2018 Science & Technology ACCOMPLISHMENTS SESSION

UNLEASHING AMERICAN ENERGY

DISCOVERY | INNOVATION | PROSPERITY

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

"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 to:

- *Improve the performance, reliability and efficiency of the existing coal-fired fleet.*
- *Advance the next generation of modular, highly efficient, and flexible coal-fired power plants.*
- *Reduce the cost of captured carbon and put it to work for America.*
- *Create new jobs, products, and markets for coal.*
- *Leverage big data and machine learning to unlock our nation's vast unconventional oil and gas reserves.*

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

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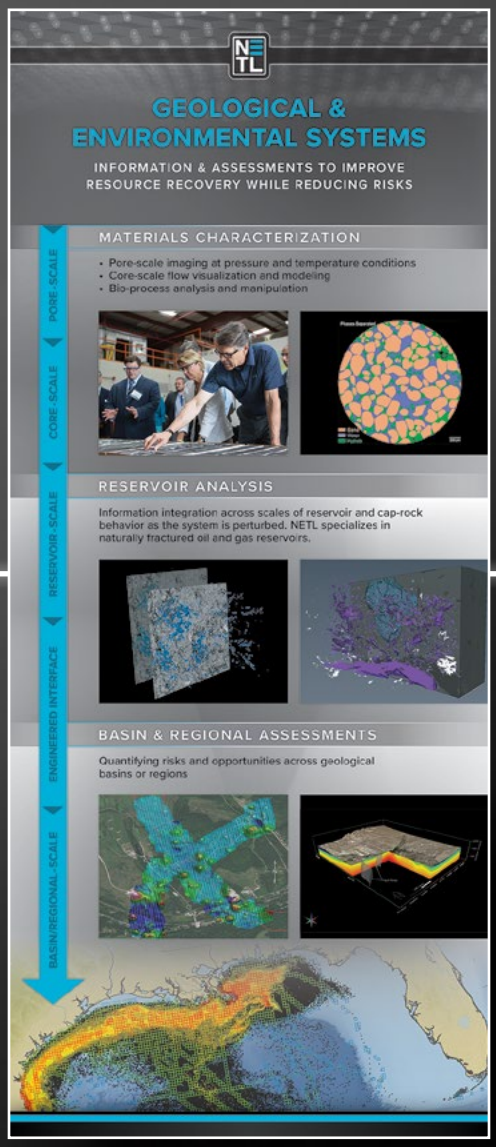
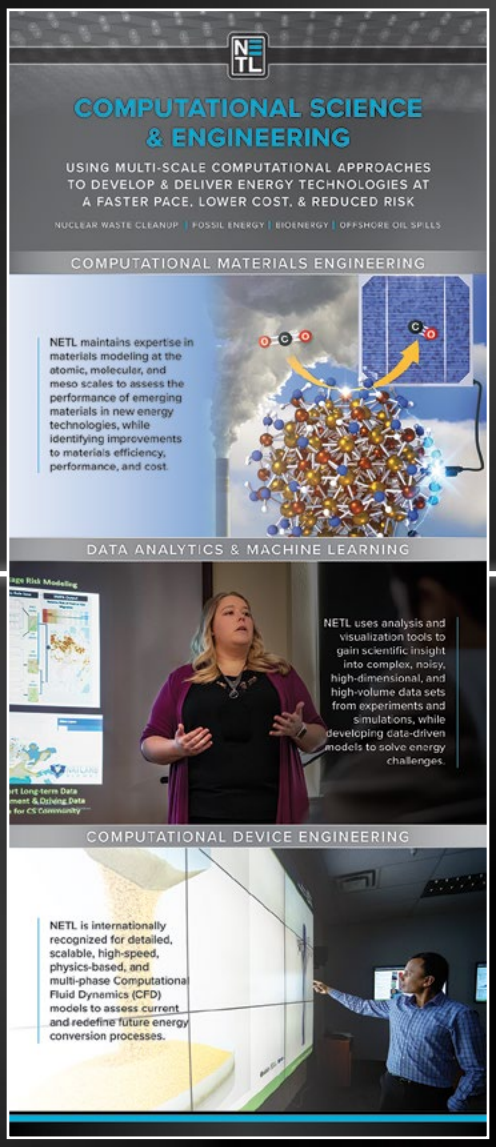
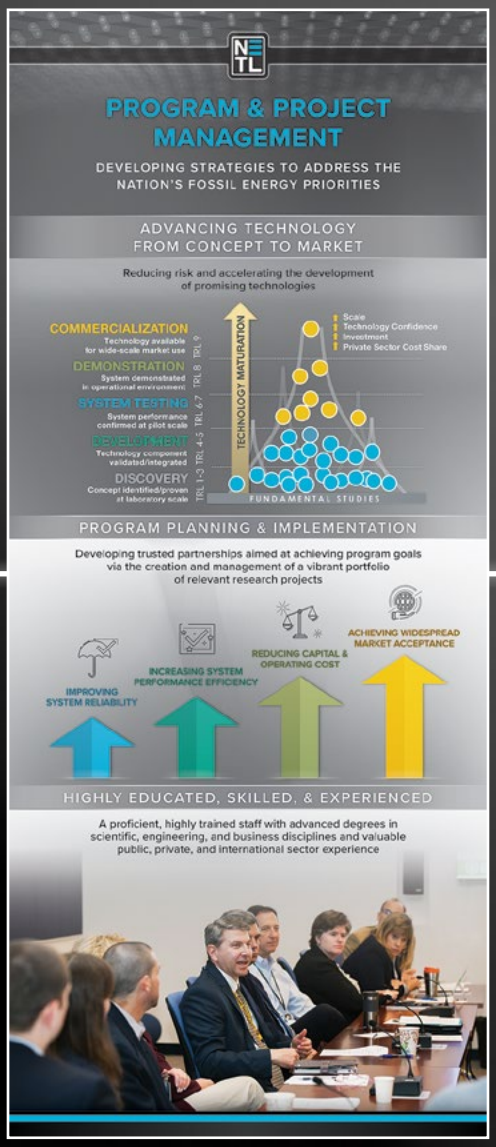
CORE COMPETENCIES

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 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 RESERVES

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

ACCOMPLISHMENTS POSTERS:

Advanced Optical Fiber Sensors for Next-Gen Energy Systems 12

Affordable, Durable Alloys for Fossil Energy Applications 14

Cybersecurity for Fossil Power Generation 16

Enabling Responsible Water Use for Power Generation 18

Institute for the Design of Advanced Energy Systems 20

Multiphase Flow Science: Computational Tools for Design and Optimization 22

New R&D Initiative for Existing Coal-Fired Power Plants 24

Rapid Manufacturing Method for High-Temperature Turbine Components 26

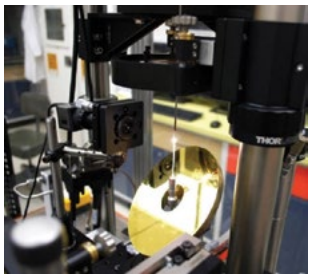
ADVANCED OPTICAL FIBER SENSORS FOR NEXT-GEN ENERGY SYSTEMS

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:

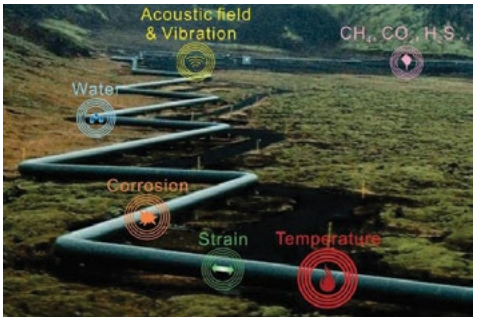
- **Power Generation** – Boilers, Fuel Cells, and Turbines
- **Carbon Storage and Oil and Gas** – Wellbore Integrity
- **Natural Gas Infrastructure** – Pipeline Integrity Monitoring



A laser heated pedestal growth system.

WORLD-CLASS SENSOR RESEARCH

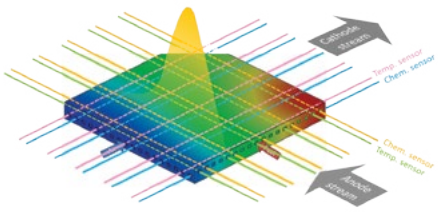
PREVENTING NATURAL GAS INFRASTRUCTURE FAILURES



- 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

HQ PROGRAM MANAGER
CHRISTOPHER FREITAS

TECHNOLOGY MANAGER
JARED CIFERNO

TECHNICAL PORTFOLIO LEAD
NATALIE PEKNEY

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

HQ PROGRAM MANAGER
ROBIE LEWIS

TECHNOLOGY MANAGER
BRIGGS WHITE

TECHNICAL PORTFOLIO LEAD
BEN CHORPENING

FWP-1022411
TASK 2.2.3
Award Value $223,000

HQ PROGRAM MANAGER
STEVEN ROSS

TECHNOLOGY MANAGER
SHAILESH VORA

TECHNICAL PORTFOLIO LEAD
GREGORY HACKETT

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.

PRESENTERS:
BENJAMIN CHORPENING and PAUL OHODNICKI

CONTACTS:

HQ PROGRAM MANAGER
ROBIE LEWIS

TECHNOLOGY MANAGER
BRIGGS WHITE

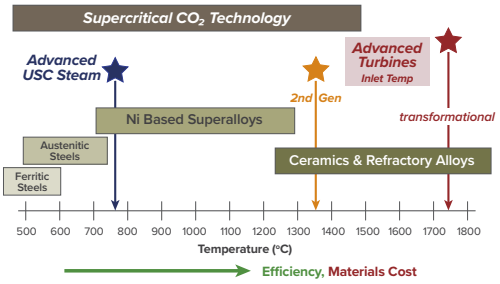
TECHNICAL PORTFOLIO LEAD
BENJAMIN CHORPENING

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



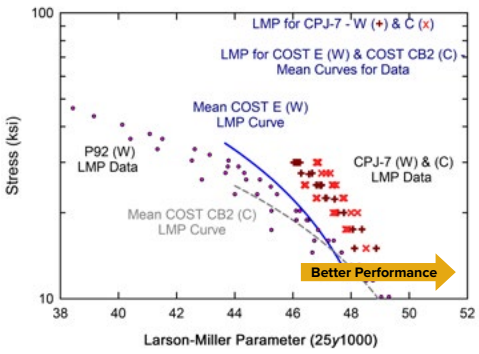
Advanced energy systems: higher operating temperatures and pressures require cost-effective, heat-resistant alloys.

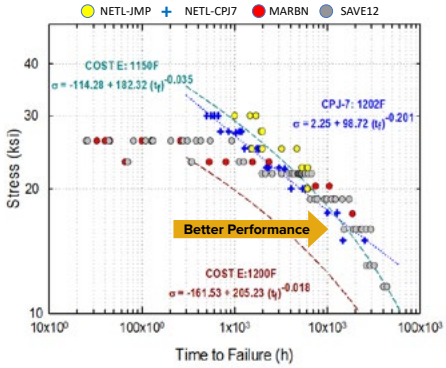
Existing fleet: changing mission profile requires materials that can resist cycling.

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 lower materials costs of advanced energy systems.

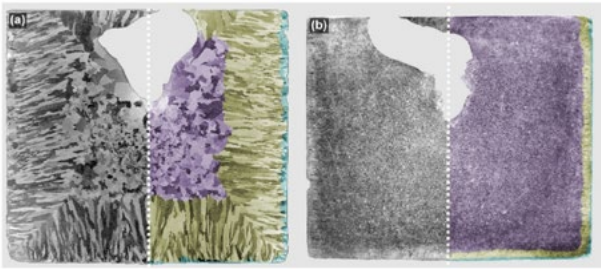
Creep behavior of NETL CPJ7 & JMP steels, compared against COST E, COST CB2, and MARBN/SAVE12





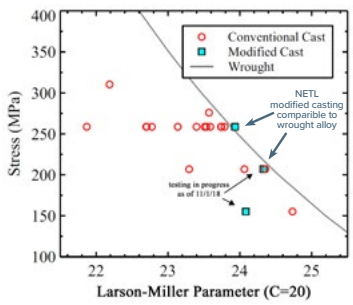
NETL CAST VERSION OF ALLOY 740: ANOTHER OPTION FOR A-USC CASTINGS

A **modified casting route was developed** that 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



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

HQ PROGRAM MANAGER
REGIS CONRAD

TECHNOLOGY MANAGER
BRIGGS WHITE

PRINCIPAL INVESTIGATORS
JEFFREY HAWK
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 NATIONAL LABORATORY

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.

PRESENTERS:
JEFFREY HAWK and DAVID ALMAN

CONTACTS:

HQ PROGRAM MANAGER
REGIS CONRAD

TECHNOLOGY MANAGER
BRIGGS WHITE

PRINCIPAL INVESTIGATORS
JEFFREY HAWK
PAUL JABLONSKI
MARTIN DETROIS
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

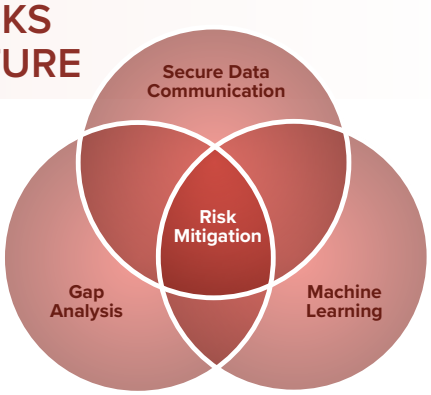
Cyber-secure engineering of sensors and other plant components

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

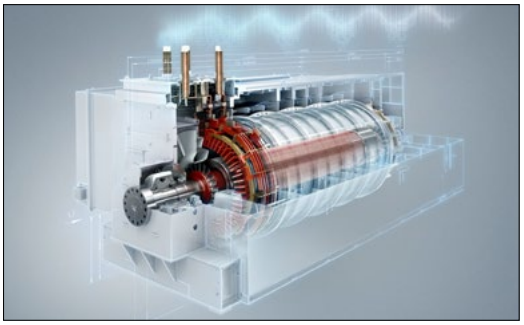
- Blockchain for secure energy – Taekion (GRID7)

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

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

HQ PROGRAM MANAGER
ROBIE LEWIS

TECHNOLOGY MANAGER
BRIGGS WHITE

PARTNERS

U.S. DEPARTMENT OF ENERGY | OFFICE OF CYBERSECURITY, ENERGY SECURITY, AND EMERGENCY RESPONSE

Southern Company

Taekion

SIEMENS

POC PHYSICAL OPTICS CORPORATION

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.

PRESENTER:
BRIGGS WHITE

CONTACTS:

HQ PROGRAM MANAGER
ROBIE LEWIS

TECHNOLOGY MANAGER
BRIGGS WHITE

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

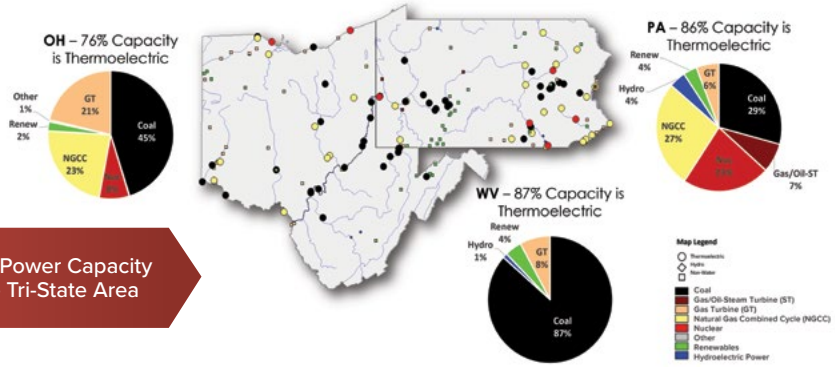
ENABLING RESPONSIBLE WATER USE FOR POWER GENERATION

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

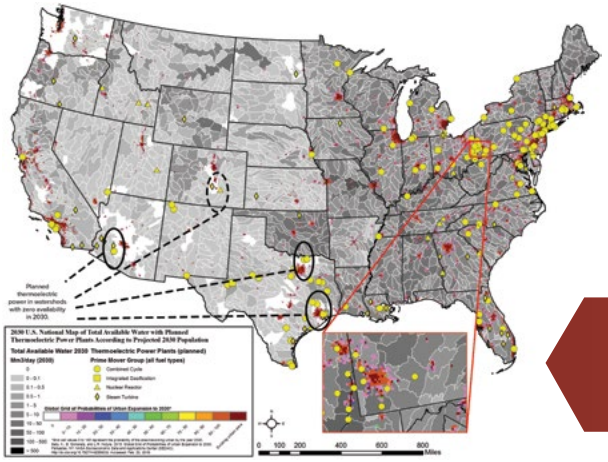
The 2018 Water Brief documents geographic Areas of Concern for water availability in the continental United States

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

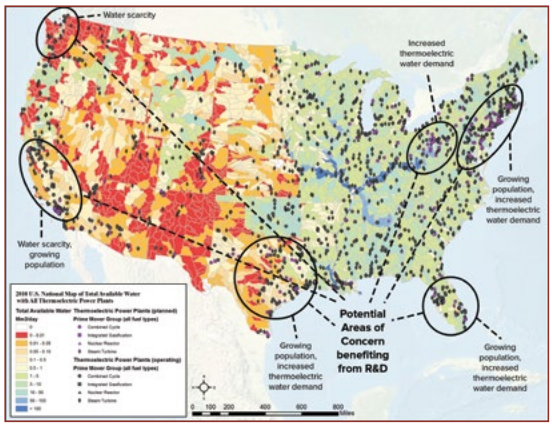
THE 2018 WATER BRIEF



- **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 (FGD) 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

HQ PROGRAM MANAGER
ROBIE LEWIS

TECHNOLOGY MANAGER
BRIGGS WHITE

FEDERAL PROJECT MANAGER
JESSICA MULLEN

ENGINEER/ENERGY ANALYST
ERIK SHUSTER

PARTNERS

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 FGD wastewater treatment. Through these recommendations, thermoelectric power generation secures efficient electricity production for years to come.

PRESENTER:
JESSICA MULLEN

CONTACTS:

HQ PROGRAM MANAGER
ROBIE LEWIS

TECHNOLOGY MANAGER
BRIGGS WHITE

FEDERAL PROJECT MANAGER
JESSICA MULLEN

ENGINEER/ENERGY ANALYST
ERIK SHUSTER

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.**

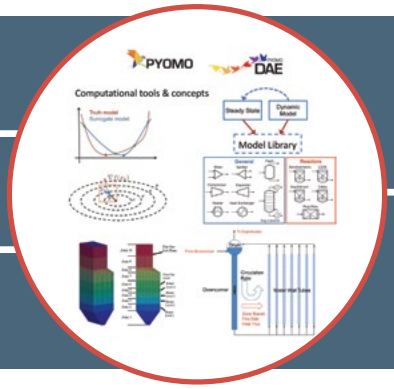
IDAES develops and utilizes multi-scale, optimization-based **computational tools** to improve the **design, analysis,** and **operation** of both the **existing fleet** and innovative, **advanced coal energy systems of the future.**

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

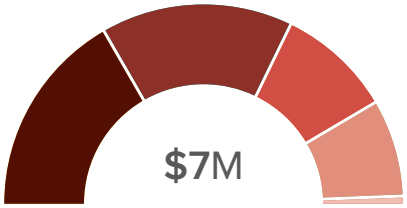
Released limited open-source software to existing stakeholders, including power producers, energy companies, chemical manufacturers, and technology developers.

QUICK FACTS

AWARD NUMBER
FWP-1022423

PROJECT BUDGET

FY18 FUNDING



SNL	$2,329,000
NETL	$2,173,860
LBNL	$1,298,940
CMU	$1,115,200
WVU	$80,000

CONTACTS

HQ PROGRAM MANAGER
BHIMA SASTRI

TECHNOLOGY MANAGER
BRIGGS WHITE

FEDERAL PROJECT MANAGER
JASON HISSAM

PRINCIPAL INVESTIGATOR
DAVID MILLER

PARTNERS

Sandia National Laboratories
BERKELEY LAB
Carnegie Mellon University
WestVirginiaUniversity

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

CONTACTS:

HQ PROGRAM MANAGER
BHIMA SASTRI

TECHNOLOGY MANAGER
BRIGGS WHITE

FEDERAL PROJECT MANAGER
JASON HISSAM

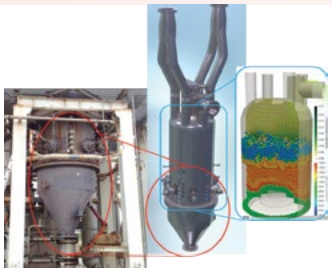
PRINCIPAL INVESTIGATOR
DAVID MILLER

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.

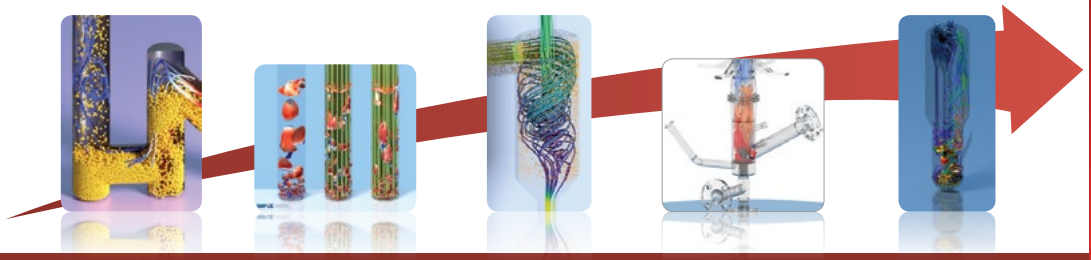
DESIGN AND OPTIMIZATION OF EFFICIENT, ROBUST, AND FLEXIBLE ENERGY SYSTEM DEVICES



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 (LBNL) 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.

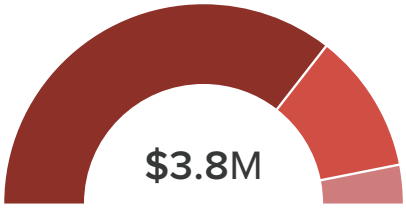
QUICK FACTS

AWARD NUMBER

DE-FE0026298
FWP-1022405

PROJECT BUDGET

DE-FE0026298



DOE	$2,857,479
CU BOULDER	$920,523
PSRI	$254,812

FWP-1022405

DOE: $2.3M

CONTACTS

HQ PROGRAM MANAGER
REGIS CONRAD

TECHNOLOGY MANAGER
BRIGGS WHITE

FEDERAL PROJECT MANAGER
JASON HISSAM

PRINCIPAL INVESTIGATOR
MADHAVA SYAMLAL
JORDAN MUSSER
WILLIAM ROGERS
CHRISTINE HRENYA

PARTNERS

University of Colorado Boulder
BERKELEY LAB
West Virginia University
B&W Babcock & Wilcox
VIRGINIA TECH.
OAK RIDGE National Laboratory
NREL
PSRI

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's relevance in tackling and solving real-world, industrial-scale problems.

PRESENTERS:
SYAM SYAMLAL and WILLIAM ROGERS

CONTACTS:

HQ PROGRAM MANAGER
REGIS CONRAD

TECHNOLOGY MANAGER
BRIGGS WHITE

FEDERAL PROJECT MANAGER
JASON HISSAM

PRINCIPAL INVESTIGATORS
MADHAVA SYAMLAL
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

CONTACTS

HQ PROGRAM MANAGERS
ROBIE LEWIS
MARGARET SCHAUS

TECHNOLOGY MANAGERS
JOHN ROCKEY
BRIGGS WHITE

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

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.

EXISTING PLANTS R&D INITIATIVE PARTNERS

ORGANIZATION CATEGORIES:

- Utility – Generator (13)
- Utility – Power Provider (1)
- Service Provider (9)
- Equipment Manufacturer (11)
- Coal Company (1)
- Research Institute (4)
- University (13)
- National Laboratory (2)

INTERNATIONAL PARTNER:
China University of Mining and Technology

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

DRAFT: 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.

PRESENTER:
GEO RICHARDS

CONTACTS:

HQ PROGRAM MANAGERS
ROBIE LEWIS
MARGARET SCHAUS

TECHNOLOGY MANAGERS
JOHN ROCKEY
BRIGGS WHITE

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

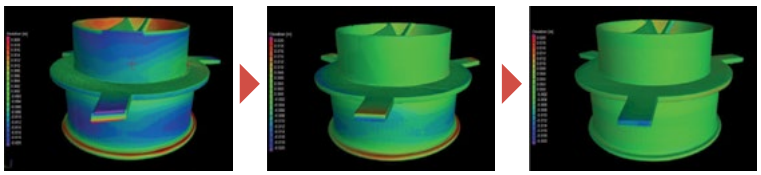
RAPID MANUFACTURING METHOD FOR HIGH-TEMPERATURE TURBINE COMPONENTS

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

HQ PROGRAM MANAGER
REGIS CONRAD

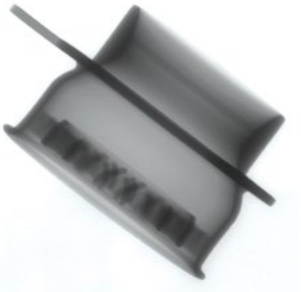
TECHNOLOGY MANAGER
RICHARD DENNIS

FEDERAL PROJECT MANAGER
PATCHARIN BURKE

PRINCIPAL INVESTIGATOR
JON MOORE

PARTNERS

MIKRO



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.

PRESENTER:
SETH LAWSON

CONTACTS:

HQ PROGRAM MANAGER
REGIS CONRAD

TECHNOLOGY MANAGER
RICHARD DENNIS

FEDERAL PROJECT MANAGER
PATCHARIN BURKE

PRINCIPAL INVESTIGATOR
JON MOORE

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) 30

Advances in Pressure Gain Combustion Turbine Systems 32

R&D Initiatives Launched for Coal Plant of the Future 34

Solid Oxide Fuel Cell Commercialization 36

Supercritical Carbon Dioxide Power Cycles 38

Testing Solid Oxide Fuel Cell (SOFC) Prototype Systems 40

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

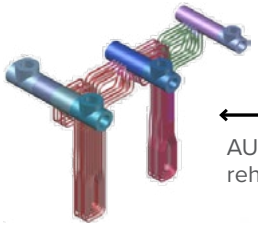
AUSC COMPONENT MANUFACTURING SCALE-UP

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.

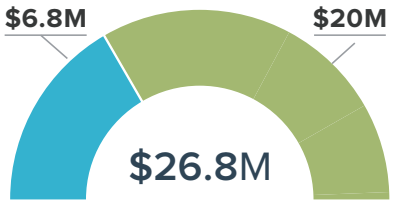
PHASE 2: CURRENT

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



- DOE
- ENERGY INDUSTRIES OF OHIO

CONTACTS

HQ PROGRAM MANAGER
REGIS CONRAD

TECHNOLOGY MANAGER
BRIGGS WHITE

FEDERAL PROJECT MANAGER
VITO CEDRO III

PRINCIPAL INVESTIGATOR
ROBERT PURGERT

PARTNERS

Energy Industries Of Ohio
EPRI ELECTRIC POWER RESEARCH INSTITUTE
ALSTOM
TE
GE
Riley Power
MetalTek INTERNATIONAL
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.

PRESENTER:
VITO CEDRO

CONTACTS:

HQ PROGRAM MANAGER
REGIS CONRAD

TECHNOLOGY MANAGER
BRIGGS WHITE

FEDERAL PROJECT MANAGER
VITO CEDRO III

PRINCIPAL INVESTIGATOR
ROBERT PURGERT

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

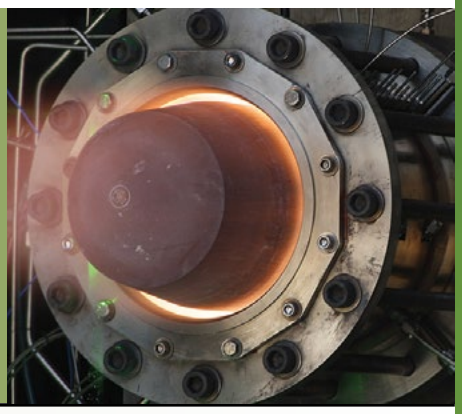
IMPROVED CYCLES, IMPROVED EFFICIENCY

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.



QUICK FACTS

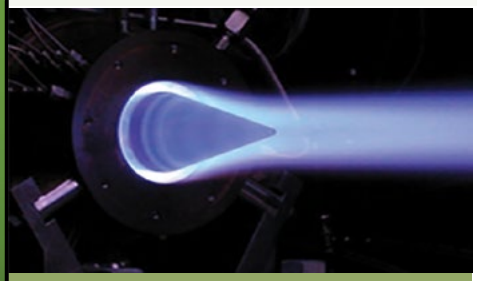
AWARD NUMBER
DE-FE0023983

PROJECT BUDGET

FY18 FUNDING

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

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.

CONTACTS

HQ PROGRAM MANAGER
REGIS CONRAD

TECHNOLOGY MANAGER
RICHARD DENNIS

FEDERAL PROJECT MANAGER
ROBIN AMES

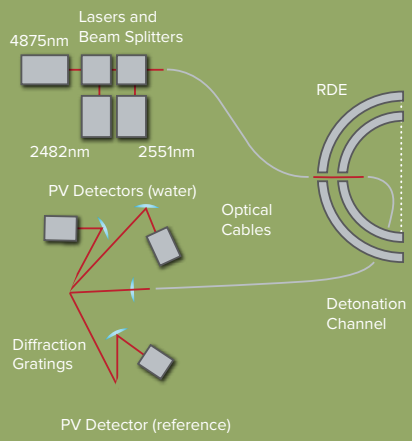
PRINCIPAL INVESTIGATOR
GLENN HAVSKJOLD

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



PARTNERS

PURDUE UNIVERSITY

THE UNIVERSITY OF ALABAMA

AEROJET ROCKETDYNE

SwRI

UCF 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:
RICHARD DENNIS and DON FERGUSON

CONTACTS:

HQ PROGRAM MANAGER
REGIS CONRAD

TECHNOLOGY MANAGER
RICHARD DENNIS

FEDERAL PROJECT MANAGER
ROBIN AMES

PRINCIPAL INVESTIGATOR
GLENN HAVSKJOLD

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

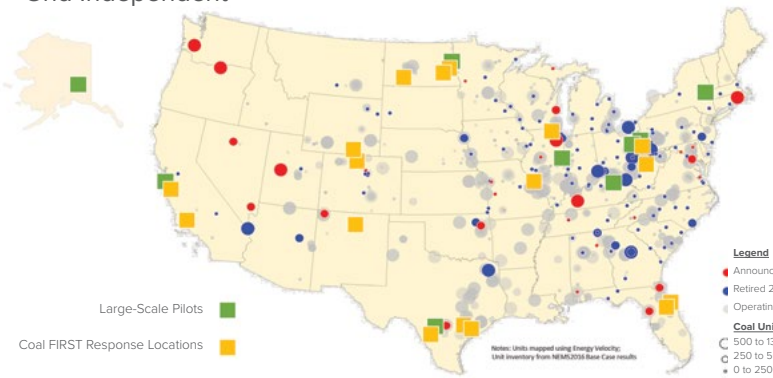
R&D INITIATIVES LAUNCHED FOR COAL PLANTS OF THE FUTURE

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.

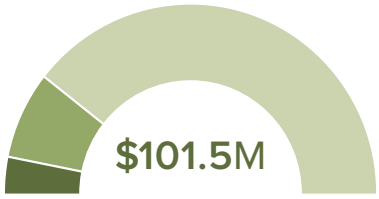
33 responses from 31 respondents were received from the Coal FIRST RFI.

QUICK FACTS

AWARD NUMBER
DE-FOA-0001788
(LARGE-SCALE PILOTS)

PROJECTED PHASE BUDGETS

(LARGE-SCALE PILOTS)



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.

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.

CONTACTS

TRANSFORMATIVE POWER GENERATION HQ PROGRAM MANAGER
MARGARET SCHAUS

TRANSFORMATIVE POWER GENERATION TECHNOLOGY MANAGER
JOHN ROCKEY

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.

PRESENTERS:
JOHN ROCKEY and GREG O'NEIL

CONTACTS:

TRANSFORMATIVE POWER GENERATION
HQ PROGRAM MANAGER
MARGARET SCHAUS

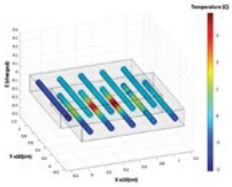
TRANSFORMATIVE POWER GENERATION
TECHNOLOGY MANAGER
JOHN ROCKEY

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

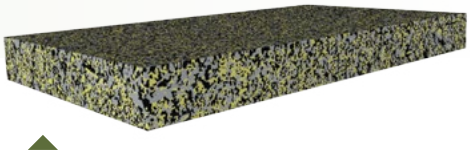
SOLID OXIDE FUEL CELL COMMERCIALIZATION

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

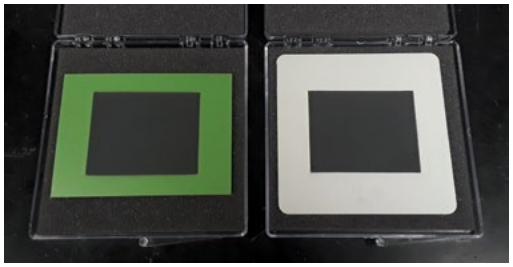
PROVING COMMERCIAL VIABILITY & SPURRING DEVELOPMENT



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.**

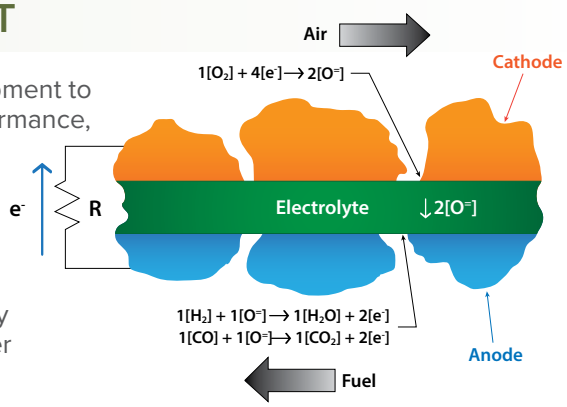
Atrex Energy constructed a 1-kW SOFC stack and evaluated for 2,000+ hours, **demonstrating higher cell performance and no**

Secretary Perry examines an 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.



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

HQ PROGRAM MANAGER
STEVEN ROSS

TECHNOLOGY MANAGER
SHAILESH VORA

FEDERAL PROJECT MANAGER
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.

PRESENTER:
GREGORY HACKETT and SHAILESH VORA

CONTACTS:

HQ PROGRAM MANAGER
STEVEN ROSS

TECHNOLOGY MANAGER
SHAILESH VORA

FEDERAL PROJECT MANAGER (TCF 1 & 2)
JAI-WOH KIM

PRINCIPAL INVESTIGATOR
GREGORY HACKETT

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

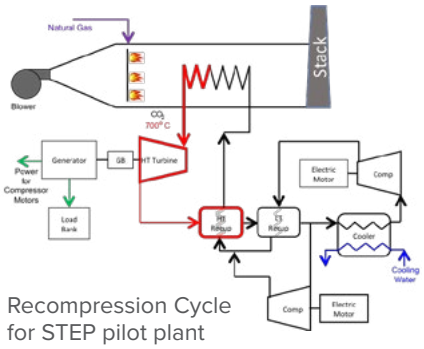
SUPERCRITICAL CARBON DIOXIDE POWER CYCLES

Advancing novel sCO_2 power cycle technologies

REVOLUTIONIZING DOMESTIC & GLOBAL POWER GENERATION

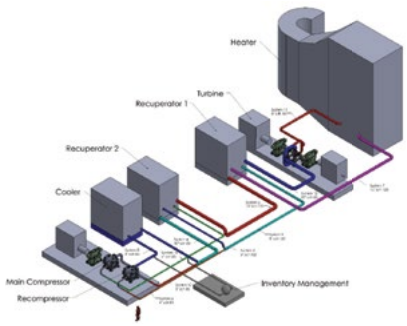
Supercritical CO_2 (sCO_2) power cycles offer the potential for power generation with **increased efficiency, lower cost of electricity, reduced costs for the customer, and reduced water consumption.**

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.

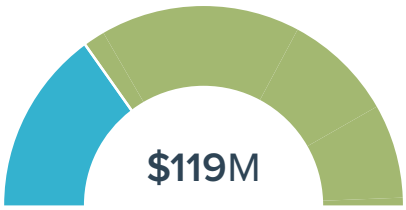
Initiated component cost collaboration amongst DOE National Labs. Pooling sCO_2 component cost quotes to improve accuracy of models and enable economics-driven plant designs.

STEP PROJECT QUICK FACTS

AWARD NUMBER
DE-FE0028979

PROJECT BUDGET

FY18 FUNDING



DOE	$84,330,971
PERFORMER	$35,138,048

CONTACTS

HQ PROGRAM MANAGER
BHIMA SASTRI

TECHNOLOGY MANAGER
RICHARD DENNIS

FEDERAL PROJECT MANAGER
ROBIN AMES

PRINCIPAL INVESTIGATOR
MICHAEL KUTIN

PARTNERS

gti®

SwRI®

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

CONTACTS:

HQ PROGRAM MANAGER
BHIMA SASTRI

TECHNOLOGY MANAGER
RICHARD DENNIS

FEDERAL PROJECT MANAGER
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.**

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

QUICK FACTS

AWARD NUMBER
DE-FE0031180

PROJECT BUDGET

FY18 FUNDING

LGFCS	$1.4M
DOE	$5.7M

CONTACTS

HQ PROGRAM MANAGER
STEVEN ROSS

TECHNOLOGY MANAGER
SHAILESH VORA

FEDERAL PROJECT MANAGER
PATCHARIN BURKE

PRINCIPAL INVESTIGATOR
CRISPIN DEBELLIS

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.

PRESENTER:
PATCHARIN (RIN) BURKE and SHAILESH VORA

CONTACTS:

HQ PROGRAM MANAGER
STEVEN ROSS

TECHNOLOGY MANAGER
SHAILESH VORA

FEDERAL PROJECT MANAGER
PATCHARIN BURKE

PRINCIPAL INVESTIGATOR
CRISPIN DEBELLIS

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 44

Advanced Membranes Lower Cost of Carbon Capture 46

Capturing CO_2 Using Less Energy at Scale 48

Catalytic Conversion of CO_2 into Value-Added Products 50

DOE's Regional Carbon Sequestration Partnerships (RCSP) Initiative 52

National Carbon Capture Center & Advanced Flash Stripper 54

National Risk Assesssment Partnership (NRAP) 56

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.

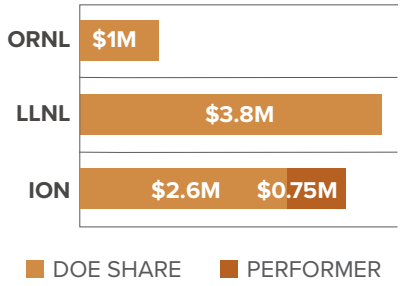
QUICK FACTS

AWARD NUMBERS

FWP-FEAA130 (ORNL)
FWP-FEW0225 (LLNL)
DE-FE0031530 (ION)

PROJECT BUDGET

FY18 FUNDING



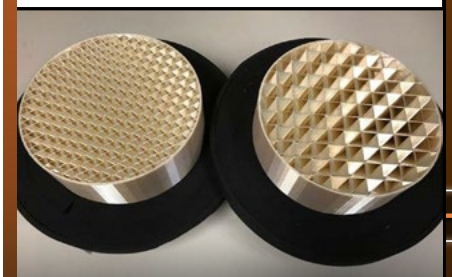
CONTACTS

HQ PROGRAM MANAGER
JOHN LITYNSKI

TECHNOLOGY MANAGER
LYNN BRICKETT

FEDERAL PROJECT MANAGERS
DAVID LANG (ORNL)
ISAAC AURELIO (LLNL)
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.

PRESENTER:
LYNN BRICKETT

CONTACTS:

HQ PROGRAM MANAGER
JOHN LITYNSKI

TECHNOLOGY MANAGER
LYNN BRICKETT

FEDERAL PROJECT MANAGERS
DAVID LANG (ORNL)
ISAAC AURELIO (LLNL)
STEVEN MASCARO (ION)

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

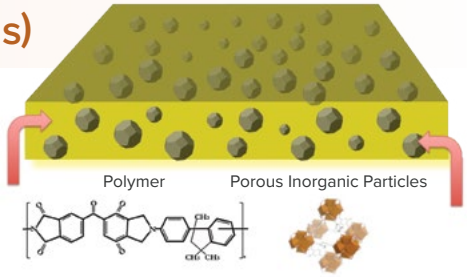
REDUCING THE COST OF CAPTURED CARBON AND PUTTING IT TO WORK FOR AMERICA

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.**



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

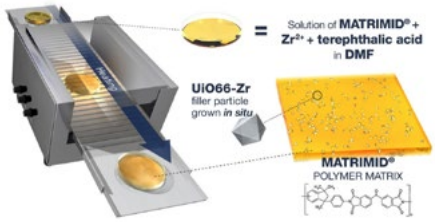
NETL analyses have shown that **materials with extremely high permeability are needed** to make membrane technology an economically viable option.

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.



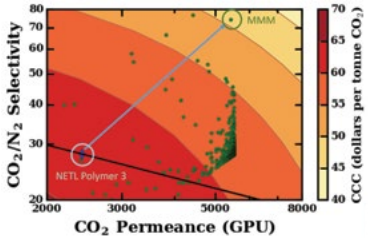
In-situ MOF growth is a possible scheme for **reducing steps for membrane scale-up.** NETL is now partnered with a commercial membrane manufacturer to **prove the scalability** of NETL's MMMs.

QUICK FACTS

AWARD NUMBER
FWP-1022402

PROJECT BUDGET

FY18 VALUE
$326,000



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).

CONTACTS

HQ PROGRAM MANAGER
JOHN LITYNSKI

TECHNOLOGY MANAGER
LYNN BRICKETT

TECHNICAL PORTFOLIO LEAD
DAVID HOPKINSON

PRINCIPAL INVESTIGATORS
DAVID HOPKINSON & JAN STECKEL

PARTNERS

NATIONAL CARBON CAPTURE CENTER
University of Pittsburgh
CCSI²
Carbon Capture Simulation for Industry Impact
NETL - Penn State
PennState
University Coalition for Fossil Energy Research

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.

PRESENTER:
DAVID HOPKINSON

CONTACTS:

HQ PROGRAM MANAGER
JOHN LITYNSKI

TECHNOLOGY MANAGER
LYNN BRICKETT

TECHNICAL PORTFOLIO LEAD
DAVID HOPKINSON

PRINCIPAL INVESTIGATORS
DAVID HOPKINSON
JAN STECKEL

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

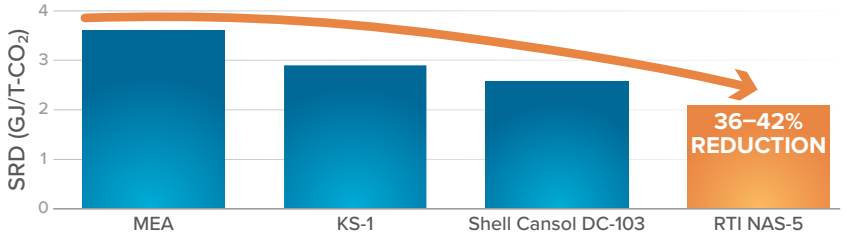
RTI's **water-lean solvent-based CO_2 capture process using coal-fired flue gas moves closer to commercialization** through testing completed at the National Carbon Capture Center and SINTEF's Tiller plant by:

- 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.

SPECIFIC REBOILER DUTY COMPARISON



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

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

arpa·e CHANGING WHAT'S POSSIBLE · BASF

FUNDING: ~$2,700,000

- Solvent screening to identify promising solvent formulations
- Lab-scale evaluation of NAS process
- Preliminary technical and economic assessments

LARGE BENCH-SCALE SYSTEM/ RELEVANT ENVIRONMENT TESTING

NETL · THE LINDE GROUP · SINTEF

FUNDING: ~$3,000,000

- Finalize NAS formulation
- Develop critical process components
- Demonstrate ≤2.0 GJ/T-CO_2 using bench-scale system
- Detailed solvent degradation studies and techno-economic analysis
- Demonstrate T&EA competitiveness and environmental permitability

COMBINED SINTEF (TILLER)

NETL · THE LINDE GROUP · SINTEF · GASSNOVA

FUNDING: ~$2,700,000

- Tiller Plant (~60 kWe)
  - Demonstrate all NAS process components
  - Quantify solvent losses and emissions
  - Test using coal-derived flue gas
  - Determine materials compatibility
  - Collect critical process data to support scale-up

TCM PATHWAY LARGE PILOT EVALUATION

CO_2 TECHNOLOGY CENTRE MONGSTAD

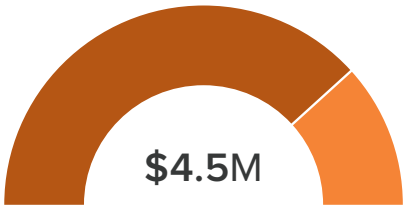
- TCM (~10 MWe)
  - Complete process unit with components at minimum size for confident scale-up
  - Collect critical process information to support detailed techno-economic assessment, emissions monitoring, and long-term testing to develop reliability, availability and maintainability metrics

QUICK FACTS

AWARD NUMBER
DE-FE0026466

PROJECT BUDGET

FY18 FUNDING



FEDERAL	$3,468,584
RTI INTERNATIONAL	$1,064,068

CONTACTS

HQ PROGRAM MANAGER
JOHN LITYNSKI

TECHNOLOGY MANAGER
LYNN BRICKETT

FEDERAL PROJECT MANAGER
STEVEN MASCARO

PRINCIPAL INVESTIGATOR
JIM ZHOU

PARTNERS

RTI INTERNATIONAL · THE LINDE GROUP · SINTEF · CO_2 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.

PRESENTER:
STEVE MASCARO

CONTACTS:

HQ PROGRAM MANAGER
JOHN LITYNSKI

TECHNOLOGY MANAGER
LYNN BRICKETT

FEDERAL PROJECT MANAGER
STEVEN MASCARO

PRINCIPAL INVESTIGATOR
JIM ZHOU

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.**

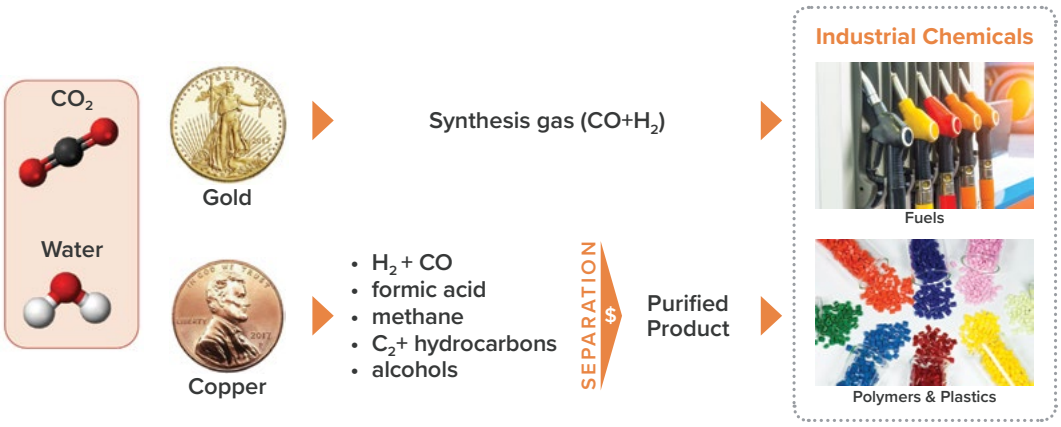
CARBON USE & REUSE BENEFITS:

- 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



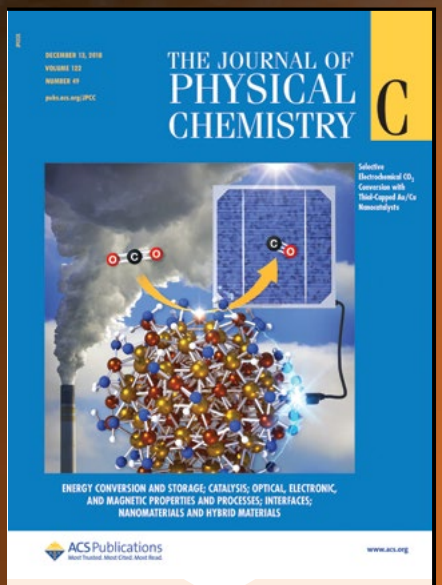
NOVEL APPROACHES FOR CATALYST DESIGN

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.



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.

QUICK FACTS

AWARD NUMBER
FWP-1022426

PROJECT BUDGET

TOTAL AWARD VALUE
$1,246,000

CONTACTS

HQ PROGRAM MANAGER
JOHN LITYNSKI

TECHNOLOGY MANAGER
LYNN BRICKETT

PRINCIPAL INVESTIGATOR
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.

PRESENTER:
DOUG KAUFFMAN

CONTACTS:

HQ PROGRAM MANAGER
JOHN LITYNSKI

TECHNOLOGY MANAGER
LYNN BRICKETT

PRINCIPAL INVESTIGATOR
DOUGLAS KAUFFMAN

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

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

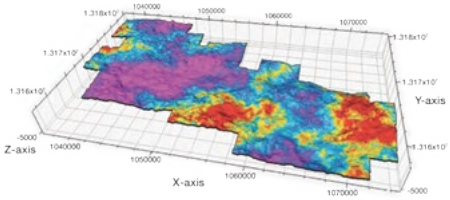
CarbonSAFE COORDINATOR
MARY SULLIVAN

IMPROVED ENERGY INDEPENDENCE

Technologies developed have helped Enhanced Oil Recovery (EOR) efforts

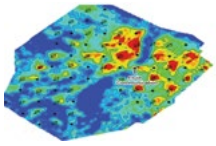
- Additional ~2.4M bbl oil recovered during three EOR injections where 4.8 MMT CO_2 were stored
- Advanced understanding of subsurface fluid migration during storage of CO_2 associated with EOR
- Developed and tested technologies that manage risk in the subsurface and plume control by geo-steering fluids

SOUTHWEST PARTNERSHIP



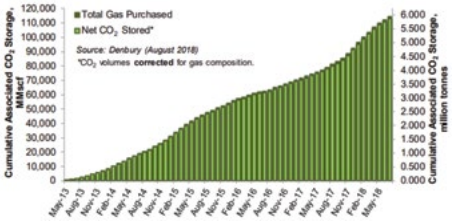
Fluid flow and transport simulations improve oil reservoir understanding

BELL CREEK ASSOCIATED STORAGE



CO_2 plume relative to injection and recovery wells during EOR

BELL CREEK ASSOCIATED STORAGE EOR



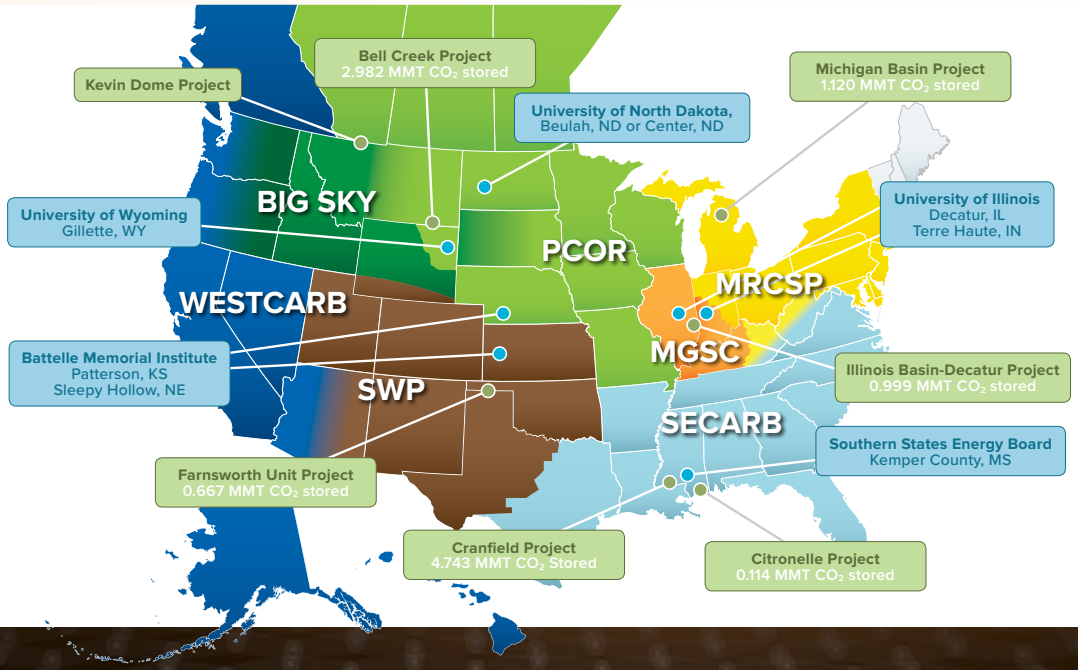
15 MMT CO_2 potential storage resource through EOR

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



DOE'S 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:
BILL ALJOE and MARY SULLIVAN

CONTACTS:

HQ PROGRAM MANAGER
DARIN DAMIANI

TECHNOLOGY MANAGER
TRACI RODOSTA

FEDERAL PROJECT MANAGER
WILLIAM ALJOE

PRINCIPAL INVESTIGATOR
MARY SULLIVAN

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

NATIONAL CARBON CAPTURE CENTER

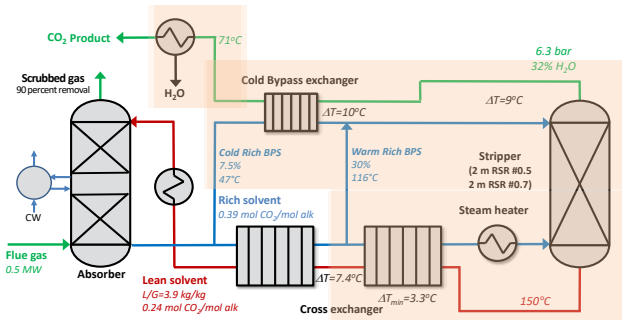
The NCCC operates existing facilities to offer **third-party technology evaluation that addresses environmental, health and safety, operational, component, and system development issues** while collaborating with technology developers.

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.**

QUICK FACTS

AWARD NUMBER

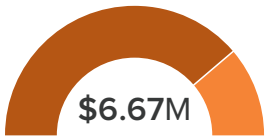
DE-FE0022596 (NCCC)
DE-FE0005654 (AFS)

PROJECT BUDGETS

NCCC

DOE $149,999,941
SOUTHERN $37,499,986

AFS



DOE $5,174,984
URS $1,494,142

CONTACTS

HQ PROGRAM MANAGER
JOHN LITYNSKI

TECHNOLOGY MANAGER
LYNN BRICKETT

FEDERAL PROJECT MANAGERS
ANDREW O'PALKO (NCCC)
BRUCE LANI (AFS)

PRINCIPAL INVESTIGATORS
JOHN NORTHINGTON (NCCC)
WILLIAM STEEN (AFS)

PARTNERS

Southern Company

Trimeric Corporation

URS

TEXAS
The University of Texas at Austin

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.

PRESENTER:
ANDY O'PALKO

CONTACTS:

HQ PROGRAM MANAGER
JOHN LITYNSKI

TECHNOLOGY MANAGER
LYNN BRICKETT

FEDERAL PROJECT MANAGERS
ANDREW O'PALKO (NCCC)
BRUCE LANI (AFS)

PRINCIPAL INVESTIGATORS
JOHN NORTHINGTON (NCCC)
WILLIAM STEEN (AFS)

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

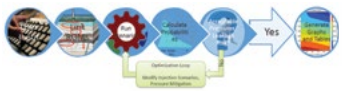
QUANTIFYING RISK FOR GEOLOGIC SYSTEMS

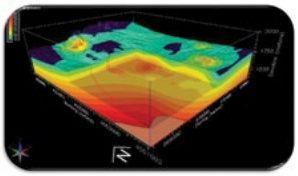
NRAP is a multi-national laboratory collaborative research project focused on understanding potential environmental risks at geologic CO_2 storage sites. Demonstrating that these risks can be quantified and managed removes barriers to full-scale technology implementation.

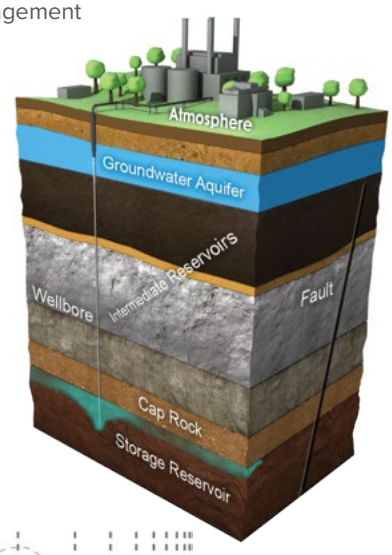
INFORMING DECISION-MAKING FOR THE SUBSURFACE

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

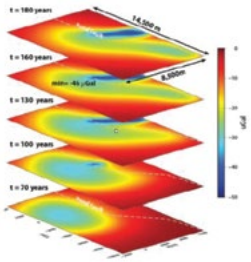
Workflow and tools for risk management and uncertainty reduction



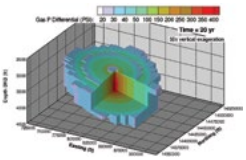


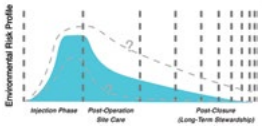


Enabling risk-based strategic monitoring design

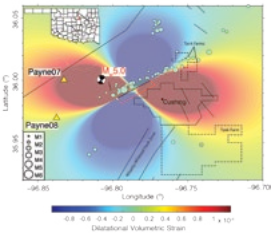


Quantifying risk and uncertainty with field-validated tools





Developing protocols to minimize ground motion



REMOVING BARRIERS TO CO_2 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.

QUICK FACTS

AWARD NUMBER
FWP-2012.04.03

PROJECT BUDGET

AWARD VLAUE
$26,757,000

NRAP's software won the 2017 R&D 100 Award, considered the "Oscars of innovation."

NRAP's award-winning tools are available at: edx.netl.doe.gov/nrap

CONTACTS

HQ PROGRAM MANAGER
DARIN DAMIANI

TECHNOLOGY MANAGER
TRACI RODOSTA

FEDERAL PROJECT MANAGER
M. KYLEE UNDERWOOD

PRINCIPAL INVESTIGATOR
ROBERT DILMORE

PARTNERS

NATIONAL RISK ASSESSSMENT 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.

PRESENTER:
ROBERT DILMORE

CONTACTS:

HQ PROGRAM MANAGER
DARIN DAMIANI

TECHNOLOGY MANAGER
TRACI RODOSTA

FEDERAL PROJECT MANAGER
GRANT BROMHAL

PRINCIPAL INVESTIGATOR
ROBERT DILMORE

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 60

Extracting Rare Earth Elements Affordably and Efficiently 62

Petra Nova & Enhanced Oil Recovery 64

Rare Earth Elements & Critical Materials 66

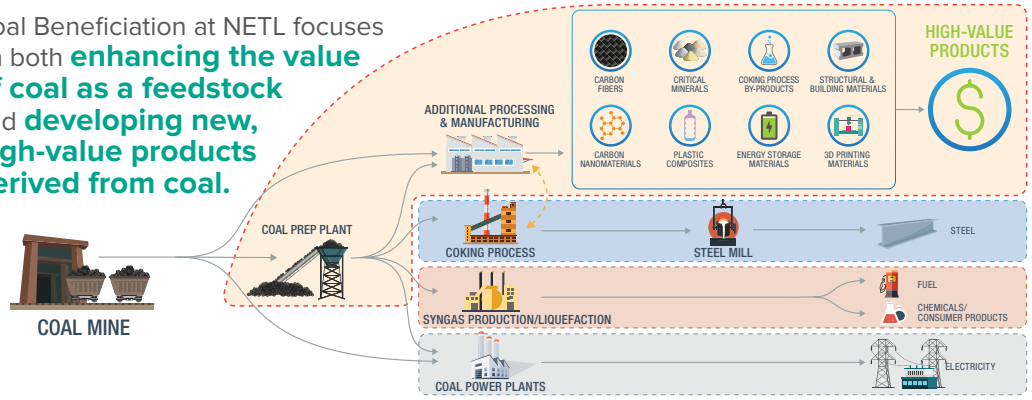
Upcycling CO_2 in a Novel Concrete 68

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

HQ PROGRAM MANAGER
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

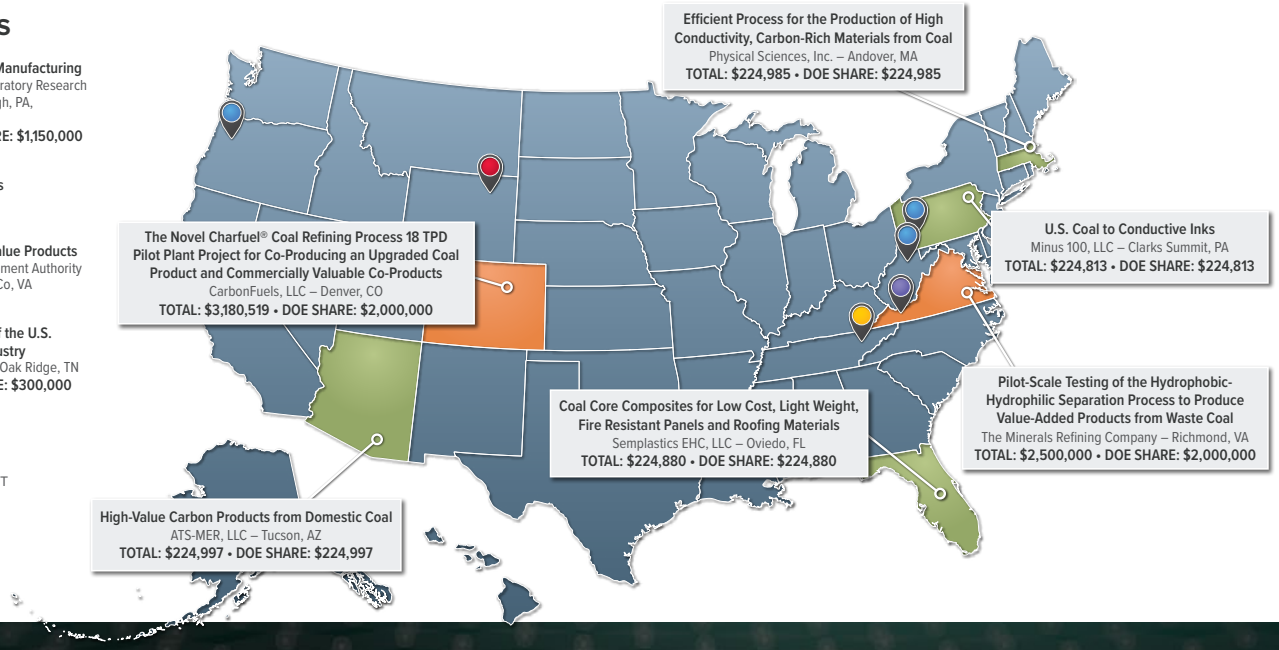
Converting Coal into Carbon Nanomaterials and Composites
Ramaco Carbon – Sheridan, WY
Public-private partnership

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



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

CONTACTS:

HQ PROGRAM MANAGER
REGIS CONRAD

TECHNOLOGY MANAGER
JOHN ROCKEY

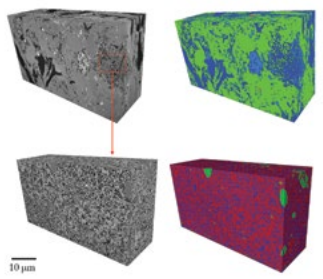
TECHNICAL PORTFOLIO LEAD
CHRISTOPHER MATRANGA

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.

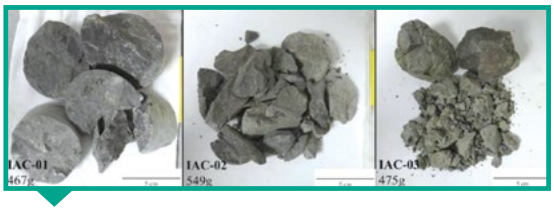
These extremely mild solvents have been tailored **to only extract easily accessible REEs, leaving most of the source material intact.** This ultimately leads to lower costs and less material to process.

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

HQ PROGRAM MANAGER
REGIS CONRAD

TECHNOLOGY MANAGER
MARY ANNE ALVIN

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.

PRESENTER:
THOMAS TARKA

CONTACTS:

HQ PROGRAM MANAGER
REGIS CONRAD

TECHNOLOGY MANAGER
MARY ANNE ALVIN

FEDERAL PROJECT MANAGER
THOMAS TARKA

PRINCIPAL INVESTIGATOR
CIRCE VERBA

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 **300 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.

QUICK FACTS

AWARD NUMBER
DE-FE0003311

PROJECT BUDGET

FY18 FUNDING

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

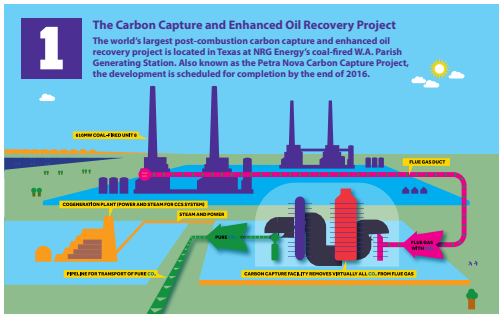
CONTACTS

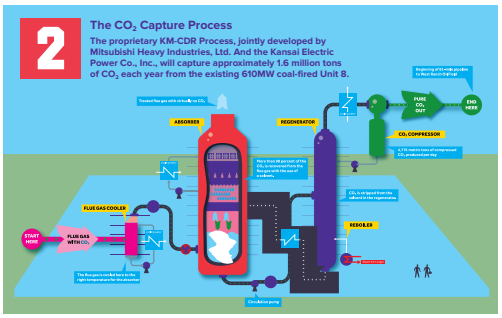
HQ PROGRAM MANAGER
ANDREW HLAKSO

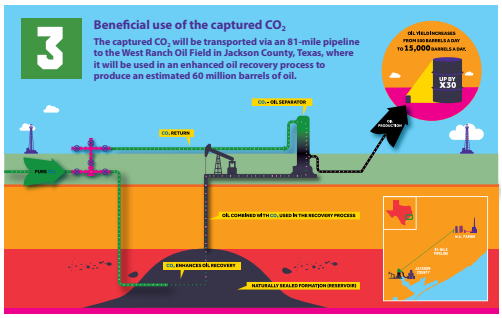
BUSINESS OFFICER
DEVON STONITSCH

FEDERAL PROJECT MANAGER
SAI GOLLAKOTA

PRINCIPAL INVESTIGATOR
GREG KENNEDY







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**. West Ranch Oil Field has also produced over 2 million barrels of oil through EOR.

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.

PARTNERS

Hilcorp

nrg

JX

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.

PRESENTER:
SAI GOLLAKOTA

CONTACTS:

HQ PROGRAM MANAGER
ANDREW HLAKSO
BUSINESS OFFICER
DEVON STONITSCH

FEDERAL PROJECT MANAGER
SAI GOLLAKOTA

PRINCIPAL INVESTIGATOR
GREG KENNEDY

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)

QUICK FACTS

AWARD NUMBER
DE-FE0027035 (UK)
DE-FE0026927 (WVU)

PROJECT BUDGET

UK TOTAL AWARD VALUE
$8,820,009

WVU TOTAL AWARD VALUE
$4,339,414

CONTACTS

HQ PROGRAM MANAGER
REGIS CONRAD

TECHNOLOGY MANAGER
MARY ANNE ALVIN

FEDERAL PROJECT MANAGERS
CHARLES E. MILLER (UK)
JESSICA MULLEN (WVU)

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

PARTNERS

West Virginia University
Blackhawk Mining, LLC
Tetra Tech
Mineral Separation Technologies
MRC Minerals Refining Company
Alliance Resource Partners, L.P.
Virginia Tech
Tetra Tech
Rockwell Automation

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.

PRESENTER:
MARY ANNE ALVIN

CONTACTS:

HQ PROGRAM MANAGER
REGIS CONRAD

TECHNOLOGY MANAGER
MARY ANNE ALVIN

FEDERAL PROJECT MANAGERS
CHARLES E. MILLER (UK)
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

UPCYCLING PROCESS OUTCOME

Basic oxygen furnace slag

Co-mingled steel slag

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

$1.35M

DOE	$1,000,000
UCLA	$350,000

CONTACTS

HQ PROGRAM MANAGER
JOHN LITYNSKI

TECHNOLOGY MANAGER
LYNN BRICKETT

FEDERAL PROJECT MANAGER
ANDREW JONES

PRINCIPAL INVESTIGATOR
GAURAV N. SANT

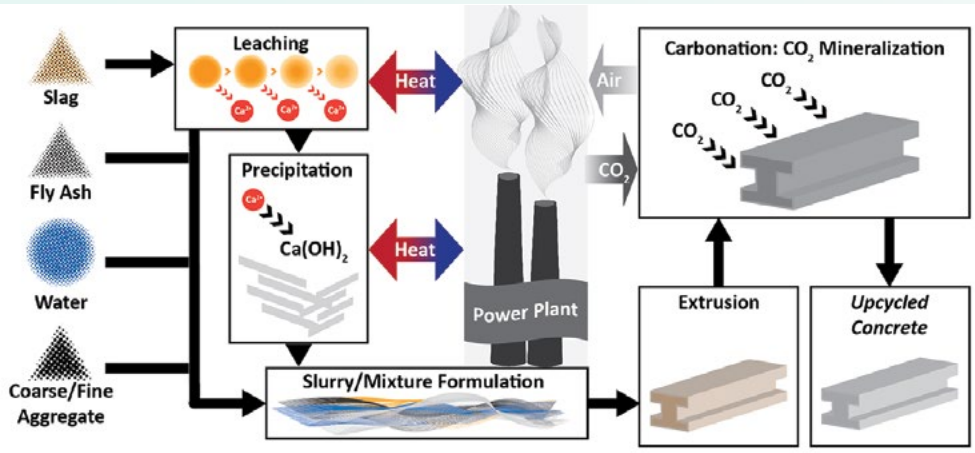
PARTNERS

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.

PRESENTER:
ANDY JONES

CONTACTS:

HQ PROGRAM MANAGER
JOHN LITYNSKI

TECHNOLOGY MANAGER
LYNN BRICKETT

FEDERAL PROJECT MANAGER
ANDREW JONES

PRINCIPAL INVESTIGATOR
GAURAV N. SANT

CREATING NEW JOBS, PRODUCTS, AND MARKETS FOR COAL

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

ACCOMPLISHMENTS POSTERS:

Advanced Stimulation to Increase Resource Recovery 72

DOE National Lab Partnership Advances Resource Recovery 74

Expanding Resource Recovery in Alaska 76

Exploring the Subsurface with 3D Imaging Technology 78

A Knowledge Management (KM) Tool for the Shale Community 80

The Mid-Atlantic Resource Imaging Experiment (MATRIX) 82

Monitoring Seismicity at Hydraulic Fracturing and CO_2 EOR Sites 84

Pioneering Integrated Tools for Optimized Resource Management 86

Offshore Risk Modeling Suite 88

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.**

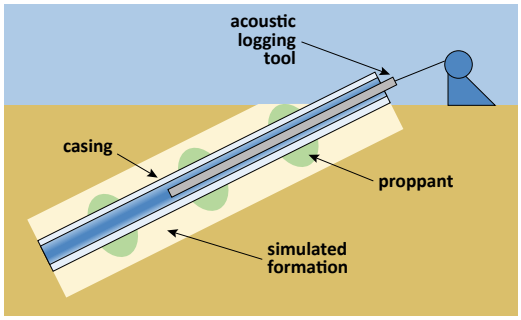
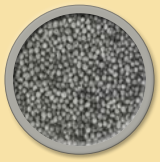


Illustration of Phase I field testing setup



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

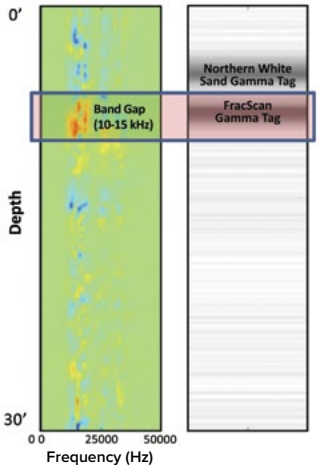
PROJECT OBJECTIVES

- 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

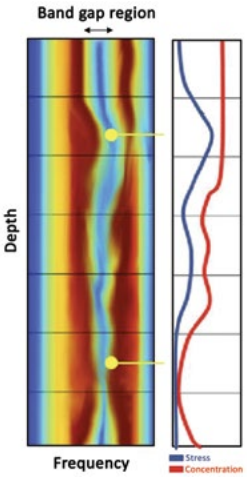
- Added at low concentrations (1–10%)
- Detected with standard acoustic logging tools
- Low-cost raw materials and production methods
- High-resolution propped fracture measurements
- Stress-dependent acoustic response
- Adaptable acoustic properties for tracer applications

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.



QUICK FACTS

AWARD NUMBER
DE-SC0017738

PROJECT BUDGET

$1,725,000

CONTACTS

HQ PROGRAM MANAGER
ELENA MELCHERT

TECHNOLOGY MANAGER
JARED CIFERNO

FEDERAL PROJECT MANAGER
STEPHEN HENRY

PRINCIPAL INVESTIGATOR
JACOB POLLOCK

PARTNER

oceanit
innovation through engineering & scientific excellence

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.

PRESENTER:
WILLIAM FINCHAM

CONTACTS:

HQ PROGRAM MANAGER
ELENA MELCHERT

TECHNOLOGY MANAGER
JARED CIFERNO

FEDERAL PROJECT MANAGER
STEPHEN HENRY

PRINCIPAL INVESTIGATOR
JACOB POLLOCK

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

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.**

QUICK FACTS

AWARD NUMBER

FWP-ESD14084
FWP-ESD14085
FWP-ESD14089

PROJECT BUDGET

TOTAL ACROSS ALL PROJECTS

$2,790,000

CONTACTS

HQ PROGRAM MANAGER
ELENA MELCHERT

TECHNOLOGY MANAGER
JARED CIFERNO

FEDERAL PROJECT MANAGER
STEPHEN HENRY

PRINCIPAL INVESTIGATORS
SEIJI NAKAGAWA
TETSU TOKUNAGA
GEORGE MORIDIS

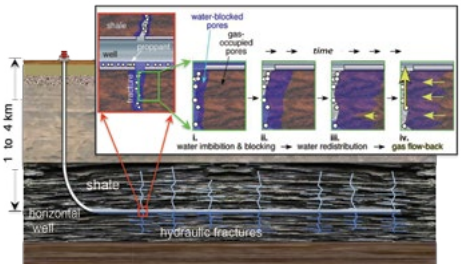
PARTNERS

BERKELEY LAB

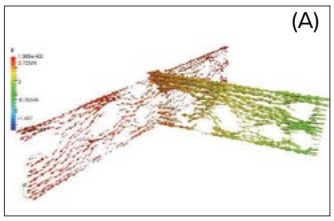
EARTH & ENVIRONMENTAL SCIENCES

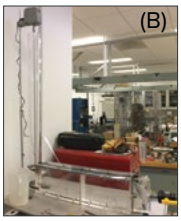
ADVANCING SUBSURFACE PHYSICAL PROCESSES

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

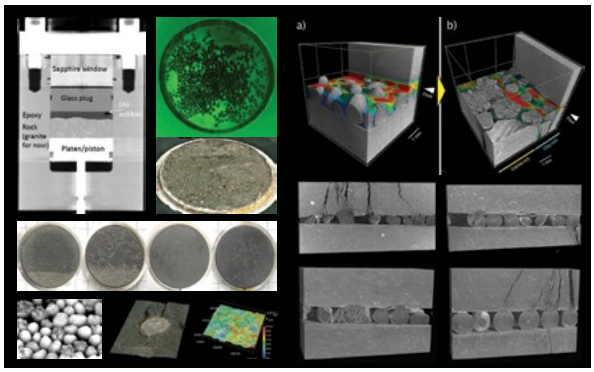




Simulation of the fluid flow and proppant transport model with proppants represented as void space (A) and picture of the lab proppant transport visualization system (B)

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.

PRESENTER:
STEPHEN HENRY and JARED CIFERNO

CONTACTS:

HQ PROGRAM MANAGER
ELENA MELCHERT

TECHNOLOGY MANAGER
JARED CIFERNO

FEDERAL PROJECT MANAGER
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 RESERVES

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.

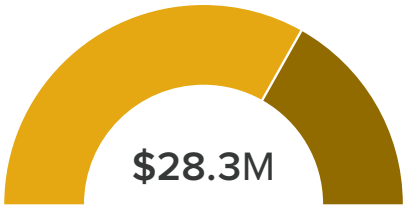
QUICK FACTS

AWARD NUMBERS

PRA: DE-FE0025387
UAF: DE-FE0031606

PROJECT BUDGET

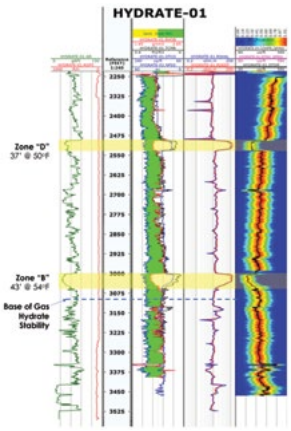
FY18 FUNDING



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

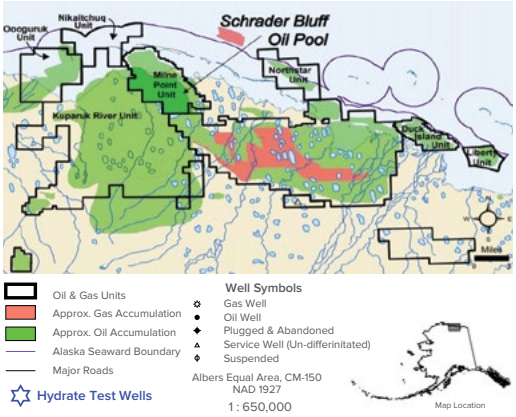
ORIGINATING DATA TO IMPROVE ARCTIC ENERGY PRODUCTION

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.



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)

CONTACTS

HQ PROGRAM MANAGER
GABBY INTIHAR

TECHNOLOGY MANAGER
JARED CIFERNO

FEDERAL PROJECT MANAGERS
PRA: SKIP PRATT
UAF: DAVID CERCONE

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

PARTNERS

PRA Petrotechnical Resources Alaska
UAF University of Alaska Fairbanks
USGS science for a changing world
Missouri S&T
bp
UND University of North Dakota
New Mexico Tech
JOGMEC
Hilcorp

EXPANDING RESOURCE RECOVERY IN ALASKA

Over the last several years, an international partnership composed of NETL, JOGMEC, Petrotechnical Resources of Alaska, and the USGS formed with an ultimate focus on investigating the behavior of a high-saturation gas hydrate reservoir through a long-term production test using Alaska's North Slope as a natural laboratory with intent to yield valuable new insights into the resource potential of natural gas hydrates. In December 2018, the team drilled an initial test well within the Prudhoe Bay Unit on the Alaska North Slope to confirm reservoir occurrence and to condition and inform planning for a longer-term test. The well was highly successful in the collection of key logging 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 pressure monitoring fiber optics. This initial success sets the stage for the longer-term gas hydrate production test to validate the stability, producibility, and sustainability of gas hydrates resources.

The Alaska North Slope Field Laboratory, operated by 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 will develop a methodology to improve recovery of heavy oils in sensitive environments that are not best suited for thermal and miscible recovery methods. This project will also provide a mechanism to improve the underutilized capacity of Trans-Alaska Pipeline System and improve the energy security of the North Slope's major oil producers, the State of Alaska, U.S. DOE, and the Nation.

PRESENTERS:
DAVID CERCONE and RICHARD BAKER

CONTACTS:

HQ PROGRAM MANAGER
GABBY INTIHAR

TECHNOLOGY MANAGER
JARED CIFERNO

FEDERAL PROJECT MANAGERS
PRA: SKIP PRATT
UAF: DAVID CERCONE

PRINCIPAL INVESTIGATORS
PRA: ROBERT HUNTER
UAF :ABHIJIT DANDEKAR and YIN ZHANG

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

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

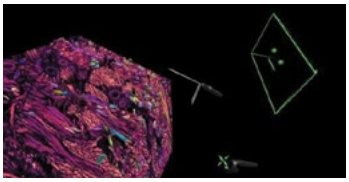
Industrial CT

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

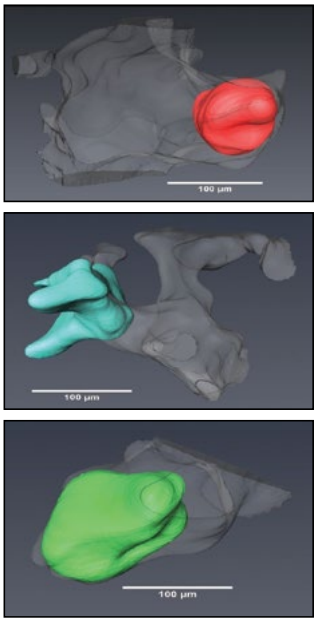
In-Situ Multiphase Flow Characterization

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

Traditional experimental approaches have used simple geometries, limiting θ measurements to a single 2D image of droplets. More recent developments utilize **CT scans** to provide the resolutions necessary to image *in situ* θ 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

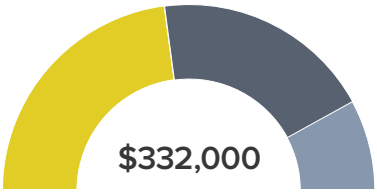
In 2018 **over 2,000 feet of core** has been scanned, processed, and made available to the scientific community on the Energy Data eXchange (EDX) to download, analyze, and expand upon.



Trapped droplets of super-critical CO_2 inside of rock pores

PROJECT BUDGET

FY18 TOTAL AWARDED



COAL	$152,000
OIL & GAS	$127,000
OFFICE OF SCIENCE	$53,000

CONTACTS

HQ PROGRAM MANAGERS
DARIN DAMIANI
ELENA MELCHERT

TECHNOLOGY MANAGERS
TRACI RODOSTA
JARED CIFERNO

TECHNOLOGY PORTFOLIO LEADS
ANGELA GOODMAN
ALEXANDRA 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.

PRESENTER:
DUSTIN CRANDALL

CONTACTS:

HQ PROGRAM MANAGERS
DARIN DAMIANI
ELENA MELCHERT

TECHNOLOGY MANAGERS
TRACI RODOSTA
JARED CIFERNO

TECHNOLOGY PORTFOLIO LEADS
ANGELA GOODMAN
ALEXANDRA HAKALA

PRINCIPAL INVESTIGATOR
DUSTIN CRANDALL

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

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

Why Knowledge Management Matters:

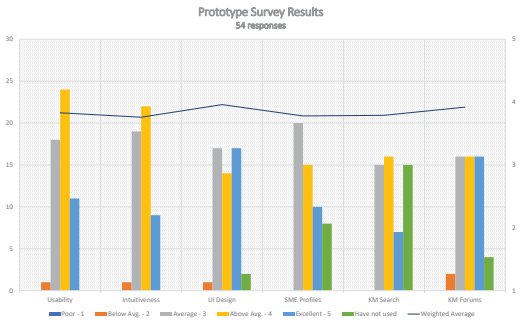
- **Millions** in lost productivity annually because of **inefficient** knowledge sharing
- U.S. workers **waste** an average of 5 hours every week **waiting** for vital information from their colleagues or **recreating** existing institutional knowledge
- 42% of institutional knowledge is acquired specifically 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

Knowledge Management

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



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**

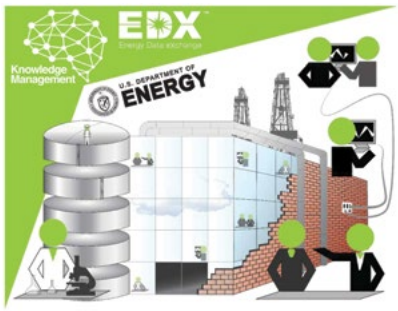
...increase the impact **and adoption of new technologies (e.g., Machine Learning)**

...**capture, share,** and **apply** expertise **across the FE complex**

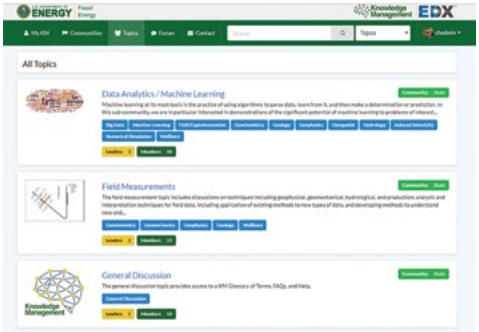
...provide best practices **and lessons learned for current and future FE community users**

...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

Idaho National Laboratory
BERKELEY LAB
Lawrence Livermore National Laboratory
Pacific Northwest NATIONAL LABORATORY
Los Alamos NATIONAL LABORATORY
OAK RIDGE National Laboratory
SLAC NATIONAL ACCELERATOR LABORATORY
Sandia National Laboratories

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:
KELLY ROSE

CONTACTS:

HQ PROGRAM MANAGER
JOHN LITYNSKI

TECHNOLOGY MANAGER
LYNN BRICKETT

FEDERAL PROJECT MANAGER
DAVID HOPKINSON

PRINCIPAL INVESTIGATORS
DAVID HOPKINSON
JAN STECKEL

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

THE MID-ATLANTIC RESOURCE IMAGING EXPERIMENT (MATRIX)

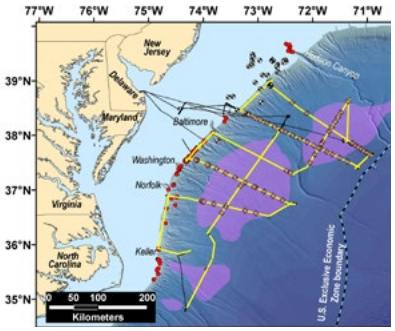
A regional-scale research expedition has collected more than 2,000 kilometers of marine seismic data, advancing scientists' understanding of gas hydrate deposits in the Mid-Atlantic Margin.

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.**

QUICK FACTS

AWARD NUMBER
DE-FE0023495

PROJECT BUDGET

TOTAL AWARD VALUE
$502,021

CONTACTS

HQ PROGRAM MANAGER
GABBY INTIHAR

TECHNOLOGY MANAGER
JARED CIFERNO

FEDERAL PROJECT MANAGER
SKIP PRATT

PRINCIPAL INVESTIGATOR
CAROLYN RUPPEL

PARTNERS

BOEM
Bureau of Ocean Energy Management

USGS

University of Delaware

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.

PRESENTER:
SKIP PRATT

CONTACTS:

HQ PROGRAM MANAGER
GABBY INTIHAR

TECHNOLOGY MANAGER
JARED CIFERNO

FEDERAL PROJECT MANAGER
SKIP PRATT

PRINCIPAL INVESTIGATOR
CAROLYN RUPPEL

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

MONITORING SEISMICITY AT HYDRAULIC FRACTURING AND CO_2 EOR SITES

Detecting seismic events using broadband seismometers on the surface and by geophones and distributed acoustic sensing (DAS) cables in the subsurface

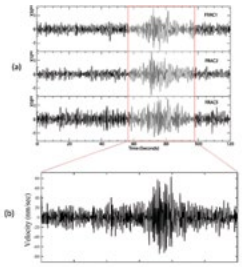
CAPTURING LPLD EVENTS IN SEISMIC DATA INTERPRETATION

Obtaining more reservoir information from the seismic data already collected.

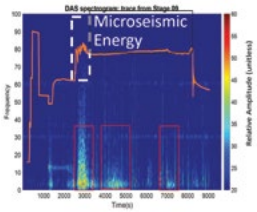
Analyzing the entire seismic waveform allows:

- 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

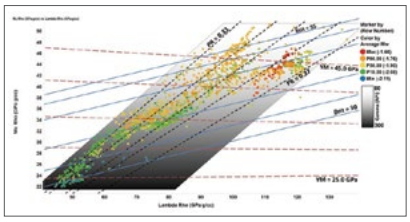


Distributed Acoustic Sensing

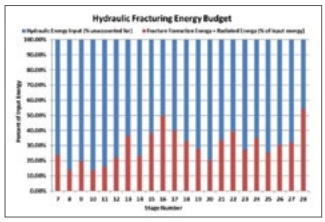
MICROSEISMIC MONITORING IS NOT ENOUGH

Traditional monitoring does not:

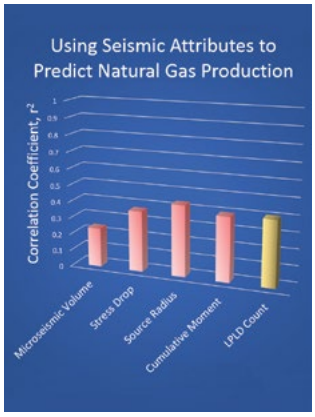
- Account for all injection energy
- Detect tensile rock failure
- Detect plastic deformation
- Detect bedding plane slip
- Predict hydrocarbon production



Λρ and Μρ inversion to identify lithology and fluid composition



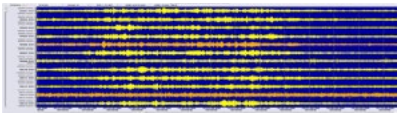
LPLD data is not currently represented



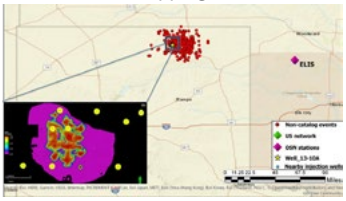
LPLD data adds to the understanding of the frac stage operation

IMPROVING MONITORING TO MAXIMIZE RESOURCE RECOVERY

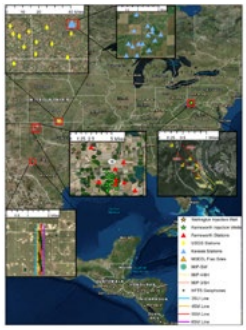
Observed an 8-min.-long LPLD event at a CO_2 EOR location



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

HQ PROGRAM MANAGER
DAREN DAMIANI

TECHNOLOGY MANAGER
TRACI RODOSTA

TECHNICAL PORTFOLIO LEAD
ANGELA GOODMAN

PRINCIPAL INVESTIGATOR
RICHARD HAMMACK

FY18 ONSHORE UNC
$312,000

HQ PROGRAM MANAGER
ELENA MELCHERT

TECHNOLOGY MANAGER
JARED CIFERNO

TECHNICAL PORTFOLIO LEAD
ALEXANDRA HAKALA

PRINCIPAL INVESTIGATOR
RICHARD HAMMACK

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 natural energy
Battelle
SWP
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.

PRESENTER:
ABHASH KUMAR

CONTACTS:

HQ PROGRAM MANAGER
DAREN DAMIANI

TECHNOLOGY MANAGER
TRACI RODOSTA

FEDERAL PROJECT MANAGER
ANGELA GOODMAN

PRINCIPAL INVESTIGATOR
RICHARD HAMMACK

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

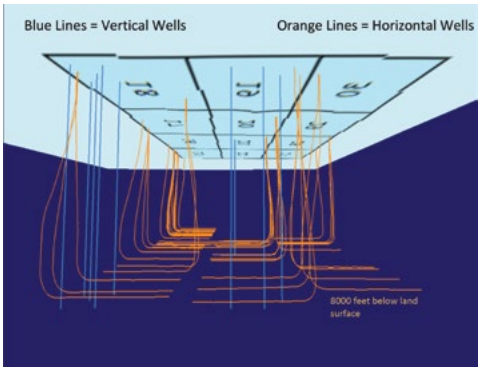
PIONEERING INTEGRATED TOOLS FOR OPTIMIZED RESOURCE MANAGEMENT

Powerful analytical tools provide effective state-level energy resources management

FACILITATING EFFICIENT RESOURCE DEVELOPMENT

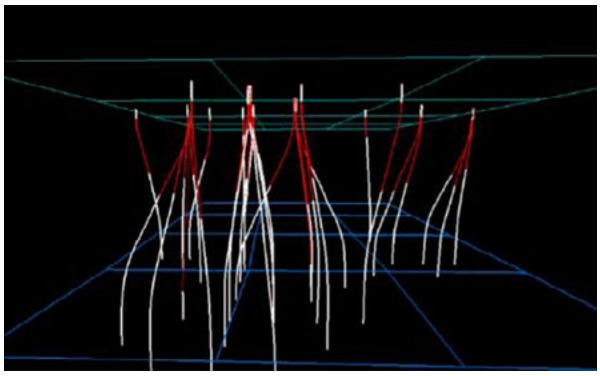
The Risk-Based Data Management System (RBDMS) is a suite of integrated software products that **allows state agencies to oversee and manage oil, gas, and Underground Injection Control (UIC) facilities and activities.**

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

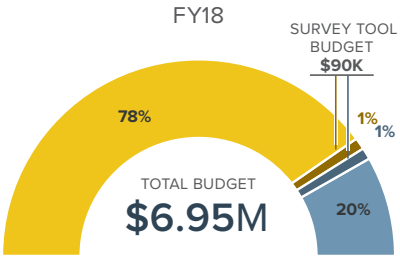
The RBDMS Directional Survey Tool is installed in California and Utah. Several additional states are interested in adding this tool. **Benefits include:**

- 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

QUICK FACTS

AWARD NUMBER
DE-FE0027702

PROJECT BUDGET



- TOTAL DOE SHARE $5.48M
- SURVEY TOOL DOE SHARE $75K

- TOTAL STATE SHARE $1.47M*
- SURVEY TOOL STATE SHARE $15K*

*REPRESENTS MINIMUM MATCH

CONTACTS

HQ PROGRAM MANAGER
ELENA MELCHERT

TECHNOLOGY MANAGER
JARED CIFERNO

FEDERAL PROJECT MANAGER
BRUCE BROWN

PRINCIPAL INVESTIGATORS
DAN YATES
PAUL JEHN

PARTNERS

GROUNDWATER PROTECTION COUNCIL

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 reserves.

PRESENTER:
BRUCE BROWN

CONTACTS:

HQ PROGRAM MANAGER
ELENA MELCHERT

TECHNOLOGY MANAGER
JARED CIFERNO

FEDERAL PROJECT MANAGER
BRUCE BROWN

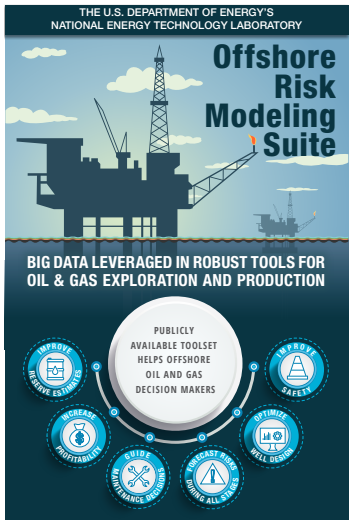
PRINCIPAL INVESTIGATORS
DAN YATES
PAUL JEHN

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

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



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

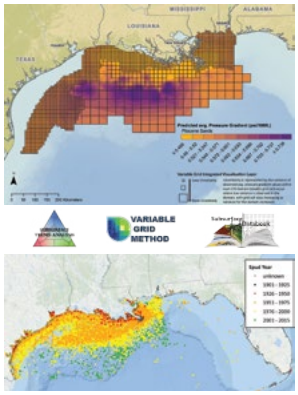
- Geohazard prediction
- Well design and maintenance
- Regulatory permitting
- Improved metocean predictions
- Optimized infrastructure

Custom DOE Smart Toolbox

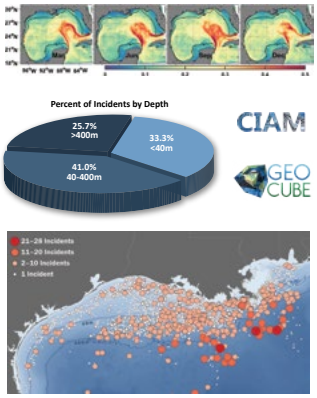
- EDX — COLLABORATION PLATFORM
- Subsurface Databook — E-NOTEBOOK
- SWIM — DECISION SUPPORT TOOL
- VARIABLE GRID METHOD — UNCERTAINTY CHARACTERIZATION
- SUBSURFACE TREND ANALYSIS — SUBSURFACE UNCERTAINITY REDUCTION MODEL
- GEO CUBE — WEB MAPPING
- BLOSOM — 4D OIL SPILL MODEL
- Cumulative Spatial Impact Layers — SPATIO-TEMPORAL ANALYSIS
- CIAM — METOCEAN MODEL

THE POWER OF DATA & SPATIO-TEMPORAL ANALYTICS

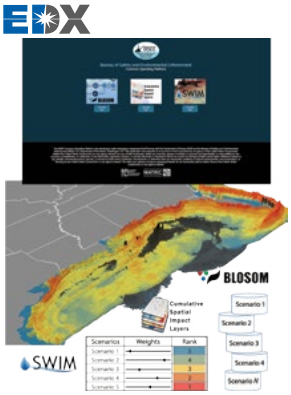
Improving Subsurface Prediction & Reducing Geohazards



Assessing Metocean Hazards



Decision Support for Oil Spill Prevention, Permitting, & Planning



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/

QUICK FACTS

65	7	15	9	2/5	2
Conference Presentations	Technical Reports	Journal Publications	News Articles	Copyrights / Trademarks	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.

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 · United States Coast Guard · NOAA · Lloyd's Register · أرامكو السعودية 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.

PRESENTER:
JENNIFER BAUER and ROY LONG

CONTACTS:

HQ PROGRAM MANAGER
ELENA MELCHERT

TECHNOLOGY MANAGER
ROY LONG

PRINCIPAL INVESTIGATOR
KELLY ROSE
JENNIFER BAUER

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

NETL IS AMERICA'S FOSSIL ENERGY RESEARCH LABORATORY

ACCOMPLISHMENTS POSTERS:

Educating the Next Generation of Energy Innovators 92

Strategic Partnerships: Building Key Relationships 94

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 and PATRICIA ADKINS-COLAINE

CONTACTS:

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MENTORS
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DAVID TUCKER

TECHNICAL PROJECT LEADS
OMER BAKSHI
DAVID TUCKER

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.

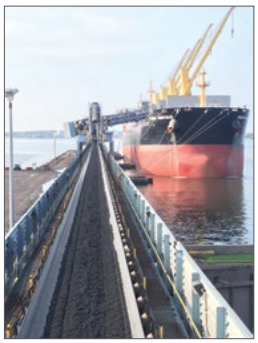
Joint research includes:

- 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

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.

NRECA & CURC members tour NETL Morgantown

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 America's Electric Cooperatives

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

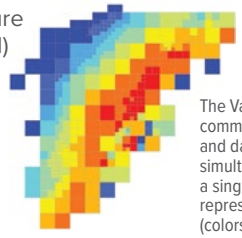
- Cybersecurity
- Customer access to consumption data
- Smart chargers for electric vehicles
- Advanced modeling/controls
- Microgrids

TECHNOLOGY TRANSFER: Technology Commercialization Fund Awards

Improving accuracy through uncertainty quantification and communication — Varigrid Explorations

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

CONTACTS:

ASSOCIATE DIRECTOR OF STRATEGIC PARTNERSHIPS
MIKE KNAGGS

NATIONAL ENERGY TECHNOLOGY LABORATORY

1450 Queen Avenue SW
Albany, OR 97321
541-967-5892

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507
304-285-4764

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236
412-386-4687

Program staff are also located in
Houston, TX and **Anchorage, AK**

CUSTOMER SERVICE
1-800-553-7681

www.NETL.DOE.gov

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