernizing America's coal fleet to provide secure, stable, and reliable power**

## TRANSFORMING & MODERNIZING THE COAL-FIRED POWER FLEET

Developmenting power plant systems and technologies that will **enable the future deployment of efficient, clean, and cost-competitive coal power plants.**

- High Efficiency
- Low Emissions
- Grid Independent
- Integrate with Intermittent Power
- $CO_2$ Capture Ready
- Domestic and International Market Pull
- Modularity and Parametric Design
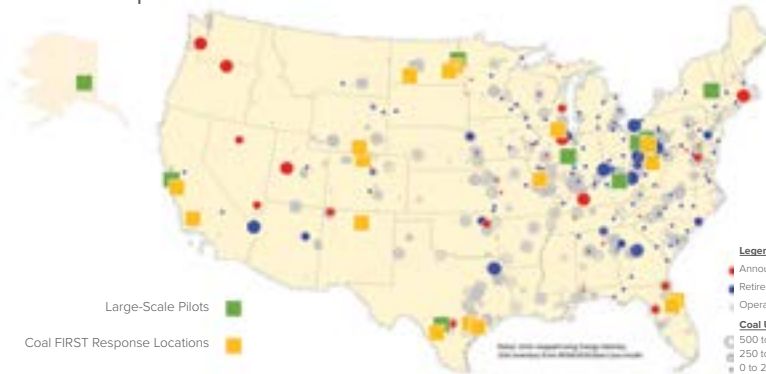


9 projects selected from DE-FOA-0001788 (Large-Scale Pilots) were awarded federal funding for Phase I.

33 responses from 31 respondents were received from the Coal FIRST RFI.

**Legend**
- Announced retirement through 2025
- Retired 2012–2016
- Operating coal units

**Coal Units** *Size By Capacity (MW)*
- 500 to 1344
- 250 to 500
- 0 to 250

Large-Scale Pilots

Coal FIRST Response Locations

### QUICK FACTS

**AWARD NUMBER**

**DE-FOA-0001788**

(LARGE-SCALE PILOTS)

### PROJECTED PHASE BUDGETS
(LARGE-SCALE PILOTS)

**$101.5M**

- PHASE I · · · · · · · · · · · · · · · · $6,500,000
- PHASE II · · · · · · · · · · · · · · · $15,000,000
- PHASE III · · · · · · · · · · · · · · · $80,000,000

## COAL FIRST INITIATIVE

This initiative will **integrate critical R&D on power plant components with currently available technologies into a first-of-a-kind system** to make coal-fired power plants more adaptive to the modern electrical grid.
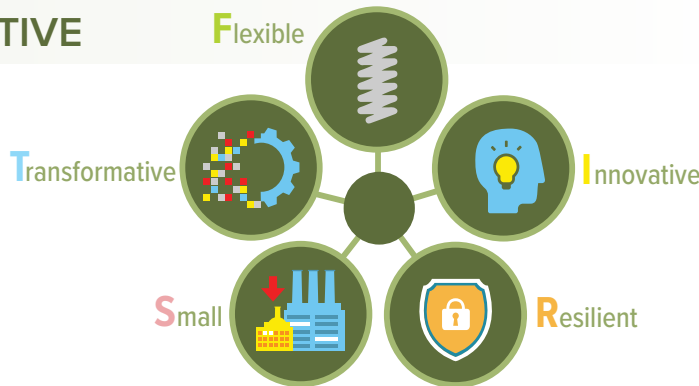


**F**lexible
**T**ransformative
**I**nnovative
**S**mall
**R**esilient

### CONTACTS

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**December 2018**
RFP seeking conceptual design for Coal-Based Power Plants of the Future with an option for Pre-Feed Feasibility study.

**Q2 of FY19**
FOA for cost-shared research and R&D projects focused on steam turbines that can be integrated into a 50–350 MW future advanced coal plant design.

**Q3 of FY19**
FOA for cost-shared R&D projects focused on critical components and advanced approaches (e.g., manufacturing, fabrication, advanced design) to support future coal plants.

## TRANSFORMATIONAL LARGE-SCALE PILOTS



This program is developing two large-scale pilot operations utilizing advanced coal conversion and/or capture technologies, representing **new ways to convert energy.**

**End of FY19**
- Complete Phase I – Pre-FEED Feasibility Studies
- Down-select to the 4–5 most promising technologies (and teams)

**End of FY21**
- Complete Phase II-Design activity
- Down-select to the 2 most promising technologies (and teams)

**End of FY26**
- Complete Phase III- Design, Construction, and Operation of 2 large-scale pilot facilities

**End of FY30**
- Transfer technology to private sector to construct and operate an advanced coal plant

# R&D INITIATIVES LAUNCHED FOR COAL PLANT OF THE FUTURE

The Coal FIRST and Transformational Large-Scale Pilot programs focus on the development of coal technologies that will enable the future deployment of efficient, clean, cost-competitive coal power plants. The Coal FIRST initiative will make coal-fired power plants of the future more adaptive to the modern electrical grid. The initiative will develop advanced power plant systems that integrate advanced components requiring R&D with currently available technologies into first-of-a-kind systems. The Fossil Fuel Large-Scale Pilots effort supports the design, construction, and operation of large test facilities for transformational coal technologies aimed at enabling step change improvements in coal-powered system performance, efficiency, and cost of electricity. The pilots supported by DOE will be used to assess the scalability and commercial potential of transformational coal technologies, helping mitigate risk and aiding in commercial adoption. Technologies from both initiatives will allow for plants that operate flexibly, maintain high reliability and resiliency, and can be deployed to accommodate an evolving electricity market.

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**JOHN ROCKEY**

## ADVANCING THE NEXT GENERATION OF MODULAR, HIGHLY EFFICIENT, AND FLEXIBLE COAL-FIRED POWER PLANTS

# SOLID OXIDE FUEL CELL COMMERCIALIZATION

Collaborating with industry to commercialize solid oxide fuel cells that generate electricity through electrochemical reactions

## PROVING COMMERCIAL VIABILITY & SPURRING DEVELOPMENT
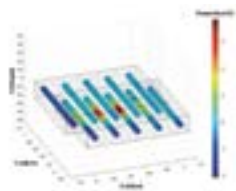
Nexceris and Watt Fuel Cell plan to **demonstrate an NETL fiber optic-based temperature/gas sensor** in small stack test.

NETL and CMU produce the **largest volume high resolution 3D reconstructions in the world.** Large volumes allow enhanced measurement of the electrode microstructure's uniformity on multiple length scales. Nonuniformity decreases performance and increases degradation.
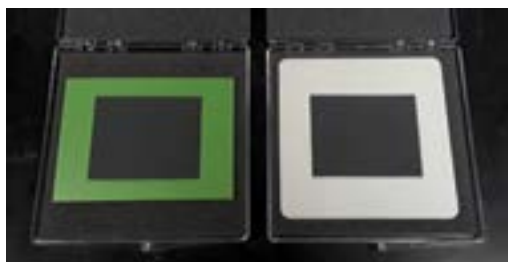
NETL and WVU developed an anode infiltration technique that was **applied to Nexceris commercial-scale fuel cells and demonstrated 5–10% improved performance over untreated cells.**

## IMPROVING PERFORMANCE & ELIMINATING DEGRADATION

Atrex Energy constructed automatic electrode engineering systems and produced cells with engineered electrodes **based on the NETL's patented single-step electrode infiltration technology.**

Atrex Energy constructed a 1-kW SOFC stack and evaluated for 2,000+ hours, **demonstrating higher cell performance and no degradation.**

Secretary Perry examines a solid oxide fuel cell during a visit to NETL

## EFFICIENT POWER GENERATION WITH REDUCED ENVIRONMENTAL IMPACT

NETL is conducting research and development to improve solid oxide fuel cell (SOFC) performance, and is collaborating with industry to demonstrate the technologies applied to their commercial fuel cells.

SOFC are electrochemical devices that convert chemical energy of a fuel directly into electrical energy, producing electricity through an electrochemical reaction rather than combustion.

Air

$1[O_2] + 4[e^-] \rightarrow 2[O^=]$

Cathode

$e^-$    R    Electrolyte    $\downarrow 2[O^=]$

$1[H_2] + 1[O^=] \rightarrow 1[H_2O] + 2[e^-]$
$1[CO] + 1[O^=] \rightarrow 1[CO_2] + 2[e^-]$

Anode

Fuel
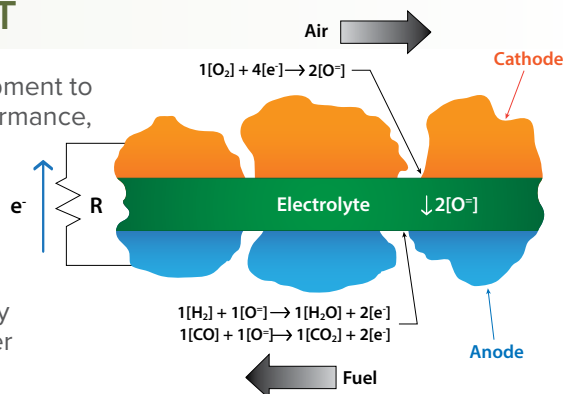
**These technologies will help create a more stable energy grid, leading to greater American energy independence.**

## QUICK FACTS

AWARD NUMBER
**FWP-1022411**

### BUDGET

FWP-1022411 (SOFC)
**TOTAL BUDGET: $6.0M**
NEXCERIS Allotment ·············· ~$50K

FWP-1022411 (TCF 1)
**TOTAL BUDGET: $500K**
NETL ································· $250K
ATREX ENERGY ····················· $250K

FWP-1022411 (TCF 2)
**TOTAL BUDGET: $1.15M**
NETL ································· $575K
WATT FUEL CELL ·················· $575K

### CONTACTS

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**JAI-WOH KIM**

PRINCIPAL INVESTIGATOR
**GREGORY HACKETT**

### PARTNERS

NEXCERIS
where energy meets environment

WATT

ATREX ENERGY
POWERFUL POSSIBILITIES

Carnegie Mellon University

West Virginia University

# SOLID OXIDE FUEL CELL COMMERCIALIZATION

NETL develops novel technologies to aid in the design and improve the performance of solid oxide fuel cells (SOFC). This emerging power system uses electrochemical reactions instead of combustion for highly efficient, low-cost production of electricity. Collaboration with universities and industry on the development, testing, and implementation of these NETL-developed technologies applied to commercial fuel cells is enhancing the path to commercialization for SOFCs.

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PRINCIPAL INVESTIGATOR
**GREGORY HACKETT**

**ADVANCING THE NEXT GENERATION OF MODULAR, HIGHLY EFFICIENT, AND FLEXIBLE COAL-FIRED POWER PLANTS**

# SUPERCRITICAL CARBON DIOXIDE POWER CYCLES

Advancing novel $sCO_2$ power cycle technologies

## REVOLUTIONIZING DOMESTIC & GLOBAL POWER GENERATION

Supercritical $CO_2$ ($sCO_2$) power cycles offer the potential for power generation with **increased efficiency, lower cost of electricity, reduced costs for the customer, and reduced water consumption.**

DOE's investment in $sCO_2$ power cycle technology will **enable the United States to take the lead in developing and commercializing $sCO_2$ power cycle deployment** for both domestic and global power generation.



Recompression Cycle for STEP pilot plant

## REDUCING BARRIERS & RISKS TO COMMERCIALIZATION



**STEP 10 MWe $sCO_2$ Power Cycle Pilot Plant:**

- Plan, design, build, and operate a pilot plant test facility
- Demonstrate cycle operability at pilot scale to inform future, larger scale-ups
- Verify performance of components
- Produce a lower cost of electricity and thermodynamic efficiency, greater than 50%

**Pilot plant design is underway for the largest indirect-fired $sCO_2$ test facility in the world.** Its groundbreaking ceremony was held on October 15, 2018, in San Antonio, Texas.

## MEETING COST & PERFORMANCE GOALS

**Systems studies indicate $sCO_2$ cost and performance advantages.** Oxy-Circulating Fluid Bed indirect $sCO_2$ power plants have been predicted to improve efficiency 1–4% points at comparable cost of electricity relative to steam. Research shows that producing a coal-fueled power plant with a 49.5% higher heating value efficiency is possible.

**Cooling integration study completed.** Models and techno-economic analyses show optimization of cooling systems can increase $sCO_2$ cycle plant efficiency.

**Material compatibility evaluated.** R&D identified advanced ultra-supercritical nickel alloys suitable for indirect $sCO_2$ systems.

**Initiated component cost collaboration amongst DOE National Labs.** Pooling $sCO_2$ component cost quotes to improve accuracy of models and enable economics-driven plant designs.

## STEP PROJECT QUICK FACTS

**AWARD NUMBER**
### DE-FE0028979

## PROJECT BUDGET

FY18 FUNDING

**$119**M
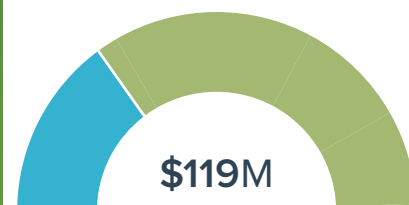
- DOE ················· $84,330,971
- PERFORMER ············ $35,138,048

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PRINCIPAL INVESTIGATOR
**MICHAEL KUTIN**

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# SUPERCRITICAL CARBON DIOXIDE POWER CYCLES

NETL is at the forefront of groundbreaking research and development advancing supercritical carbon dioxide ($sCO_2$) power cycles toward commercialization. Construction of a 10 MWe $sCO_2$-based pilot plant facility is underway, and will be a vital proving ground for larger scale power cycle operation and component performance. This novel power cycle that utilizes $sCO_2$ as the working fluid offers the potential for producing power with greater efficiency and at lower costs compared to current steam-based plants. Key research at NETL is closing technology gaps, and systems studies are optimizing plant configurations and showing the magnitude of performance benefits possible.

PRESENTERS:
**RICHARD DENNIS and ROBIN AMES**

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**ROBIN AMES**

PRINCIPAL INVESTIGATOR
**MICHAEL KUTIN**

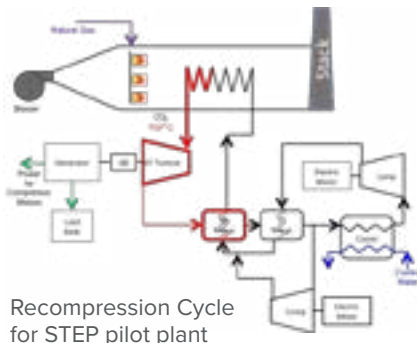## ADVANCING THE NEXT GENERATION OF MODULAR, HIGHLY EFFICIENT, AND FLEXIBLE COAL-FIRED POWER PLANTS

# TESTING SOLID OXIDE FUEL CELL (SOFC) PROTOTYPE SYSTEMS

Prototype testing to support development of a combustion-free method of power generation

## DEVELOPING EFFICIENT, LOW-COST ELECTRICITY

Fuel cells are electrochemical devices that directly convert the chemical energy in fuels into electrical energy—**eliminating steps required for conventional energy conversion systems.**

Fuel cells systems are capable of operating with natural gas or coal-based fuel, and **do not require combustion of the fuel to produce heat and the associated thermal and mechanical steps to produce electrical power.**

### BENEFITS

| Higher efficiency | Ease of $CO_2$ capture | Fuel flexibility | Lower emissions | Low water use | Modularity |
|---|---|---|---|---|---|

## DEMONSTRATING SOFC POWER GENERATION

LG Fuel Cell Systems, Inc. (LGFCS) has demonstrated a 250-kWe rated SOFC prototype system at a test site in Ohio where the system operates on natural gas and develops electricity, connecting directly to the grid.

**The prototype SOFC power system** incorporates current technologies and operates under a range of environmental conditions to **assess progress of system durability, performance, and operating cost toward commercial readiness.**


Site Layout
Generator Module
Site Preparation
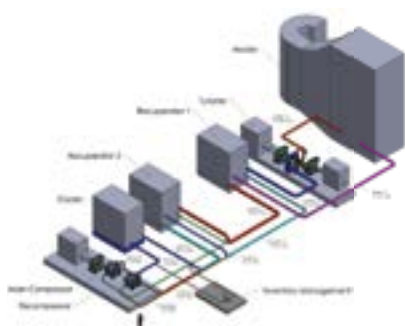250 kW PRODUCT DEMONSTRATOR

## HIGH-EFFICIENCY POWER GENERATION



### ACCOMPLISHMENTS

- 1,800 hours on load
- Power to grid: 250 kW-AC
- Efficiency: 61% DC/55% AC
- Power Degradation: 0.3% per 1,000 hrs
- Emissions: Meets $NO_x$ standards

### FEATURES

- Fully integrated system
- Pipeline natural gas for fuel
- Unmanned operation

## PROTOTYPE SYSTEM MANUFACTURING


Integrated Block Assembly
Inner Vessel Segment
Fuel Cell Assembly

# TESTING SOLID OXIDE FUEL CELL (SOFC) PROTOTYPE SYSTEMS

Solid oxide fuel cells (SOFCs) are capable of operating with natural gas or coal-based fuel and produce power to the grid electrochemically, eliminating the need for combustion and its associated thermal and mechanical steps. LG Fuel Cell Systems (LGFCS) is advancing prototype testing to support reliable and efficient SOFC power generation. They designed, assembled, and ran the fully integrated 250 kWe prototype SOFC system to assess durability, performance, and operating cost. The performance is in line with product expectation: 250 kWac power to the grid, >60% DC efficiency, and 80% fuel utilization. This prototype testing is a key step in the continued development and scale-up of SOFC technology towards commercialization.

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## ADVANCING THE NEXT GENERATION OF MODULAR, HIGHLY EFFICIENT, AND FLEXIBLE COAL-FIRED POWER PLANTS

# REDUCING THE COST OF CAPTURED CARBON AND PUTTING IT TO WORK FOR AMERICA

## ACCOMPLISHMENTS POSTERS:

# ADVANCED MANUFACTURING FOR AFFORDABLE CARBON CAPTURE

3D printing to produce rapid prototypes with the potential to capture $CO_2$ more efficiently and economically

## IMPROVING PERFORMANCE THROUGH ADDITIVE MANUFACTURING
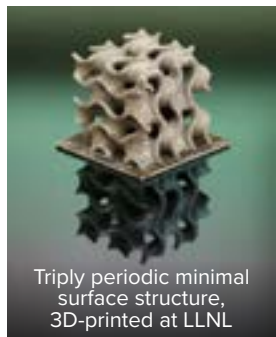

Triply periodic minimal surface structure, 3D-printed at LLNL

Additive manufacturing, utilizing 3D printing, enables the development of carbon capture devices that **intensify thermodynamic operations, improve process performance, and reduce equipment size,** lowering capital and operating costs.

## DEVELOPING TRANSFORMATIONAL MATERIALS

**Oak Ridge National Laboratory (ORNL)** is using additive manufacturing to produce intensified devices that combine multiple thermodynamic operations, improving solvent-based technologies that capture $CO_2$ from coal-fired flue gas.

**Lawrence Livermore National Laboratory (LLNL)** is designing and fabricating high-efficiency reactors using novel geometries that support advanced solvents for transformational carbon capture.

**ION Engineering (ION)** is developing a 3D-printed absorber with integrated packing and internal cooling capabilities to help optimize solvent-based capture.

## REDUCING THE COST OF CARBON CAPTURE

**ORNL Prints Intensified Device for $CO_2$ Capture**

ORNL 3D printed an aluminum version of a column packing structure with built-in heat exchange.

**LLNL Develops High Resolution Techniques**

LLNL created silicon-based gyroid structures with one micrometer resolution using stereo-lithography.

**ION Prints Absorbers for $CO_2$ Capture Testing**

ION 3D printed two absorbers on plastic for initial testing and plans to print metal absorbers in early FY19.

## QUICK FACTS

AWARD NUMBERS
**FWP-FEAA130 (ORNL)
FWP-FEW0225 (LLNL)
DE-FE0031530 (ION)**

## PROJECT BUDGET

FY18 FUNDING

| | |
|---|---|
| ORNL | $1M |
| LLNL | $3.8M |
| ION | $2.6M  $0.75M |

■ DOE SHARE   ■ PERFORMER

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STEVEN MASCARO (ION)**

PRINCIPAL INVESTIGATORS
**XIN SUN (ORNL)
JOSHUAH STOLAROFF (LLNL)
ERIK MUELEMAN (ION)**


Packing with different cell densities, 3D printed at ORNL

# ADVANCED MANUFACTURING FOR AFFORDABLE CARBON CAPTURE

DOE researchers are advancing the efficiency and economics of carbon capture systems through the use of additive manufacturing. Oak Ridge National Laboratory, Lawrence Livermore National Laboratory, and ION Engineering are producing rapid prototypes using state-of-the-art 3D-printing processes to enhance the solvent-based capture of $CO_2$. By furthering the advancement and development of 3D-printed, rapid prototype materials, these technologies offer the potential to improve process performance and reduce the capital and operating costs of capturing $CO_2$ from coal-based power plants.

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## REDUCING THE COST OF CAPTURED CARBON AND PUTTING IT TO WORK FOR AMERICA

# ADVANCED MEMBRANES LOWER THE COST OF CARBON CAPTURE

Highly permeable and selective membranes for post-combustion capture

## HIGH-PERFORMING MIXED MATRIX MEMBRANES (MMMs)

Developing stable, transformational membranes with high $CO_2$ selectivity and permeability can **significantly reduce the cost for post-combustion capture.** Membranes with higher permeability lead to a **reduced area requirement, smaller capital cost, and a smaller equipment footprint.**



Polymer          Porous Inorganic Particles
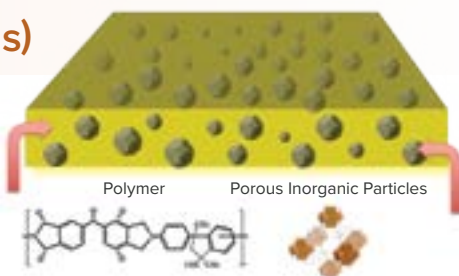
*A mixed matrix membrane (MMM) consists of a polymer matrix with particles such as metal organic frameworks (MOFs) embedded in the matrix to enhance gas transport. The best MMMs for $CO_2$ capture need high performance polymers with mechanical toughness, nanosized MOFs with uniform dispersion, an optimized support layer, and a thin, defect-free selective layer.*

## PROMISING OPTION FOR LARGE-SCALE GAS SEPARATION



*NETL's membrane flue gas test unit at the National Carbon Capture Center, where membranes are being tested for long-term stability under real conditions including moisture and contaminants*

NETL analyses have shown that **materials with extremely high permeability are needed** to make membrane technology an economically viable option.

NETL is developing **innovative technologies and materials for bench-scale testing** in a slipstream of actual flue gas. NETL is currently working with a commercial membrane manufacturer to scale up this technology for demonstration in a small hollow fiber module.

## ECONOMIC GROWTH AND LOW-COST ENERGY

**Several mixed matrix membranes were developed** that have $CO_2$ permeability >5000 Barrer and $CO_2/N_2$ selectivity of ~30, well above the Robeson Upper Bound. This membrane is now one of the **highest performance membrane materials reported for $CO_2$ capture from post-combustion flue gas.**

Preliminary results suggest that the performance is stable when exposed to humidified gas.
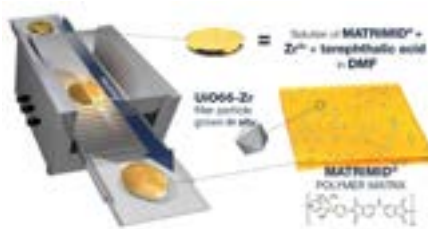


In-situ MOF growth is a possible scheme for **reducing steps for membrane scale-up.** NETL is now partnered with a commercial membrane manufacturer to **prove the scalability** of NETL's MMMs.
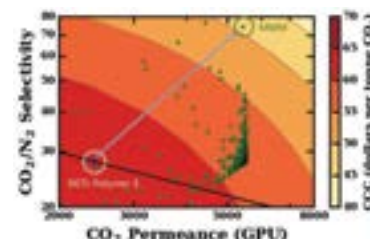
*The chart shows the total cost of carbon capture for different hypothetical MOFs paired with one particular polymer as a function of the properties of the MOFs. Compared to a pure polymer, MMMs can dramatically reduce the cost of carbon capture (CCC).*

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**DAVID HOPKINSON & JANICE STECKEL**

## PARTNERS

# ADVANCED MEMBRANES LOWER COST OF CARBON CAPTURE

NETL's powerful computational tools enable researchers to predict how well more than a million hypothetical Mixed Matrix Membranes (MMMs) will separate carbon dioxide from flue gas. This technique revolutionizes NETL's capabilities for developing MMMs with unprecedented $CO_2$ permeability and $CO_2/N_2$ selectivity. Utilizing this technique allowed NETL to develop an MMM that operates in the ultra-high permeability regime, which is well suited for post-combustion carbon capture. These membranes are now being scaled up for demonstration using actual flue gas at the National Carbon Capture Center in Wilsonville, Alabama, advancing their commercial feasibility.

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**REDUCING THE COST OF CAPTURED CARBON AND PUTTING IT TO WORK FOR AMERICA**

# CAPTURING $CO_2$ USING LESS ENERGY AT SCALE

Validating a water-lean solvent process that can reduce energy use and decrease the cost required for carbon capture compared to current technologies

## MAKING COAL-FIRED POWER PLANTS CLEANER

RTI's **water-lean solvent-based $CO_2$ capture process using coal-fired flue gas moves closer to commercialization** through testing completed at the National Carbon Capture Center and SINTEF's Tiller plant by:

- Increasing solvent performance
- Designing and building unique non-aqueous solvent (NAS) process modifications for the Tiller plant
- Performing long-term testing of non-aqueous solvent at larger scale on coal-derived flue gas

## MODIFICATIONS IMPROVE $CO_2$ CAPTURE PERFORMANCE

Interstage coolers, a new regenerator packing section, and a rich solvent preheater have improved the NAS-based $CO_2$ capture process.

## LONG-TERM TESTING COMPLETED ON COAL-FIRED FLUE GAS

- 1,200 hours of NAS testing at the SINTEF Tiller plant
- Captured 90% of the $CO_2$ contained in the flue gas at a specific reboiler duty of about 2.6 MJ/kg $CO_2$

### SPECIFIC REBOILER DUTY COMPARISON



Bar chart: SRD (GJ/T-$CO_2$) on y-axis (0 to 4). MEA ~3.6, KS-1 ~2.9, Shell Cansol DC-103 ~2.6, RTI NAS-5 with **36–42% REDUCTION**.

## PATH TO COMMERCIALIZATION

| DOE ARPA-E PROJECT | DOE NETL PROJECT | DOE NETL PROJECT (CURRENT) | FUTURE DEVELOPMENT | COMMERCIAL |
|---|---|---|---|---|
| 2010–2013 | 2014–2016 | 2015–2018 | 2018–2021 | 2021+ |
| TRLs 1–3 | TRL 4 | TRLs 5–6 | TRLs 7–8 | TRL 9 |

| LAB-SCALE DEVELOPMENT/ EVALUATION | LARGE BENCH-SCALE SYSTEM/ RELEVANT ENVIRONMENT TESTING | COMBINED SINTEF (TILLER) | TCM PATHWAY LARGE PILOT EVALUATION |
|---|---|---|---|
| arpa·e / BASF | NETL / THE LINDE GROUP / SINTEF | NETL / THE LINDE GROUP / SINTEF GASSNOVA | CO2 TECHNOLOGY CENTRE MONGSTAD |
| **FUNDING: ~$2,700,000** | **FUNDING: ~$3,000,000** | **FUNDING: ~$2,700,000** | |
| • Solvent screening to identify promising solvent formulations <br> • Lab-scale evaluation of NAS process <br> • Preliminary technical and economic assessments | • Finalize NAS formulation <br> • Develop critical process components <br> • Demonstrate ≤2.0 GJ/T-$CO_2$ using bench-scale system <br> • Detailed solvent degradation studies and techno-economic analysis <br> • Demonstrate T&EA competitiveness and environmental permitability | • Tiller Plant (~60 kWe) <br>   - Demonstrate all NAS process components <br>   - Quantify solvent losses and emissions <br>   - Test using coal-derived flue gas <br>   - Determine materials compatibility <br>   - Collect critical process data to support scale-up | • TCM (~10 MWe) <br>   - Complete process unit with components at minimum size for confident scale-up <br>   - Collect critical process information to support detailed techno-economic assessment, emissions monitoring, and long-term testing to develop reliability, availability and maintainability metrics |

## QUICK FACTS

AWARD NUMBER
**DE-FE0026466**

## PROJECT BUDGET

FY18 FUNDING



**$4.5M**
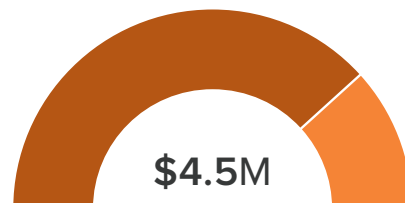
● FEDERAL ···················· $3,468,584
● RTI INTERNATIONAL ···· $1,064,068

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RTI INTERNATIONAL

THE LINDE GROUP

SINTEF

CO2 TECHNOLOGY CENTRE MONGSTAD

GASSNOVA
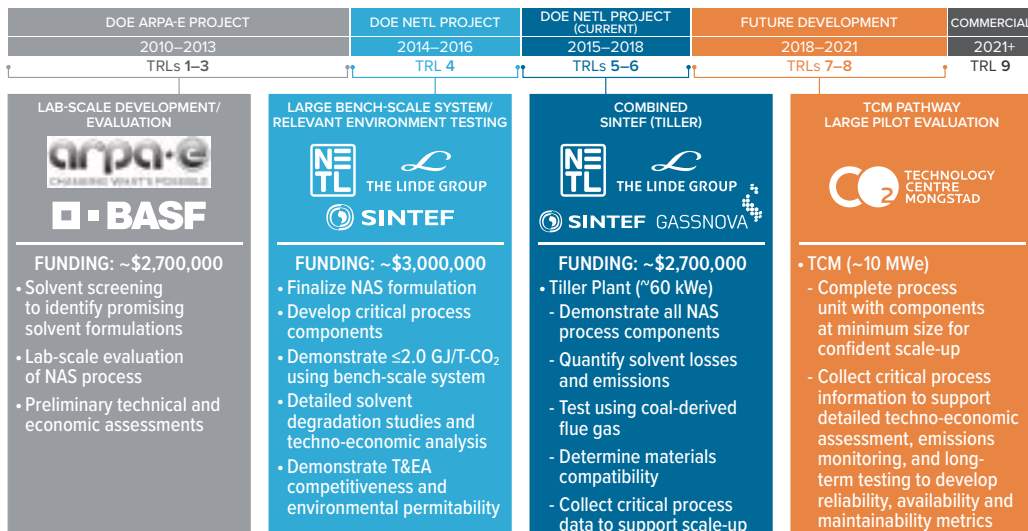
# CAPTURING CO$_2$ USING LESS ENERGY AT SCALE

Current carbon capture technology often utilizes water-based solvents that require a high amount of heat to separate the solvent from the capture CO$_2$ — an inefficient and expensive process. NETL research is pioneering next-generation solvents that contain little water. The use of these water-lean or non-aqueous solvents (NAS) to capture CO$_2$ is moving closer to commercialization through testing completed at progressively larger scales at the National Carbon Capture Center and SINTEF's Tiller plant. Testing will validate that their NAS process can capture 90% of the CO$_2$ in flue gas using less energy and at a lower cost compared to current capture technologies.

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**REDUCING THE COST OF CAPTURED CARBON AND PUTTING IT TO WORK FOR AMERICA**

# CATALYTIC CONVERSION OF $CO_2$ INTO VALUE-ADDED PRODUCTS

Evaluating new and existing processes for converting waste $CO_2$ into higher-value, industrially relevant chemicals and materials

## CONVERTING $CO_2$ INTO CHEMICALS FOR INDUSTRY

This project identifies, develops, and evaluates new technologies for converting $CO_2$ into chemicals that can be sold to **offset $CO_2$ capture costs, reduce demand for petrochemical-based feedstocks,** and **develop new markets and job opportunities.**

### CARBON USE & REUSE BENEFITS:

- Increases energy security due to reduced oil imports
- Facilitates clean and safe development of energy resources
- Provides U.S. industry with low-cost options for reducing GHG emissions

## CREATING VALUABLE PRODUCTS FROM $CO_2$

**Early-stage research creates new catalyst materials and reactor designs to selectively convert $CO_2$ into useful chemicals such as:**

FUELS | ALCOHOLS | HYDROCARBONS | CARBON MONOXIDE | POLYMERS | PLASTICS



$CO_2$
Water
Gold → Synthesis gas (CO+H$_2$)

Copper →
- $H_2$ + CO
- formic acid
- methane
- $C_2$+ hydrocarbons
- alcohols

SEPARATION $ → Purified Product

**Industrial Chemicals**
Fuels
Polymers & Plastics
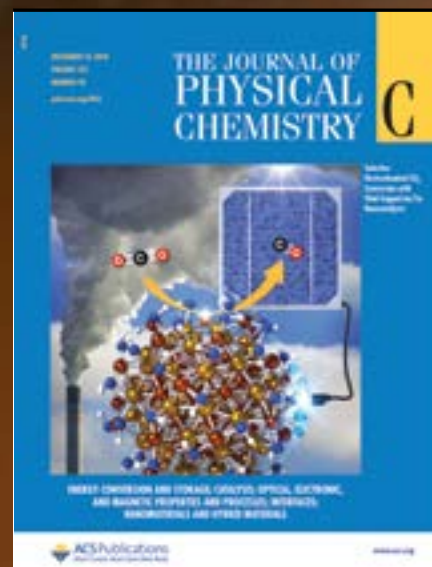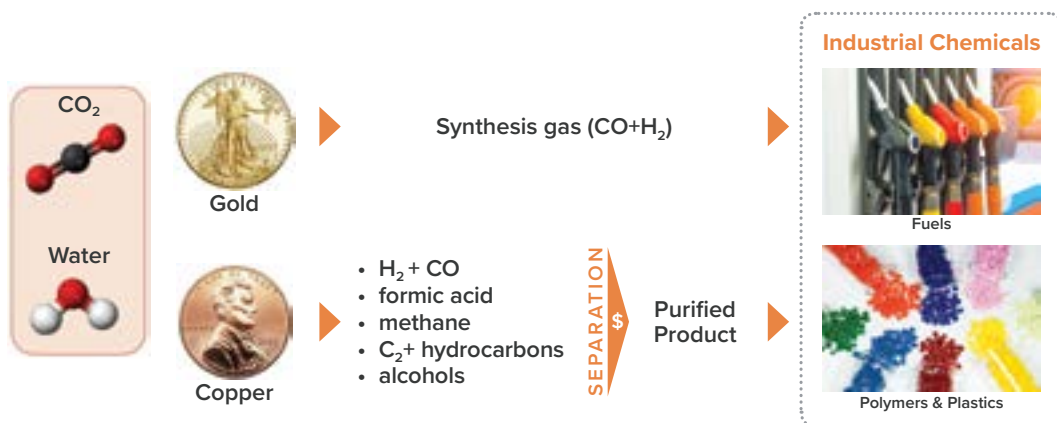
Gold-Copper nanocatalysts retain performance with ~50% reduction in gold and demonstrate success with ligand-capped nanocatalysts. They were chosen for *The Journal of Physical Chemistry C's* December 2018 cover, which includes a manuscript about the results.

## NOVEL APPROACHES FOR CATALYST DESIGN

### MICROWAVE-ASSISTED THERMAL $CO_2$ CONVERSION

**New metal oxide catalysts use microwaves to thermally convert $CO_2$ and methane.** Mixed metal oxides absorb microwaves and instantaneously generate heat. This greatly reduces associated heat management issues and makes high-temperature reactions like methane dry reforming with $CO_2$ practical.

### ELECTROCATALYTIC $CO_2$ REDUCTION

**A new nano-porous copper-oxide catalyst for electrochemical $CO_2$ reduction demonstrates 10–60 times better selectivity compared to commercially available copper materials.** This is a significant breakthrough that uses inexpensive material to drastically improve selectivity and performance.

## QUICK FACTS

AWARD NUMBER
**FWP-1022426**

## PROJECT BUDGET

TOTAL AWARD VALUE
**$1,246,000**

## CONTACTS

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**DOUGLAS KAUFFMAN**

# CATALYTIC CONVERSION OF $CO_2$ INTO VALUE-ADDED PRODUCTS

NETL is developing new technologies that convert carbon dioxide ($CO_2$) streams into industrially relevant chemicals. The project leverages materials design expertise, world-class characterization faculties, and cutting-edge computational capabilities to produce catalysts that convert $CO_2$ emissions into value-added products, like hydrocarbons, polymers, and plastics. Sale of these $CO_2$-derived chemicals and products will offset capture costs, reduce the carbon footprint of traditional fossil-fuel processes, and allow sustainable use of current fossil-fuel resources.

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## REDUCING THE COST OF CAPTURED CARBON AND PUTTING IT TO WORK FOR AMERICA

# NATIONAL CARBON CAPTURE CENTER & ADVANCED FLASH STRIPPER

Developing technologies under realistic conditions to reduce the cost of advanced coal-fueled power plants with $CO_2$ capture

## ENABLING TESTING AND SCALE-UP OF ADVANCED POWER GENERATION TECHNOLOGIES

The National Carbon Capture Center (NCCC) **accelerates the commercialization of advanced technologies to reduce emissions.**

Recent testing of an Advanced Flash Stripper (AFS) at NCCC demonstrated its potential to **reduce energy requirements** and **lower the cost of $CO_2$ capture.**

The National Carbon Capture Center in Wilsonville, AL

## RESOLVING INDUSTRY CHALLENGES COLLABORATIVELY

The NCCC operates existing facilities to offer **third-party technology evaluation that addresses environmental, health and safety, operational, component, and system development issues** while collaborating with technology developers.

Southern Company announced the NCCC had **surpassed 100,000 hours of technology testing since opening in 2009.**

The NCCC **operated two major test runs at the Post-Combustion Carbon Capture Center** where technology developers conducted roughly **5,400 hours of testing.**

## FURTHERING RESEARCH AND REDUCING COSTS

Strippers are equipment in carbon capture systems that remove $CO_2$ from solvent for reuse. The Advanced Flash Stripper improves on this technology by lowering the energy requirement for $CO_2$ removal.
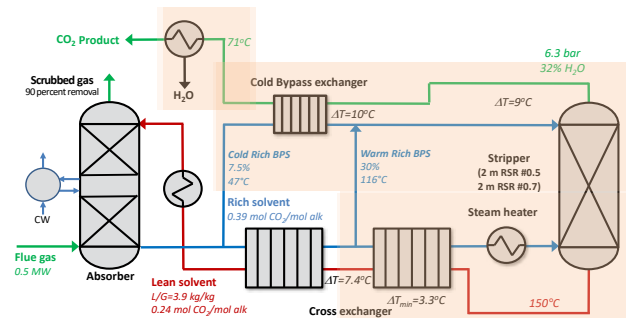
Schematic of the Advanced Flash Stripper tested at NCCC

AFS's preliminary NCCC testing at the 0.5MW scale with piperazine solvent shows the heat duty for the AFS ranged between 2.0–2.5 GJ/tonne $CO_2$.

These results **demonstrate AFS can lower energy requirements of regeneration for some solvents.**

# NATIONAL CARBON CAPTURE CENTER & ADVANCED FLASH STRIPPER

The National Carbon Capture Center (NCCC) provides the support, infrastructure, and real-world operating conditions needed to accelerate the commercial maturation of advanced fossil-energy technologies. The NCCC has recently surpassed 100,000 hours of testing enabling systems, processes, and equipment—such as an advanced flash stripper—to lower energy requirements for $CO_2$ capture and advance breakthroughs in mitigating $CO_2$ emissions. The data generated at the NCCC empowers decision-makers on technology readiness, environmental performance, and economic viability of carbon capture from power plants, pioneering solutions for a more sustainable energy future.

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## REDUCING THE COST OF CAPTURED CARBON AND PUTTING IT TO WORK FOR AMERICA

# NATIONAL RISK ASSESSMENT PARTNERSHIP (NRAP)

Developing risk assessment tools, methods, and insights needed for safe, permanent geologic $CO_2$ storage

## QUANTIFYING RISK FOR GEOLOGIC SYSTEMS

NRAP is a multi-national laboratory collaborative research project focused on understanding potential environmental risks at geologic $CO_2$ storage sites. Demonstrating that these risks can be quantified and managed removes barriers to full-scale technology implementation.

**NRAP** — National Risk Assessment Partnership

BERKELEY LAB

NETL — NATIONAL ENERGY TECHNOLOGY LABORATORY

Pacific Northwest NATIONAL LABORATORY

Los Alamos NATIONAL LABORATORY

Lawrence Livermore National Laboratory

## INFORMING DECISION-MAKING FOR THE SUBSURFACE

**Establishing workflows and protocols for risk-informed decision-making helps to ensure robust operations and efficient, effective site monitoring.**

Workflow and tools for risk management and uncertainty reduction
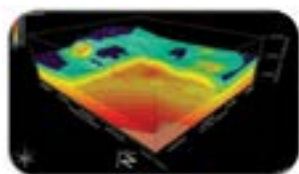
Quantifying risk and uncertainty with field-validated tools
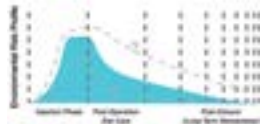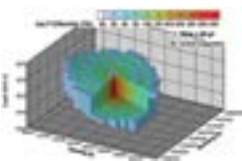
Enabling risk-based strategic monitoring design
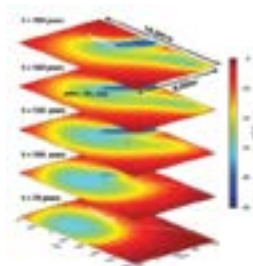
Developing protocols to minimize ground motion
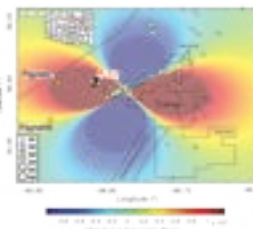
## REMOVING BARRIERS TO CO₂ STORAGE DEPLOYMENT

**NRAP Toolsets Applied to Field Laboratory Sites:**
The NRAP tools have been tested on at least seven CarbonSAFE pre-feasibility projects, two Regional Carbon Sequestration Partnership large-scale field projects, and Taiwan's Industrial Technology Research Institute pre-feasibility sites. The ability to assess the potential risk at a site could lead to the selection of an appropriate site for safe, secure, and affordable storage.

**Developing Insights to Inform Post-injection Site Closure:**
Researchers are establishing a technical basis to support the cost-effective and safe closure of geologic carbon storage projects, using NRAP's risk-based tools and methods.

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## PARTNERS

AMERICAN ELECTRIC POWER

bp

ExxonMobil

Schlumberger

EPA United States Environmental Protection Agency

NRDC

WHITING

RPC

USGS science for a changing world

SOUTHERN STATES ENERGY BOARD

THE UNIVERSITY OF UTAH

ieaghg

Stanford University

ZURICH

b resource

MIT Massachusetts Institute of Technology

# NATIONAL RISK ASSESSMENT PARTNERSHIP (NRAP)

The National Risk Assessment Partnership (NRAP) leverages DOE's capabilities in science-based predictive modeling of engineered geologic systems to overcome barriers to large-scale deployment of geologic carbon storage. NRAP develops and demonstrates computational tools and methods to quantitatively assess and effectively manage risks related to potential leakage and ground motion at storage sites, and to inform monitoring design that builds confidence in system performance and verifies containment integrity.

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PRINCIPAL INVESTIGATOR
**ROBERT (BOB) DILMORE**

## REDUCING THE COST OF CAPTURED CARBON AND PUTTING IT TO WORK FOR AMERICA

# REGIONAL CARBON SEQUESTRATION PARTNERSHIPS (RCSP) INITIATIVE

Setting the stage for safe and reliable $CO_2$ storage

## SAFE AND RELIABLE $CO_2$ STORAGE

**>10.6 MMT of $CO_2$**
permanently stored

Assessed techniques for tracking $CO_2$ plume and ensuring non-migration of $CO_2$ to groundwater and atmosphere.

### CONTACTS

HQ PROGRAM MANAGER
**DARIN DAMIANI**

TECHNOLOGY MANAGER
**TRACI RODOSTA**

RCSP COORDINATOR
**WILLIAM ALJOE**

CarbonSAFE COORDINATOR
**MARY SULLIVAN**

## IMPROVED ENERGY INDEPENDENCE

**Technologies developed have helped Enhanced Oil Recovery (EOR) efforts**

- Additional ~2.4M bbl oil recovered during three EOR injections where 4.8 MMT $CO_2$ were stored

- Advanced understanding of subsurface fluid migration during storage of $CO_2$ associated with EOR

- Developed and tested technologies that manage risk in the subsurface and plume control by geo-steering fluids

**SOUTHWEST PARTNERSHIP**
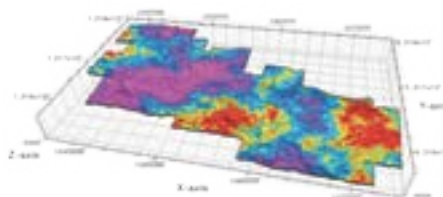


Fluid flow and transport simulations improve oil reservoir understanding

### BELL CREEK ASSOCIATED STORAGE
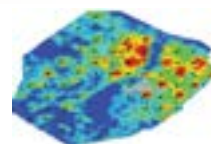


$CO_2$ plume relative to injection and recovery wells during EOR

### BELL CREEK ASSOCIATED STORAGE EOR



15 MMT $CO_2$ potential storage resource through EOR
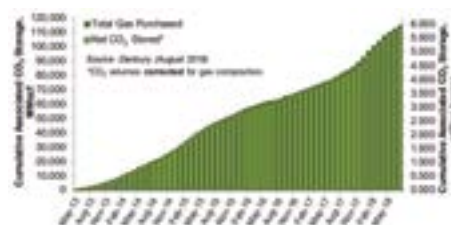
## RCSP LESSONS LEADING TO INDUSTRIAL SCALE $CO_2$ STORAGE

CarbonSAFE initiative builds on RCSP knowledge to **reduce technical risk, uncertainty, and cost** of 50+ MMT scale storage projects.

**Focus is on:**

- Detailed technical/economic feasibility

- Identification, detailed characterization and modeling of geologic storage sites

- Improved understanding of data and information needed for Class VI



Kevin Dome Project

Bell Creek Project
2.982 MMT $CO_2$ stored

Michigan Basin Project
1.120 MMT $CO_2$ stored

University of North Dakota,
Beulah, ND or Center, ND

University of Illinois
Decatur, IL
Terre Haute, IN

University of Wyoming
Gillette, WY

BIG SKY

PCOR

MRCSP

WESTCARB

Battelle Memorial Institute
Patterson, KS
Sleepy Hollow, NE

MGSC

Illinois Basin-Decatur Project
0.999 MMT $CO_2$ stored

SWP

SECARB

Farnsworth Unit Project
0.667 MMT $CO_2$ stored

Southern States Energy Board
Kemper County, MS

Cranfield Project
4.743 MMT $CO_2$ Stored

Citronelle Project
0.114 MMT $CO_2$ stored

# REGIONAL CARBON SEQUESTRATION PARTNERSHIPS (RCSP) INITIATIVE

The innovative storage projects performed through the RCSP initiative exceeded Government Performance and Results Act injection targets and demonstrated safe and permanent $CO_2$ storage to operators, industry, regulators, non-governmental organizations, the financial community, local governments, and the public. The effort successfully advanced technologies and methods that improved the understanding of $CO_2$ behavior in the subsurface, contributing not only to $CO_2$ storage but also to understanding Enhanced Oil Recovery processes essential to achieving American energy independence. Advancements are paving the way to continued innovative development to ensure that the country has the tools and capabilities needed for reduced risk, uncertainty, and cost of industrial scale $CO_2$ storage.

PRESENTERS:
**WILLIAM (BILL) ALJOE and MARY SULLIVAN**

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**MARY SULLIVAN**

## REDUCING THE COST OF CAPTURED CARBON AND PUTTING IT TO WORK FOR AMERICA

# CREATING NEW JOBS, PRODUCTS, AND MARKETS FOR COAL

# ACCOMPLISHMENTS POSTERS:

# EXPANDING THE U.S. COAL VALUE CHAIN

**Expanding markets for coal and promoting manufacturing of high-value carbon products**

## EXTRACTING THE FULL VALUE OF COAL RESOURCES

Coal Beneficiation at NETL focuses on both **enhancing the value of coal as a feedstock** and **developing new, high-value products derived from coal.**



### CONTACTS

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**REGIS CONRAD**

TECHNOLOGY MANAGER
**JOHN ROCKEY**

TECHNICAL PORTFOLIO LEAD
**CHRISTOPHER MATRANGA**

## GROWING COAL MARKETS & THE VALUE CHAIN

### COAL BENEFICIATION HAS THREE PRIMARY R&D AREAS:

**COAL TO CARBON PRODUCTS**

Produces cost-competitive, high-value carbon fibers and nanomaterials for structural materials, 3D printing materials, energy storage and electrode materials, carbon composites, and other non-traditional materials.

**FEEDSTOCK UPGRADING**
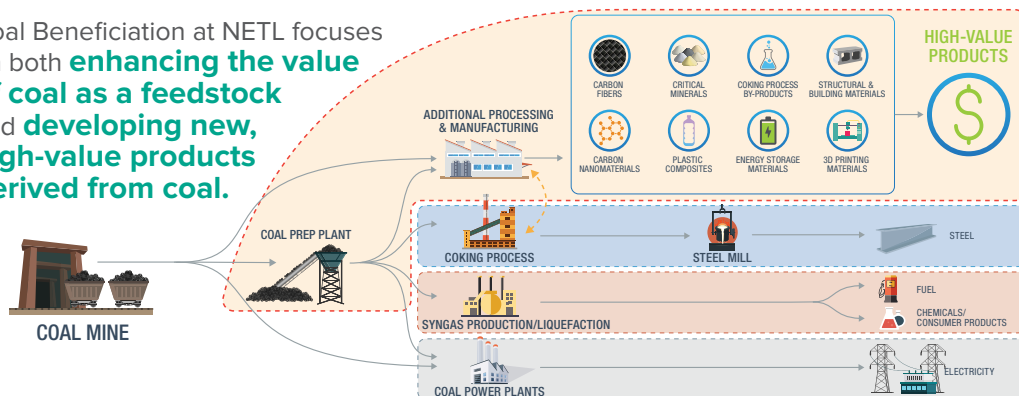
Expands markets for power generation and steelmaking with new coal cleaning, treatment, and processing technologies.

**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.

## SPURRING INNOVATION

### NETL RIC PROJECTS

**Coal-Based Carbon Materials Manufacturing**
National Energy Technology Laboratory Research and Innovation Center – Pittsburgh, PA, Morgantown WV, Albany, OR
**TOTAL: $1,150,000 • DOE SHARE: $1,150,000**

**Converting Coal into Carbon Nanomaterials and Composites**
Ramaco Carbon – Sheridan, WY
**Public-private partnership**

**Transforming Coal into High-Value Products**
Russell County Industrial Development Authority and Virginia Carbonite – Russell Co, VA
**Public-private partnership**

**Technical Economic Analysis of the U.S. Value-Added Coal Product Industry**
Oak Ridge National Laboratory – Oak Ridge, TN
**TOTAL: $300,000 • DOE SHARE: $300,000**

● COOPERATIVE AGREEMENT
● SBIR GRANT



**Efficient Process for the Production of High Conductivity, Carbon-Rich Materials from Coal**
Physical Sciences, Inc. – Andover, MA
**TOTAL: $224,985 • DOE SHARE: $224,985**

**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
**TOTAL: $3,180,519 • DOE SHARE: $2,000,000**

**U.S. Coal to Conductive Inks**
Minus 100, LLC – Clarks Summit, PA
**TOTAL: $224,813 • DOE SHARE: $224,813**

**Pilot-Scale Testing of the Hydrophobic-Hydrophilic Separation Process to Produce Value-Added Products from Waste Coal**
The Minerals Refining Company – Richmond, VA
**TOTAL: $2,500,000 • DOE SHARE: $2,000,000**

**Coal Core Composites for Low Cost, Light Weight, Fire Resistant Panels and Roofing Materials**
Semplastics EHC, LLC – Oviedo, FL
**TOTAL: $224,880 • DOE SHARE: $224,880**

**High-Value Carbon Products from Domestic Coal**
ATS-MER, LLC – Tucson, AZ
**TOTAL: $224,997 • DOE SHARE: $224,997**

# EXPANDING THE U.S. COAL VALUE CHAIN

DOE's Coal Beneficiation research is creating new physical and chemical processing technologies to prepare coal for high-value carbon product manufacturing, and is expanding markets for existing coal products with new coal cleaning, treatment, and processing technologies. High-value carbon products, such as carbon fiber, carbon additives for cements and structural composites, and battery and electrode materials, represent new business opportunities in unconventional industries for coal. Feedstock upgrading increases traditional domestic and global markets for U.S. coal in power generation and steelmaking, while expanding existing coal property databases informs potential consumers on the extraordinary value of coal resources. In-house research at NETL has indicated that coal-based carbon nanomaterials, such as graphene quantum dots, reduce material costs by at least 10-fold and can be used to improve the mechanical strength of cement and polymer composites; filter organic and metal impurities from water supplies; and improve the performance of batteries and supercapacitors.

PRESENTERS:
**JOHN ROCKEY and CHRISTOPHER MATRANGA**

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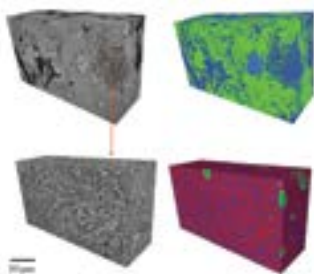
TECHNICAL PORTFOLIO LEAD
 **CHRISTOPHER MATRANGA**

## CREATING NEW JOBS, PRODUCTS, AND MARKETS FOR COAL

# EXTRACTING RARE EARTH ELEMENTS AFFORDABLY AND EFFICIENTLY

Creating an economically competitive domestic supply of crucial Rare Earth Element (REE) materials

## RESPONSIBILE, COST-COMPETITIVE TECHNOLOGY



**NETL researchers have extracted REEs from coal and underclays with a minimally invasive technique.**

These extremely mild solvents have been tailored **to only extract easily accessible REEs, leaving most of the source material intact.** This ultimately leads to lower costs and less material to process.

Advanced 3D characterization and identification of mineral phases enables discovery of revolutionary extraction schemes.

## TARGETING WASTE PRODUCTS & SELECT COAL SEAMS

NETL geoscientists discovered underclays that have **considerable levels of ion-exchangeable REEs,** similar to those found in Chinese REE deposits.

Producing REEs from these mining waste materials represents **a potential new value stream for coal mining operations.**



Preliminary research has uncovered **three promising Appalachian underclays containing up to ~30% of ion-exchangeable REEs.**

**Discovering ion-exchangeable REEs could represent a breakthrough for economic extraction of REEs in coal-related strata and the reuse of coal refuse and byproducts.**

## REE RECOVERY FOR SECURITY & ECONOMIC PROMISE

NETL's selective extraction solutions have the potential to extract REEs using mild liquids found in nature, such as lemon juice or vinegar, minimizing potential environmental impacts. This method is selective and is **expected to reduce the amount of extraction waste, ultimately reducing cost.**

### NEXT STEPS

**Leverage NETL's unique capabilities in advanced characterization, sub-surface flow modeling, and process engineering to develop innovative extraction systems. Focus will be placed on waste streams from coal preparation plants, waste coal piles, and select coal seams.**

## QUICK FACTS

AWARD NUMBER
### FWP-1022420

## PROJECT BUDGET

TOTAL AWARD VALUE
### $2.3 million

## CONTACTS

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TECHNICAL PORTFOLIO LEAD
**THOMAS TARKA**

PRINCIPAL INVESTIGATOR
**CIRCE VERBA**



REEs, a group of 17 elements, are an integral component of many products, including smart phones, lasers, DVDs, LEDs, and computer hard drives.

**Roughly 50% of goods imported into the United States contain REE, valued at approximately $1.2 trillion dollars.**

# EXTRACTING RARE EARTH ELEMENTS AFFORDABLY AND EFFICIENTLY

The discovery of coal seams that have ion-exchangeable rare earth elements (REE) significantly accelerates the commercial viability of sourcing domestic REE from U.S. coal and coal byproducts. Developing REE-selective extraction solutions that employ mild, natural solvents facilitates the preferential removal of ion-exchangeable REEs, which in turn enables the advancement of innovative and economically competitive REE processes that minimize potential environmental impacts. NETL's unique capabilities in advanced characterization, subsurface flow modeling, and process engineering empower researchers to develop groundbreaking processes that extract high-value and critical elements from our nation's vast coal resources. REEs are incorporated in products worth trillions of dollars and are essential materials in clean energy and national defense technologies.

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## CREATING NEW JOBS, PRODUCTS, AND MARKETS FOR COAL

# PETRA NOVA & ENHANCED OIL RECOVERY

An innovative, retrofitted post-combustion carbon capture system is forging a path for U.S. coal-fired plants.

## BOOSTING DOMESTIC OIL PRODUCTION

Petra Nova, **the largest post-combustion carbon capture system in the world**, demonstrates the economic and environmental advantages of amine-based carbon capture technology in removing $CO_2$ from treated flue gas produced by an existing coal-fired electrical generating station.

- **Captures 90%** of $CO_2$ from a 240 MW slipstream of processed flue gas from the ~610 MW Unit 8
- Purified $CO_2$ for EOR can **permanently sequester $CO_2$ underground**
- Boosts oil production from **500 barrels per day to over 5,000 barrels per day**

## INCREASING ENERGY SECURITY

The project **advances integrated carbon capture and storage technologies from demonstration to commercial viability** by compressing and transporting pipeline-quality $CO_2$ to a storage site for use in enhanced oil recovery (EOR).

Petra Nova deployed the world's largest commercial-scale post-combustion carbon capture technology at the W.A. Parish Generating Station. The project uses the proprietary KS-1™ solvent, facilitating low-energy requirements, solvent consumption, and waste products compared to conventional solvents.



**1** The Carbon Capture and Enhanced Oil Recovery Project
The world's largest post-combustion carbon capture and enhanced oil recovery project is located in Texas at NRG Energy's coal-fired W.A. Parish Generating Station. Also known as the Petra Nova Carbon Capture Project, the development was completed near the end of 2016.

**2** The $CO_2$ Capture Process
The proprietary KM-CDR Process, jointly developed by Mitsubishi Heavy Industries, Ltd. and the Kansai Electric Power Co., Inc., can capture approximately 1.6 million tons of $CO_2$ each year from the existing 610MW coal-fired Unit 8.

**3** Beneficial use of the captured $CO_2$
The captured $CO_2$ is transported via an 81-mile pipeline to the West Ranch Oil Field in Jackson County, Texas, where it is used in an enhanced oil recovery process to produce an estimated 60 million barrels of oil.

## ENABLING COST-EFFECTIVE CARBON CAPTURE FOR EOR

As of September 2018, Petra Nova has **captured nearly 2 million short tons of $CO_2$ for storage**.

Petra Nova was the winner of the **2017 POWER Plant of the Year Award**, given annually to plants that lead the industry in technology deployment, efficiency, and environmental considerations.

## QUICK FACTS

AWARD NUMBER
**DE-FE0003311**

## PROJECT BUDGET

FY18 FUNDING

**$469**M

- DOE .................... $190,132,425
- PERFORMER ............ $279,048,195

## CONTACTS

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**GREG KENNEDY**

## PARTNERS

Hilcorp

nrg

JX Nippon Oil & Gas Exploration

# PETRA NOVA & ENHANCED OIL RECOVERY

Petra Nova's retrofitted post-combustion carbon capture system is transforming the coal-fired electric generation industry by actively demonstrating 90% carbon dioxide ($CO_2$) capture, generating a revenue stream from the sales of captured $CO_2$. The $CO_2$ revenue stream reduces the capture capital investment, while the captured $CO_2$ increases oil production in enhanced oil recovery (EOR) operations, where it is ultimately sequestered underground.
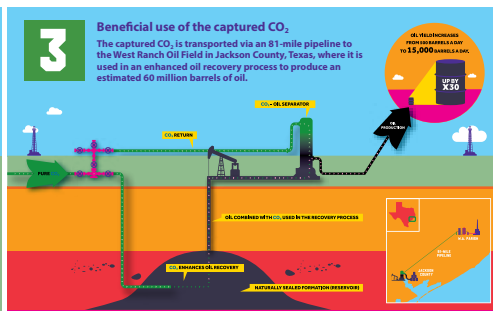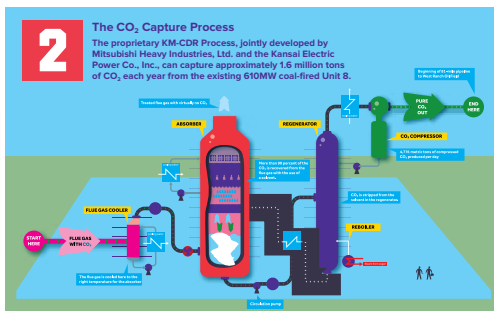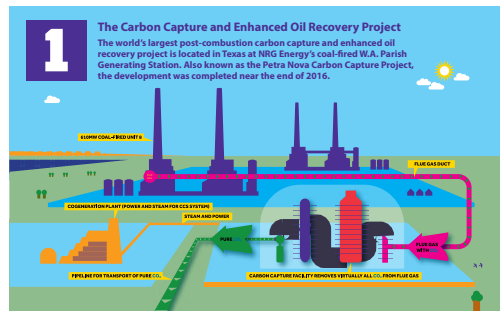
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## CREATING NEW JOBS, PRODUCTS, AND MARKETS FOR COAL

# RARE EARTH ELEMENTS & CRITICAL MINERALS

Developing critical technology, conditions, and data necessary to design, construct, and operate facilities to recover domestic rare earth elements from coal, coal refuse, clay/shale over/under burden materials, power-generation ash, and acid mine drainage.

## PIONEERING TECHNOLOGIES FOR RECOVERY OF DOMESTIC RARE EARTH ELEMENTS (REES)

**Development** and **testing of conventional and potentially transformational separation technologies** at small-scale processing facilities for recovering REEs from coal and coal by-products in a **cost-effective and environmentally benign manner**

These technologies are being developed to provide a **domestic supply** of rare earth oxides, **reduce costs** and **increase efficiency** for processing, and **provide additional economic opportunities** to coal mining communities.

## IMPROVING COST & ADDING VALUE TO COAL PRODUCTION

The **University of Kentucky** (UK) is testing a 1/4 ton/hr (230 kg/hr) pilot-scale plant for the extraction of REEs from Central Appalachian and Illinois Basin bituminous coal preparation plant refuse materials.

**West Virginia University** (WVU) is operating a bench-scale facility using approximately 150–200 g/hr (0.33–0.44 lb/hr) of solid residues generated from acid mine drainage (AMD).

## ACCOMPLISHMENTS & OPERATING FACILITIES

**University of Kentucky.**

- Using continuous solvent extraction in the laboratory, UK produced a mixed rare earth product from coal refuse. This product contained a rare earth oxide concentrate of up to 98% (equivalent to 80% on an elemental basis)—**the highest quality REE product generated to date by external participants.**
- Initiated testing at pilot-scale facility

**West Virginia University.**

- Produced 5% REE pre-concentrate at >90% REE recovery using AMD solids from the Northern and Central Appalachian Basins in laboratory experiments
- Testing a continuously operating bench-scale unit that will yield 3 g/hr (0.007 lb/hr) of REE concentrate (purity ≥2% by weight)

# RARE EARTH ELEMENTS & CRITICAL MATERIALS

Within its first five years, NETL's Feasibility of Recovering Rare Earth Elements Program met and exceeded an extremely aggressive schedule for demonstrating production of dual-use, high-purity, market-ready rare earth elements (REEs) from coal-based materials. RD&D efforts are now focused on extraction, separation, and recovery of REEs in our nation's first domestic, bench- and small pilot-scale, operating, coal-based REE-processing systems. NETL is accelerating these conventional and transformational technologies toward commercialization, reestablishing coal as a valued, sought-after resource. Through recent achievements, these projects accelerate growth of our nation's economy and strengthen national security by bringing jobs back onto America's shores and reducing our dependence on foreign supplies of these valuable REE materials.

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**JESSICA MULLEN (WVU)**

PRINCIPAL INVESTIGATORS
**RICK HONAKER (UK)**
**PAUL ZIEMKIEWICZ (WVU)**

## CREATING NEW JOBS, PRODUCTS, AND MARKETS FOR COAL

# UPCYCLING CO$_2$ IN A NOVEL CONCRETE

Utilizing CO$_2$ and industrial byproducts to create CO$_2$-negative upcycled concrete that performs as well, or better, than traditional construction materials

## NEW, VALUE-ADDED PRODUCT

Flue gas-borne CO$_2$ and repurposed abundant industrial wastes, such as crystalline slags and fly ash, can be used to create "upcycled concrete." This value-added product **provides the coal power industry with a viable path to significantly reduce its carbon emissions.**

The "upcycled concrete" production process also **minimizes external energy needs** by fully utilizing low-grade heat sourced from the flue gas, which **decreases operating costs.**
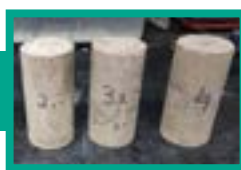
### EXAMPLES OF INDUSTRIAL WASTE FEEDSTOCKS

Basic oxygen furnace slag

Co-mingled steel slag

### UPCYCLING PROCESS OUTCOME

Cylindrical mortar specimens

## LOWER NET CO$_2$ EMISSIONS FROM COAL

- **Upcycling industrial wastes and CO$_2$** uses coal combustion and metal processing wastes (slags) as precursors for scalable CO$_2$ mineralization.

- **Process design** integrated solution incorporates aspects of calcium leaching, portlandite (Ca(OH)$_2$) precipitation, mixture formulation, and structural shape stabilization—while maximizing CO$_2$ uptake.

- **Ordinary Portland Cement (OPC) concrete replacement** is a novel CO$_2$-negative upcycled concrete that performs as well as or better than standard OPC-based concrete.

## QUICK FACTS

### AWARD NUMBER
**DE-FE0029825**

### PROJECT BUDGET

FY18 FUNDING

**$1.35**M

- DOE ·············· $1,000,000
- UCLA ·············· $350,000

### CONTACTS

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PRINCIPAL INVESTIGATOR
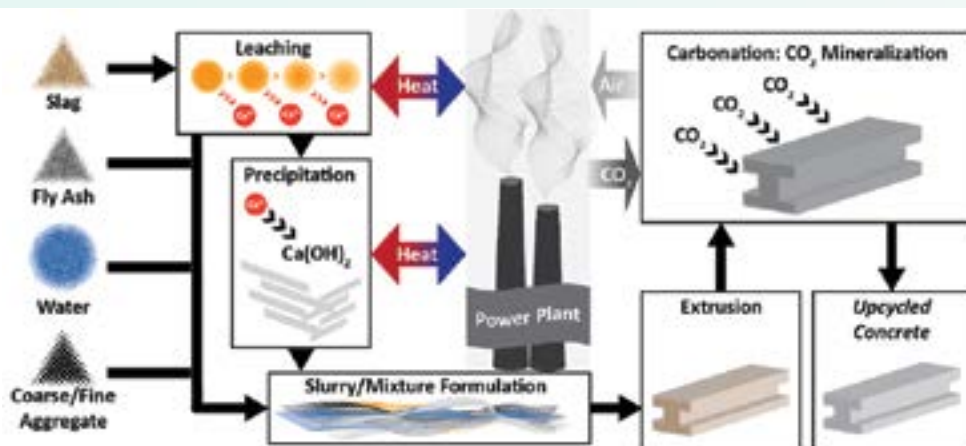**GAURAV N. SANT**

### PARTNERS

UCLA

ASU Arizona State University

HEADWATERS RESOURCES

## INTEGRATED TECHNOLOGY PRODUCTION PROCESS



- Results indicate the **upcycled concrete process yields a construction material** with a CO$_2$ uptake >6% by mass and strength development from carbonation.

- **Results confirm direct evidence of low-temperature portlandite synthesis from slags.**

# UPCYCLING CO$_2$ IN A NOVEL CONCRETE

The University of California, Los Angeles' "CO$_2$-negative" upcycled concrete production process simultaneously utilizes CO$_2$ and industrial byproducts, such as fly ash and slags, to create a novel replacement for Ordinary Portland Cement with equivalent or superior performance. The integrated CO$_2$ mineralization process facilitates low-temperature portlandite precipitation from calcium-rich slags and yields upcycled concrete with CO$_2$ uptake of more than 6% by mass and consequent strength development from carbonation. Beneficial utilization of flue gas-borne CO$_2$ along with repurposing abundant industrial wastes to create a value-added product provides the coal power industry with a viable path to significantly reduce its carbon emissions.

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## CREATING NEW JOBS, PRODUCTS, AND MARKETS FOR COAL

# LEVERAGING BIG DATA AND MACHINE LEARNING TO UNLOCK OUR NATION'S VAST UNCONVENTIONAL OIL AND GAS RESOURCES

# ACCOMPLISHMENTS POSTERS:

# ADVANCED STIMULATION TO INCREASE RESOURCE RECOVERY

**Advanced materials for characterizing hydraulic fractures**

## SMART PROPPANTS TO REFINE FRACTURE DIAGNOSTICS

Researchers at Oceanit Laboratories have performed a pilot field demonstration of an acoustically-responsive proppant (FracScan) in a shallow buried environment.

The results established **concentration dependence of the acoustic response, along with a load-dependent response that could indicate closure stress in a formation.**
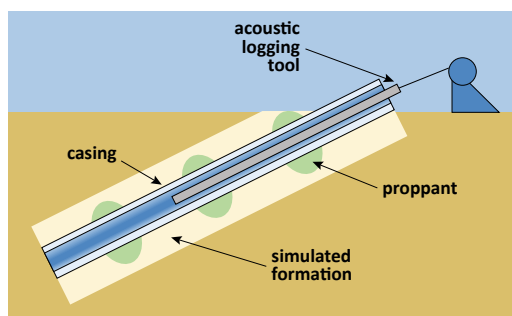


Illustration of Phase I field testing setup

Proppants are solid materials that keep a hydraulic fracture open.

Acoustically responsive proppants **can be more reliably tracked to improve fracture characterization.**

**FracScan could allow operators to make more informed well completion decisions while optimizing performance and streamlining production.**

## IMPROVING EFFICIENCY TO OPTIMIZE RESOURCE RECOVERY

### PROJECT OBJECTIVES

- Proppant design and production
- Proppant characterization and laboratory testing
- Production scale-up
- Pilot-scale field testing
- Commercialization planning
- Full-scale field deployment planning

### TECHNOLOGY FEATURES & BENEFITS

- Added at low concentrations (1–10%)
- Detected with standard acoustic logging tools
- Low-cost raw materials and production methods
- High-resolution propped fracture measurements
- Stress-dependent acoustic response
- Adaptable acoustic properties for tracer applications

### QUICK FACTS

AWARD NUMBER
**DE-SC0017738**

### PROJECT BUDGET

**$1,725,000**

### CONTACTS

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**STEPHEN HENRY**

PRINCIPAL INVESTIGATOR
**JACOB POLLOCK**

### PARTNER



## FIELD VALIDATION & NEXT STEPS
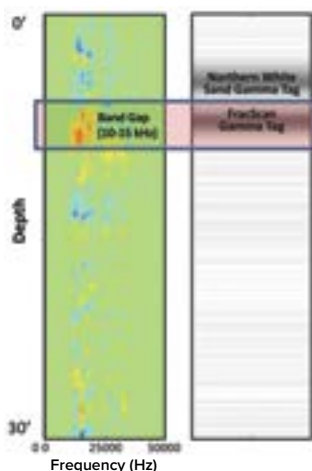


Pilot field results were analyzed to determine size and position of buried proppant deposits.

Phase II research will focus on expanding particle production size, improving detection mechanisms, and engaging in more robust field testing.
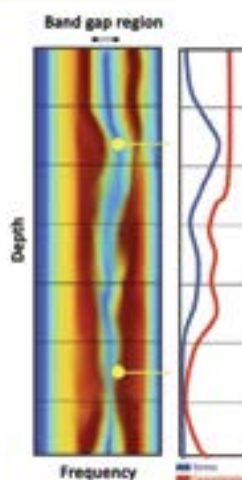
# ADVANCED STIMULATION TO INCREASE RESOURCE RECOVERY

Oceanit Laboratories' transformational smart proppant technology enables high-resolution mapping of propped fracture networks in unconventional oil and gas reservoirs. Oceanit's FracScan proppant offers several key benefits over current fracture diagnostic technologies, including the ability to measure proppant location, concentration, and closure stress, as well as to manipulate acoustic properties for tracer applications. FracScan proppant delivers a cost-effective and accurate fracture diagnostic approach to enable optimized well completions and improved hydrocarbon recovery. This method is made possible by using low-cost materials and production methods, low concentration requirements, and compatibility with standard well configurations and logging tools.

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**JACOB POLLOCK**

## LEVERAGING BIG DATA AND MACHINE LEARNING TO UNLOCK OUR NATION'S VAST UNCONVENTIONAL OIL AND GAS RESOURCES

# DOE NATIONAL LAB PARTNERSHIP ADVANCES RESOURCE RECOVERY

A multi-variant approach to understanding tight reservoir production potential

## IMPROVING RECOVERY OF UNCONVENTIONAL OIL AND NATURAL GAS

Research at Lawrence Berkeley National Laboratory (LBNL) investigates fundamental processes involved in hydrocarbon recovery from tight reservoirs to **improve the viability and recovery efficiency from unconventional resources.**

This research addresses issues that impact reservoir development and recovery, including:

- **Water imbibition**
- **Fracture conductivity sustainability**
- **Enhanced oil recovery**
- **Proppant transport and fate**

LBNL is advancing technologies and methodologies that **increase domestic oil and natural gas production and support American energy independence.**

It will **spur innovative approaches and help solve scientific questions that can catalyze industry-driven technology.**

## ADVANCING SUBSURFACE PHYSICAL PROCESSES

By employing innovative modeling, simulations, and experimental methods, LBNL is helping solve challenges inherent to improving the recovery efficiency from unconventional oil and natural gas resources.
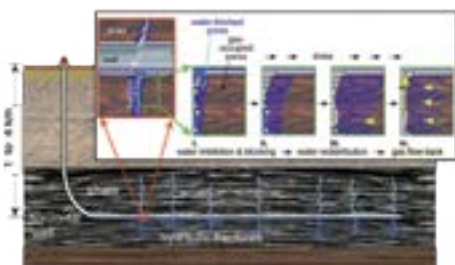


Hydraulically fractured horizontal well schematic



(A) (B)

Simulation of the fluid flow and proppant transport model with proppants represented as void space (A) and picture of the lab proppant transport visualization system (B)

## ADVANCING RECOVERY RESEARCH

- **Identified imbibition mechanisms and their relation to water block in a variety of organic-rich shales.**
- **Investigated proppant behavior in complex fracture networks using a 3D numerical model for fluid flow and proppant transport, and a lab-scale proppant transport visualization system.**
- **Studied temporal changes in fracture aperture and permeability, shale deformation, and proppant fate in shales using a core-scale fracture compaction system.**
- **Evaluated shale composition, bedding orientation, and proppant type in fracture conductivity using a micro-scale fracture compaction system.**
- **Investigated EOR techniques in tight oil reservoirs, as well as those for displacement and viscosity reduction.**
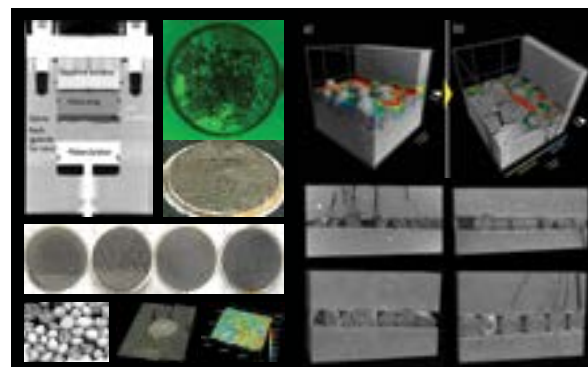


Multi-scale laboratory visualization experiments of fracture conductivity and proppant fate

# DOE NATIONAL LAB PARTNERSHIP ADVANCES RESOURCE RECOVERY

Lawrence Berkeley National Laboratory (LBNL) advances innovative approaches to improve production from unconventional oil and gas resources through a systematic investigation of the fundamental processes involved in hydrocarbon extraction from shale. LBNL enhances the fundamental understanding of hydrocarbon storage, release, and flow in unconventional reservoirs, enabling the development of transformational technologies and methodologies to improve the economic viability, recovery efficiency, and ultimate recovery of unconventional oil and gas resources. These results are achieved by examining a range of issues that impact reservoir development, sustainability, and production.

PRESENTERS:
**STEPHEN HENRY and JARED CIFERNO**

CONTACTS:

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**STEPHEN HENRY**

PRINCIPAL INVESTIGATORS
**SEIJI NAKAGAWA**
**TETSU TOKUNAGA**
**GEORGE MORIDIS**

## LEVERAGING BIG DATA AND MACHINE LEARNING TO UNLOCK OUR NATION'S VAST UNCONVENTIONAL OIL AND GAS RESOURCES

# EXPANDING RESOURCE RECOVERY IN ALASKA

Two research projects on Alaska's North Slope investigating methods and technologies targeting challenging fossil energy resources.

## EVALUATING GAS PRODUCTION POTENTIAL FROM HYDRATE IN ALASKA'S "NATURAL LAB"

- USGS estimates indicate roughly 85 trillion cubic feet (Tcf) of recoverable hydrates in Alaska's North Slope (ANS)
- There have been no prior long-term production tests in the world
- Alaska is the only location in the world where gas hydrate recoverability can be tested and monitored over the necessary extended timeframes, and the site can be the focus of continued experimental studies over the next decade
- Methane hydrates R&D in Alaska provides the foundation for potential accelerated development of the estimated 51,000 Tcf in the Outer Continental Shelf (Lower 48)

## ENHANCED OIL RECOVERY (EOR) ON ALASKA'S NORTH SLOPE

The ANS contains **an estimated 20-25 billion barrels of heavy oil** in its West Sak and Ugnu reservoirs.

Conventional EOR is ineffective in the ANS. Other methods, such as thermal and miscible flooding, are not viable due to permafrost and the miscibility pressure of the reservoir fluid.

The ANS Field Laboratory, operated by UAF and Hilcorp Alaska, **addresses gaps in understanding heavy oil resource behavior** through polymer EOR in an arctic environment near the Prudhoe Bay Oil Field.
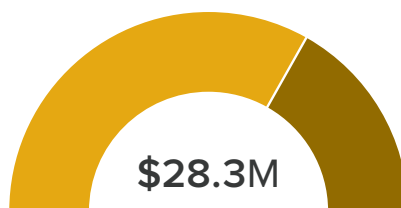
## ORIGINATING DATA TO IMPROVE ARCTIC ENERGY PRODUCTION

### ANS WELL LOG
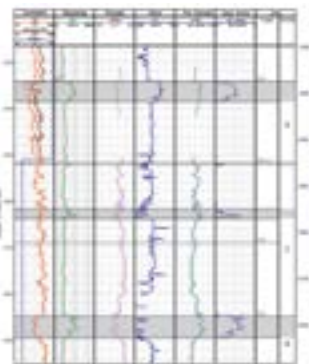
### NORTH SLOPE OIL & GAS ACTIVITY, 2005–2006

Field data from injector and producer wells at Milne Point field and modeling and core flood experimental results will be used to optimize injection fluid viscosity and rates.



Schrader Bluff Oil Pool

Oil & Gas Units
Approx. Gas Accumulation
Approx. Oil Accumulation
Alaska Seaward Boundary
Major Roads
★ Hydrate Test Wells

Well Symbols
⊕ Gas Well
• Oil Well
▫ Plugged & Abandoned
△ Service Well (Un-differentiated)
▲ Suspended

Albers Equal Area, CM-150
NAD 1927
1 : 650,000

Map Location
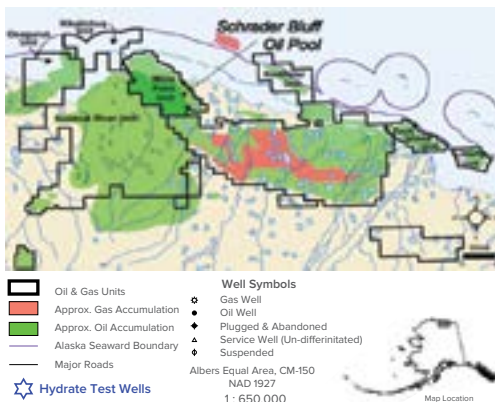
## AIDING U.S. ENERGY INDEPENDENCE

- Stratigraphic Test Well completed in Dec. 2018 confirmed presence of viable production zones (two hydrate bearing sands (~ 30 ft each) with exceptional reservoir quality)
- Plethora of subsurface data secured, including a full suite of geophysical measurements (i.e., resistivity, NMR, sonic, etc.) and 39 sidewall pressure cores
- Distributed Acoustic Sensors and Distributed Temperature Sensors permanently deployed downhole for long-term reservoir monitoring

**Next steps include distributing the data to project collaborators and initiating comprehensive analysis to underpin a long-term production test well, second monitoring well and surface facilities to process gas, water and solids.**

### The ANS Field Lab is:

- Investigating the first-ever polymer flood for heavy oil resources on the ANS
- Assessing polymer flooding vs. incremental oil recovery and evaluating water-oil ratio changes
- Supporting efficient operation and long-term viability of the Trans Alaska Pipeline System (TAPS)

## QUICK FACTS

### AWARD NUMBERS
**PRA: DE-FE0025387**
**UAF: DE-FE0031606**

## PROJECT BUDGET

FY18 FUNDING



**$28.3M**

● PRA (THROUGH STW) ......... $18,800,000
● UAF ......... $9,494,141

## CONTACTS

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**UAF: DAVID CERCONE**

PRINCIPAL INVESTIGATORS
**PRA: ROBERT HUNTER**
**UAF: ABHIJIT DANDEKAR & YIN ZHANG**

## PARTNERS

# EXPANDING RESOURCE RECOVERY IN ALASKA

An international partnership comprised of NETL, JOGMEC, Petrotechnical Resources of Alaska, and the USGS has formed in the last several years with an ultimate focus on investigating the behavior of high-saturation gas hydrate reservoirs through a long-term production test, with Alaska's North Slope serving as a "natural laboratory." In December 2018, a stratigraphic test well was drilled within the Prudhoe Bay Unit on the Alaska North Slope to confirm reservoir occurrence, and to condition and inform planning for an envisioned long-term production test. The well was highly successful in the collection of key geophysical well log data and retrieval of reservoir samples. It also resulted in the completion of the well, which will function as a future monitoring well through the installation of temperature and acoustic monitoring sensors via fiber optics. This initial success sets the stage for a potential longer-term gas hydrate production test to validate the stability and producibility of gas hydrates resources.

The Alaska North Slope Field Laboratory, operated by the University of Alaska Fairbanks (UAF) and Hilcorp Alaska, is addressing critical gaps in understanding heavy oil resource behavior through polymer-enhanced oil recovery in an Arctic environment near the Prudhoe Bay Oil Field. This project is developing a methodology to improve recovery of heavy oils in sensitive environments where thermal and miscible recovery methods cannot be implemented. The field lab also supports the improvement of the underutilized capacity of Trans-Alaska Pipeline System and the energy security of the North Slope's major oil producers, the State of Alaska, U.S. DOE, and the nation.

PRESENTERS:
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## LEVERAGING BIG DATA AND MACHINE LEARNING TO UNLOCK OUR NATION'S VAST UNCONVENTIONAL OIL AND GAS RESOURCES

# EXPLORING THE SUBSURFACE WITH 3D IMAGING TECHNOLOGY

Using cutting-edge technology to improve scientific understanding of the subsurface and enhance geologic carbon storage

## REAL ROCKS AT REAL CONDITIONS

- Multiscale imaging capability that ranges from sub-micron to millimeters
- Up to 10,000 psi and 300 °F while undergoing flow and mechanical processes
- Non-destructive digital acquisition and archiving


Industrial CT


Medical CT


Micro CT

## IMMERSIVE VIRTUAL REALITY VISUALIZATION

IstoVisio, Inc. recently developed a **scientific data visualization and annotation system called called syGlass®**, primarily for biomedical applications.

This technology allows the operator to move freely and rotate 360° to better visualize datasets. **While immersed in the data, users can slice through the data, segment manually, and perform measurements.** This system enables analysis in 3D and is well suited for energy data analysis.

## TRANSFORMING ENERGY DATA ANALYSIS

### In-Situ Multiphase Flow Characterization

Wettability is a primary control on $CO_2$ residual trapping during geologic carbon storage. **Determining the contact angle ($\theta$) between $CO_2$ and brine within rock pores is paramount to accurately estimating storage efficiency.**

Traditional experimental approaches have used simple geometries, limiting $\theta$ measurements to a single 2D image of droplets. More recent developments utilize **CT scans** to provide the resolutions necessary to image *in situ* $\theta$ of fluids in 3D at representative conditions. **The use of virtual reality to measure these angles is quicker and as accurate than other methods.**

### Non-destructive Core Characterization

In 2018 **over 2,000 feet of core** has been scanned, processed, and made available to the scientific community on the Energy Data eXchange (EDX) to download, analyze, and expand upon.
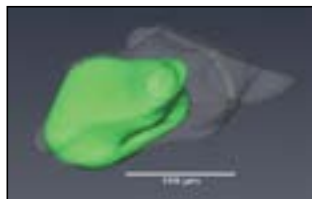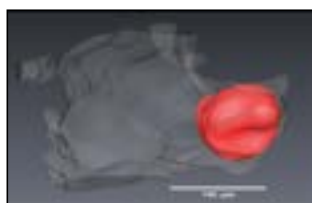

Trapped droplets of super-critical $CO_2$ inside of rock pores

## PROJECT BUDGET

### FY18 TOTAL AWARDED



**$332,000**
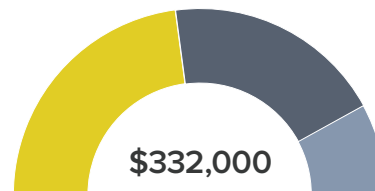
- COAL ............................ $152,000
- OIL & GAS ..................... $127,000
- OFFICE OF SCIENCE ........ $53,000

## CONTACTS

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**ANGELA GOODMAN**
**ALEXANDRA (ALE) HAKALA**

PRINCIPAL INVESTIGATOR
**DUSTIN CRANDALL**

## PARTNERS

# EXPLORING THE SUBSURFACE WITH 3D IMAGING TECHNOLOGY

NETL is leveraging cutting-edge technology from the medical community to improve understanding of subsurface interactions. These resources are utilized to enhance geologic carbon storage, along with oil and gas recovery parameters. NETL combines computed tomography (CT) scanning technology with immersive virtual reality visualization to enable analysis of core samples at real conditions. Cores are imaged by the CT scanners, under representative subsurface pressures and temperatures, and uploaded into a virtual reality system called syGlass. syGlass allows operators to slice through data and perform measurements in 3D. The combination of these cutting-edge technologies allows energy data to be analyzed with increased accuracy and efficiency.

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## LEVERAGING BIG DATA AND MACHINE LEARNING TO UNLOCK OUR NATION'S VAST UNCONVENTIONAL OIL AND GAS RESOURCES

# A KNOWLEDGE MANAGEMENT (KM) TOOL FOR THE SHALE COMMUNITY

**Connecting FE-HQ and National Lab researchers for more efficient and effective communication, coordination, and knowledge curation**

## COLLECT, CURATE, AND SHARE KNOWLEDGE

**Knowledge Management**

**JOIN DOE'S KM AT:**
**HTTPS://EDX.NETL.DOE.GOV/KM**

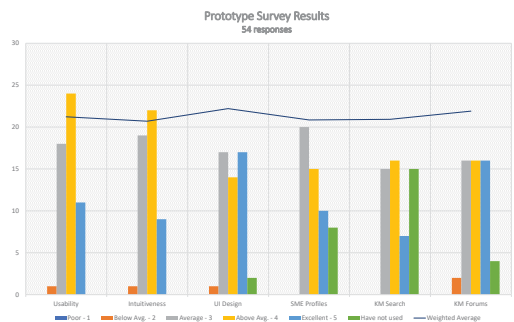**Why Knowledge Management Matters:**

- **Millions** in lost productivity annually because of **inefficient** knowledge sharing
- U.S. workers **waste** an average of 5 hours every week **waiting** for vital information from their colleagues or **recreating** existing institutional knowledge
- 42% of institutional knowledge is acquired specifically for an employee's current role and is **not shared by any of their coworkers**
- **When these expert employees leave their job**, coworkers lose access to 42% of that job related knowledge

All DOE personnel can join FE's virtual KM community.

**Email** kmsupport@netl.doe.gov **for help or to join today**



Prototype Survey Results
54 responses

## A KM SYSTEM TO PRESERVE CURRENT KNOWLEDGE AND CATALYZE FUTURE R&D

Now with DOE FE's Shale R&D KM tool, you can...

...locate **DOE affiliated** experts **rapidly to get answers you need**
...synergize **investment and efforts across multiple teams**
...increase the impact **and adoption of new technologies (e.g., Machine Learning)**
...**capture, share,** and **apply** expertise **across the FE complex**

...provide best practices **and lessons learned for current and future FE community users**
...reduce learning time
...curate knowledge from shale workforce **before they depart the FE community (aging workforce, interns, etc.)**



**Connect** with policy, project/program management, and subject matter experts from within the DOE complex



**Read & Post** to Technical Topic Forums & Threads

## BUILDING AN ACTIVE COMMUNITY OF RESEARCHERS

The KM Tool Shale R&D prototype has **successfully demonstrated how to connect National Labs and HQ**, allowing for the fostering of information throughout the scientific community, breaking down the silos between organizations and **leading to more efficient use of information resources.**



**FUTURE DEVELOPMENT STEPS:**

- Potential to expand to include other FE R&D communities (Carbon Storage, Offshore, Hydrates, Extreme Materials, Midstream, etc.)
- Smart Tool capabilities to help connect KM users from HQ and labs with information within their community
- Increase amount of knowledge and information saved
- Generate a resource for information mining

## QUICK FACTS

### AWARD NUMBER
## FWP-1022431

- 209 registered KM **users**
- Spanning 10 National Labs + HQ
- Over 300 **forum posts** to date
- Over 3,500 **views** to date
- **Prototype** focused on the shale R&D community and launched Aug. 6, 2018
- **Hosted** via DOE FE's virtual data computing platform, EDX
- Finalized development of v. 1 tool coming FY19

### What does this tool do?

- Creates a **virtual DOE FE Shale R&D community**
- **Facilitates** knowledge and information curation and **sharing**
- **Promotes connections & discoverability of people** (Managers, SMEs, researchers, interns, etc.)
- Makes day-to-day program and R&D **more efficient**
- **Reduces redundancy** and curates knowledge for reuse

### Who does it benefit?

- FE HQ, Project Management, and National Labs
- Tax payers, the public, and extramural stakeholders

## CONTACTS

**IT/DEVELOPMENT SUBTEAM**
**KELLY ROSE, NETL**
**CHAD ROWAN, NETL ATTAIN**

**COMMUNITIES OF PRACTICE SUBTEAM**
**JOE MORRIS, LLNL**
**ALEXANDRA HAKALA, NETL**
**TIM KNEAFSEY, LBNL**
**PAUL JOHNSON, LANL**

## PARTNERS

# A KNOWLEDGE MANAGEMENT (KM) TOOL FOR THE SHALE COMMUNITY

The DOE KM tool is an internal DOE instrument that connects and supports the FE R&D community. Built for Shale R&D, the current beta tool focuses upon five main topic areas, including laboratory measurements, field measurements, modeling, machine learning/data analytics, and general discussion. There are already more than 200 individuals using the advanced features like SME profiles, forums, notifications, and a managed list of approved keywords to drive future development and functionality. The KM Tool has succeeded in allowing for the fostering of information throughout the scientific community, breaking down the silos between organizations, and leading to more efficient use of information resources. Examples of this progress are topic enhancements to Oil and Gas Shale, potential for future oil and gas (i.e. Offshore and/or Midstream) communities, and cost-effective extension to Clean Coal topics.

PRESENTER:
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## LEVERAGING BIG DATA AND MACHINE LEARNING TO UNLOCK OUR NATION'S VAST UNCONVENTIONAL OIL AND GAS RESOURCES

# THE MID-ATLANTIC RESOURCE IMAGING EXPERIMENT (MATRIX)

A regional-scale research expedition has collected more than 2,000 kilometers of marine seismic data, advancing scientists' understanding of gas hydrate deposits in the Mid-Atlantic Margin.

## UNLEASHING GAS HYDRATE ENERGY POTENTIAL

In 2018, the research vessel Hugh R. Sharpe returned from a 1,270-mile expedition along the Mid-Atlantic Margin between New Jersey and North Carolina.

- Represented the highest quality, deepest penetration data the USGS has ever collected
- Produced new, improved data on the offshore distribution of methane hydrates

**These hydrates represent a new energy source with substantial production potential not yet fully characterized.**
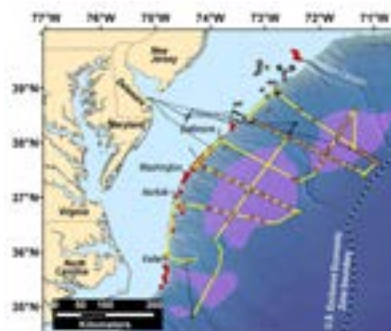


*MATRIX collected seismic data along over 2,000 km of track line, shown in yellow.*

## DELIVERING DATA TO ACCELERATE NEW ENERGY SOURCES



*The research vessel, Hugh R. Sharpe, docked in Lewes, Delaware.*

**Data collected by the MATRIX expedition:**

- Fills a gap in modern seismic data acquisition
- Improves the understanding of gas hydrate deposits
- Identifies deposits, faults, and markers that help interpret the history of the Atlantic Ocean Basin
- Provides data to further refine resource estimates

## ADVANCING UNDERSTANDING OF GAS HYDRATES

Methane hydrates, cage-like lattices of ice that contain trapped methane molecules, revert to water and natural gas when thawed and depressurized. **One cubic meter of gas hydrates releases roughly 164 cubic meters of natural gas.**

A recent Bureau of Ocean Energy Management (BOEM) study estimated that the **mean in-place gas hydrate resource in sand reservoirs in the Atlantic Outer Continental Shelf is 15,785 trillion cubic feet.** MATRIX advances the understanding of these energy resources, **paving the way for new energy feedstocks.**

# THE MID-ATLANTIC RESOURCE IMAGING EXPERIMENT (MATRIX)

The Mid-Atlantic Resource Imaging Experiment (MATRIX), jointly sponsored by the U.S. Geological Survey (USGS), the Methane Hydrates R&D Program at DOE, and the Bureau of Ocean Energy Management, acquired more than 2,000 kilometers of marine seismic data along the mid-Atlantic margin that image gas hydrate features and other geologic structures below the seafloor. MATRIX produced data that fills a gap in modern seismic data acquisition along the U.S. Atlantic margin and will, for years to come, support broader analyses of the margin's hazards, stratigraphy, and deep structure by the USGS, other agencies, and the academic community.

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## LEVERAGING BIG DATA AND MACHINE LEARNING TO UNLOCK OUR NATION'S VAST UNCONVENTIONAL OIL AND GAS RESOURCES

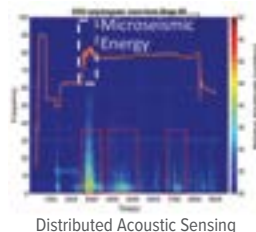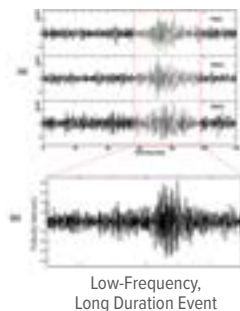# MONITORING SEISMICITY AT HYDRAULIC FRACTURING AND CO$_2$ EOR SITES

## CAPTURING LPLD EVENTS IN SEISMIC DATA INTERPRETATION

**Obtaining more reservoir information from the seismic data already collected.**

**Analyzing the entire seismic waveform allows:**

- Significant low-frequency seismic energy ignored by microseismic monitoring platforms
- Low-frequency waveforms can be detected with surface seismometer arrays, costing less
- Interpretation of low-frequency waveforms

Long-Period, Long Duration Event (LPLD)

Low-Frequency, Long Duration Event

Distributed Acoustic Sensing

## MICROSEISMIC MONITORING IS NOT ENOUGH

**Traditional monitoring does not:**

- Account for all injection energy
- Detect bedding plane slip
- Detect tensile rock failure
- Predict hydrocarbon production
- Detect plastic deformation

Λρ and Mρ inversion to identify lithology and fluid composition

LPLD data is not currently represented

LPLD data adds to the understanding of the frac stage operation
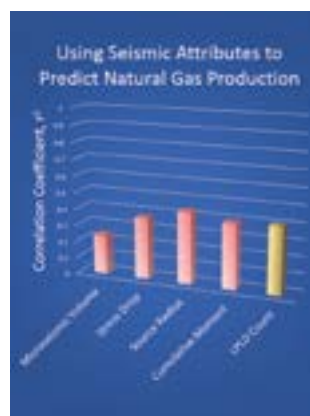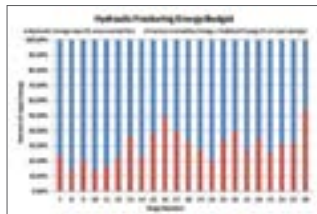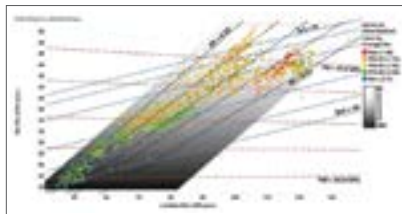
## IMPROVING MONITORING TO MAXIMIZE RESOURCE RECOVERY

Observed an 8-min.-long LPLD event at a CO$_2$ EOR location
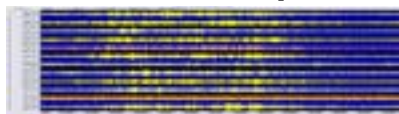
First detection and mapping of LPLD events

- Developed first ever workflow for locating LPLD events at injection sites
- High-Frequency Test Site

Surface-based seismic monitoring base station

## PROJECT BUDGETS & CONTACTS

**FY18 CARBON STORAGE**

### $191,000

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**RICHARD HAMMACK**

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**FY18 ONSHORE UNC**

### $312,000

HQ PROGRAM MANAGER
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## PARTNERS

West Virginia University

KU THE UNIVERSITY OF KANSAS

Northwestern University

UNIVERSITY of HOUSTON

Virginia Tech

KU KANSAS GEOLOGICAL SURVEY The University of Kansas

gti

LAREDO PETROLEUM, INC.

northeast

BATTELLE

IRIS PASSCAL

# MONITORING SEISMICITY AT HYDRAULIC FRACTURING AND CO$_2$ EOR SITES

NETL significantly expanded the amount of diagnostic information that can be obtained from hydraulically fractured shale reservoirs by analyzing previously ignored low-frequency seismic data that is already being collected by modern geophones, seismometers, and distributed acoustic sensing (DAS) cables. Microseismic analysis, the current industry tool for monitoring hydraulic fracture growth, is inappropriate for shale reservoirs because the hydrocarbon source rock is too weak to emit seismic waveforms in the required 100-300 Hz frequency range. NETL is now examining seismic waveforms with frequencies below 100 Hz that are recorded during microseismic monitoring but have previously been discarded as noise. An analysis of these low-frequency waveforms has identified low amplitude events of extremely long duration that occur when pumping pressures and rate are at their maximum. This knowledge gained from this research could allow for the extended life and increased productivity of many unconventional resources.

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## LEVERAGING BIG DATA AND MACHINE LEARNING TO UNLOCK OUR NATION'S VAST UNCONVENTIONAL OIL AND GAS RESOURCES

# PIONEERING INTEGRATED TOOLS FOR OPTIMIZED RESOURCE MANAGEMENT

**Powerful analytical tools provide effective state-level energy resources management**

## FACILITATING EFFICIENT RESOURCE DEVELOPMENT

The Risk-Based Data Management System (RBDMS) is a suite of integrated software products that **allows state agencies to oversee and manage oil, gas, and Underground Injection Control (UIC) facilities and activities.**

Increased drilling results in more well bores from a single pad and greater density of well-bore paths in the same geologic area. **Tools like RBDMS allow more accurate permitting, construction, and management of wells.**
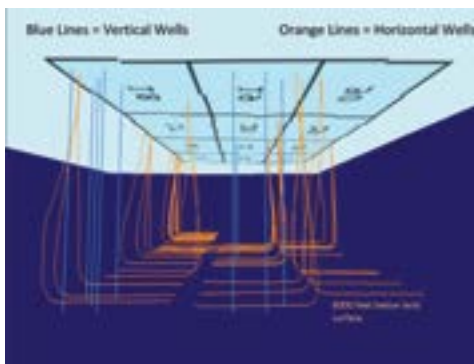


**3D VIEW**

## OPTIMIZING RESERVES USING DIRECTIONAL SURVEYS
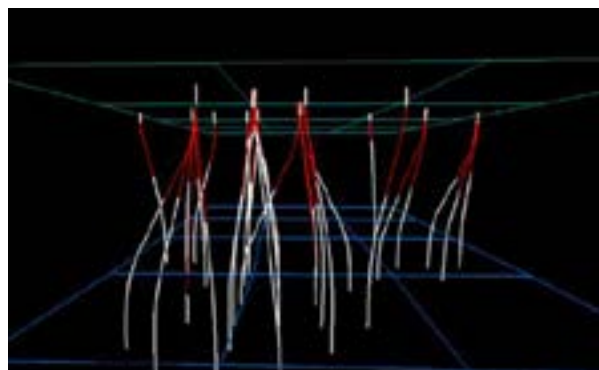


Viewing 3D boreholes (red) with cement intervals (white) in Global Mapper

Horizontal and directional drilling provides optimal access to reserves and reduces the number of well pads required to recover oil and gas resources. It also introduces more complexity for state agencies reviewing drilling applications to ensure effective resource recovery.

The RBDMS Directional Survey Tool **provides state agencies more robust data analysis when reviewing directional drilling activities.**

**The Directional Survey Tool offers a standard Electronic Data Delivery format for operators to submit survey data to state agencies.**

## CRITICAL DECISION-MAKING TOOLS

Accurate mapping of directional and horizontal wellbores **better inform agency staff to make decisions** regarding:

- Spacing and mineral rights
- Anti-collision planning
- Injection well zone isolation
- Fracture stimulation communication avoidance

The RBDMS Directional Survey Tool is installed in California and Utah. Several additional states are interested in adding this tool. **Benefits include:**

- Electronic survey data available for agency and industry use
- Expedited permit approvals based on data availability
- Improved efficiency for area of review (AOR) evaluations
- Greater GIS data availability

# PIONEERING INTEGRATED TOOLS FOR OPTIMIZED RESOURCE MANAGEMENT

The Risk-Based Data Management System (RBDMS) streamlines communication between government agencies and industry by improving the accuracy of information provided for sectors such as permitting, construction, and well management. As industry practices develop and become increasingly complex, so too does the information that needs to be shared with state government agencies. The RBDMS provides a standardized communication tool that shares robust data sets, including well details and strategic planning, which facilitates more efficient decision-making for various state government agencies and industry. RBDMS' enhanced communication platform helps to safely and effectively unlock our nation's vast unconventional oil and gas resources.

PRESENTER:
**BRUCE BROWN**

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**JARED CIFERNO**

FEDERAL PROJECT MANAGER
**BRUCE BROWN**

PRINCIPAL INVESTIGATORS
**DAN YATES**
**PAUL JEHN**

## LEVERAGING BIG DATA AND MACHINE LEARNING TO UNLOCK OUR NATION'S VAST UNCONVENTIONAL OIL AND GAS RESOURCES

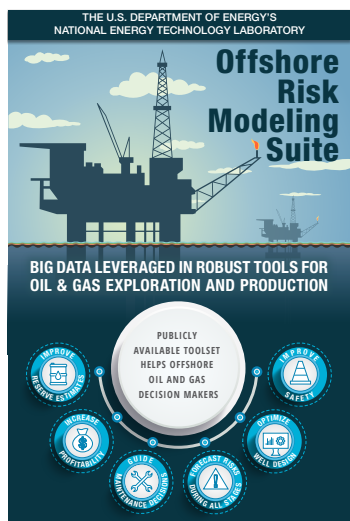# OFFSHORE RISK MODELING SUITE

**Equipping decision-makers with smart, data-driven tools and resources for efficient, effective, and safe offshore exploration and production**

## INCREASING PROFITABILITY & IMPROVING SAFETY



THE U.S. DEPARTMENT OF ENERGY'S NATIONAL ENERGY TECHNOLOGY LABORATORY

**Offshore Risk Modeling Suite**

BIG DATA LEVERAGED IN ROBUST TOOLS FOR OIL & GAS EXPLORATION AND PRODUCTION

PUBLICLY AVAILABLE TOOLSET HELPS OFFSHORE OIL AND GAS DECISION MAKERS

NETL's unprecedented Offshore Risk Modeling (ORM) Suite is a growing collection of authoritative, easy-to-use, publicly available online tools and data that help offshore oil and gas decision-makers increase profitability, improve safety, and enable environmental stewardship.

### OFFERING INTELLIGENT ANALYTICS TO TACKLE IMPORTANT ISSUES

- Geohazard prediction
- Well design and maintenance
- Regulatory permitting
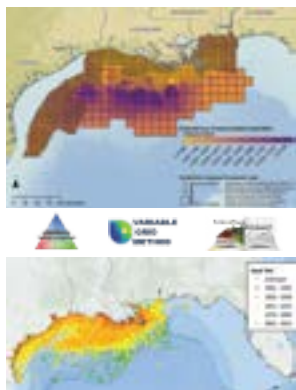- Improved metocean predictions
- Optimized infrastructure

**Custom DOE Smart Toolbox**

| Tool | Description |
|------|-------------|
| EDX | COLLABORATION PLATFORM |
| | E-NOTEBOOK |
| SWIM | DECISION SUPPORT TOOL |
| VARIABLE GRID METHOD | UNCERTAINTY CHARACTERIZATION |
| | SUBSURFACE UNCERTAINTY REDUCTION MODEL |
| GEO CUBE | WEB MAPPING |
| BLOSOM | 4D OIL SPILL MODEL |
| | SPATIO-TEMPORAL ANALYSIS |
| CIAM | METOCEAN MODEL |

## QUICK FACTS

| **65** Conference Presentations | **7** Technical Reports | **15** Journal Publications | **9** News Articles | **2/5** Copyrights / Trademarks | **2** Awards |
|---|---|---|---|---|---|

**NETL's ORM suite** was initiated in 2011 to support **DOE FE32** goals for **offshore spill prevention.** To date, tools from the ORM suite have been leveraged for **6 additional projects:**

- **2014–present** NETL and PNNL collaborated to adapt the ORM suite into a worst case discharge platform for BSEE (Dept. of Interior)
- **2015–2017** PNNL and NETL collaborated to characterize dispersant effectiveness and improve dispersant modeling for BSEE (Dept. of Interior)
- **2016–present** NETL is leveraging data and tools from ORM for development of a DOE FE22 Offshore Carbon Storage Methodology
- **2017–present** NETL is leveraging tools from ORM to improve characterization and extend life cycle for offshore infrastructure and materials
- **New starts:**
  - NETL is leveraging ORM to support dynamic analyses to inform offshore leasing for BOEM (Dept. of Interior)
  - NETL is adapting VGM for 3D and 4D modeling for optimizing oil and gas exploration (TCF)

The initial $2.5 million in funding has spurred an **additional $3.5 million in new projects** that rely on ORM data and tools.

## THE POWER OF DATA & SPATIO-TEMPORAL ANALYTICS

### Improving Subsurface Prediction & Reducing Geohazards



### Assessing Metocean Hazards



Percent of Incidents by Depth

- 25.7% >400m
- 33.3% <40m
- 41.0% 40-400m

CIAM

GEO CUBE
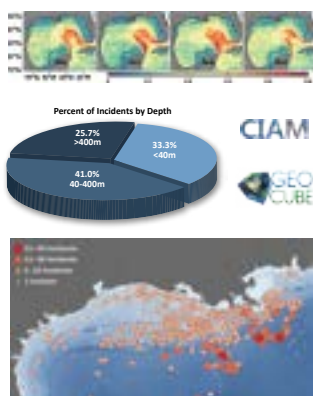
### Decision Support for Oil Spill Prevention, Permitting, & Planning



EDX

BLOSOM

SWIM
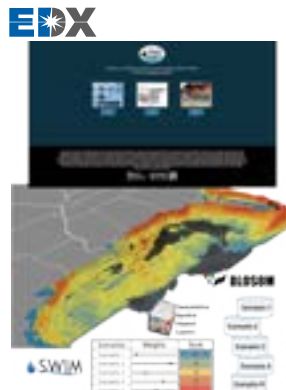
## FUTURE WORK

Virtualize tools online and expand ORM with **materials, cement, and infrastructure data** to assess offshore infrastructure life span and reduce hazards.

To access the ORM Suite or learn more about NETL's offshore research, please visit https://edx.netl.doe.gov/offshore/

## CONTACTS

HQ PROGRAM MANAGER
**ELENA MELCHERT**

TECHNOLOGY MANAGER
**ROY LONG**

PRINCIPAL INVESTIGATORS
**KELLY ROSE**
**JENNIFER BAUER**

## STAKEHOLDERS



AUSTRALIAN INSTITUTE OF MARINE SCIENCE

BSEE Bureau of Safety and Environmental Enforcement

Shell

SPE International

BOEM Bureau of Ocean Energy Management

NOAA

Lloyd's Register

saudi aramco

# OFFSHORE RISK MODELING SUITE

Since 2011, NETL has been developing the Offshore Risk Modeling (ORM) suite, a flexible set of custom data, tools, and models that integrate innovative spatio-temporal analytics, machine learning, big data, and advanced visualization technologies to support DOE's offshore spill prevention, operational efficiency, and safety goals. Five years of development produced terabytes of new data and seven trademarked or copyrighted tools built into the ORM suite that can be used independently or in combination to support data-driven analytics for offshore systems to improve global energy, environmental, and economic conditions. NETL has demonstrated how the ORM suite can be used to help improve reserves estimates, increase profitability, guide safety and maintenance decisions, forecast risks, and optimize well/facilities designs. These pioneering applications of the ORM suite, and the data science innovations driving them, have garnered national and global attention. This has translated into millions of dollars of funding from DOE-FE and external stakeholders for new projects that apply the ORM suite to address additional energy systems and help inform a range of industry and regulatory decisions. To date, the ORM suite has been adapted to address energy infrastructure, carbon storage, geothermal, rare-earth element, induced seismicity, energy materials, and other oil and gas system needs.

PRESENTERS:
**JENNIFER BAUER and ROY LONG**

CONTACTS:

HQ PROGRAM MANAGER
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PRINCIPAL INVESTIGATORS
**KELLY ROSE**
**JENNIFER BAUER**

## LEVERAGING BIG DATA AND MACHINE LEARNING TO UNLOCK OUR NATION'S VAST UNCONVENTIONAL OIL AND GAS RESOURCES

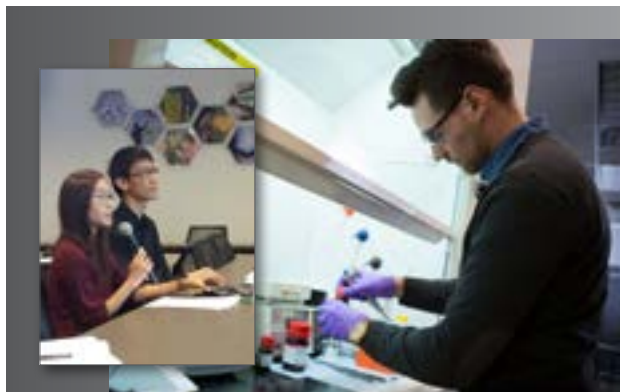# NETL IS AMERICA'S FOSSIL ENERGY RESEARCH LABORATORY

# ACCOMPLISHMENTS POSTERS:

# EDUCATING THE NEXT GENERATION OF ENERGY INNOVATORS

Providing hands-on research experience and inspiring Research Associates to explore new ideas

## OVERCOMING ENERGY CHALLENGES



Post-doc Robert Fryer contributed to NETL research on thin-film characterization, deposition, and testing of harsh-environment **surface acoustic wave (SAW) gas sensors** during his Postgraduate Research Program (PGRP) appointment as part of the University Coal Research Outreach Initiative.

The SAW sensors allow real-time measurement of conditions to **improve efficiencies, material lifetimes, and reduce overall costs.**

In 2018, the team successfully produced high-quality metal oxide thin films with smooth structures that are suitable for SAW devices. The films enable the SAW sensors to be tuned for sensitivity to varying temperatures and gas conditions.

Nana Zhou performs research in the one-of-a-kind **Hybrid Performance (HYPER) facility** for NETL's PGRP. Focused on airflow regulation and control development, her contributions will help build a novel cyber physical reformer and internal combustion engine into the hybrid power system.

Nana's scientific and technical accomplishments include **16 peer-reviewed papers, multiple presentations, and session chair at international conferences.** Nana has been a Research Advisor to 18 undergraduate and graduate students. In addition, she **organized the 2018 CIESESE Technical Forum,** which drew an attendance of 50 researchers and administrators from five consortium universities, two national labs, and DOE headquarters.



## ENABLING SUCCESS

**309** Program Participants

**98** Papers Published in a Peer-Reviewed Journal

**21** Technical Reports

**214** Conference Presentations

**25** Conference Publications

**7** Patents Submitted

## IMPACTING AMERICA'S FUTURE ENERGY LANDSCAPE

*"NETL provided me access to brilliant researchers who have broadened my perspective, laboratory instruments, and hands-on research experience. Gaining this hands-on research experience has made me a better chemist and materials researcher."*
**– 2018 Professional Internship Program (PIP) Participant**

*"NETL's PIP Program has helped me grow as a scientist and begin to realize my dreams."*
**– 2018 Professional Internship Program (PIP) Participant**

**96%** of PIP & PGRP participants agreed/strongly agreed that the program enriched their academic experience and professional skills.

**100%** of Faculty Research Program participants agreed/strongly agreed that the program enriched their professional status.

### CONTACTS

GRADUATE EDUCATION PROGRAM MANAGER
**PATRICIA ADKINS-COLIANE**

MENTORS
**PAUL OHODNICKI
DAVID TUCKER**

TECHNICAL PROJECT LEADS
**OMER BAKSHI
DAVID TUCKER**

# EDUCATING THE NEXT GENERATION OF ENERGY INNOVATORS

NETL offers opportunities to participate in energy-related research through highly competitive internships and research fellowship programs. The Graduate Education Programs play an instrumental role in fulfilling NETL's mission to serve as an energy educator. The programs help to ensure that NETL has a robust supply of scientists and engineers to meet the nation's future science and technology needs. Robert Fryer and Nana Zhou are two excellent examples of Research Associates whose successes and contributions positively impact technological and scientific advancement at NETL.

PRESENTERS:
**OMER BAKSHI, PATRICIA ADKINS-COLAINE, and DAVID TUCKER**

CONTACTS:

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# STRATEGIC PARTNERSHIPS: BUILDING KEY RELATIONSHIPS

Engaging stakeholders to build the Lab's capabilities, deliver on its mission, and develop a world-class reputation.

## DEVELOPING PARTNERSHIPS

**OAK RIDGE National Laboratory**

Exploring new ways to create high-value products from coal, develop materials for extreme environments, and utilize advanced manufacturing techniques.

Joint research includes:

- Reducing water consumption in energy production
- Developing advanced electrical grids, microgrids, and cybersecurity technologies for energy infrastructure
- Innovating advanced manufacturing technology for energy production, especially fossil energy technologies

**Xcoal ENERGY & RESOURCES**

NETL oversaw sampling of the 62,000-ton cargo shipped by Xcoal at the CNX Marine Terminal in Baltimore, MD:

- Paid for samples to be tested at an independent laboratory
- Compared the test results with Centrenergo's specifications
- Evaluated the coal's combustion performance in a Centrenergo boiler

**RAMACO CARBON**

NETL and Ramaco Carbon are identifying and collaborating on R&D in three primary areas:

1. The conversion of coal to value-added products such as carbon fiber and carbon nanomaterials
2. The use of computational modeling for developing coal beneficiation processes
3. The development of technologies for extracting rare earth elements from coal, beneficiated coal, coal-byproducts and mining byproducts

This partnership will enhance NETL's materials engineering and manufacturing capabilities.

## ENGAGING STAKEHOLDERS

**UAF UNIVERSITY OF ALASKA FAIRBANKS**

NETL's participation at The University of Alaska Fairbanks (UAF) Lab Day **strengthened relationships with Alaska stakeholders.**

The Lab Day's site visits **explored research collaborations between UAF and DOE National Laboratories.**

**CURC CARBON UTILIZATION RESEARCH COUNCIL — ADVANCING FOSSIL ENERGY SOLUTIONS**

CURC has been one of NETL's most important stakeholders.

CURC advocates for research, development, demonstration, and widespread deployment of technologies, such as those pursued at NETL, that **will support the continued and long-term use of coal.**

NRECA & CURC members tour NETL Morgantown

**NRECA America's Electric Cooperatives**

NETL has sponsored many projects with NRECA aimed at **developing and enhancing the smart grid system** centered on:

- Cybersecurity
- Customer access to consumption data
- Smart chargers for electric vehicles
- Advanced modeling/controls
- Microgrids

## TECHNOLOGY TRANSFER: Technology Commercialization Fund Awards

**Improving accuracy through uncertainty quantification and communication**

**Varigrid** Exploitions

This collaborative project will mature NETL's Variable Grid Method (VGM) technology into a commercially ready application.

**The outcome of this industry-centric approach will help keep costs relatively low, foster rapid industry adoption, and facilitate broad market penetration.**
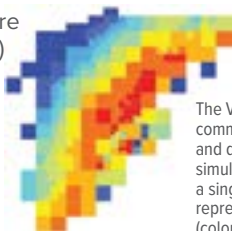
The Variable Grid Method communicates both data and data uncertainties simultaneously in a single layer that represents the data (colors) and uncertainty (grid cell size).

**Cooperative development of technologies to improve small-scale solid oxide fuel cell systems**

WATT

NETL's Solid Oxide Fuel Cell (SOFC) Program has developed several advanced technologies to significantly increase the efficiency and reliability of SOFC systems.

**The final product will increase performance and durability, and will lower cost for electricity generated by the unit.**

WATT's SOFC system provides clean, efficient power on demand with no engine noise or exhaust.

# STRATEGIC PARTNERSHIPS: BUILDING KEY RELATIONSHIPS

The Strategic Partnerships division builds key relationships by engaging stakeholders in industry, academia, and government. Strategic Partnerships conducts outreach that strengthens NETL's reputation and promotes its research capabilities. By participating in conferences and exhibitions, site visits, MOUs, CRADAs, and technology transfer, NETL promotes its research and fosters strong external collaborations. Strategic Partnerships plays an instrumental role fulfilling NETL's vision — to be renowned as a fossil energy science and engineering resource that delivers world-class technology solutions today and tomorrow.

PRESENTER:
**MIKE KNAGGS**

CONTACT:

ASSOCIATE DIRECTOR OF STRATEGIC PARTNERSHIPS
**MIKE KNAGGS**

# NETL

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**Houston, TX** and **Anchorage, AK**

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## 2018
Science & Technology
## ACCOMPLISHMENTS
SESSION