

2019

Science & Technology

# ACCOMPLISHMENTS



## UNLEASHING AMERICAN ENERGY

DISCOVERY | INNOVATION | PROSPERITY



U.S. DEPARTMENT OF  
**ENERGY**



NATIONAL  
ENERGY  
TECHNOLOGY  
LABORATORY

# WELCOME

## MESSAGE FROM THE DIRECTOR



The keyword for NETL's work and innovation is impact. The technologies NETL and its research partners are developing enable fossil fuels to produce clean, reliable and affordable energy to increase domestic manufacturing, invest in improving our nation's energy infrastructure, improve the reliability and resilience of the electrical grid, and expand domestic energy production — among other benefits.

Together with our colleagues at the Office of Fossil Energy, we plan and execute the nation's fossil energy research program. Through early-stage transformational and applied energy research, NETL is enabling and accelerating the discovery, development and deployment of affordable energy technologies to the public and ensuring America's energy security and prosperity.

These 2019 Science & Technology Accomplishments are an outstanding selection of the noteworthy achievements our researchers are generating as we pursue our mission to discover, integrate and mature technology solutions to enhance the nation's energy foundation and protect the environment for future generations. In addition to the world-class expertise of our in-house research teams, NETL partners with exceptional talent across the nation to develop technologies that enable fossil fuels to efficiently and sustainably power our economy and support our energy security.

The Lab maintains nationally recognized technical competencies in geological and environmental systems, materials engineering and manufacturing, energy conversion engineering, systems engineering and analysis, and computational science and engineering. Enabled by our unique facilities, we apply our core science and engineering capabilities toward:

- *Improving the performance, reliability, and efficiency of the existing coal-fired fleet.*
- *Advancing the next generation of modular, highly efficient, and flexible coal-fired power plants.*
- *Reducing the cost of captured carbon and put it to work for America.*
- *Creating new jobs, products, and markets for coal.*
- *Leveraging big data and machine learning to unlock our nation's vast unconventional oil and natural gas resources.*

NETL is working to solve these complex challenges through innovative research at our laboratory and with our partners, while also moving them into the market. Our Lab is making an impact. We focus our research portfolio on technologies that have positive impacts on our nation and people's lives.

Fossil fuels have supported our nation's prosperity and economic advancement for generations. Globally, we use a predominance of fossil energy, and that picture will remain the same into the foreseeable future. However, as we look further ahead toward an energy landscape that includes diverse and sustainable energy sources, NETL is forging the path forward. The successes that follow are just a few examples of this important and ongoing work.

Sincerely,

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

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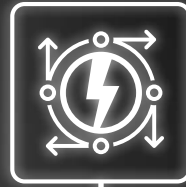
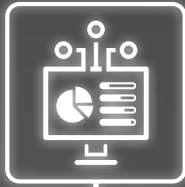
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# CORE COMPETENCIES

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.





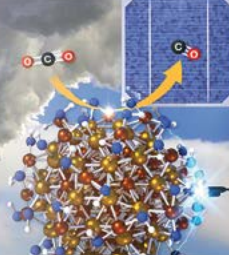
## COMPUTATIONAL SCIENCE & ENGINEERING

USING MULTI-SCALE COMPUTATIONAL APPROACHES TO DEVELOP & DELIVER ENERGY TECHNOLOGIES AT A FASTER PACE, LOWER COST, & REDUCED RISK

NUCLEAR WASTE CLEANUP | FOSSIL ENERGY | BIOENERGY | OFFSHORE OIL SPILLS


COMPUTATIONAL MATERIALS ENGINEERING

NETL maintains expertise in materials modeling at the atomic, molecular, and meso scales to assess the performance of emerging materials in new energy technologies, while identifying improvements to materials efficiency, performance, and cost.




DATA ANALYTICS & MACHINE LEARNING


NETL uses analysis and visualization tools to gain scientific insight into complex, noisy, high-dimensional, and high-volume data sets from experiments and simulations, while developing data-driven models to solve energy challenges.



COMPUTATIONAL DEVICE ENGINEERING

NETL is internationally recognized for detailed, scalable, high-speed, physics-based, and multi-phase Computational Fluid Dynamics (CFD) models to assess current and redefine future energy conversion processes.






## ENERGY CONVERSION ENGINEERING

INNOVATIVE ENERGY SYSTEMS FOR CLEAN POWER, FUELS, & CHEMICALS

THERMAL SCIENCES | ELECTRO-SCIENCES | REACTION ENGINEERING


THERMAL SCIENCES

The Thermal Sciences Team uses hydrodynamic and reaction data to demonstrate concept viability in NETL's Chemical Looping Reactor and other advanced power system technologies, including Pressure Gain Combustion and Advanced Controls for the modern power plant.




ELECTRO-SCIENCES


The Electro-Sciences Team applies electro-optical, electrochemical, and magneto-hydrodynamic principles to advance technologies for current and future power-generation systems. High-temperature and high-pressure sensors are developed using NETL's capability in electro-optics, while capabilities in magneto-hydrodynamics are applied to achieve direct power extraction using hot electrically charged flows from combustion and a magnetic field (in place of a turbine and generator).



REACTION ENGINEERING

The Reaction Engineering Team focuses on advanced catalytic systems and alternative energetic systems, such as electromagnetic energies, which include radiofrequency, microwave, and plasmas, for conversion of materials into energy and value-added products.



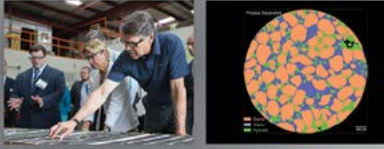


## GEOLOGICAL & ENVIRONMENTAL SYSTEMS

INFORMATION & ASSESSMENTS TO IMPROVE RESOURCE RECOVERY WHILE REDUCING RISKS

MATERIALS CHARACTERIZATION

- Pore-scale imaging at pressure and temperature conditions
- Core-scale flow visualization and modeling
- Bio-process analysis and manipulation



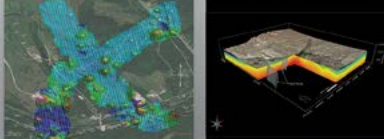
RESERVOIR ANALYSIS

Information integration across scales of reservoir and caprock behavior as the system is perturbed. NETL specializes in naturally fractured oil and gas reservoirs.



BASIN & REGIONAL ASSESSMENTS

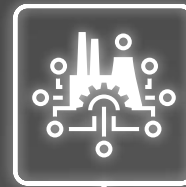
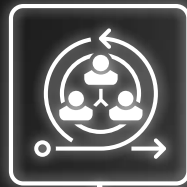
Quantifying risks and opportunities across geological basins or regions.



PORE-SCALE  
CORE-SCALE  
RESERVOIR-SCALE  
ENGINEERED INTERFACE  
BASIN/REGIONAL SCALE





As an applied energy lab, NETL utilizes its six core competencies to address a variety of national challenges, including computational research and scale-up; developing more efficient energy conversion processes; demonstrating novel advanced energy systems; and enabling sustainable, efficient development and production of our domestic fossil energy resources. NETL's world-leading competencies which are relevant to DOE's unique mission are described here as a function of resources (i.e., team, facilities, and/or equipment).





### MATERIALS ENGINEERING & MANUFACTURING

DELIVERING FUNCTIONAL & STRUCTURAL MATERIALS SOLUTIONS TO ENABLE ADVANCED ENERGY SYSTEMS & TECHNOLOGIES



**DESIGN & DISCOVERY**  
 Harnessing the power of computational modeling with targeted experiments to accelerate materials development and deployment.

**SYNTHESIS, PROCESSING, & MANUFACTURING**  
 Methods that readily translate to industrial practice.

**CHARACTERIZATION & PERFORMANCE**  
 Laboratory evaluation at conditions relevant to real-life service.

**INNOVATION & IMPACT**


Advanced Alloys • Environmental Barrier Coatings & Materials  
 Sensors for Process Monitoring & System Integrity • Oxygen Carriers  
 Carbon Products from Coal • Rare Earth Elements • CO<sub>2</sub> Capture Materials  
 CO<sub>2</sub> Utilization • Electrochemical & Magnetic Materials

ELEVEN R&D 100 AWARDS (2008–2019)


### PROGRAM EXECUTION & INTEGRATION

DEVELOPING STRATEGIES TO ADDRESS THE NATION'S FOSSIL ENERGY PRIORITIES

**ADVANCING TECHNOLOGY FROM CONCEPT TO MARKET**  
 Reducing risk and accelerating the development of promising technologies.




**PROGRAM PLANNING & IMPLEMENTATION**  
 Developing trusted partnerships aimed at achieving program goals via the creation and management of a vibrant portfolio of relevant research projects.



**HIGHLY EDUCATED, SKILLED, & EXPERIENCED**

A proficient, highly trained staff with advanced degrees in scientific, engineering, and business disciplines and valuable public, private, and international sector experience.



### SYSTEMS ENGINEERING & ANALYSIS

A CRITICAL ANALYTICAL ASSET DRIVING R&D THROUGH ASSESSMENT OF TECHNOLOGY, PROCESSES, & MARKETS

**PROCESS SYSTEMS ENGINEERING RESEARCH**  
 Building next-generation capabilities to identify, synthesize, and optimize innovative energy systems.



**PROCESS & COST ENGINEERING**  
 Assessing current and advanced energy system performance and cost to drive R&D.



**RESOURCE & SUBSURFACE ANALYSIS**  
 Discerning the most cost-effective fossil energy resources and storage opportunities.



**LIFE CYCLE ANALYSIS**  
 Expanding environmental and impact assessment of current and emerging energy technology to consider the entire life cycle—cradle to grave.



**MARKET & INFRASTRUCTURE ANALYSIS**  
 Assessing the impact of market dynamics, regulations, and policies on the uptake of fossil energy technologies.



# FE ROADMAP OBJECTIVES

## GOAL

## OBJECTIVES

**1**

**Develop secure and affordable fossil energy technologies to realize the full value of domestic energy resources**

**1.1** Develop transformational technologies that will underpin the coal-based facilities of the future

**1.2** Develop technologies to maximize the value from fossil energy resources, including their production and use

**1.3** Engineer the subsurface to maximize recovery and efficient use of resources (e.g., hydrocarbon and storage space) while ensuring environmental stewardship

**1.4** Create smart infrastructure technologies for fossil energy

**2**

**Enhance U.S. economic and energy security through prudent policy, advanced technology, and the use of strategic reserves**

**2.2** Advance technologies to improve the efficiency, reliability, emissions, and performance of existing fossil-based power generation



## SUMMARY PERFORMANCE MEASURES

- By the end of FY 2023, advance at least two engineering studies of advanced high-efficiency, low-emission (HELE) coal-fired systems that have flexible operating capacity to meet baseload and load-following requirements needed for the evolving grid.
  - By the end of FY 2023, improve the average modeled efficiency (heat rate) of an advanced or new coal plant by 5% from the 2017 baseline of 38% (i.e., to 40%).
  - By CY 2030, R&D technologies are available to support a new coal-fired power plant with CO<sub>2</sub> capture with a cost of electricity at least 30% lower than a supercritical PC plant with CO<sub>2</sub> capture, or approximately \$30 per tonne of CO<sub>2</sub> captured.
- 
- By the end of CY 2020, develop separation technologies at the pilot-scale capable of producing 10 pounds per day of commercial-grade rare earth oxides from coal waste products.
- 
- By the end of FY 2022, develop basin-specific technologies for unconventional resources, including emerging plays, and pursue and build upon unconventional oil and gas big data analytics and high-performance computing capabilities to improve modeled recovery of shale oil and gas by 20%, from current baseline of 10 to 12% recovery efficiency.
  - By the end of FY 2022, complete a methane hydrate stratigraphic well test on the Arctic North Slope.
- 
- By the end of FY 2022, identify at least one potential alloy for a multi-purpose pipe capable of transporting natural gas, hydrogen, and CO<sub>2</sub>.
  - By the end of FY 2022, develop technologies that will reduce modeled fugitive methane emissions from natural gas transmission and distribution infrastructure by 50% to a level of 13.4 million metric tons (MMT) CO<sub>2</sub> from the current level of 26.7 MMT CO<sub>2</sub>, as identified in the EPA's Greenhouse Gas Inventory.
- 
- By the end of FY 2022, improve the average modeled efficiency (heat rate) of a typical plant in the existing fleet by 5% from the 2017 baseline of 31% (i.e., to 32.5%).
  - By CY 2030, for retrofitting an existing coal-fired power plant with CO<sub>2</sub> capture, ensure capture technologies are available to reduce the cost of capture by 30% (actual cost of capture varies for each unit). (Baseline: NETL Cost and Performance Baseline Series; 2012 Capture Technology).

# 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 NATURAL GAS RESOURCES**

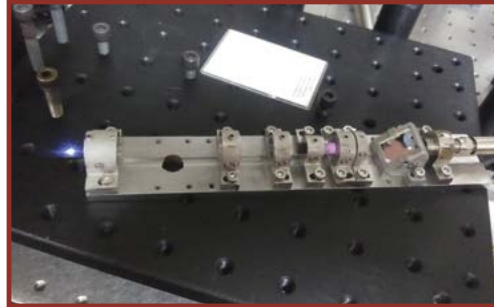
# BREAKTHROUGH IN LASER-INDUCED BREAKDOWN SPECTROSCOPY LEADS TO PATENT

Award-winning probe developed for use in harsh, remote environments simplifies and improves measurement and analysis

## ADVANCEMENT OF A ROBUST RESEARCH CAPABILITY FOR MINIMALLY INVASIVE MEASUREMENTS

NETL researchers are rapidly advancing the development of laser-induced breakdown spectroscopy (LIBS), a **cost-effective, quick and precise measurement method**.

Using short, powerful laser pulses to initiate dielectric breakdowns, LIBS produces a bright flash of light that is returned through a fiber optic cable to a spectrometer for analysis.

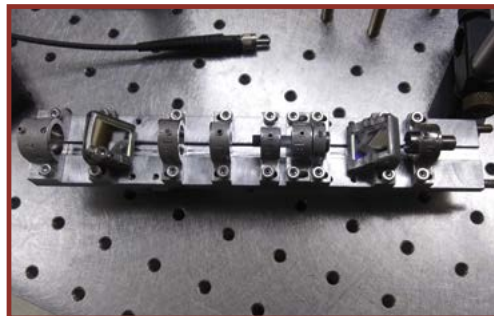


## NETL-DRIVEN APPROACH IMPROVES CURRENT LIBS CAPABILITIES

NETL researchers modified their LIBS design to **reduce the number of optical components and simplify probe construction**.

The novel probe developed:

- **Maximizes the amount and quality of light returned** for analysis
- **Reduces the complexity and cost of the laser head**
- Increases the usefulness of LIBS research



This effort won a **2019 R&D 100 Award** and was awarded **U.S. Patent No. 10,145,737**.



AWARD NUMBER  
**FWP-1022427**  
Task 71

### PROJECT BUDGET

TOTAL AWARD VALUE

**\$273,000**

### CONTACTS

HQ PROGRAM MANAGER  
**ROBIE LEWIS**

TECHNOLOGY MANAGER  
**SYDNI CREDLE**

TECHNICAL PORTFOLIO LEAD  
**BENJAMIN CHORPENING**

FEDERAL PROJECT MANAGER  
**STEVEN RICHARDSON**

TASK PRINCIPAL INVESTIGATOR  
**DUSTIN MCINTYRE**

CORE COMPETENCY



FE ROADMAP OBJECTIVE: **1.3**

# BREAKTHROUGH IN LASER-INDUCED BREAKDOWN SPECTROSCOPY LEADS TO PATENT

PRESENTER: **DUSTIN MCINTYRE**

NETL researchers revolutionized a laser-induced breakdown spectroscopy (LIBS) subsurface monitoring tool that, because of its simplified construction, reduces the amount of fabrication and alignment needed, thereby minimizing costs. Developed for use in harsh, remote environments, the improved technology requires only two mirrors, as opposed to four in previous versions. By reducing the complexity and cost of the laser head, the probe maximizes the amount and quality of light returned for improved analysis and increases the usefulness of LIBS research. This effort won a 2019 R&D 100 Award and was awarded U.S. Patent No. 10,145,737.

CORE COMPETENCY:



ENERGY CONVERSION  
ENGINEERING

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



# IDAES CAPABILITIES AND USER BASE EXTENDED BY RELEASE OF PSE FRAMEWORK, TUTORIALS

Advanced process systems engineering capabilities to optimize fossil energy systems

## IMPROVING POWER PLANT EFFICIENCY, RELIABILITY, AND 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.**

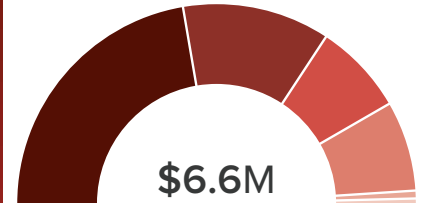


**IDAES**  
Institute for the Design of Advanced Energy Systems

AWARD NUMBER  
**FWP-1022423**

## PROJECT BUDGET

FY19 FUNDING



● NETL	\$3,000,000
● SNL	\$1,600,000
● LBNL	\$1,000,000
● CMU	\$1,000,000
● WVU	\$75,000
● ND	\$50,000

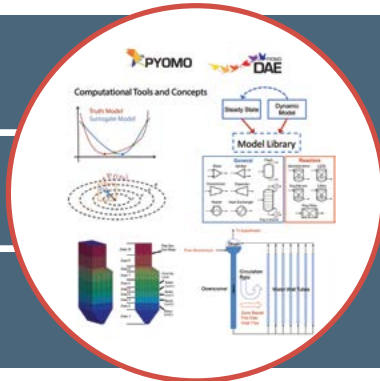
## NEXT-GENERATION COMPUTATIONAL FRAMEWORK

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

## CONTACTS

HQ PROGRAM MANAGER

**BHIMA SASTRI**

TECHNOLOGY MANAGER

**SYDNI CREDLE**

FEDERAL PROJECT MANAGER

**JASON HISSAM**

PRINCIPAL INVESTIGATOR

**DAVID MILLER**

## MEETING POWER INDUSTRY NEEDS



### OPTIMIZATION OF EXISTING PLANTS

Executed CRADA with Tri-State Generation and Transmission Association, Inc. Applied advanced computational tools to their Escalante Generating Station to provide insight into reducing the minimum load, improving efficiency, and avoiding potential equipment failures due to load following.



### ENERGY CHALLENGES OF THE FUTURE

IDAES is developing models of novel energy systems as part of DOE's Coal FIRST (Flexible, Innovative, Resilient, Small, Transformative) Program. These models will be used to examine new conceptual designs in order to identify the most promising process configurations for future energy applications.



### CONTINUAL DIALOGUE WITH INDUSTRY

Achieved full open-source release of the IDAES tools with significant interest from industry. A public workshop on the tools was conducted at the Fundamentals of Computer-Aided Process Design (FOCAPD) conference.

Continued growth of industrial stakeholder group, with regular interactions for feedback.

## PARTNERS



Sandia National Laboratories



Carnegie Mellon University



West Virginia University



## CORE COMPETENCIES



COMPUTATIONAL SCIENCE and ENGINEERING



SYSTEMS ENGINEERING and ANALYSIS

FE ROADMAP OBJECTIVES: **1.1, 2.2**

# IDAES CAPABILITIES AND USER BASE EXTENDED BY RELEASE OF PSE FRAMEWORK, TUTORIALS

PRESENTER: **ANTHONY BURGARD**

The Institute for the Design of Advanced Energy Systems (IDAES) develops and utilizes multi-scale, optimization-based computational tools to improve the design and operation of fossil energy systems – both the existing fleet and the innovative, advanced coal energy systems of the future. The open-source, next-generation IDAES computational platform revolutionizes industry decision-making by enabling large-scale optimization to gain system-wide insights to enhance the operation, profitability, efficiency, and design of energy systems. In 2019, IDAES worked extensively with the Escalante Generating Station to improve flexibility and efficiency, while also rolling out the computational platform to multiple stakeholders through its initial open-source release and two major workshops.

CORE COMPETENCIES:



COMPUTATIONAL SCIENCE  
and ENGINEERING



SYSTEMS ENGINEERING  
and ANALYSIS

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

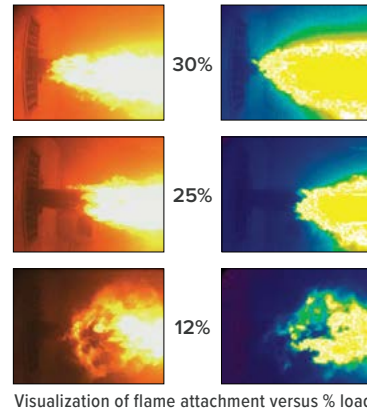


# IMPROVED EFFICIENCY, LONGEVITY, AND COMPETITIVENESS OF EXISTING COAL FLEET

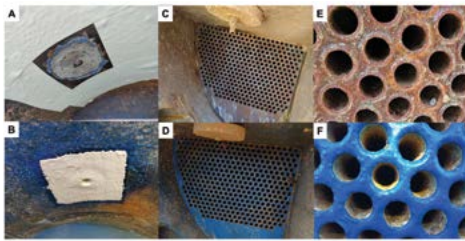
Three technology improvement projects at existing coal plants are demonstrating early progress in improving performance and reducing cost – aiding in fleet efficiency, longevity, and competitiveness

## EXTENDED LOW-LOAD BOILER SYSTEM INSTALLED

GE Steam Power is developing an advanced pulverizer and burner control system to **improve the performance and economics of existing coal-fired power plants** by extending low-load boiler operation lower than is currently achievable. The project team **installed all operation-critical components and supported unit startup** during the host site outage in April-May 2019. Upcoming testing has the potential to validate the capability of the extended low-load boiler system to safely and reliably extend the minimum load operating point on an existing full-scale utility boiler.



## COATING TECHNOLOGY DEMONSTRATED

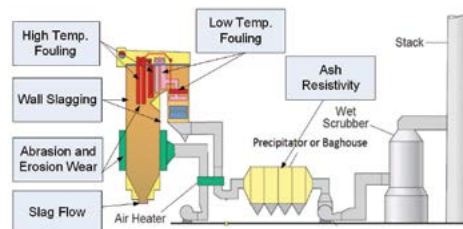


A shell-and-tube exchanger at the Hawaiian Electric Company's Kahe Power Plant **required emergency intervention to repair a leak**. A roughly 6x6- inch area of new carbon steel was welded into place as part of the repair (A), and was **protected from further seawater corrosion and biofouling using Oceanit's**

**HeatX™ surface treatment** (B). Normally, this exchanger would require a cleaning to remove biofouling every 6 months (C, E); after application of HeatX™, minimal fouling was observed even after 24 months with no cleaning (D, F). This demonstration shows that HeatX™ can be effectively applied for spot treatment and in-place repair if required, and can **greatly extend operational availability and lifetime**.

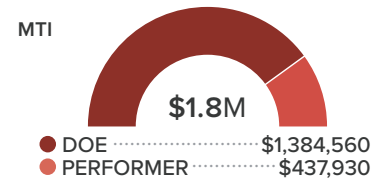
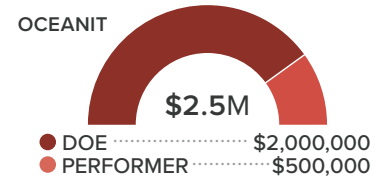
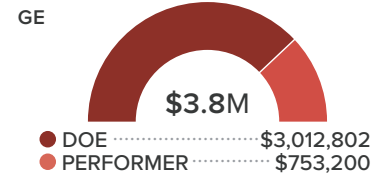
## COMBUSTION SYSTEM PERFORMANCE INDICES AND COAL TRACKER PROGRAM SUCCESSFULLY TESTED

Microbeam Technologies Inc.'s (MTI) Combustion System Performance Indices and Coal Tracker (CSPI-CT) Program was **installed at Otter Tail Power's (OTP) Coyote Station**. A week-long field test was conducted at the OTP site. Power plant performance was tracked during the field test, and the CSPI-CT was used to predict performance. The system provides as-fired coal quality parameters for each burner in the boiler and can **improve boiler performance and reliability through predictions of the impacts of coal quality on boiler operations**.



AWARD NUMBERS  
 DE-FE0031546 (GE)  
 DE-FE0031533 (Oceanit)  
 DE-FE0031547 (MTI)

### PROJECT BUDGET



### CONTACTS

HQ PROGRAM MANAGER  
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TECHNOLOGY MANAGER  
**JOHN ROCKEY**

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**JASON HISSAM (MTI)**

PRINCIPAL INVESTIGATOR  
**STANLEY BOGUSZEWSKI (GE)**  
**MATTHEW NAKATSUKA (OCEANIT)**  
**SHUCHITA PATWARDHAN (MTI)**

### PARTNERS



### CORE COMPETENCIES



FE ROADMAP OBJECTIVES: 1.1, 2.2



# IMPROVED EFFICIENCY, LONGEVITY, AND COMPETITIVENESS OF EXISTING COAL FLEET

PRESENTER: **VENKAT VENKATARAMAN**

The GE Steam Power, Oceanit Laboratories, and Microbeam Technologies projects are demonstrating early progress while performing installation and initial testing of technologies in actual coal-fired power plants. The GE Steam Power project team installed all operation-critical components and supported unit startup during the host site outage in April-May 2019. The Oceanit Laboratories project team utilized their HeatX™ anti-corrosion coating to support an emergency heat exchanger repair at the Hawaiian Electric Company's Kahe Power Plant.

The Microbeam Technologies project team installed and field tested their as-fired coal quality analyzer for each burner in the boiler as part of a performance and reliability improvement effort. The success of these projects shows the technological feasibility for improving performance and reducing cost – aiding in fleet efficiency, longevity, and competitiveness.

CORE COMPETENCIES:



ENERGY CONVERSION  
ENGINEERING



PROGRAM EXECUTION  
and INTEGRATION

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



# MOF-BASED CHEMICAL SENSORS RAISE THE BAR, WIN PATENT

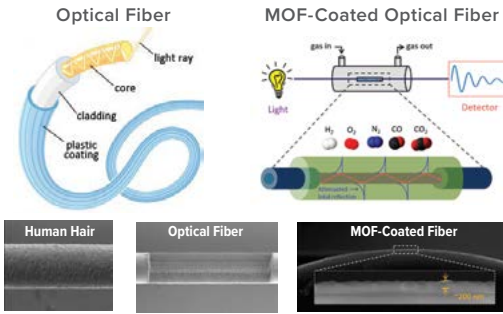
Novel chemical sensors that improve sensing and quantification of CO<sub>2</sub> are critical to ensuring safe and cost-effective monitoring of carbon storage sites

## ENHANCED CHEMICAL SENSOR PERFORMANCE

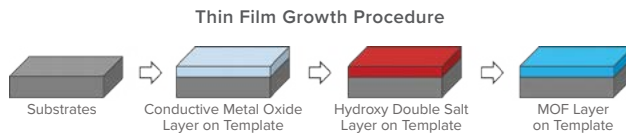
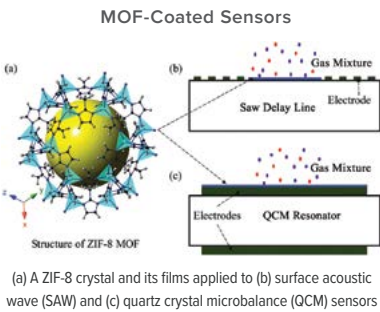
Metal-organic framework (MOF)-based chemical sensors have been demonstrated to be highly selective, sensitive, and reversible for CO<sub>2</sub> sensing across a range of platforms, including **optical fiber** and **surface acoustic wave-based sensors**.

MOF-coated sensors can be used in:

- Geological formations for CCS
- Flue gas of power plants
- Natural gas pipelines



## RAPID FABRICATION WITH ABILITY TO MODIFY FOR GASES

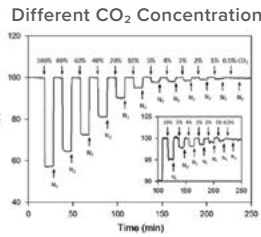
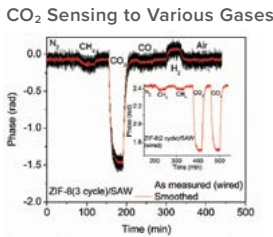


Thin and compact MOF films can be **rapidly and uniformly** formed at room temperature and tightly bound on the surface of optical fiber, which is **critical for manufacturing of MOF-based sensor devices**.

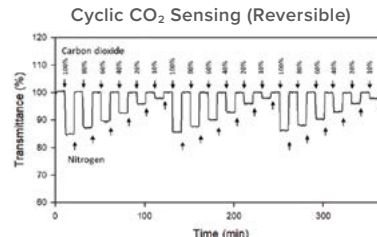
Redox-active molecules (tetracyanoquinodimethane [TCNQ]) enhanced **sensitivity and stability in MOF sensor**.

## NOVEL MOF-COATED CHEMICAL SENSORS

### IMPROVED SENSING PERFORMANCE

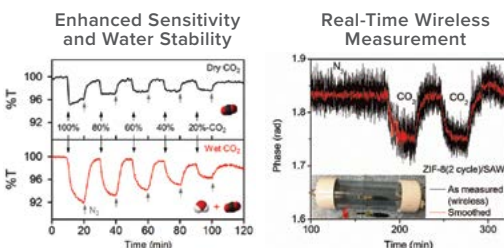


### FAST RESPONSE TIME



## BREAKTHROUGH EXPERIMENTS

Robust Monitoring Systems • MOF-Coated Surface Acoustic Wave (SAW) Gas Sensors • Sensor Stability and Adequate Responses in Aqueous Environment



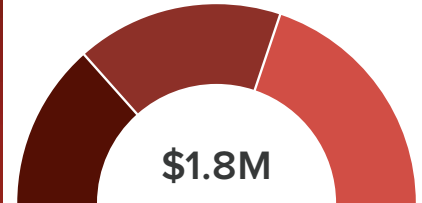
SAW sensors were developed using ZIF-8 MOF as the sensing overlayer for monitoring CO<sub>2</sub> and CH<sub>4</sub>. **This measurement can be done wirelessly.**

Successfully modified CO<sub>2</sub> sensors for water vapor mitigation. **This approach alleviates the negative effects of water vapor.**

Demonstrated a prototype **field configuration** for development of CO<sub>2</sub> Fiber Optic Sensors and Solar-Powered Telemetry system.

AWARD NUMBER  
**FWP-1022403**  
Task 23

## PROJECT BUDGET



• FY18	.....	\$477,273
• FY19	.....	\$600,000
• FY20-21	.....	\$700,273

## U.S. PATENT

No. 10,274,421

## CONTACTS

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TECHNOLOGY MANAGER  
**TRACI RODOSTA**

FEDERAL PROJECT MANAGER  
**SANDRA BOREK**

PRINCIPAL INVESTIGATOR  
**KI-JOONG KIM**

## PARTNERS



## CORE COMPETENCIES



FE ROADMAP OBJECTIVE: **1.3**

# MOF-BASED CHEMICAL SENSORS RAISE THE BAR, WIN PATENT

PRESENTER: **KI-JOONG KIM**

NETL has been able to revolutionize diagnostic and decision-making capabilities with next-generation nonporous-material-enabled sensors. The technology is designed to quickly and precisely detect and quantify CO<sub>2</sub> as part of a detection network designed to ensure that CO<sub>2</sub> is not migrating unexpectedly at carbon storage sites. Through NETL's patented fabrication method, the metal-organic frameworks (MOFs) nanocomposite materials can be engineered to detect and quantify various gases or chemical vapors under ambient and subsurface conditions.

The integration of the MOF-coated sensor results in a more robust and reliable wellbore monitoring platform for the monitoring of gases that is critical to ensure safe and cost-effective monitoring across the energy industry.

CORE COMPETENCIES:



ENERGY CONVERSION  
ENGINEERING



MATERIALS ENGINEERING  
and MANUFACTURING

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



# PATENTS FILED ON LOW-COST TUNABLE SORBENTS TO CLEAN WASTEWATER STREAMS

With flexibility to meet tightening emission regulations or recover critical materials from waste, the BIAS platform can deliver repeated value in the energy sector

## SMALL QUANTITIES, BIG PROBLEMS

Trace metals in waste streams are costly to remove but necessary for environmental health and safety.

<b>TRACE METAL TREATMENT REQUIRES:</b>	Handling Large Volumes of Solution	Limiting Removal of Major, Benign Components	Process Reliability
<b>SORPTIVE PROCESSES PROVIDE:</b>	Small Footprints and Short Residence Times	Selective Removal of Target Species	High Reusability and Minimal Moving Parts

## BASIC IMMOBILIZED AMINE SORBENT APPLICATIONS

### BIAS Platform

**Se from FGD Effluents**  
Low-cost compliance with effluent limitation guidelines for small/medium sources

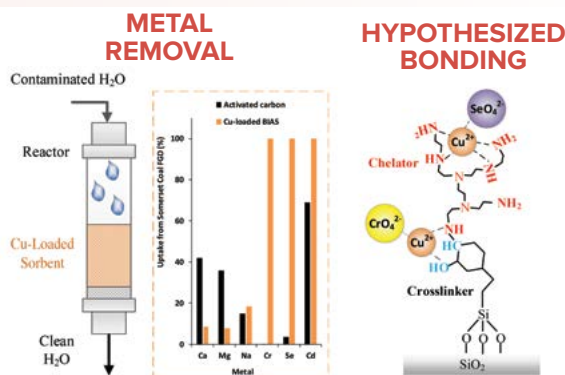
**Pb from Municipal Water**  
Massive cost savings enabled by avoiding replacement of lead pipes with point-of-use water treatment

**Rare Earths from Coal Waste**  
High selectivity enables value-add waste remediation with low-cost process

## AN EXPANDING INTELLECTUAL PROPERTY PORTFOLIO

Three new provisional patents, filed in 2019, further establish the scientific novelty and unique capabilities of the BIAS platform.

Patents create license opportunities for radioactive waste remediation and heavy metal effluent compliance.



Gray, M.L.; Kail, B.W.; Wang, Q.; Wilfong, W.C.; Shi, F., A Method for Radioactive Contaminant Removal from Wastewater, U.S. Provisional Application No. 62814531, Mar. 2019.

Gray, M.L.; Kail, B.W.; Wilfong, W.C.; Wang, Q.; Shi, F., Metal-Loaded BIAS Sorbents for Improved Capture of Heavy Metals from Liquid Sources. Provisional Application no. 62875364, July 2019.

Gray, M.L.; Kail, B.W.; Wilfong, W.C.; Wang, Q.; Shi, F., Novel Multi-Functionalized Basic Immobilized Amine Sorbents for the Removal of Metal Contaminants from Wastewater (19N-04). Provisional Application no. 62875829, July 2019.

AWARD NUMBER  
**FWP-1022428**  
Task 2

RIC Water Management

## PROJECT BUDGET

TOTAL DOE INVESTMENT  
**\$250,000**

## CONTACTS

HQ PROGRAM MANAGER  
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**BRIGGS WHITE**

TECHNICAL PORTFOLIO LEADS  
**NICHOLAS SIEFERT, TOM TARKA**

PRINCIPAL INVESTIGATOR  
**MAC GRAY**

## PARTNERS



west virginia department of environmental protection

## CORE COMPETENCY



FE ROADMAP OBJECTIVE: **1.3**

# PATENTS FILED ON LOW-COST TUNABLE SORBENTS TO CLEAN WASTEWATER STREAMS

PRESENTER: **MAC GRAY**

The basic immobilized amine sorbent (BIAS) platform enables chemists and engineers to tune the selectivity of trace metal removal media, reducing process costs and waste generation. The three provisional patents filed on the BIAS platform create unique and novel license opportunities for radioactive waste remediation and heavy metal effluent compliance. Removing trace toxic or valuable metals from municipal and industrial waste effluents can be expensive.

The BIAS platform provides an affordable, scalable approach towards both meeting tightening environmental health and safety regulations and reclaiming critical materials vital to national security. The repertoire of BIAS chemistry allows customized sorbents to target removal of selenium from flue gas desulfurization effluents, lead from municipal water, and rare earths from coal waste, resulting in massive cost savings compared to conventional approaches.

CORE COMPETENCY:



ENERGY CONVERSION  
ENGINEERING

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

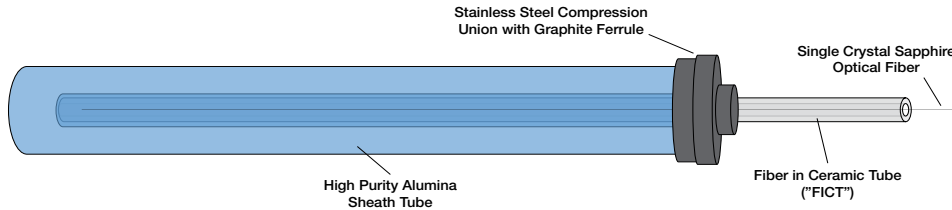


# TEMPERATURE SENSOR SURVIVES PROLONGED HARSH CONDITIONS OF COAL-FIRED BOILERS

Enabling real-time, accurate, and reliable temperature monitoring at distributed locations—a paradigm shift in ultra-high temperature sensing—improves power plant efficiency and safety

## SEAMLESS INTEGRATION OF DISTRIBUTED TEMPERATURE SENSING FOR NEXT GENERATION PLANT CONTROL SYSTEMS

Virginia Tech developed a sensor technology based on single-crystal sapphire optical fiber that **overcomes the harsh environment challenges that severely limit the integration of silica-based optical fiber sensing technologies, and validated the technology in coal- and gas-fired industrial boilers.**

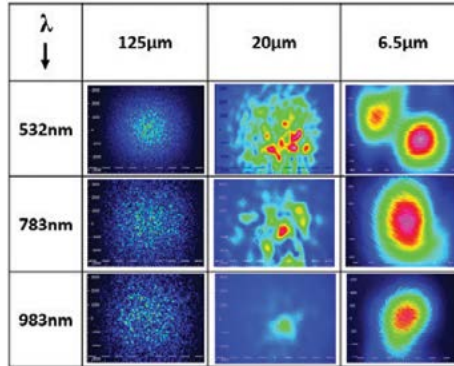


The technology enables real-time and distributed sensing of temperature, which is a **critical component of intelligent control architectures** and **enables control strategies that improve efficiencies and safety of power plants.**

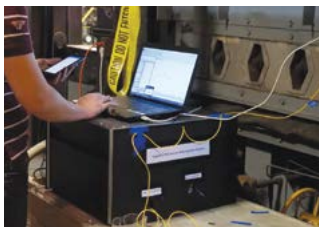
## INNOVATION FOR OPERATION IN EXTREME ENVIRONMENTS

Sensor system development resulted in **first-of-a-kind technological breakthroughs**, including:

- Fabrication of sub-micron and single mode single crystal sapphire fibers via a novel and precise wet-acid etching technique
- Observation of Raman Stokes and Anti-Stokes peaks in sapphire fiber
- Measurement of fiber attenuation in the time domain in sapphire fiber
- Distributed Raman temperature measurements in sapphire fiber



## VALIDATED FROM LAB- THROUGH INDUSTRIAL-SCALE



**Laboratory**  
Peak Temperature: 1,400°C

**Laboratory**  
Duration: 110 hours  
Temperature: 1,000°C



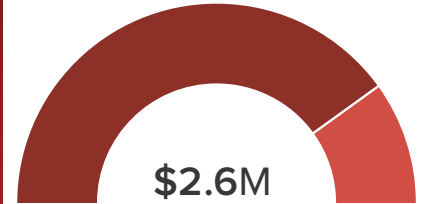
**Coal-fired Boiler – Virginia Tech Central Steam Plant**  
Duration: 42 days  
Peak Temperature:  $\approx$  700°C

**Gas-fired Boiler – Virginia Tech Central Steam Plant**  
Duration: 48 days  
Peak Temperature:  $\approx$  950°C

AWARD NUMBER  
**DE-FE0012274**

## PROJECT BUDGET

FY19 FUNDING



- DOE ..... \$2,100,000
- PERFORMER ..... \$525,000

## CONTACTS

HQ PROGRAM MANAGER  
**ROBIE LEWIS**

TECHNOLOGY MANAGER  
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PRINCIPAL INVESTIGATOR  
**GARY PICKRELL**

## PARTNERS



## CORE COMPETENCIES



ENERGY CONVERSION  
ENGINEERING



MATERIALS ENGINEERING  
and MANUFACTURING



PROGRAM EXECUTION  
and INTEGRATION

FE ROADMAP OBJECTIVE: **1.1**

# TEMPERATURE SENSOR SURVIVES PROLONGED HARSH CONDITIONS OF COAL-FIRED BOILERS

PRESENTER: **ROBIE LEWIS**

Virginia Tech has advanced a harsh environment sensor technology based on single-crystal sapphire optical fiber from concept to full industrial validation. The novel sensor endured rigorous testing in both coal- and gas-fired boilers, where temperatures peaked at about 700°C and 950°C, respectively. The sensor system enables real-time, accurate, and reliable temperature monitoring at distributed locations within a power plant's boiler system – a breakthrough in ultra-high temperature sensing – reducing operating costs and improving safety through greater operational control.

CORE COMPETENCIES:



ENERGY CONVERSION  
ENGINEERING



MATERIALS ENGINEERING  
and MANUFACTURING



PROGRAM EXECUTION  
and INTEGRATION

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



# ADDITIVE MANUFACTURING OF POWER PLANT ALLOYS

Advancing our understanding of new classes of materials that can enable ultra-supercritical steam conditions, improving fleet efficiencies

## FABRICATING NICKEL-BASED SUPERALLOY AND CREEP STRENGTH ENHANCED FERRITIC STEEL COUPONS

In a collaboration between the University of Pittsburgh and United Technologies Research Center, **Wire + Arc Additive Manufacturing (WAAM)**, a promising advanced manufacturing technique, was used to **fabricate coupons for testing from two different alloys:**



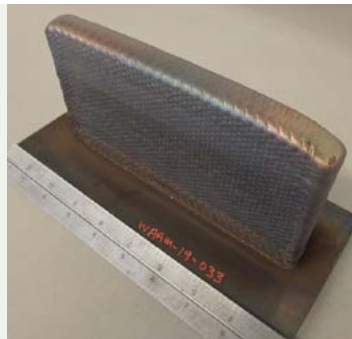
- **Grade 91** – a popular creep strength enhanced ferritic alloy
- **Inconel 740H** – a nickel-based superalloy designed to withstand advanced ultra-supercritical steam conditions



## CHARACTERIZING SAMPLES WITH VARIOUS BUILDING PARAMETERS

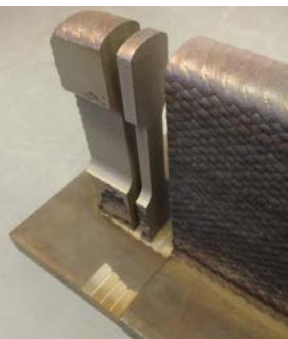
Multiple coupons of each alloy were fabricated for evaluation, **each with different building parameters**, such as:

- Electric current
- Wire feed rate
- Travel speed
- Coupon width



The microstructure (as polished and as etched) and various properties (hardness, porosity, density, etc.) of the coupons were characterized.

This information will be used in future work to **benchmark an integrated computational materials engineering model for alloys with a graded structure.**



AWARD NUMBER  
**DE-FE0031637**

### PROJECT BUDGET

FY19 FUNDING



- DOE ..... \$750,000
- PERFORMER ..... \$187,500

### CONTACTS

HQ PROGRAM MANAGER  
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**RICHARD DUNST**

PRINCIPAL INVESTIGATOR  
**WEI XIONG**

### PARTNERS



### CORE COMPETENCIES



FE ROADMAP OBJECTIVE: **1.1**



# ADDITIVE MANUFACTURING OF POWER PLANT ALLOYS

PRESENTER: **RICHARD DUNST**

The University of Pittsburgh and United Technologies Research Center are advancing an additive manufacturing method known as Wire + Arc Additive Manufacturing (WAAM) to produce high-value, harsh environment alloys appropriate for use in advanced ultra-supercritical (AUSC) coal-fired power systems. Samples whose mechanical properties are near to those of the wrought alloys were fabricated from two alloys, Inconel 740H and Grade 91. This additive manufacturing approach enables economic production of AUSC components with tailored properties.

CORE COMPETENCIES:



MATERIALS ENGINEERING  
and MANUFACTURING



PROGRAM EXECUTION  
and INTEGRATION

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



# ADVANCED MAGNETIC MATERIALS PATENTED FOR ELECTRIC POWER, RENEWABLES, VEHICLES, MACHINES

New, patented technique for permeability engineering of more efficient, reliable, and power-dense soft magnetic cores, essential to America's electricity delivery system

## MAGNETIC COMPONENTS CRITICAL TO U.S. ELECTRICITY SYSTEM

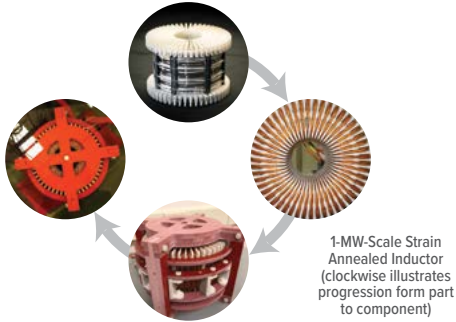
Advanced magnetic components are essential to America's electricity delivery system, ultimately powering homes, businesses, and more to **drive the nation's economy and enhance quality of life.**

The evolution of the nation's energy infrastructure, demand for more efficient electrical machinery, and increasing electrification of transportation will benefit from advanced power magnetics research aimed at developing **more efficient, reliable, and power-dense solutions.**

## END-USE TESTING OF NOVEL MAGNETIC MATERIALS

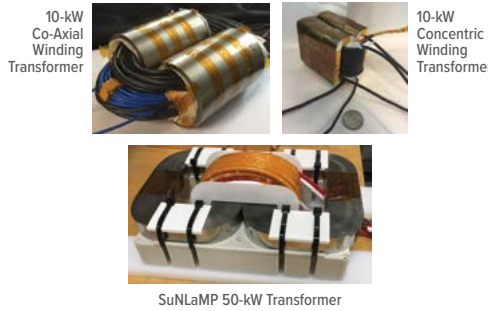
### Inductors

Stability in high temperatures and magnetics properties have been applied to full-scale inductor cores



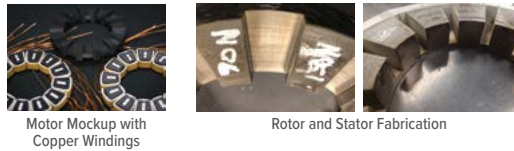
### Transformers

Eaton will test the materials use in advanced transformer designs for solar PV energy storage and grid applications



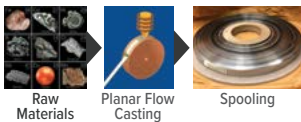
### Motors

Next generation electrical machines using rare earth (RE)-free design

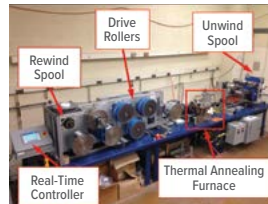


## MARKET-READY TECH TO IMPACT ELECTRIFICATION AND GRID MODERNIZATION COMBINES NOVEL MATERIAL AND MANUFACTURING

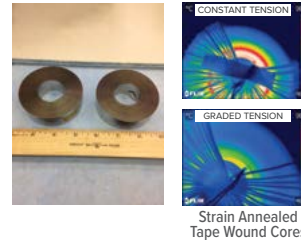
### MELT ALLOY



### PERFORM STRAIN ANNEALING



### FABRICATE AND TEST CORE



CARNEGIE SCIENCE AWARDS

AWARDS

R&D 100 CONFERENCE & AWARDS

## FUNDING SOURCES

SuNLAMP (EERE)  
CIRCUITS (ARPA-E)  
BREAKERS (ARPA-E)  
TRAC (OE)  
AMO (EERE)

## U.S. PATENT

No. US10168392B2

### Journal Paper

Byerly, K., Ohodnicki, P.R., Moon, S.R. et al.  
JOM (2018) 70: 879.

<https://doi.org/10.1007/s11837-018-2857-5>

## CONTACT

PRINCIPAL INVESTIGATOR  
KEVIN BYERLY

## PARTNERS

Metglas®, Inc.

EATON

Carnegie Mellon University

## CORE COMPETENCY



FE ROADMAP OBJECTIVES: 1.1, 2.2

# ADVANCED MAGNETIC MATERIALS PATENTED FOR ELECTRIC POWER, RENEWABLES, VEHICLES, MACHINES

PRESENTER: **KEVIN BYERLY**

NETL's new, patented (U.S. Patent 10,168,392 B2) technique for manipulating and engineering the permeability of soft magnetic cores demonstrates widespread application for higher power-density and greater efficiency power conversion technologies. This technology has been applied to full-scale inductor cores and will be tested by Eaton Corporation and applied to cores for use in advanced transformer designs for solar photovoltaic and energy storage grid integration. NETL's work on this advanced class of soft magnetic materials is essential to America's electricity delivery system, ultimately powering homes, businesses, and more to drive the nation's economy and enhance quality of life.

CORE COMPETENCY:



MATERIALS ENGINEERING  
and MANUFACTURING

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



# AWARD-WINNING STUDY BOOSTS sCO<sub>2</sub> POWER CYCLE COMMERCIALIZATION

Quantifying potential efficiency gains from sCO<sub>2</sub> power plants through techno-economic analyses at NETL's Research and Innovation Center (RIC) to optimize plant design for increased efficiency and reduced energy costs

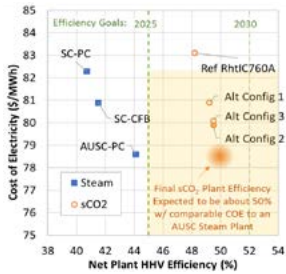
## HIGHLIGHTING THE BENEFITS OF AN INNOVATIVE POWER CYCLE

NETL is leading efforts to perform techno-economic analyses on various configurations of **sCO<sub>2</sub>-based power plants to quantify the benefits** of this novel technology compared to current technologies and **optimize designs** of plants to **minimize cost of electricity (COE)**.

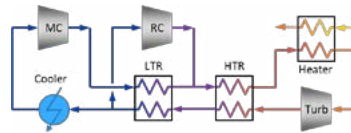
### sCO<sub>2</sub> POWER CYCLE BENEFITS

- Higher efficiency
- Reduced costs for the customer
- Lower COE
- Reduced water consumption
- Direct-fired cycle can produce a high purity stream of CO<sub>2</sub> ready for use/reuse or storage

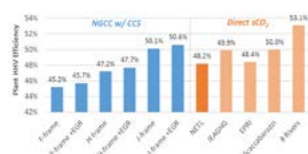
## sCO<sub>2</sub> POWER CYCLES OFFER POTENTIAL FOR POWER GENERATION WITH IMPROVED EFFICIENCIES



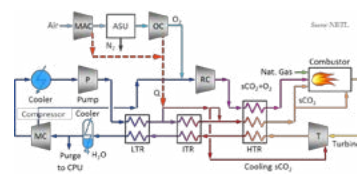
Indirect sCO<sub>2</sub> power plants without carbon capture and storage (CCS) showed a **3–5 percentage point improvement in efficiency** relative to steam cycles at the same turbine inlet temperature, with **comparable or slightly lower COE**.



## NETL TECHNOECONOMIC ANALYSES



Natural gas-fired **direct sCO<sub>2</sub> power plant yielded a 2–3 percentage point increase in efficiency and comparable COE** compared to a baseline natural gas combined cycle (NGCC) plant with CCS.



A series of sub-system focus area studies are underway with the goal of delivering **COE-optimized plant designs** for indirect sCO<sub>2</sub> plants in FY20 and for direct sCO<sub>2</sub> plants in FY21.

## LED A COLLABORATION WITH U.S. NATIONAL LABS TO ACCELERATE sCO<sub>2</sub> POWER CYCLE COMMERCIALIZATION

- NETL's Energy Process Analysis Team led a collaboration that published sCO<sub>2</sub> component cost correlations developed from a pooled database of sCO<sub>2</sub> component vendor quotes
- Correlations span multiple sCO<sub>2</sub> applications and size ranges and should enable a shift from efficiency to COE-based sCO<sub>2</sub> plant optimization

Awarded Best Paper at 2019 ASME Turbo Expo sCO<sub>2</sub> Track



AWARD NUMBER  
**FWP-1022408**

### PROJECT BUDGET

FY19 FUNDING



● DOE SHARE ..... \$813,000

### CONTACTS

- HQ PROGRAM MANAGER  
**REGIS CONRAD**
- TECHNOLOGY MANAGER  
**RICH DENNIS**
- TECHNICAL PORTFOLIO LEAD  
**PETER STRAKEY**
- PRINCIPAL INVESTIGATOR  
**NATHAN WEILAND**

### PARTNERS



### CORE COMPETENCIES



ENERGY CONVERSION ENGINEERING



SYSTEMS ENGINEERING and ANALYSIS

FE ROADMAP OBJECTIVE: **1.1**

# AWARD-WINNING STUDY BOOSTS sCO<sub>2</sub> POWER CYCLE COMMERCIALIZATION

PRESENTER: **RICH DENNIS**

NETL quantifies the potential gains from power plants based on supercritical carbon dioxide (sCO<sub>2</sub>) power cycles using technoeconomic analyses. Plant configurations based on sCO<sub>2</sub> power cycles have increased efficiencies over current baseline power plants along with comparable or lower electricity costs.

These analyses highlighting the potential of this novel power cycle lead the way for sub-system focus studies that are currently underway to deliver cost of electricity (COE)-optimized plant designs for indirect- and direct-fired sCO<sub>2</sub>-based power plants with the lowest COE. Supporting this effort, NETL also leads a collaboration with U.S. national labs to share component cost correlations to lead a shift to COE-based plant optimization and to accelerate sCO<sub>2</sub> power cycle commercialization.

CORE COMPETENCIES:



ENERGY CONVERSION  
ENGINEERING



SYSTEMS ENGINEERING  
and ANALYSIS

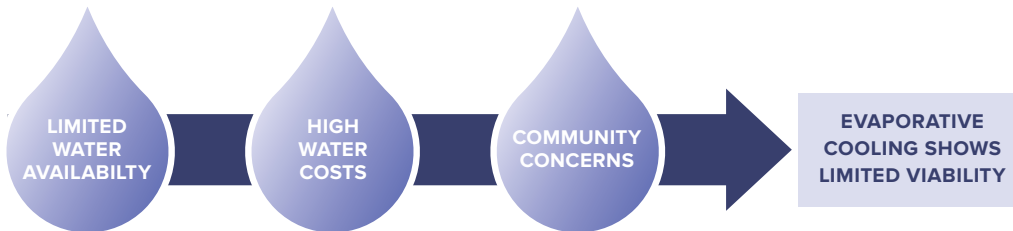
**ADVANCING THE NEXT GENERATION  
OF MODULAR, HIGHLY EFFICIENT,  
AND FLEXIBLE COAL-FIRED POWER**



# BENCHMARKS SHOW DRY COOLING COST-COMPETITIVE AND SUSTAINABLE

Competitive electricity costs are achievable with dry and hybrid cooling, demonstrating feasibility of a major sustainability upgrade to the fleet

## DRY COOLING REDUCES WATER WITHDRAWALS 100% FOR GAS, 75% FOR COAL PLANTS



However, evaporative cooling for power generation remains the #1 water withdrawal in the United States.

## DRY AND HYBRID COOLING IS COST-COMPETITIVE

CO <sub>2</sub> Capture	Plant Type	Cost of Electricity, \$/MWH		
		Evaporative	Hybrid	Dry
<b>Without Capture</b>	PC	81.7	81.5	80.6
	NGCC	57.7	57.6	56.8
<b>With Capture</b>	PC	142.0	141.6	151.7
	NGCC	87.1	86.7	89.5

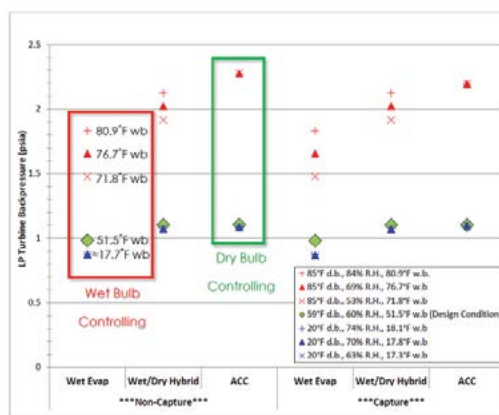
Analysis results support business case for adoption of dry cooling, a more sustainable technology, and cost benchmarks for new technologies.

## LOW-PRESSURE TURBINE BACKPRESSURE KEY

The low-pressure (LP) turbine backpressure is a key performance parameter impacted by changes in ambient conditions. Lower turbine backpressures indicate increase in net power generation and system efficiency.

- For each plant configuration assessed, high ambient dry bulb temperatures cause a reduction in the effectiveness of the steam cycle and a higher LP turbine backpressure is observed than at design ambient conditions
- PC systems with carbon capture exhibit significant decrease in net power and efficiency with dry cooling due to the high water temperature provided to the CO<sub>2</sub> capture system
- For NGCC systems (both with and without CO<sub>2</sub> capture), net power and efficiency decrease significantly with increasing temperature, as the fixed volume combustion turbine is the primary power producer and is sensitive to changes in ambient air density

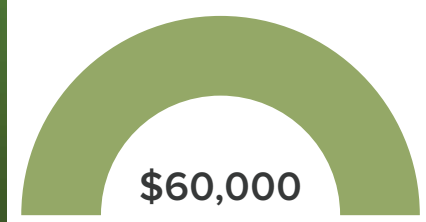
LP TURBINE BACKPRESSURE FOR PC AT ISO CONDITIONS



AWARD NUMBER  
**DE-FE0025912**  
MESA Activity 201.012  
Sub-Activity 1

### PROJECT BUDGET

FY19 FUNDING



### CONTACTS

HQ PROGRAM MANAGER  
**REGIS CONRAD**

TECHNOLOGY MANAGER  
**BRIGGS WHITE**

FEDERAL PROJECT MANAGER  
**ERIC GROL**

### CORE COMPETENCY



FE ROADMAP OBJECTIVE: 1.3

# BENCHMARKS SHOW DRY COOLING COST-COMPETITIVE AND SUSTAINABLE

PRESENTER: **ERIC LEWIS**

Evaporative cooling for thermal power generation is the top surface water withdrawal in the United States. Converting to or building with dry or a wet/dry hybrid cooling system offers operators a major tool to improve plant sustainability. However, the economic motivations of such a choice were not previously clear. NETL researchers have demonstrated that for greenfield plants, dry cooling is a cost-competitive option. The analysis made on the cost and performance of dry and hybrid cooling on fossil energy power systems evaluates the cost and performance of supercritical pulverized coal and natural gas combined cycle power plants (with and without 90% CO<sub>2</sub> capture) with wet, dry, and hybrid cooling systems.

The results provide cost and performance benchmarks for state-of-the-art power plant cooling systems that advanced technologies can be measured against since there is a trend in the construction of alternative cooling technologies, with about 5% of operating cooling systems installed at large-scale generating facilities using a form of alternative cooling. A secondary benefit is that the analysis shows the impact of a range of ambient conditions (such as those in the eastern and western United States) on water consumption for plant cooling. Dry and hybrid cooling technologies are a sustainable, cost-competitive alternative to evaporative cooling—reducing water use, cost, and environmental concerns, and paving the way to potential major sustainability upgrades to the fleet.

CORE COMPETENCY:



SYSTEMS ENGINEERING  
and ANALYSIS

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



# BETTER SOLUTIONS FASTER WITH ENHANCEMENTS TO MFiX MULTIPHASE FLOW DESIGN SOFTWARE

World-class expertise, combined with the MFiX Suite of powerful, open-source computational fluid dynamics software tools, enables transformational design and optimization of multiphase flow energy systems – reducing project time and costs

## NEW MFiX SUITE RELEASES ENHANCE CODE CAPABILITIES



### Three New Releases: MFiX 19.1–19.3 and Machine Learning Tools

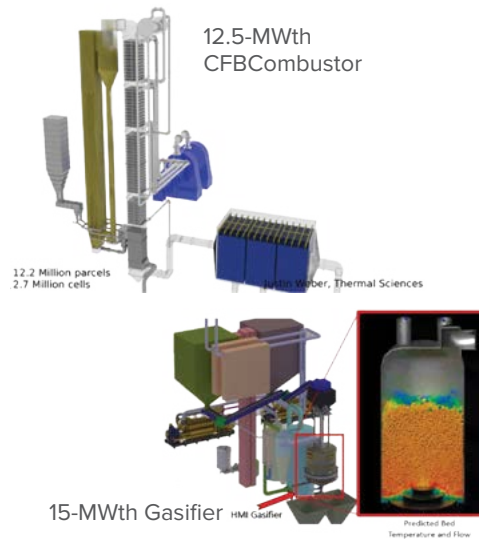
- Enhanced user interfaces
- Advanced tools for complex flow, modeling, and post-processing
- Toolsets to guide design strategies
- Developed a Machine Learning compatible fluid solver in Tensorflow and achieved a 3x speed-up on GPUs
- Developed a novel Machine Learning accelerated chemistry solver which can reduce time to solution for reacting models by as much as 30%



VISIT [MFiX.NETL.DOE.GOV](http://MFiX.NETL.DOE.GOV)

## APPLICATIONS AND ACCOMPLISHMENTS

- MFiX-PIC simulations of NETL's 50-kWth chemical looping reactor with gaseous fuel—complements experiments and enables exploring 'what-if' scenarios, such as using different fuels
- MFiX-PIC simulations of advanced boiler designs—improving performance of existing plants and the future fleet
- MFiX-Exa marching towards exascale performance—54X speed-up demonstrated on Summit, one of the world's fastest supercomputers
- MFiX researchers helping in University of Alaska modular gasifier scale-up — reducing risk on a \$46M power plant
- NETL researchers tailor MFiX tools to study novel sorbent and reactor designs
- NETL leverages MFiX and partners with NREL and ORNL to resolve technical issues with a developmental biomass reactor



## IMPACTS OF MFiX AND MFS GROUP

- All-time MFiX user registrations topped 5,600 in FY 2019—helping academic and industry stakeholders worldwide
- MFiX is being used to study novel reactor configurations that are candidates for FE's Coal FIRST initiative—helping enable the coal fleet of the future
- NETL is using MFiX to support scale-up of a commercial gasifier design—strong collaboration with FE's Gasification Systems Program
- NETL-MFS Group partnerships create synergy in R&D development, such as in NREL's bioprocess integration and scale-up experimental program
- MFS Group study of pilot- and commercial- scale fluidized-bed combustion systems for coal and biomass fuels — supporting FE's Transformative Power Generation Program

AWARD NUMBER  
**FWP-1022405**

### PROJECT BUDGET

**\$4,126,000**

### CONTACTS

HQ PROJECT MANAGER  
**BHIMA SASTRI**

TECHNOLOGY MANAGER  
**SYDNI CREDLE**

FEDERAL PROJECT MANAGER  
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PRINCIPAL INVESTIGATORS  
**MEHRDAD SHAHNAM**  
**JORDAN MUSSER**  
**JEFF DIETIKER**  
**MARY ANN CLARKE**  
**DIRK VANESSENDELFT**  
**TERRY JORDAN**  
**JUSTIN WEBER**  
**WILLIAM ROGERS**

### PARTNERS



### CORE COMPETENCY



FE ROADMAP OBJECTIVE: **1.1**



# BETTER SOLUTIONS FASTER WITH ENHANCEMENTS TO MFiX MULTIPHASE FLOW DESIGN SOFTWARE

PRESENTERS: **DIRK VANESSENDELFT, TERRY JORDAN,**  
and **CHRIS GUENTHER**

NETL's Multiphase Flow Science (MFS) R&D enables design, optimization, and troubleshooting of efficient, robust, and flexible energy conversion devices and energy systems. MFS's MFiX Suite leverages three decades of world-class multiphase flow research and empowers transformational design and optimization of multiphase flow energy systems—reducing technology development time, cost, computational time, and power consumption. MFiX code capabilities with enhanced interfaces and incorporation of machine learning/AI are resulting in greatly increased speed and utility for complex problem solving.

Wide-ranging deployment of the MFiX platform for simulating NETL's own advanced experimental units—from collaborations with industry to simulation of configurations in FE's Coal FIRST Initiative and Transformative Power Generation Program—demonstrate NETL MFS's relevance in tackling and solving real-world, industrial-scale problems and aiding in accomplishing the overall mission of DOE. These tools enable NETL to harness the rapid advances in HPC and data science to transform energy technologies and markets.

CORE COMPETENCY:



COMPUTATIONAL SCIENCE  
and ENGINEERING

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



# DOWNSELECTED COAL FIRST POWER PLANT DESIGNS MOVE TO ENGINEERING PHASE

Development is underway on next-generation coal-fired power plants that will evolve the infrastructure to be cleaner, more efficient, stable, and adaptive to meet the nation's future electricity needs

## CONCEPTUAL DESIGN PHASE COMPLETE; PRE-FRONT-END ENGINEERING DESIGN (PRE-FEED) PHASE UNDERWAY

Final conceptual design reports have been completed for all 13 Coal FIRST (Flexible, Innovative, Resilient, Small, Transformative) projects. Seven of the recipients are now working in the pre-FEED phase of the project, expected to be complete in April 2020. This represents a significant step for the Coal FIRST initiative.

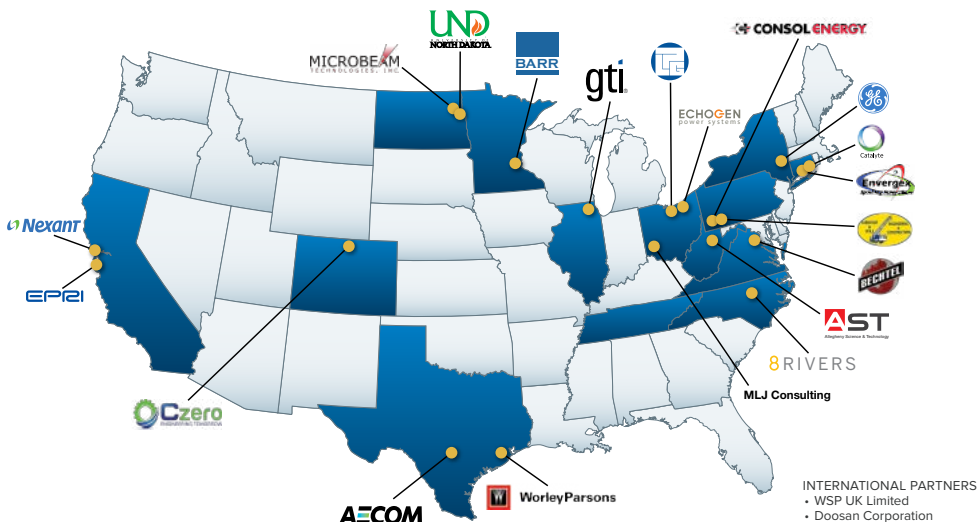


## COAL FIRST INITIATIVE – DEVELOPING THE COAL POWER PLANT OF THE FUTURE

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.

Plants would be **small and modular, cost less to build, have near-zero emissions**, and could be located strategically to provide extra stability to the grid. The smaller power plant of the future would provide highly efficient, cleaner, stable power to meet the needs of an ever-changing electricity grid.

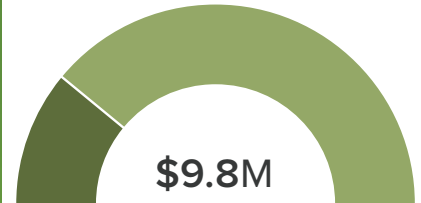
## PARTNERING WITH INDUSTRY: COAL FIRST PRE-FEED PARTNERS



RFP NUMBER  
**89243319RFE000015**

### PROJECT BUDGET

FY19 FUNDING



- 13 CONCEPTUAL DESIGN ..... \$2,186,515
- 7 PRE-FEED ..... \$7,589,275

### CONTACTS

HQ PROGRAM MANAGER  
**RAJ GAIKWAD**

TECHNOLOGY MANAGER  
**JOHN ROCKEY**

FEDERAL PROJECT MANAGERS  
**ROBIN AMES**  
**SETH LAWSON**  
**VENKAT VENKATARAMAN**

PRINCIPAL INVESTIGATOR  
7 PRE-FEED PROJECTS:  
**ADAM GOFF**  
**JESSE GOELLNER**  
**CHAD HAUGEN**  
**DANIEL CONNELL**  
**DR. TIMOTHY HELD**  
**HORST HACK**  
**DR. JOHN GULEN**

### CORE COMPETENCIES



FE ROADMAP OBJECTIVE: **1.1**

# DOWNSELECTED COAL FIRST POWER PLANT DESIGNS MOVE TO ENGINEERING PHASE

PRESENTER: **SETH LAWSON**

The Coal FIRST (Flexible, Innovative, Resilient, Small, Transformative) Initiative is advancing R&D to achieve, in partnership with industry, a pilot-scale plant using technology that will underpin the coal-fired power plant of the future. Conceptual design studies, the initial phase of Coal FIRST, have been completed for all 13 projects. Seven of the concept design recipients are now working in the pre-front end engineering design (pre-FEED) phase of the project, expected to be complete in April 2020.

This represents a significant step for the Coal FIRST Initiative. Coal FIRST 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 that are small and modular, cost less to build, have near-zero emissions, and provide highly efficient, cleaner, stable power to meet the needs of an ever-changing electricity grid.

CORE COMPETENCIES:



ENERGY CONVERSION  
ENGINEERING



PROGRAM EXECUTION  
and INTEGRATION



SYSTEMS ENGINEERING  
and ANALYSIS

**ADVANCING THE NEXT GENERATION  
OF MODULAR, HIGHLY EFFICIENT,  
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# FINAL STEP TO FULL-SCALE DEMONSTRATION OF ADVANCED ULTRA-SUPERCRITICAL (AUSC) POWER PLANTS

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

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.

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.



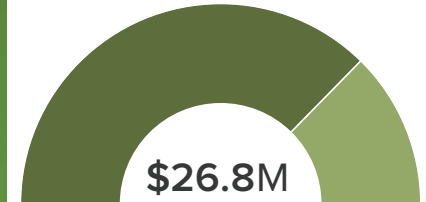
**INC740 Ingot** – Largest Inconel 470 Ingot cast to date – 31,440 lbs. This ingot will be used to extrude large diameter thick wall pipe sections for fabrication into AUSC boiler superheater steam headers

Panel photos and T91 tube membrane panel – AUSC Boiler tube membrane panels fabricated from T91 creep resistant steel

AWARD NUMBER  
**DE-FE0025064**

## PROJECT BUDGET

FY19 FUNDING



- FEDERAL ..... \$19,986,000
- PERFORMER ..... \$6,764,000

## CONTACTS

- HQ PROGRAM MANAGER  
**ROBERT SCHRECENGOST**
- TECHNOLOGY MANAGER  
**BRIGGS WHITE**
- FEDERAL PROJECT MANAGER  
**VITO CEDRO III**
- PRINCIPAL INVESTIGATOR  
**ROBERT PURGERT**
- CONTRACT SPECIALIST  
**JOHN GOLOVACH**
- CONTRACTING OFFICER  
**JEFF KOOSER**

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 PHASES



1

AUSC Superheater/Reheater Assembly

### 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

In Phase II the key components and sub-assemblies of an AUSC boiler, steam turbine, and steam piping system will be fabricated at sizes equivalent to an 800-MWe power plant. Fabrication of AUSC boiler components began in FY2019. Production of these components will demonstrate the capability of U.S. manufacturers to produce AUSC power plant parts.

2

AUSC Steam Turbine Nozzle Carrier Casting

## PARTNERS



## CORE COMPETENCIES



FE ROADMAP OBJECTIVE: **2.2**

# FINAL STEP TO FULL-SCALE DEMONSTRATION OF ADVANCED ULTRA-SUPERCRITICAL (AUSC) POWER PLANTS

PRESENTER: **VITO CEDRO**

The final phase of the Advanced Ultra-Supercritical (AUSC) Component project will demonstrate manufacturing capabilities in the United States to fabricate key nickel superalloy components and sub-assemblies for AUSC boilers, steam turbines, and steam piping systems at sizes equivalent to an 800-MWe power plant. AUSC technology is the next frontier in coal-fired power generation and is effective in realizing cost savings for CO<sub>2</sub> capture power; AUSC plants are up to 25% more efficient than average power plants, enabling improvements needed to compete economically and sustainably against low-cost gas and variable renewables. The current phase of the project builds on Phase I, where potential U.S. suppliers of AUSC nickel superalloy components were identified and components and sub-assemblies to fabricate in Phase II were determined.

CORE COMPETENCIES:



ENERGY CONVERSION  
ENGINEERING



PROGRAM EXECUTION  
and INTEGRATION

**ADVANCING THE NEXT GENERATION  
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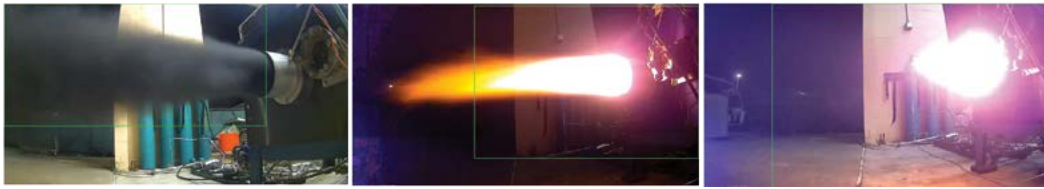


# FIRST FIRE OF A COAL ROTATING DETONATION ENGINE IN THE U.S.

Coal rotating detonation engines are an emerging technology for efficient and clean power generation through pressure gain combustion

## COAL-BASED DETONATION AS A MEANS OF HEAT ADDITION IN POWER GENERATION

For the first time in the United States, **the University of Central Florida (UCF)** detonated coal within a rotating detonation engine (RDE), a pressure gain combustion system. In a separate test, UCF accomplished the **first ever detonation wave measurements in an RDE** using advanced high-speed laser diagnostics leveraging particle image velocimetry (PIV). This effort demonstrates the potential for using a new, efficient, and clean mode of coal combustion in an RDE. The PIV measurement capability **will enable quantification of flow field characteristics** which, until now, could only be observed qualitatively or modeled based on theory alone.



AWARD NUMBER  
**DE-FE0031545**

### PROJECT BUDGET

FY19 FUNDING

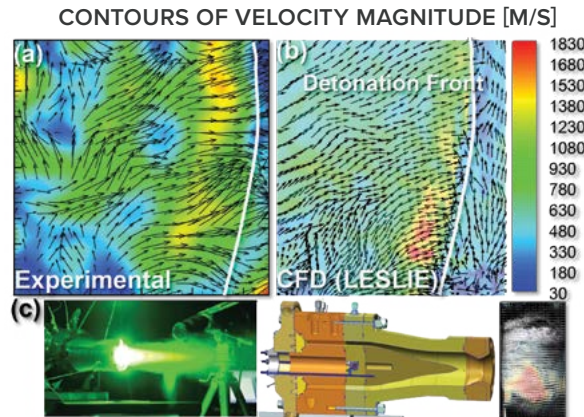


- DOE ..... \$999,915
- PERFORMER ..... \$290,973

## FIRST RDE DETONATION VELOCITY MEASUREMENTS

Advanced high-speed laser diagnostics leveraging PIV were conducted and augmented for the detonation wave measurements in an RDE. Recently demonstrated for the first time, detonation wave velocimetry measurements were taken inside the RDE with the technique shown in the figure (a, b, c).

Detonation wave velocimetry measurements offer high-fidelity data for CFD comparison and validation, and enable the quantification of pressure gain achieved through the RDE.



### CONTACTS

HQ PROGRAM MANAGER  
**RAJ GAIKWAD**

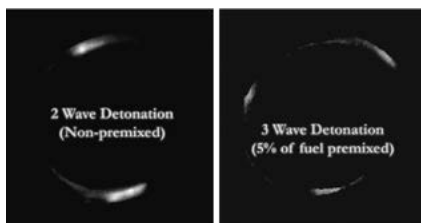
TECHNOLOGY MANAGER  
**JOHN ROCKEY**

FEDERAL PROJECT MANAGER  
**SETH LAWSON**

PRINCIPAL INVESTIGATOR  
**DR. KAREEM AHMED**

## ACTIVE CONTROL OF DETONATION WAVE DYNAMICS THROUGH PARTIAL PREMIXING

Fuel stratification was explored by premixing 5% of the fuel. This resulted in 3-wave detonation at 70% Chapman-Jouguet state (CJ), as opposed to 2-wave detonation at 80% CJ without premixing.



This **innovative dynamic control method results in three reacting waves for the same flow, generating more energy.** (i.e., higher pressure gain.)

Furthermore, this will enable understanding of the physics of detonations in RDEs and help validate CFD models.

### PARTNERS



### CORE COMPETENCIES



FE ROADMAP OBJECTIVE: **1.1**

# FIRST FIRE OF A COAL ROTATING DETONATION ENGINE IN THE U.S.

PRESENTER: **MATTHEW ADAMS**

For the first time in the United States, the University of Central Florida (UCF) detonated coal within a rotating detonation engine (RDE), a pressure gain combustion system. In a separate test, UCF accomplished the first-ever detonation wave measurements in an RDE using advanced high-speed laser diagnostics leveraging particle image velocimetry (PIV). The PIV measurement capability will enable quantification of flow field characteristics which, until now, could only be observed qualitatively or modeled based on theory alone. This effort demonstrates that coal RDEs are an emerging technology for efficient and clean power generation through pressure gain combustion.

CORE COMPETENCIES:



ENERGY CONVERSION  
ENGINEERING



PROGRAM EXECUTION  
and INTEGRATION

**ADVANCING THE NEXT GENERATION  
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# FIRST ROTATING MEASUREMENTS TAKEN AT STEADY THERMAL AERO RESEARCH TURBINE (START) FACILITY

The START Lab is the most sophisticated continuous flow research facility in the world for the study of advanced cooling and flow leakage in gas turbines – optimizing performance across the fleet

## STATE-OF-THE-ART FACILITY WITH UNMATCHED CAPABILITY

The START Lab pushes the boundaries of current experimental capabilities for gas turbine research because it is a continuous duration facility that operates at conditions representative of modern gas turbine engines.

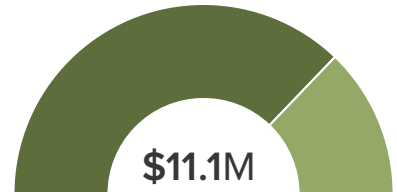
DOE's investment in the START facility enables the United States to have unmatched testing capability for improving cooling designs that will lead to improved turbine performance across the turbine fleet.



AWARD NUMBER  
**DE-FE0025011**

## PROJECT BUDGET

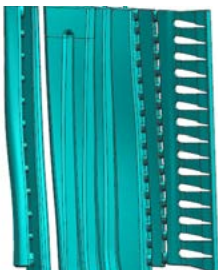
FY19 FUNDING



- DOE ..... \$8,226,916
- PERFORMER ..... \$2,840,205

## PUSHING THE BOUNDARIES OF BLADE COOLING

### Baseline Cooling Design



- A DOE blade has been developed to use as a baseline against other designs with the same aerodynamics but with advanced internal and external cooling features
- Advanced features extend beyond current state-of-the-art original equipment manufacturer (OEM) designs
- Includes longer duration testing than any other facility under rotating and elevated temperature conditions
- Uses advanced thermal imaging, telemetry, and data collection systems

## CONTACTS

- HQ PROGRAM MANAGER  
**REGIS CONRAD**
- TECHNOLOGY MANAGER  
**RICH DENNIS**
- FEDERAL PROJECT MANAGER  
**PATCHARIN BURKE**
- PRINCIPAL INVESTIGATOR  
**DR. KAREN THOLE**
- CONTRACT SPECIALIST  
**ANGELA HARSHMAN**
- CONTRACTING OFFICER  
**MARTY BYRNES**

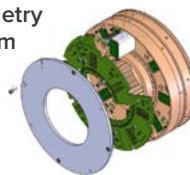
## FIRST ROTATING MEASUREMENTS MADE

- Instrumentation development is a primary focus of the START Lab
- Duration of tests and elevated temperatures are challenging for instrumentation
- Thin film heat flux gauges, fast response aerodynamic probe (FRAP) system, developed and manufactured at PSU
- Tied to telemetry system for data collection and thermal imaging for verification
- 16-hour test proves validity of technology and enables first-of-a-kind data collection for future rotating tests

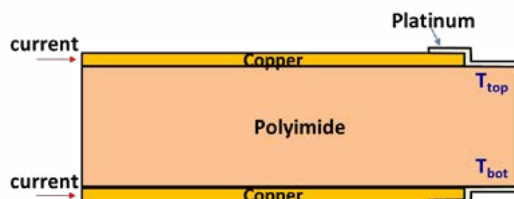
### Thermal Imaging System



### Telemetry System



### Heat Flux Gauges



## PARTNERS



## CORE COMPETENCIES



FE ROADMAP OBJECTIVE: **1.1**



# FIRST ROTATING MEASUREMENTS TAKEN AT STEADY THERMAL AERO RESEARCH TURBINE (START) FACILITY

PRESENTER: **PATCHARIN BURKE**

The Steady Thermal Aero Research Turbine (START) facility is the most sophisticated continuous flow research platform in the world for the study of advanced cooling and flow leakage in gas turbines. The START rig is pushing the boundaries of experimental capabilities with a testing duration under rotating conditions that is more than 11,000 times longer than the nearest comparable rig in the United States.

The START facility serves as a test bed for instrumentation development and data collection, which is a primary focus of the lab. To date, a state-of-the-art rotating telemetry system, imbedded heat flux gauges, Fast Response Aerodynamic Probe (FRAP) system, and kulite sensors have been developed and tested to deliver first-of-a-kind continuous data on heat flux and cooling under rotating conditions – all of which help optimize performance across the fleet.

CORE COMPETENCIES:



ENERGY CONVERSION  
ENGINEERING



PROGRAM EXECUTION  
and INTEGRATION

**ADVANCING THE NEXT GENERATION  
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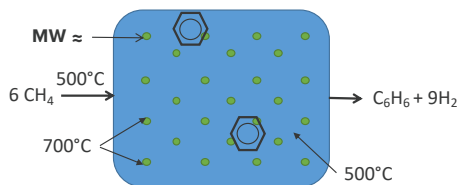
# GASIFICATION PRODUCTION BOOSTED UP TO 6X BY MICROWAVE CONVERSION TECHNOLOGY

Patent filed for innovative method of fuel conversion using microwave technology coupled with microwave-sensitive catalysts, which increases fuel production while requiring less energy

## HIGHLY SELECTIVE AND ENERGY-EFFICIENT

Selective heating with microwaves (MW) promote reaction sites for desired reactions while making undesired reactions unfavorable. Due to reduced bulk-phase temperatures, significant energy savings are possible.

Microwaves can operate in pulsed-power mode to promote desired reaction mechanisms, increasing the overall yield.



AWARD NUMBER  
**FWP-1022405**

## PRINCIPAL INVENTORS

**DUSHYANT SHEKHAWAT**  
**MARK SMITH**  
**DAVID BERRY**  
**VICTOR ABDELSAYED**  
**CHRISTINA WILDFIRE**  
**MIKE SPENCER**

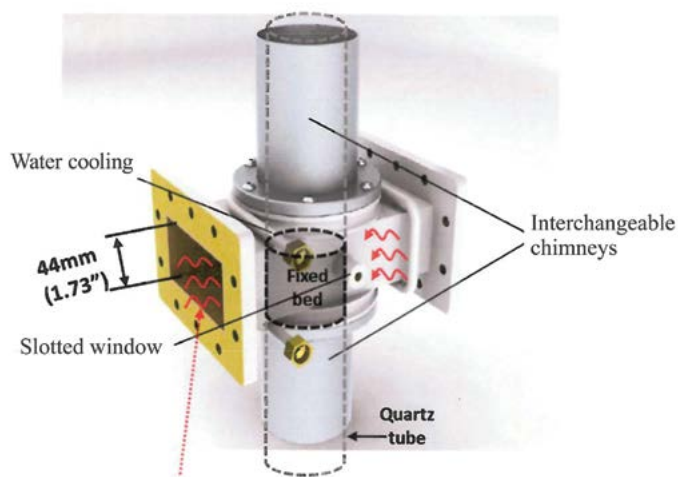
## SLEEK AND COMPACT DESIGN

Microwave reactors provide fixed frequency and variable frequency microwaves to test section.

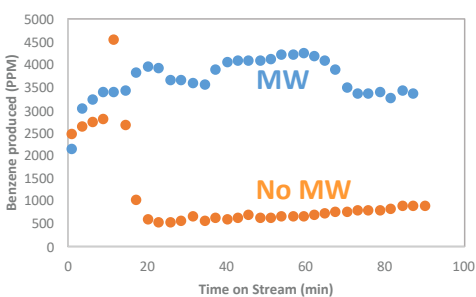
Microwave Vector Network Analyzers (VNAs) measure the electric and magnetic properties of catalysts. These are coupled with NETL-developed high-temperature coaxial airline sample holder cells to get properties as functions of temperature.

System is first-of-a-kind gas-catalyst reaction environment under controlled in-situ reaction conditions.

A Vibrating Sample Magnetometer (VSM) Unit is used to study electromagnetic properties of materials from cryogenic temperatures to elevated temperatures up to 1,000°C, as well as magnetic fields up to 2 Teslas.

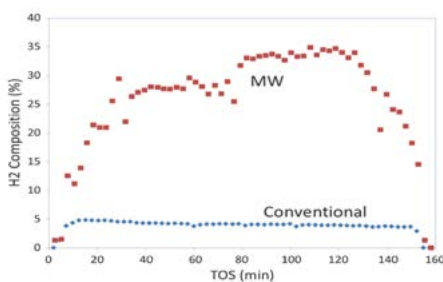


## SIGNIFICANT IMPROVEMENT TO PRODUCT YIELDS



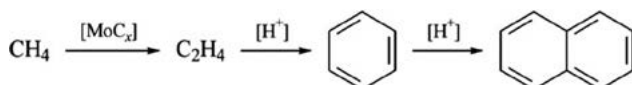
Using microwaves during H<sub>2</sub>- and CH<sub>4</sub>-rich gasification results in increased benzene yield.

Microwave power and frequency can be adjusted to selectively activate specific reaction sites and species.



Hydrogen production during low-temperature coal gasification enhanced by up to six times.

Microwaves can selectively push changes in chemical equilibria while requiring far less energy than traditional catalytic processes.



## CONTACTS

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PRINCIPAL INVESTIGATOR  
**MARK SMITH**

CORE COMPETENCY



FE ROADMAP OBJECTIVE: 1.1

# GASIFICATION PRODUCTION BOOSTED UP TO 6X BY MICROWAVE CONVERSION TECHNOLOGY

PRESENTERS: **JONATHAN LEKSE** and **MARK SMITH**

An experienced research team under the Advanced Reaction Systems subprogram has created an innovative thermo-chemical system that uses microwaves in the presence of a plasma catalyst to drastically improve the yields for a number of fuel conversion methods. This has been demonstrated under laboratory conditions by converting methane into benzene with up to 500% higher yields in less than one-tenth the time compared to conventional thermo-catalytic methods.

The technology is demonstrated to be compatible with a variety of other applications, such as coal gasification, reforming, and Fischer-Tropsch (F-T) synthesis. A patent for this ground-breaking technology has been filed by NETL and is currently awaiting approval.

CORE COMPETENCY:



ENERGY CONVERSION  
ENGINEERING

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



# HIGH-EFFICIENCY COMBINED CYCLE POWER ENABLED BY ADVANCED COMBUSTOR DESIGN

Incorporating multiple design features for a high-efficiency, low-emissions combustor for combined cycle applications

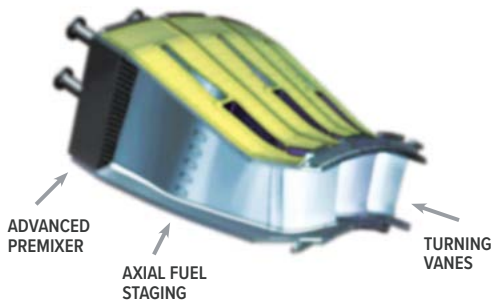
## HIGH-EFFICIENCY COMBINED CYCLE POWER

GE Power is developing advanced low-NO<sub>x</sub> combustion technology for advanced gas turbines **capable of 65% (or greater) efficiency in combined cycle application**. This technology advancement will also benefit gas turbines used in coal-based IGCC applications with pre-combustion carbon capture and hydrogen as the resulting fuel.

The combustor leverages GE's multi-tube mixer combustor developed under previous NETL projects into an integrated combustion, transition, and first-stage vane for operation at over 3,100°F turbine inlet temperature. Planned 2020-2021 full-scale tests will advance the integrated system to Technology Readiness Level (TRL) 6 (from TRL 3 when the project began) to support future commercialization efforts.

## INNOVATIVE FEATURES

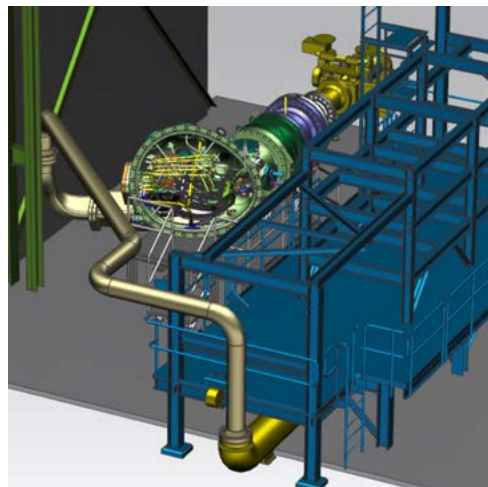
**3,100F INTEGRATED SYSTEM**  
Combines GE's Multi-Tube Mixer Combustor and First-Stage Vane



This revolutionary full-scale combustor design incorporates GE Power's latest innovations across combustion, aerodynamics, heat transfer, materials, additive manufacturing, and other multidisciplinary fields based on extensive engineering analysis, computational modeling, and pilot-scale testing that was completed during earlier tasks. Results indicate significant performance and cost reduction are possible with this integrated system.

## DESIGN COMPLETED FOR FULL-SCALE TEST ARTICLE

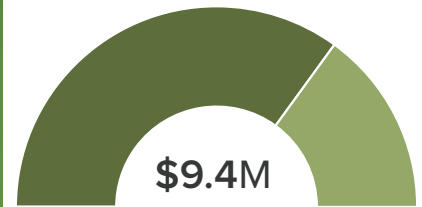
GE has completed the design of the full-scale test article and manufacturing is underway. Multiple units will be tested at GE's Greenville Gas Turbine Technology in a hot cascade arrangement that includes more than 400 pieces of instrumentation. This testing will validate design predictions and confirm high efficiency with low-NO<sub>x</sub> operation for the next generation of gas turbines.



AWARD NUMBER  
**DE-FE0023965**

## PROJECT BUDGET

FY19 FUNDING



● DOE .....	\$6,608,516
● PERFORMER .....	\$2,832,221

## CONTACTS

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**LARRY THOMAS**

CONTRACT SPECIALIST  
**PATRICK MAYLE**

CONTRACTING OFFICER  
**SUE MILTENBERGER**

## PARTNERS



GE Power  
GE Global Research

## CORE COMPETENCIES



ENERGY CONVERSION  
ENGINEERING



PROGRAM EXECUTION  
and INTEGRATION

FE ROADMAP OBJECTIVE: **1.1**

# HIGH-EFFICIENCY COMBINED CYCLE POWER ENABLED BY ADVANCED COMBUSTOR DESIGN

PRESENTER: **MARK FREEMAN**

Combustion turbines in combined cycle configuration are the most efficient producers of power from fossil fuels with the goal of 65% or greater efficiency. GE Power is developing an advanced low-NO<sub>x</sub> combustor for gas turbines that leverages their multi-tube mixer combustor developed under previous NETL projects into an integrated combustion, transition, and first-stage vane for operation at temperatures over 3,100°F.

The revolutionary combustor incorporates a multidisciplinary approach to design using extensive engineering analysis and computational modeling that improves efficiency while lowering emissions. The design for the full-scale test article is complete, and fabrication of the unit is in process. The full-scale, full-load test will be conducted at GE's gas turbine technology laboratory as the final step before finalizing the full design for commercialization and production.

CORE COMPETENCIES:



ENERGY CONVERSION  
ENGINEERING



PROGRAM EXECUTION  
and INTEGRATION

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



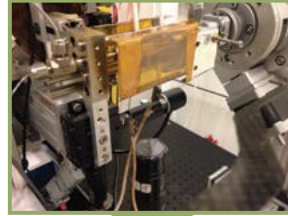
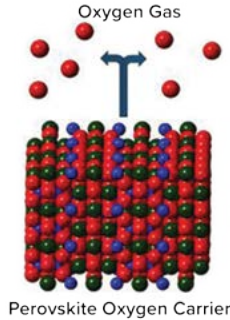
# OXYGEN SEPARATION AND STORAGE TECHNOLOGY PROMISES LOW COST, EFFICIENCY

Setting the stage for commercial use of oxygen carrier materials by reducing their cost and improving performance

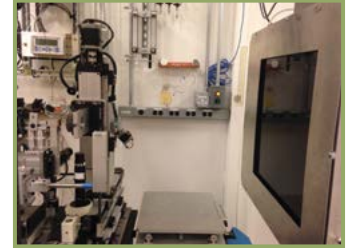
## POTENTIAL TO SEPARATE OXYGEN FROM AIR AND STORE OXYGEN IN EFFICIENT AND LOW-COST NEW WAYS

### Applications

- Oxygen Blown Gasification
- Oxy-Combustion
- Oxygen Sensor Materials
- Solid Oxide Fuel Cells
- Medical Oxygen Supply
- Aerobic Wastewater Treatment



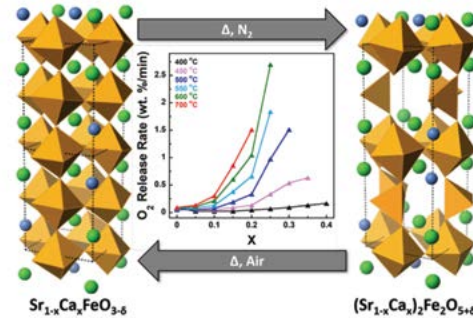
Perovskite sample undergoing testing



Oxygen carrier R&D by NETL at Argonne National Lab's beamline

## UNDERSTANDING AND TAILORING OXYGEN CARRIER STRUCTURE/PROPERTIES

- Oxygen carrier materials: complex metal oxides which absorb oxygen from the air and release it as a pure oxygen stream
- Perovskite structure controlled by chemical composition
- Performance and efficiency are linked to structure
- $Sr_{1-x}Ca_xFeO_3$  was selected based on process conditions and tailored for higher uptakes and faster reaction rates
- NETL is collaborating with ThermoSolv for additional testing and scale-up
- Efforts are reducing cost and increasing performance of oxygen carrier materials



AWARD NUMBER  
**FWP-1022405**

*Advanced  
Reaction Systems*

### PROJECT BUDGET

**\$615,000**

### CONTACTS

HQ PROJECT MANAGER  
**JAI-WOH KIM**

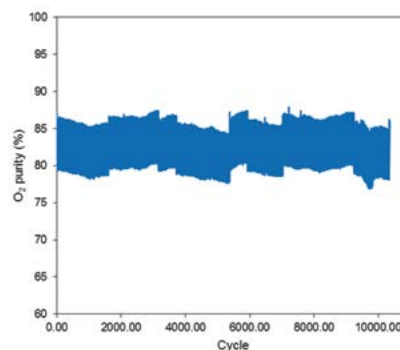
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**BRIAN DRESSEL**

PRINCIPAL INVESTIGATOR  
**JONATHAN W. LEKSE**

## DURABILITY/STABILITY TESTING HAS SET STAGE FOR PATENTING OXYGEN CARRIER MATERIALS AND EVENTUAL COMMERCIAL USE

- A  $Sr_{1-x}Ca_xFeO_3$  perovskite sample demonstrated stability over 10,000 cycles
- Material cost reduced by 20% and performance increased by 15% compared to currently used carrier
- NETL pursuing patent
- Improvements in stability and reduction of costs are leading to eventual commercial use
- For small- to medium- scale oxygen production, oxygen carriers offer cost and space savings compared to a traditional ASU



### PARTNERS

**THERMOSOLV LLC**

### CORE COMPETENCIES



ENERGY CONVERSION  
ENGINEERING



MATERIALS ENGINEERING  
and MANUFACTURING

FE ROADMAP OBJECTIVE: **1.1**

# OXYGEN SEPARATION AND STORAGE TECHNOLOGY PROMISES LOW COST, EFFICIENCY

PRESENTER: **JONATHAN LEKSE**

NETL's efforts in research and development of oxygen carrier materials are setting the stage for commercial deployment of air separation technology, offering reduced cost and increased performance over conventional alternatives. Applications are varied from supplying oxygen for modular and innovative fossil energy systems such as oxygen-blown gasification to oxy-combustion cycles, to medical oxygen supply and aerobic wastewater treatment, demonstrating that the cost savings and efficiency improvements of this technology will be wide-ranging in industry.

Successes in identifying and refining carrier materials and their structures, and in leveraging collaborations with industrial partners, have resulted in stable and high-performing formulations which are patentable and will underpin commercialization of this innovative oxygen production technology.

CORE COMPETENCIES:



ENERGY CONVERSION  
ENGINEERING



MATERIALS ENGINEERING  
and MANUFACTURING

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



# PREDICTION OF HIGH-TEMPERATURE CREEP IN STRUCTURAL ALLOYS IMPROVED

New models for long-term creep and fatigue testing will enable faster development of new structural alloys that can be used to refurbish aging power plant assets and design new facilities

## LIFE PREDICTION MODELING FOR STRUCTURAL COMPONENTS SERVES PLANTS OLD AND NEW

- The average age of the coal fleet was 46 years in 2018, far beyond typical 30-year design lifetime
- In addition to non-competitive operational cost, failure of major capital equipment is a leading driver of plant retirement
- Development of new alloys and components is often limited by need for lengthy creep and fatigue testing

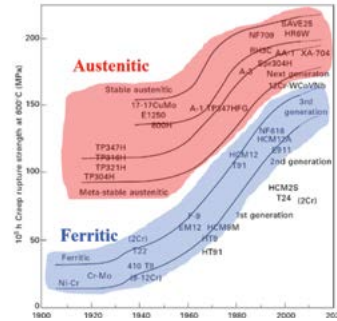
IMPROVED LONG-TERM CREEP MODELS WILL CONTRIBUTE TO ACCELERATED DEVELOPMENT OF COST-COMPETITIVE, HIGH-PERFORMANCE STRUCTURAL ALLOYS AND IMPROVE PLANNING CAPABILITIES FOR PLANT RETIREMENT OR REBURISHMENT

## LONG-TERM CREEP BEHAVIOR OF HIGH-PERFORMANCE STRUCTURAL ALLOYS

The goal is to develop a physics-based mechanistic long-term creep model for existing ferritic alloys to know when and how a material will fail in order to inform efficient power plant design .

- The hottest part of the boiler experiences hoop stresses as high as 100 MPa and temperatures around 550°C or higher
- Performance is determined by 100,000 hours creep rupture strength at 600°C
- Although austenitic steels have better performance, they are more expensive than ferritic steels

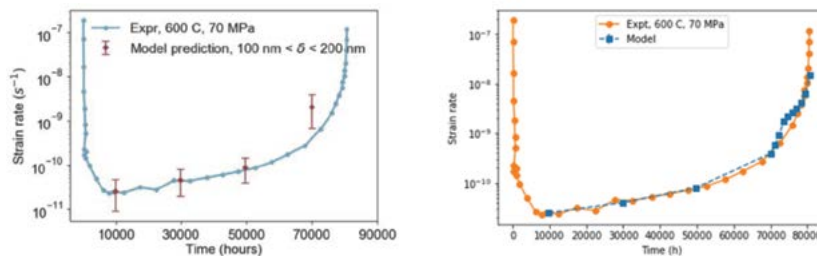
### HISTORICAL IMPROVEMENT OF CREEP RUPTURE STRENGTH OF BOILER STEELS



F. Abe, T. Kern, R. Viswanathan, "Creep Resistant Steels," Elsevier 1st Ed., 2008.

## QUESTEK'S MECHANISTIC CREEP-MODELING TOOLKIT

QuesTek developed and validated a pioneering creep model used to predict the long-term creep performance of materials for base alloys and weldments in fossil energy systems under wide thermal and mechanical conditions facilitating faster qualifications of materials.

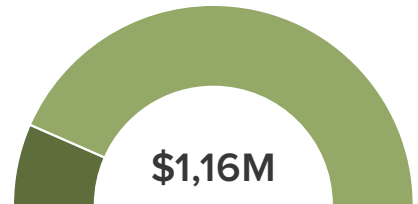


Creep models showing creep rate as a function of time for Grade 91 steel from Phase I (left) and Phase II (right).

The model captures diffusional and power law creep behavior for Grade 91 steels and can easily be applied to other alloys, such as creep strength enhanced ferritic steels. The model could advance microstructure design for improved creep properties surpassing previous models that overestimated creep rupture times and thus the performance of ferritic alloys under similar conditions.

AWARD NUMBER  
**DE-SC0015922**

### PROJECT BUDGET



- PHASE I .....\$154,827
- PHASE II .....\$1,009,586

### CONTACTS

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- CONTRACT SPECIALIST  
**LATRICE JERNIGAN**
- CONTRACTING OFFICER  
**MARK SOJKA**

### PARTNERS



**QuesTek**  
INNOVATIONS LLC

### CORE COMPETENCIES



FE ROADMAP OBJECTIVE: **1.1**



# PREDICTION OF HIGH-TEMPERATURE CREEP IN STRUCTURAL ALLOYS IMPROVED

PRESENTER: **OMER BAKSHI**

Improved long-term creep models are crucial for managing aging coal fleet assets. The design of new facilities requires consideration of structural integrity over time horizons difficult to model and impossible to experimentally simulate. QuesTek Innovations' creep model for high-performance structural alloys enables accelerated development of cost-competitive, high-performance structural alloys for future coal plants by advancing both planning capabilities for plant retirement and refurbishment for plants exceeding their design life by 50%.

While most conventional creep models require direct fitting to different sets of experimental data for different materials, QuesTek's model provides a flexible platform by capturing diffusional and power law creep behavior. Originally validated for Grade 91 steels, QuesTek's model can easily be applied to other alloys such as creep strength enhanced ferritic steels, boosting microstructure design for improved creep properties that abate failure of major capital equipment, a leading driver of plant retirement.

CORE COMPETENCIES:



MATERIALS ENGINEERING  
and MANUFACTURING



PROGRAM EXECUTION  
and INTEGRATION

**ADVANCING THE NEXT GENERATION  
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# SUPERCRITICAL CARBON DIOXIDE (sCO<sub>2</sub>) POWER CYCLES FOR LOW-COST ENERGY

New sCO<sub>2</sub> power cycle pilot plant will prove critical capabilities of a novel technology for more efficient power generation at lower cost, making the United States a leader in domestic and global power generation

## IMPROVING DOMESTIC AND GLOBAL POWER GENERATION

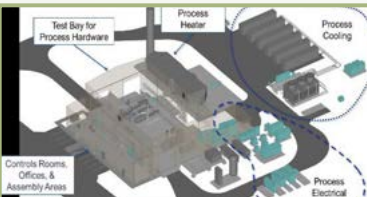
Supercritical CO<sub>2</sub> (sCO<sub>2</sub>) power cycles offer potential for power generation with **increased efficiency, lower cost of electricity, reduced customer costs, and reduced water consumption.**



## RECONFIGURABLE FLEXIBLE PILOT TEST FACILITY

DOE's investment in sCO<sub>2</sub> power cycle technology through the **10-MWe sCO<sub>2</sub> power cycle pilot plant** enables the United States to lead in developing and commercializing sCO<sub>2</sub> power cycle deployment for both domestic and global power generation.

## CRITICAL CONSTRUCTION AND MAJOR EQUIPMENT FABRICATION UNDERWAY



**KEY PROGRESS** towards completing the **LARGEST INDIRECT-FIRED sCO<sub>2</sub> POWER CYCLE TEST FACILITY IN THE WORLD**

- Site grading, foundations, underground raceways and plumbing
- Major equipment being manufactured in parallel, including low-temperature recuperator, process coolers, compressor, cooling tower, turbine stop valves



Closed a key technology gap to enable use of a critical material of construction



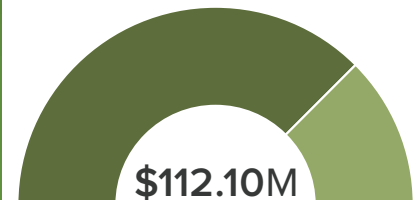
- **Primary heater** - modules fabricated using specialty welding procedures for finned **Inconel 740H** tubing
- A significant accomplishment for **large-scale manufacture of components** utilizing **Inconel 740H** materials
- Weld procedures were **developed under the DOE/FE Advanced Ultra-Supercritical Materials Program**

**REDUCING BARRIERS AND RISKS TO COMMERCIALIZATION**

AWARD NUMBER  
**DE-FE0028979**

## PROJECT BUDGET

FY19 FUNDING



- DOE ..... \$84,330,971
- PERFORMER ..... \$27,772,137

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**JANET LAUKAITIS**

## PARTNERS



## CORE COMPETENCIES



FE ROADMAP OBJECTIVE: **1.1**

# SUPERCRITICAL CARBON DIOXIDE (sCO<sub>2</sub>) POWER CYCLES FOR LOW-COST ENERGY

PRESENTER: **ROBIN AMES**

NETL is at the forefront of groundbreaking research and development to advance supercritical carbon dioxide (sCO<sub>2</sub>) power cycles toward commercialization. The DOE-funded 10-MWe sCO<sub>2</sub>-based pilot plant is a vital proving ground to demonstrate the critical capabilities of a fully integrated, functional, electricity-generating power plant using transformational sCO<sub>2</sub>-based power cycle technology. Significant progress has been completed on the construction of the pilot plant and the manufacture of its key equipment, including the process heater, where novel welding procedures developed in the DOE/FE Advanced Ultra-Supercritical Materials Program for Inconel 740H materials have been put into practice.

This novel power cycle using sCO<sub>2</sub> as the working fluid offers potential for higher efficiency at lower cost compared to current steam-based plants – positioning the United States as a leader in domestic and global power generation.

CORE COMPETENCIES:



ENERGY CONVERSION  
ENGINEERING



PROGRAM EXECUTION  
and INTEGRATION

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



# THERMAL STABILITY ENABLES LONGER DURATION OPERATIONS AT ROTATING DETONATION COMBUSTOR

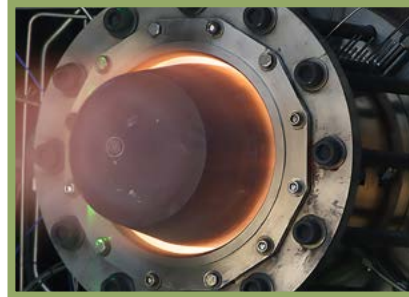
New rotating detonation combustion rig puts NETL at the forefront of pressure gain combustion research with extended duration testing

## 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%.

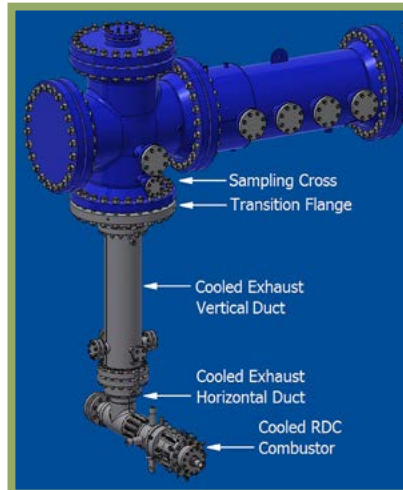
The rapid detonation of RDEs causes the turbine to react as if the flow were steady. Therefore, RDEs avoid the pressure loss and resulting decrease in efficiency that occurs with conventional gas turbine engines.

### RDE Would Replace the Traditional Combustion Process



## FIRST-OF-A-KIND ROTATING DETONATION RIG

- NETL has installed and operated a first-of-a-kind water-cooled RDE rig that allows for extended duration testing
- Thermal stability allows for study of steady and transient state operation
- Unique equipment positions NETL to better understand detonation wave stability and transitioning between operational conditions and fuel compositions

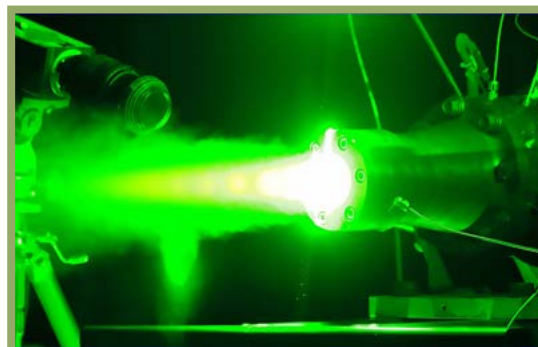


## COLLABORATIVE RESEARCH IMPROVES RESULTS

Researchers at NETL and leading research universities collaborate to complement each other's work and accelerate development of RDEs.

- Turbine integration and high efficiency diffuser with Purdue
- Improved sensors for measurements inside the detonation chamber at the University of Central Florida
- GPU-centric solver coupled with a novel artificial neural network physics engine to greatly speed up 3D reacting flow computations for complex geometries with the University of Michigan

### ROTATING DETONATION COMBUSTOR



AWARD NUMBER  
**FWP-1022408**

### PROJECT BUDGET

FY19 FUNDING



● DOE SHARE ..... \$875,000

### CONTACTS

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**PETER STRAKEY**

PRINCIPAL INVESTIGATOR  
**DON FERGUSON**

### PARTNERS



### CORE COMPETENCY



FE ROADMAP OBJECTIVE: 1.1

# THERMAL STABILITY ENABLES LONGER DURATION OPERATIONS AT ROTATING DETONATION COMBUSTOR

PRESENTERS: **DON FERGUSON** and **RON BREault**

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. NETL has installed and operated a first-of-a-kind water-cooled rotating detonation engine (RDE) rig that allows for extended-duration testing. This unique equipment positions NETL to be a leader in RDE research through better understanding of detonation wave stability and transitioning between operational condition and fuel compositions.

CORE COMPETENCY:



ENERGY CONVERSION  
ENGINEERING

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



# ADVANCING CAPABILITIES IN MANAGING STORAGE RESERVOIRS AND TREATING EXTRACTED BRINE WATER

Evaluating active reservoir management strategies through brine injection and extraction, and testing brine treatment technologies to ensure safe and reliable CO<sub>2</sub> storage

## IMPROVING RESERVOIR PRESSURE MANAGEMENT FOR EFFICIENT AND SAFE CO<sub>2</sub> STORAGE

The University of North Dakota Energy and Environmental Research Center (UNDEERC) is in the operational stage of a brine extraction and storage test (BEST) field project.

This field project consists of two complementary components:

- Validate brine extraction strategies through field testing, employing reservoir simulation and monitoring, for active reservoir management (ARM). Water is being injected as a proxy for CO<sub>2</sub>.
- Implement and operate a test bed facility to evaluate brine treatment technologies for high total dissolved solids (TDS) extracted waters.

EERC site, with treatment facility in background

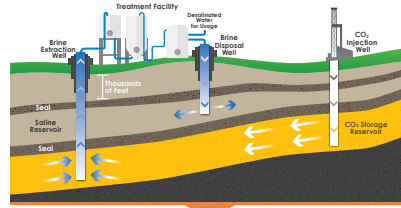
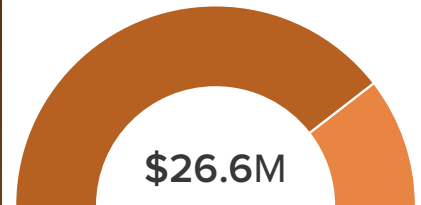


Diagram of CO<sub>2</sub> injection, formation brine extraction, and treatment process

AWARD NUMBER  
**DE-FE0026160**

### PROJECT BUDGET

FY19 FUNDING

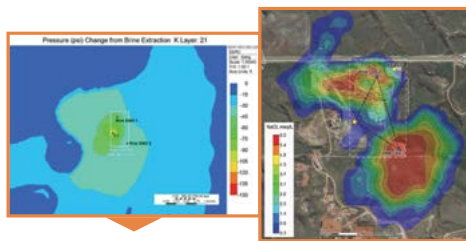


- DOE.....\$18,766,809
- EERC.....\$4,915,165

## SIGNIFICANCE OF THE BEST FIELD PROJECT

### ACTIVE RESERVOIR MANAGEMENT

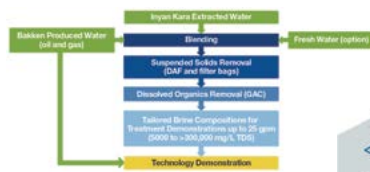
- ARM utilizes brine extraction well(s) to manage formation pressure and plume movement through the storage reservoir
- ARM minimizes the plume footprint, increasing the storage capacity, injectivity, and efficiency
- ARM relieves pressure on the sealing formation (caprock) and can be used to geo-steer injected fluids, reducing risk



Modeling prediction of potential pressure change resulting from brine extraction

### BRINE TREATMENT TEST BED FACILITY

- Test pilot-scale technologies capable of treating high-TDS brine
- Enable development, pilot-scale testing, and advancement of commercially viable extracted water treatment technologies that can meaningfully reduce brine disposal volumes and provide an alternate source of water and/or salable byproducts for beneficial use



Extracted water pretreatment flow diagram



EERC site operational diagram

### CONTACTS

- HQ PROGRAM MANAGER  
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- PRINCIPAL INVESTIGATOR  
**JOHN HAMLING**
- CONTRACT SPECIALIST  
**SHELDON FUNK**
- CONTRACTING OFFICER  
**SUE MILTENBERGER**

### PARTNERS



## ONGOING FIELD WORK

- Initiated ARM testing in May 2019 and extended duration ARM testing began in January 2020
- Well interference testing and reservoir performance characterization were completed in November 2019
- ARM strategies are being validated by injecting Bakken-produced water into the Inyan Kara formation in the Williston Basin, North Dakota, through two saltwater disposal (SWD) wells; water is then being extracted from the Inyan Kara through a project well 1,300 feet away
- Successfully tested and benchmarked the performance of NETL's Mechanical Vapor Recompression brine treatment technology on high-salinity brines in August 2019



Satellite map of the BEST Site, including the extraction well and the brine treatment test bed facility

### CORE COMPETENCIES



FE ROADMAP OBJECTIVE: **1.3**

# ADVANCING CAPABILITIES IN MANAGING STORAGE RESERVOIRS AND TREATING EXTRACTED BRINE WATER

PRESENTER: **ANDREA MCNEMAR**

The UNDEERC Brine Extraction Storage Test (BEST) field project consists of two complementary components: (1) testing active reservoir management (ARM) strategies to mitigate pressure buildup and plume movement within the formation; and (2) operating a brine treatment testbed facility to test pilot-scale water treatment technologies on the extracted, high-salinity brine. The long-term benefits of utilizing ARM at a storage site include increased storage capacity, reduced stress on the sealing formation, and a reduced storage footprint.

These benefits contribute to the overall goal of ensuring safe, economical, and long-term storage of CO<sub>2</sub> in the subsurface. Additionally, treatment of the extracted brine can reduce the amount of brine requiring disposal and produce salable products for beneficial reuse.

CORE COMPETENCIES:



GEOLOGICAL and  
ENVIRONMENTAL SYSTEMS



PROGRAM EXECUTION  
and INTEGRATION

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



# CCUS SUCCESSFULLY DEMONSTRATED TWICE

Approximately 5 million tonnes of CO<sub>2</sub> captured and stored

## OPERATIONAL INTEGRATION OF CARBON CAPTURE UTILIZATION AND STORAGE (CCUS) DEMONSTRATED

Demonstration-scale projects successfully integrated CCUS

systems at an operating coal power plant and an ethanol plant.



Archer Daniel Midlands (ADM)



Petra Nova (PN)

## CCUS TECHNOLOGY PROVED VIABLE AND SAFE

The Petra Nova Carbon Capture Project, the largest CCUS project installed at an existing coal plant, uses the Mitsubishi Heavy Industries advanced solvent-based absorption system to capture approximately 3.5 million tonnes of CO<sub>2</sub> and produce 4.2 million barrels of oil (through enhanced oil recovery [EOR]) as of December 31, 2019.

The Archer Daniel Midlands project separated about 1.5 million tonnes of CO<sub>2</sub> (as of December 31, 2019) through dehydration and compression with storage in the Mount Simon Sandstone saline formation.

Combined, these two traditional storage techniques, EOR and saline storage, demonstrate the safety and viability of CCUS.



## PATHWAY TO FUTURE CCUS APPLICATIONS

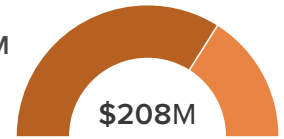
Demonstration of advanced commercial-scale CO<sub>2</sub> separation, compression, transport, injection for EOR or storage, monitoring, and verification facilitates the understanding and future deployment of CCUS technologies under development, which could reduce the capital and operating expenses for CO<sub>2</sub> abatement at power and industrial facilities.

The Petra Nova project has utilized CO<sub>2</sub> to increase production of the West Ranch Oil Field from 500 barrels per day (bpd) to approximately 6,000 bpd, and the ADM Industrial CCS project could potentially facilitate CO<sub>2</sub> utilization in the future.

AWARD NUMBERS  
DE-FE0001547 (ADM)  
DE-FE0003311 (PN)

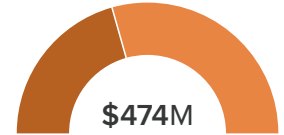
### PROJECT BUDGET

ADM



- DOE ..... \$141,405,945
- PERFORMER ..... \$66,536,254

PN



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

### CONTACTS

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**HEATHER QUEDENFELD**  
FEDERAL PROJECT MANAGER  
**SAI GOLLAKOTA**  
PRINCIPAL INVESTIGATOR  
**SCOTT MCDONALD (ADM)**  
**GREG KENNEDY (PN)**

### PARTNERS

ADM



PN



### CORE COMPETENCIES



ENERGY CONVERSION ENGINEERING



GEOLOGICAL and ENVIRONMENTAL SYSTEMS



PROGRAM EXECUTION and INTEGRATION

FE ROADMAP OBJECTIVE: 1.1



# CCUS SUCCESSFULLY DEMONSTRATED TWICE

PRESENTER: **SAI GOLLAKOTA**

The Petra Nova Carbon Capture and the Archer Daniel Midlands projects have successfully demonstrated the operational integration of carbon capture, utilization, and storage (CCUS) at an operating coal power plant and an ethanol plant. As of December 31, 2019, the Petra Nova Carbon Capture Project captured approximately 3.5 million tonnes of CO<sub>2</sub> and produced 4.2 million barrels of oil through enhanced oil recovery (EOR), while the Archer Daniel Midlands project separated about 1.5 million tonnes of CO<sub>2</sub> through dehydration and compression with storage in the Mount Simon Sandstone saline formation. Advanced commercial-scale CCUS technologies are safe and viable strategies for power and industrial facilities to lower the cost of carbon reduction processes.

CORE COMPETENCIES:



ENERGY CONVERSION  
ENGINEERING



GEOLOGICAL and  
ENVIRONMENTAL SYSTEMS



PROGRAM EXECUTION  
and INTEGRATION

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

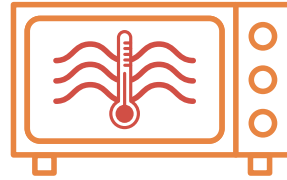


# CO<sub>2</sub> UTILIZATION BOOSTED BY MICROWAVE-ASSISTED CATALYST

Efficient and economical microwave-assisted catalysts provide groundbreaking solutions to carbon utilization challenges

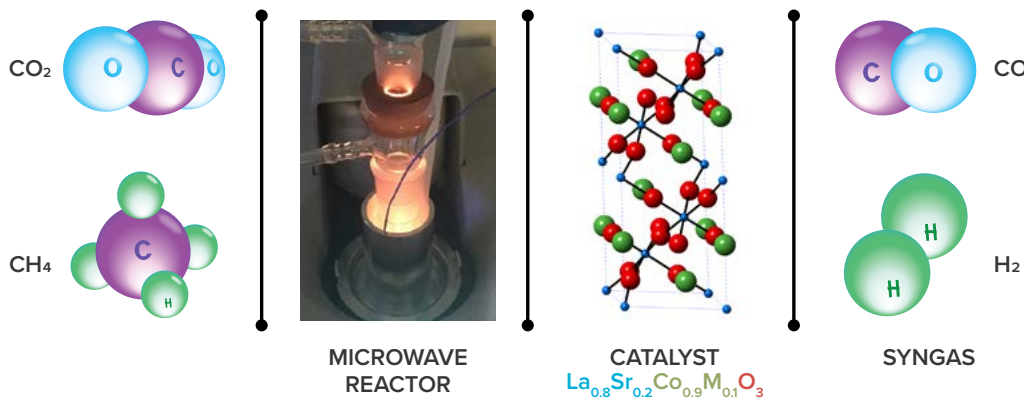
## THE POWER OF CATALYSTS AND MICROWAVES

Microwave-assisted thermal catalysis is a promising approach that can instantaneously heat catalysts to **remarkably high temperatures**, **drastically reducing energy demands** and lessening heat management considerations.



## CATALYST DEVELOPMENT LEADS TO PATENT APPLICATION

NETL's patent-pending catalyst contains a unique chemical composition that improves microwave absorption and CH<sub>4</sub>/CO<sub>2</sub> conversion to syngas. **The microwave catalyst has achieved approximately 90% single pass conversion at low power input.**



AWARD NUMBER  
**FWP-1022426**

## PROJECT BUDGET

FY19 FUNDING

**\$1.02M**

● DOE SHARE ..... \$1,024,000

## CONTACTS

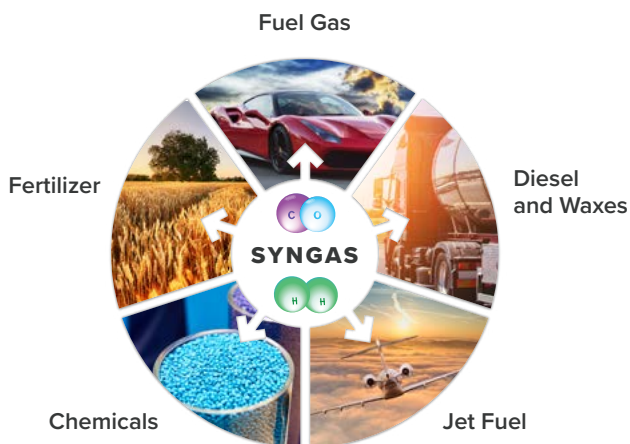
HQ PROGRAM MANAGER  
**AMISHI KUMAR**

TECHNOLOGY MANAGER  
**JOSEPH STOFFA**

TECHNICAL PORTFOLIO LEAD  
**DOUGLAS KAUFFMAN**

PRINCIPAL INVESTIGATOR  
**DOUGLAS KAUFFMAN**

## PRODUCTION OF CARBON-NEUTRAL SYNTHESIS GAS



**Microwave-assisted catalyst reactions** can provide a viable direct method for dry reforming of methane to carbon-neutral synthesis gas. "Conventional" dry reforming technologies are not economically viable due to the high reaction temperatures needed.

## PARTNER

RESEARCH & INNOVATION CENTER



CORE COMPETENCY



FE ROADMAP OBJECTIVE: 1.2

# CO<sub>2</sub> UTILIZATION BOOSTED BY MICROWAVE-ASSISTED CATALYST

PRESENTER: **DOUGLAS KAUFFMAN**

NETL researchers harness the power of microwaves to instantaneously heat catalysts to remarkably high temperatures. Combining microwaves with NETL's novel catalyst compositions facilitates CO<sub>2</sub> utilization reactions with reduced energy demands and heat management considerations. NETL's microwave-assisted thermal catalysis strategy enables conversion of two greenhouse gases – carbon dioxide and methane – into carbon neutral synthesis gas, which is used for synthesis of numerous chemicals and fuels. Leveraging NETL's first-class catalyst team to design catalysts specifically to improve microwave absorption enabled 90% single pass conversion and has resulted in a patent application. Inventing novel and economical microwave-assisted catalysts provides groundbreaking solutions to CO<sub>2</sub> utilization challenges.

CORE COMPETENCY:



ENERGY CONVERSION  
ENGINEERING

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



# CO<sub>2</sub>-SCREEN TOOL ASSISTS PLANNERS, POLICYMAKERS IN CARBON STORAGE

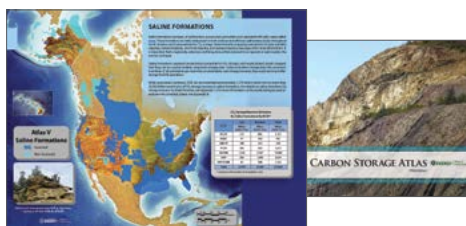
Policymakers and potential investors need reliable storage estimates of long-term sustainability for use in public policy and business investment decisions

## RESOURCE ASSESSMENTS: ESTIMATING PROSPECTIVE CO<sub>2</sub> STORAGE IN THE SUBSURFACE

Provides DOE defensible CO<sub>2</sub> storage methods and tools to quantify prospective storage for the Carbon Storage Atlas, NETL's Regional Carbon Sequestration Partnerships, and CarbonSAFE projects.

- New tool fills an information gap; when used it will provide **shale storage potential** for any site nationwide
- National carbon storage efforts (including CarbonSAFE and the Regional Initiatives) will use the tool to assess shale as a **storage resource for specific settings**
- Use of the tool will result in a better understanding of the nation's shale deposits as a **carbon storage resource**, increasing storage options and volume

Prospective CO <sub>2</sub> Storage Resource for U.S. and Parts of Canada		
Regional Carbon Storage Partnerships	Billion Metric Tons	
	Low	High
Oil and Natural Gas Reservoirs	186	232
Unmineable Coal	54	113
Saline Onshore – Version 1.0	2,379	21,633
Shale Formations – Version 2.0		
Saline Offshore		
Residual Oil Zones – Version 3.0		



AWARD NUMBER  
**FWP-1022403**  
Task 2  
Award Value \$190,909



Team: Angela Goodman, Sean Sanguinito, Eugene Myshakin, Bob Dilmore, Grant Bromhal, Harpreet Singh, Scott Frailey, Alex Azenkeng, Beth Kurz, Wes Peck, Charlie Gorecki

## CO<sub>2</sub>-SCREEN: STATISTICAL ANALYSIS TOOL CAPABLE OF ESTIMATING CO<sub>2</sub> STORAGE RESOURCE

Excel (Data Inputs)

GoldSim (Monte Carlo)

Geologic data is linked to a Gold Sim model that calculates prospective CO<sub>2</sub> storage via Monte Carlo simulation

Excel (Data Outputs)

### CO<sub>2</sub>-SCREEN (Version 1.0, 2.0, 3.0, 4.0)

- Storage prospective Resource Estimation Excel analysis
- Version 1.0 = Saline Formations
  - **Version 2.0 = Shale Formations**
  - Version 3.0 = Residual Oil Zones
  - Version 4.0 = Converted to Python

### >500 Downloads Through January 2020



## CONTACTS

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FEDERAL PROJECT MANAGER  
**SANDRA BOREK**

PRINCIPAL INVESTIGATOR  
**ANGELA GOODMAN**

## CO<sub>2</sub>-SCREEN: CURRENT AND FUTURE WORK

CO<sub>2</sub>-SCREEN is currently available to the public on EDX:  
<https://edx.netl.doe.gov/dataset/co2-screen-version-3-0-beta>



### Major Impacts of DOE Storage Methods

- Quantitative statistical methods estimate CO<sub>2</sub> storage resource across the United States:
  - First-of-its-kind storage method **provides accuracy and storage volume estimates** for shale
  - Results from using the tool will impact global energy policy for CCS by providing additional **storage resource data** for formations not previously included in estimates (shale)
  - **Publicly available** via peer-reviewed journals, Carbon Storage Atlas, EDX, and GoldSim
- Policymakers and potential investors need reliable estimates to provide long-term sustainability to use for **informed decisions**
- **Reliable data prevents waste of valuable resources** if storage estimates are made based on inaccurate data

### Open Source

- Currently have a working version of CO<sub>2</sub>-SCREEN that uses python
- Working on the graphical user interface



### Additional Capabilities

- Add enhanced oil recovery or offshore to the tool
- Add ArcGIS compatibility



### CORE COMPETENCIES



GEOLOGICAL and ENVIRONMENTAL SYSTEMS



SYSTEMS ENGINEERING and ANALYSIS

FE ROADMAP OBJECTIVES: 1.1, 1.3

# CO<sub>2</sub>-SCREEN TOOL ASSISTS PLANNERS, POLICYMAKERS IN CARBON STORAGE

PRESENTER: **ANGELA GOODMAN**

The CO<sub>2</sub> Storage prospective Resource Estimation Excel aNalysis (CO<sub>2</sub>-SCREEN) v2.0 tool and method combine to deliver justifiable carbon storage estimates in shale formations that can be used to help steer public policy and business investment decisions. The tool can be used to assess a potential storage site's ability to store CO<sub>2</sub> during efforts to identify commercial storage opportunities. This collaborative effort produced a tool capable of providing a high-level assessment of shale storage potential at the regional and national scale for Carbon Storage initiatives. Accurately determining the volume of CO<sub>2</sub> that can be safely stored in a given geologic formation is critical to informing high-level decision-making during current and future CCS scenarios.

CORE COMPETENCIES:



GEOLOGICAL and ENVIRONMENTAL SYSTEMS



SYSTEMS ENGINEERING and ANALYSIS

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



# COMMERCIALIZATION OF CAPTURE TECHNOLOGIES PUSHED IN DOE PARTNERSHIP WITH INDUSTRY AND ACADEMIA

Combining research expertise and capabilities of the national laboratories with industry and academia to deliver novel material solutions

## COLLABORATION ENABLES RAPID SCALE-UP, COMMERCIALIZATION, AND COST REDUCTION

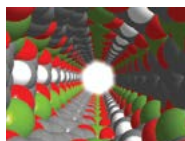
Collaboration with academia and industry accelerated advancements in novel technologies, enabling improved energy efficiencies and reduced capital and operating expenses for carbon capture.



## THREE DOE NATIONAL LABORATORIES PARTNER WITH INDUSTRY AND ACADEMIA TO ADVANCE SCALE-UP AND COMMERCIALIZATION OF CARBON CAPTURE TECHNOLOGIES

### Lawrence Berkeley National Laboratory (LBNL)

has partnered with Inventys and Mosaic Materials to scale-up a novel CO<sub>2</sub> capture technology, **Amine-Appended Metal-Organic Framework (MOF)**, at the National Carbon Capture Center.



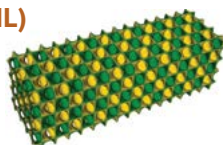
MOFs are a class of porous solids suitable for large gas separations owing to their large internal surface areas. MOF technology offers **high tunability, high CO<sub>2</sub> selectivity**, and significant **energy savings** compared to competing technologies. MOF's **cooperative-binding** technology allows the CO<sub>2</sub>-loaded materials to be regenerated using only **moderate** temperature or pressure swing.

### PARTNERS



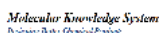
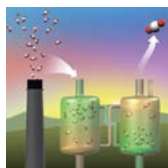
### Lawrence Livermore National Laboratory (LLNL)

designed and fabricated **high-efficiency reactors** that support advanced solvents to achieve transformational carbon capture. They developed several classes of reactor geometries via triply periodic minimal surface (TPMS) additive manufacturing architectures. LLNL printed **silicone gyroid reactors** over a six-inch diameter structure that demonstrates **30%** improved material utilization with advanced solvents compared to conventional reactors. This technology can also be applied to sorbent and membrane processes.



### Pacific Northwest National Laboratory (PNNL)

has worked with industry partners to focus on comprehensive testing of a **new water-lean CO<sub>2</sub>BOL solvent** to collect CO<sub>2</sub> capture performance data for water-lean solvent. This solvent functions only in **5-10 wt.% water**. It doesn't show any foaming behavior and overcomes past high-viscosity challenges. The projected reboiler duty for the novel solvent is **2.0 GJ/metric tonnes CO<sub>2</sub>**, which is **44% lower** than the MEA comparison case. Oxidative degradation of this solvent is **42% lower** than MEA.

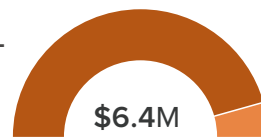


AWARD NUMBERS  
FWP-70924 (PNNL)  
FWP-FEW0225 (LLNL)  
FWP-FP00006194 (LBNL)

### PROJECT BUDGET

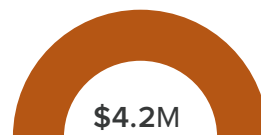
FY19 FUNDING

PNNL



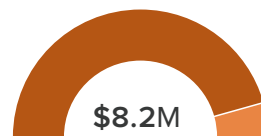
● DOE ..... \$5,792,000  
● PERFORMER ..... \$580,015

LLNL



● DOE ..... \$4,200,000

LBNL



● DOE ..... \$7,399,969  
● PERFORMER ..... \$755,055

### CONTACTS

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**ISAAC AURELIO (LLNL)**  
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PRINCIPAL INVESTIGATOR  
**DAVID HELDEBRANT (PNNL)**  
**JOSHUAH STOLAROFF (LLNL)**  
**JEFFREY LONG (LBNL)**

### CORE COMPETENCIES



ENERGY CONVERSION  
ENGINEERING



PROGRAM EXECUTION  
and INTEGRATION

FE ROADMAP OBJECTIVE: **1.1**

# COMMERCIALIZATION OF CAPTURE TECHNOLOGIES PUSHED IN DOE PARTNERSHIP WITH INDUSTRY AND ACADEMIA

PRESENTER: **ANDREW AURELIO**

The Discovery of Carbon Capture Substances and Systems Initiative (DOCCSS) combines the research expertise and capabilities of the national laboratories with industry and academia to accelerate novel carbon capture technologies that improve energy efficiency and reduce capital cost for CO<sub>2</sub> capture processes. Three examples of collaborative work that is advancing carbon capture technology commercialization: Lawrence Berkeley National Laboratory partnered with Inventys and Mosaic Materials to scale-up a novel CO<sub>2</sub> capture technology, amine appended metal-organic frameworks (MOFs), at the National Carbon Capture Center.

MOFs are a class of sorbents that offer significant energy savings for CO<sub>2</sub> capture by providing large surface area, high tunability, and high CO<sub>2</sub> selectivity. Lawrence Livermore National Laboratory designed and fabricated high-efficiency reactors that support advanced solvents for CO<sub>2</sub> capture to achieve reduced capital cost solutions for CO<sub>2</sub> capture technologies. Pacific Northwest National Laboratory worked with industry partners to develop and test a new water-lean solvent that significantly reduces the energy load for carbon capture and offers high stability.

CORE COMPETENCIES:



ENERGY CONVERSION  
ENGINEERING



PROGRAM EXECUTION  
and INTEGRATION

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



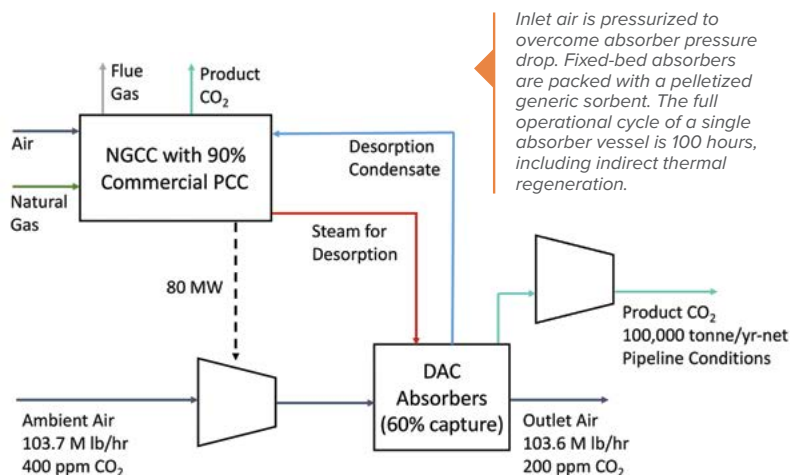
# DIRECT AIR CAPTURE STUDY ENABLES INDEPENDENT APPRAISAL OF CO<sub>2</sub> REMOVAL PLANS

A new sorbent-based DAC case study establishes an independent performance and cost reference to inform future technology development

## ESTABLISHING A PERFORMANCE AND COST REFERENCE FOR DAC

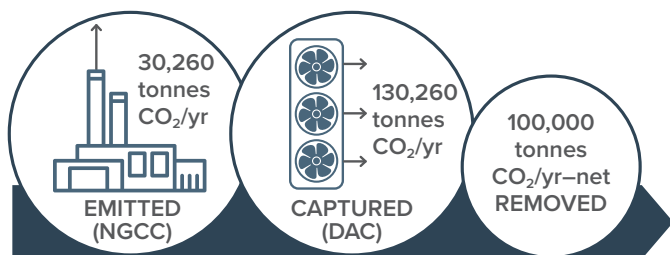
In response to growing public awareness of **direct air capture (DAC) as a carbon capture technology**, NETL has developed a sorbent-based DAC case study.

NETL's **transparent, methodologically sound performance and cost estimates** for DAC systems are crucial to informing future technology development in this emerging field.



## SYSTEM PERFORMANCE DATA

### CAPTURE PERFORMANCE

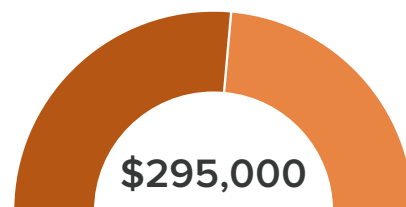


### UTILITY REQUIREMENTS

- DAC AIR FAN AUXILIARY LOAD 80 MWe
- NGCC NATURAL GAS DEMAND 33,500 lb/hr
- NGCC WATER DEMAND 902 gpm

AWARD NUMBER  
**DE-FE0025912**

### PROJECT BUDGET



- PHASE I (Sorbents) ..... \$155,000
- PHASE II (Solvents) ..... \$140,000

## INFORMING FUTURE TECHNOLOGY DEVELOPMENT



**STUDY RESULTS AND SENSITIVITY STUDIES IDENTIFY CRITICAL PARAMETERS AND SUGGEST FUTURE R&D OBJECTIVES.**

- REDUCE PRESSURE DROP**
  - Novel concepts (monolith, SCR honeycomb)
- OPTIMIZE PLANT CONFIGURATION**
  - Alternative layouts for air dispersion and system pressure drop
  - Vessel sizing for alternate sorbent structures
- CONSIDER ALTERNATE SYSTEM CONCEPTS**
  - High capacity factor, low-carbon electricity
- DEVELOP ADVANCED MATERIALS**
  - Sorbent thermal resistance for direct heating
  - Improved kinetics/CO<sub>2</sub> loading

### CONTACTS

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**TIM FOUT**

PRINCIPAL INVESTIGATORS  
**JESSICA VANWAGONER**  
**ALEX ZOELLE**

### CORE COMPETENCY



FE ROADMAP OBJECTIVE: **1.1**



# DIRECT AIR CAPTURE STUDY ENABLES INDEPENDENT APPRAISAL OF CO<sub>2</sub> REMOVAL PLANS

PRESENTER: **JESS VANWAGONER**

In response to growing public awareness of direct air capture (DAC) as a carbon capture technology, NETL has developed a sorbent-based DAC case study. NETL's transparent, methodologically sound performance and cost estimates for DAC systems are crucial to informing future technology development in this emerging field. Results from this base case and sensitivity studies serve to identify critical parameters and suggest future R&D objectives in terms of materials and process optimization. This case study also provides an independent point for comparison and validation of technology developers' proposed performance and cost.

CORE COMPETENCY:



ENERGY CONVERSION  
ENGINEERING

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



# EICP SEALS A CHANNEL IN WELLBORE CEMENT

EICP\* leak-sealing technology enhances the security of geologic CO<sub>2</sub> storage, advancing the technology of next-generation coal plants and lending to applications in the oil and gas industries

## NOVEL WELLBORE SEALING TECHNOLOGY SUCCESSFULLY TESTED

EICP leak-sealing technology was successfully tested in a 1,000-foot deep vertical well at the Gorgas power plant in Walker County, Alabama. The field test involved alternating injections of biologically produced enzymes and urea-calcium solutions into a leaking well over a four-day period. The enzyme-induced chemical reactions caused calcite crystals to precipitate within very fine channels in the wellbore cement, resulting in a 94% reduction of apparent permeability in the channels. Additional testing will be conducted during the summer of 2020 to determine whether the wellbore seal has maintained its integrity over time.

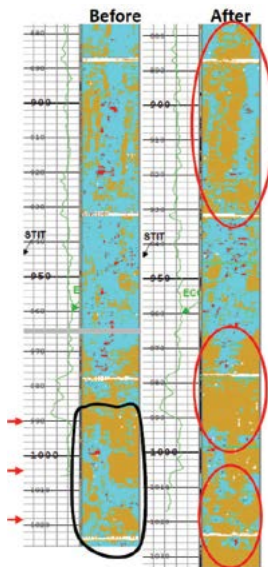


During field testing at the Gorgas power plant (Walker County, AL) solutions are pumped into bailers and inserted into the well.

## EFFECTIVE METHOD FOR PREVENTING LEAKAGE

The components of the EICP leak-sealing technology are much less viscous than existing wellbore sealing materials, typically fine cements.

The reduced viscosity allows the sealant to penetrate very fine fractures, ultimately resulting in a more effective method of preventing leakage of stored CO<sub>2</sub> or other fluids through the wellbore.



USI IBC logs before and after EICP treatment, where tan=solids, blue=liquid, and red=gas detected. Fluids were injected into three potential locations (990, 1,004, 1,017 to 1,019 feet below ground surface) indicated by red arrows. Before production of CO<sub>2</sub> and EICP treatment, a channel was observed in the solid material detected behind the casing (black circle on left panel). After EICP treatment, a significant amount of solid was detected (red circles on right panel).

## CROSSCUTTING IMPACT

The EICP sealing technology can advance the next generation of coal plants by creating technological options for enhancing the security of geologic CO<sub>2</sub> storage by providing a way to mitigate vertical CO<sub>2</sub> pathways within a wellbore. It also has many crosscutting applications in the oil and gas industry.

\*EICP: enzyme-induced calcium carbonate precipitation - advanced mineral precipitation cementing strategy developed at Montana State University (MSU).

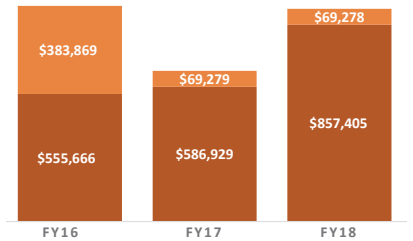
AWARD NUMBER  
**DE-FE0026513**

### PROJECT BUDGET

TOTAL FUNDING



- DOE ..... \$2,000,000
- PERFORMER ..... \$522,426



### CONTACTS

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### PARTNERS



Montana Emergent Technologies (MET)  
Loudon Technical Services (LTS)

### CORE COMPETENCIES



FE ROADMAP OBJECTIVE: **1.3**

# EICP SEALS A CHANNEL IN WELLBORE CEMENT

PRESENTER: **BILL ALJOE**

Montana State University developed a novel wellbore sealing technology that is being utilized to successfully prevent unwanted migration of stored CO<sub>2</sub> and other fluids through the portions of a wellbore that are designed to seal the wellbore. The technology, enzyme-induced calcium carbonate precipitation, produces a 94% reduction of apparent permeability in cracks or channels that would allow the unwanted migration of fluids within a wellbore. The sealing technology advances the next generation of coal plants by creating technological options for enhancing the security of geologic CO<sub>2</sub> storage and has many crosscutting applications in the oil and gas industry.

CORE COMPETENCIES:



GEOLOGICAL and  
ENVIRONMENTAL SYSTEMS



PROGRAM EXECUTION  
and INTEGRATION

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



# EMISSIONS REDUCTION PATH FOR COAL INDUSTRY IN CARBON-NEGATIVE CONCRETE REINFORCEMENT

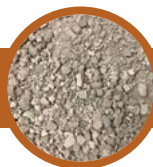
Utilizing CO<sub>2</sub> and industrial byproducts to create CO<sub>2</sub>-negative upcycled concrete that performs as well, or better, than traditional construction materials

## NEW, VALUE-ADDED PRODUCT

Flue gas-borne CO<sub>2</sub> and repurposed abundant industrial wastes, such as crystalline slags and fly ash, can be used to create “upcycled concrete.” This value-added product **provides the coal power industry with a viable path to significantly reduce its carbon emissions.**

The “upcycled concrete” production process also **minimizes external energy needs** by fully utilizing low-grade heat sourced from the flue gas, which **decreases operating costs.**

### EXAMPLES OF INDUSTRIAL WASTE FEEDSTOCKS



Basic Oxygen Furnace Slag



Co-Mingled Steel Slag

### UPCYCLING PROCESS OUTCOME



Cylindrical Mortar Specimens

## COMPRESSIVE STRENGTH INCREASED UPON CARBONATION

Tested carbonated and non-carbonated mortar samples composed of fly ash-portlandite blends as binder prepared using mechanical compaction

Results show **carbonated mortars have higher compressive strength than moist-cured mortars** (>15 MPa target achieved)

- Direct correlation between strength and CO<sub>2</sub> incorporation/carbonate formation; higher CO<sub>2</sub> uptake is attributed to higher levels of portlandite (Ca(OH)<sub>2</sub>) in the mixture

Compressive strength increases with increased compaction pressure



Compacted 2-inch cube specimens

AWARD NUMBER  
**DE-FE0029825**

### PROJECT BUDGET

**\$1.35M**

● DOE	.....	\$999,999
● UCLA	.....	\$300,000
● ASU	.....	\$50,000

### CONTACTS

HQ PROGRAM MANAGER  
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**ANDREW JONES**

PRINCIPAL INVESTIGATOR  
**GAURAV N. SANT**

CONTRACT SPECIALIST  
**BETHAN YOUNG**

CONTRACTING OFFICER  
**ANGELA HARSHMAN**

### PARTNERS



### CORE COMPETENCIES



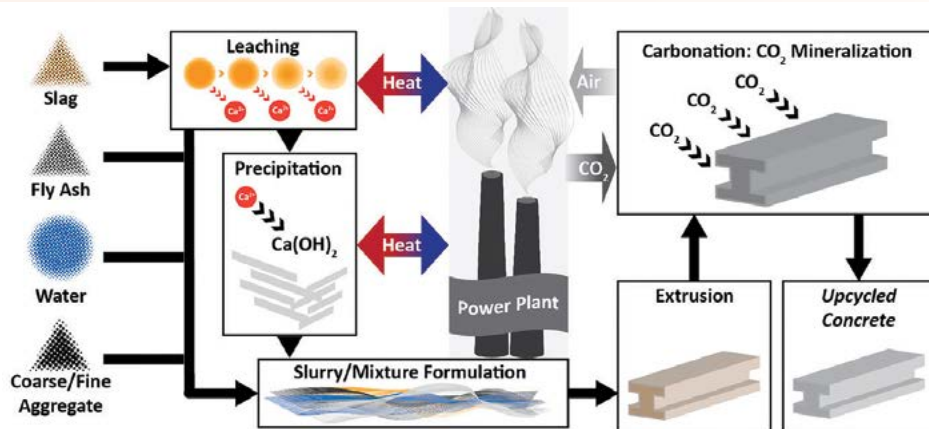
MATERIALS ENGINEERING  
and MANUFACTURING



PROGRAM EXECUTION  
and INTEGRATION

FE ROADMAP OBJECTIVE: 1.2

## INTEGRATED TECHNOLOGY PRODUCTION PROCESS



Integrated “bolt-on” technology solution incorporates aspects of calcium leaching, portlandite precipitation, mixture formulation, and structural shape stabilization —while maximizing CO<sub>2</sub> uptake.

### “UPCYCLED CONCRETE” ADVANTAGES:

- Performance-equivalent or superior to ordinary Portland cement (OPC)-based concrete.
- CO<sub>2</sub>-negative material while OPC production emits substantial CO<sub>2</sub>.

# EMISSIONS REDUCTION PATH FOR COAL INDUSTRY IN CARBON-NEGATIVE CONCRETE REINFORCEMENT

PRESENTER: **ANDREW JONES**

The University of California, Los Angeles' (UCLA) integrated CO<sub>2</sub> mineralization process facilitates the beneficial utilization of flue gas-borne CO<sub>2</sub> and industrial wastes, such as fly ash and slags, to generate a value-added product. Precise control of low-temperature portlandite precipitation from calcium-rich slags along with optimization of concrete mortar formulations while maximizing CO<sub>2</sub> uptake of portlandite-enriched mortars has resulted in a concrete product with a compressive strength of  $\geq 15$  MPa. The development of "upcycled" concrete with strength and durability comparable to traditional ordinary Portland cement (OPC)-based concrete provides an alternative construction material that substantially reduces carbon emissions ("CO<sub>2</sub> -negative") relative to OPC concrete production.

CORE COMPETENCIES:



MATERIALS ENGINEERING  
and MANUFACTURING



PROGRAM EXECUTION  
and INTEGRATION

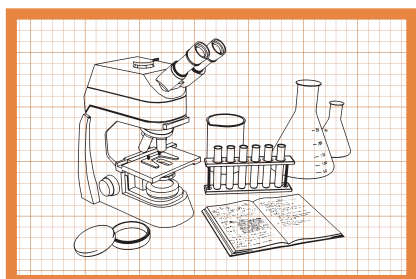
## REDUCING THE COST OF CAPTURED CARBON AND PUTTING IT TO WORK FOR AMERICA



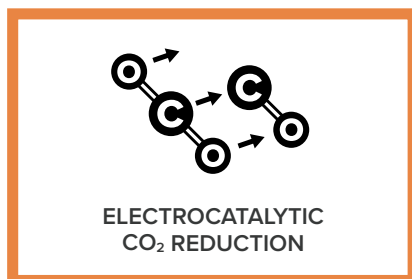
# NOVEL CATALYSTS ENHANCE CONVERSION OF CO<sub>2</sub> INTO HIGH-VALUE CHEMICALS

Innovative catalysts convert waste CO<sub>2</sub> into higher-value, industrially relevant chemicals and materials and eliminates expensive precious metals

## PROMISING ELECTROCHEMICAL TECHNOLOGY DEVELOPMENT



Early-stage research enriches fundamental knowledge and leads to development of **highly active and robust catalysts**.

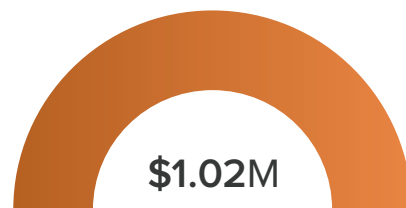


Controlling catalyst morphology is an innovative design principle to **eliminate precious metals** from CO<sub>2</sub> conversion catalysts.

AWARD NUMBER  
**FWP-1022426**

## PROJECT BUDGET

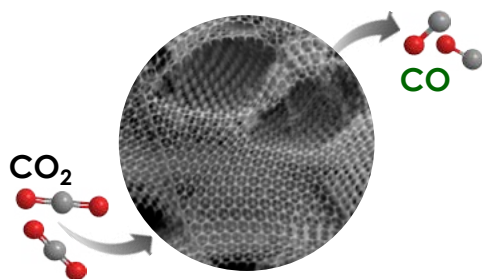
FY19 FUNDING



● DOE SHARE .....\$1,024,000

## NETL DEVELOPS NOVEL CO<sub>2</sub> CONVERSION CATALYST

### Shape Controlled Catalysis



NETL's new strategy to control the 3D morphology of CO<sub>2</sub> conversion catalysts **eliminates expensive precious metals** (gold and silver) while retaining selectivity and performance - **a major breakthrough for CO<sub>2</sub> catalyst development**. Replacing gold with copper leads to an estimated cost savings of **\$50,000 per kilogram of catalyst**.

## CONTACTS

HQ PROGRAM MANAGER  
**AMISHI KUMAR**

TECHNOLOGY MANAGER  
**JOSEPH STOFFA**

TECHNICAL PORTFOLIO LEAD  
**DOUGLAS KAUFFMAN**

PRINCIPAL INVESTIGATOR  
**DOUGLAS KAUFFMAN**

## RAPID ADVANCEMENTS IN CO<sub>2</sub> CONVERSION

- **NETL's work provides insights on structure–property relationships** of oxide-derived copper catalyst for CO production from fossil fuel-generated CO<sub>2</sub> emissions
- **NETL's innovations lead to a publication in the prestigious *Journal of Materials Chemistry A***, with an impact factor of 10.7, and a **Provisional Patent submission**



## PARTNER

RESEARCH & INNOVATION CENTER



CORE COMPETENCY



FE ROADMAP OBJECTIVE: 1.2

# NOVEL CATALYSTS ENHANCE CONVERSION OF CO<sub>2</sub> INTO HIGH-VALUE CHEMICALS

PRESENTER: **DOUGLAS KAUFFMAN**

NETL researchers are using an innovative catalyst design principle to achieve a major breakthrough in CO<sub>2</sub> utilization research. Precise three-dimensional control of catalyst morphology eliminates expensive precious metals such as gold and silver while retaining exceptional catalyst performance. This cutting-edge design strategy, combined with NETL's world-class catalyst synthesis and characterization abilities, enables rapid advancements in CO<sub>2</sub> conversion technology. The highly active and robust catalysts developed at NETL have led to a provisional patent submission and publication in the prestigious *Journal of Materials Chemistry A*. Converting waste CO<sub>2</sub> into chemicals offsets CO<sub>2</sub> capture costs, facilitates clean and safe development of energy resources, and develops new markets and job opportunities.

CORE COMPETENCY:



ENERGY CONVERSION  
ENGINEERING

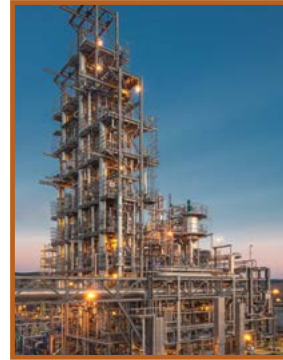
## REDUCING THE COST OF CAPTURED CARBON AND PUTTING IT TO WORK FOR AMERICA



# OVER 110,000 TESTING HOURS PERFORMED AT NATIONAL CARBON CAPTURE CENTER IN 10 YEARS

Unprecedented field testing facility for accelerating transformational carbon capture technologies

The National Carbon Capture Center (NCCC) celebrated **10 years** of technology development in 2019, totaling more than **110,000 hours** of technology testing. **More than 60 technologies** have been field tested, of which **37** were transformational post-combustion capture technologies.



## ACCELERATING COMMERCIALIZATION OF ADVANCED CAPTURE TECHNOLOGIES

The NCCC accelerates the commercialization of advanced solvent, sorbent, membrane, cryogenic systems, and materials to reduce carbon dioxide emissions. The NCCC provides a crucially accessible and versatile testing platform for third-party transformational capture technology developers to determine the viability of capture technologies using actual gas from operating fossil fuel plants.



## COST REDUCTION AND SCALE-UP

Field testing at laboratory- to small pilot-scales (up to 60 TPD) has accelerated technology development while reducing carbon capture cost by one-third, mitigating technology scale-up risk, and communicating progress and lessons learned.



AWARD NUMBER  
**DE-FE0022596**

### PROJECT BUDGET

FY19 FUNDING



- DOE ..... \$166,385,107
- PERFORMER ..... \$41,596,277

### CONTACTS

HQ PROGRAM MANAGER  
**LYNN BRICKETT**

TECHNOLOGY MANAGER  
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FEDERAL PROJECT MANAGER  
**ANDREW O'PALKO**

PRINCIPAL INVESTIGATOR  
**JOHN NORTHINGTON**

### PARTNERS



### CORE COMPETENCIES



FE ROADMAP OBJECTIVE: **1.1**



# OVER 110,000 TESTING HOURS PERFORMED AT NATIONAL CARBON CAPTURE CENTER IN 10 YEARS

PRESENTER: **ANDREW O'PALKO**

The National Carbon Capture Center (NCCC) provides versatile platform and infrastructure to accelerate commercialization of advanced solvents, sorbents, membranes, cryogenic systems, and materials to reduce CO<sub>2</sub> emissions. NCCC celebrated 10 years of technology development in 2019, exceeding 110,000 hours of CO<sub>2</sub> capture technology field testing on 60 technologies, including 37 transformational technologies. NCCC enabled CO<sub>2</sub> capture processes to mitigate CO<sub>2</sub> emissions by lowering capital and operating costs. The data generated in NCCC has empowered decision-makers on economic feasibility and technological advancement to mitigate technology scale-up risk.

CORE COMPETENCIES:



ENERGY CONVERSION  
ENGINEERING



PROGRAM EXECUTION  
and INTEGRATION

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



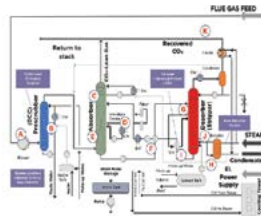
# SCALABLE, LOW-COST CARBON CAPTURE DEMONSTRATED AT COAL PLANTS

Pilot projects demonstrate the scalability and commercial potential of efficient, low-cost carbon capture technologies at coal plant facilities

## THREE PILOT PROJECTS ADVANCE

Three 10-MWe-scale transformational CO<sub>2</sub> capture technology projects are moving forward from successful Phase I feasibility studies to show scalability and commercial potential through Phase II front-end engineering design (FEED) studies. Successful projects may be selected for advancement to Phase III for construction and operation of domestic large-scale pilot facilities.

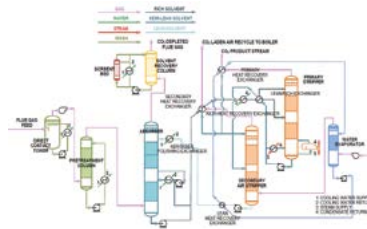
**University of Illinois at Urbana-Champaign's (UIUC)** amine-based post-combustion CO<sub>2</sub> capture technology uses optimized **BASF OASE®** solvent that enables efficient CO<sub>2</sub> capture from low-pressure source at **lower solvent circulation rate** and offers **high stability** compared to competing technologies. High-operation stripper pressure (**3.4 bar**) reduces CO<sub>2</sub> compression cost; advanced stripper **inter-stage heater** reduces steam consumption; and **dry-bed/water wash configuration** reduces solvent loss.



## PARTNERS



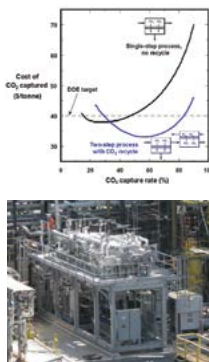
**University of Kentucky's** process-oriented advanced solvent technology uses smaller columns with low operating cost. Advanced solvent has low degradation and offers fast kinetics. A **secondary air stripper** incorporated into the solvent regeneration step reduces regeneration load and strips **17 wt.%** of the total CO<sub>2</sub> absorbed. This process captures CO<sub>2</sub> at a rate of **90%**. Total required regeneration energy is only **1,200-1,400 Btu/lb-CO<sub>2</sub>**. Heat-integrated cooling tower improves plant efficiency, **lowering capital expenditures (CAPEX) and operating expenses (OPEX).**



## University of Kentucky



**Membrane Technology and Research Inc.'s (MTR)** transformational **Large Area Plate-and-Frame** membrane modules capture **200 metric tons/day** of CO<sub>2</sub>. MTR's advanced membrane technology offers at least 10 times more permeance for CO<sub>2</sub> separation compared to conventional membranes. High permeance reduces required membrane area, **lowering CAPEX**. Their two-stage membrane process reduces CO<sub>2</sub> capture cost significantly at **60% capture rate**. Low pressure drop modules **reduce parasitic energy**.



## MTR

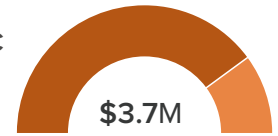


AWARD NUMBERS  
**DE-FE0031581 (UIUC)**  
**DE-FE0031583 (UKRF)**  
**DE-FE0031587 (MTR)**

## PROJECT BUDGET

FY19 FUNDING

UIUC



- DOE ..... \$2,988,359
- PERFORMER ..... \$748,325

UKRF



- DOE ..... \$2,229,364
- PERFORMER ..... \$557,477

MTR



- DOE ..... \$2,946,940
- PERFORMER ..... \$736,868

## CONTACTS

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**ISAAC AURELIO (UKRF)**  
**SAI GOLLAKOTA (MTR)**

PRINCIPAL INVESTIGATOR  
**KEVIN O'BRIEN (UIUC)**  
**KUNLEI LIU (UKRF)**  
**RICHARD BAKER (MTR)**

## CORE COMPETENCIES



ENERGY CONVERSION  
 ENGINEERING



PROGRAM EXECUTION  
 and INTEGRATION

FE ROADMAP OBJECTIVE: **1.1**

## STEP-CHANGE IMPROVEMENTS IN PERFORMANCE

Advancing transformational CO<sub>2</sub> capture technologies to a 10-MWe scale enables demonstration of step-change improvements in carbon capture system performance, efficiency, and cost. By performing FEED studies and eventually building and operating a large-scale pilot facility at a coal-fired power plant, these projects will demonstrate the scalability and commercial potential of transformational coal technologies, helping to mitigate risk and advance commercial deployment.

# SCALABLE, LOW-COST CARBON CAPTURE DEMONSTRATED AT COAL PLANTS

PRESENTER: **ANDREW JONES**

Three 10-MWe-scale transformational CO<sub>2</sub> capture technology projects have completed feasibility studies and moved forward to Phase II front-end engineering design (FEED) studies to scale-up and commercialize coal plant facility carbon capture technologies. University of Illinois at Urbana-Champaign's amine-based post-combustion CO<sub>2</sub> capture technology uses an advanced high-stability solvent that enables efficient CO<sub>2</sub> capture via a low-pressure absorber, low solvent circulation rate, and high-pressure solvent regeneration, resulting in reduced operating and capital costs.

University of Kentucky's process-oriented advanced solvent technology offers fast kinetics, low degradation, and efficient heat integration to lower energy load and equipment cost. Membrane Technology and Research Inc.'s transformational large-area plate-and-frame membrane modules offer high CO<sub>2</sub> permeance and low pressure drop, enabling reduced capital and operational expenditures for carbon capture processes. Advancing transformational CO<sub>2</sub> capture technologies to 10-MWe scale enables demonstration of step-change improvements in carbon capture system performance, efficiency, and cost.

CORE COMPETENCIES:



ENERGY CONVERSION  
ENGINEERING



PROGRAM EXECUTION  
and INTEGRATION

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



# COAL-BASED NANOMATERIALS UTILIZED IN COMPUTER MEMORY DEVICES

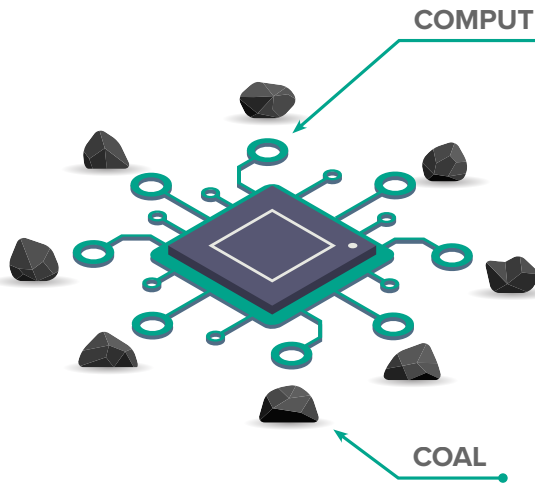
Coal-based nanomaterials boost the efficiency of computer memory devices – enabling the development of edge computing, electronics, and artificial intelligence technologies

## COAL IN COMPUTERS

Coal-based nanomaterials manufactured at NETL are used at the **University of Illinois Urbana-Champaign** to fabricate a computer memory device called a **memristor**. The partnership will enable new commercialization opportunities for coal-based materials in high-tech industries.



## IMPROVING PERFORMANCE AND REDUCING COSTS



Coal-based nanomaterials improve the energy consumption, processing speeds, durability, and manufacturing costs of memristor memory devices in comparison to the conventional devices currently used in computers. These improvements will enable faster and more efficient computing for the Internet of Things (IoT), artificial intelligence, and edge computing.

AWARD NUMBER  
**FWP-1022432**

## PROJECT BUDGET

FY19 FUNDING

**\$250K**

● DOE SHARE ..... \$250,000

## CONTACTS

HQ PROGRAM MANAGER  
**TRACI RODOSTA**

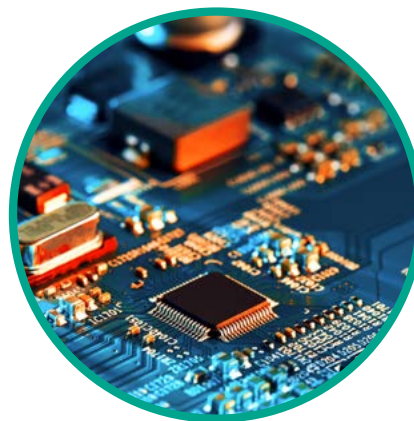
TECHNOLOGY MANAGER  
**JOSEPH STOFFA**

FEDERAL PROJECT MANAGER  
**CHRISTOPHER MATRANGA**

PRINCIPAL INVESTIGATOR  
**CONGJUN WANG**  
**CHRISTOPHER MATRANGA**

## RETHINKING COAL: COMPUTING, ELECTRONICS, AND ENERGY STORAGE

Coal-based materials can be **insulators** or **conductors** depending on how they are processed - opening new opportunities for use in computing, electronics, and energy storage.



RESEARCH & INNOVATION CENTER



CORE COMPETENCY



FE ROADMAP OBJECTIVE: 1.2

# COAL-BASED NANOMATERIALS UTILIZED IN COMPUTER MEMORY DEVICES

PRESENTER: **CONGJUN WANG**

NETL researchers are advancing technologies for producing coal-based nanomaterials. By partnering with the University of Illinois at Urbana-Champaign, coal-based nanomaterials were utilized to fabricate a computer memory device, facilitating new commercialization opportunities for coal in high-tech industries. Additionally, these coal-based nanomaterials improve energy consumption, processing speeds, and durability of computer memory devices while reducing manufacturing costs.

NETL's expertise in processing methods unlock unique insulating or conducting properties of coal-based nanomaterials, advancing technologies needed for the Internet of Things (IoT), artificial intelligence, and edge computing. NETL coal-based nanomaterials open new opportunities for coal in computing, electronics, and energy storage.

CORE COMPETENCY:



MATERIALS ENGINEERING  
and MANUFACTURING

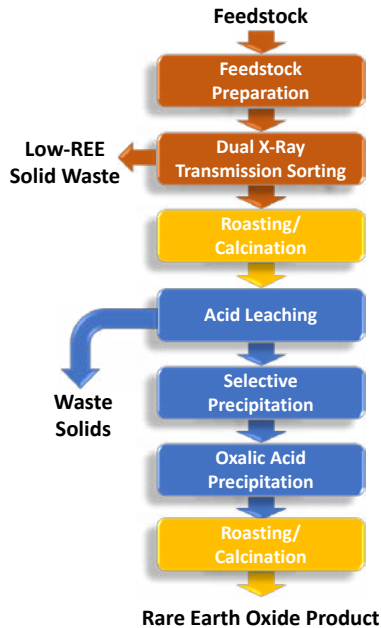
CREATING NEW JOBS, PRODUCTS,  
AND MARKETS FOR COAL



# ECONOMICS IMPROVED FOR RARE EARTH PRODUCTS FROM COAL

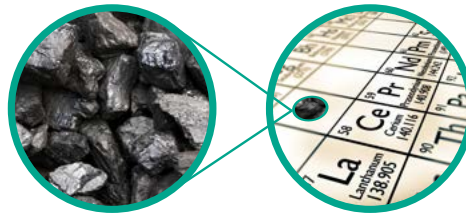
Pilot processing facility produces concentrated quality rare earth products from coal and coal byproduct streams while reducing acid concentration, providing new economic opportunities to coal mining communities

## LOWER COSTS OF ACID LEACHING RARE EARTHS FROM COAL



Roasting coal-based feedstocks upstream of acid leaching drives off volatile materials, increases the interior surface area of the coal particles, and allows a **one-order-of-magnitude reduction in the concentration of acid.**

Rare earth elements (REEs) are the building blocks of our nation's technology future.



## 80% CONCENTRATION OF MIXED RARE EARTHS

University of Kentucky's innovative process and facility consistently produces over 80% concentration of mixed rare earths on an elemental basis (98% on an oxide basis) - **among the highest quality REE product generated to date by external participants.**



PANORAMIC VIEW OF UNIVERSITY OF KENTUCKY'S PILOT-SCALE PLANT IN WESTERN KENTUCKY

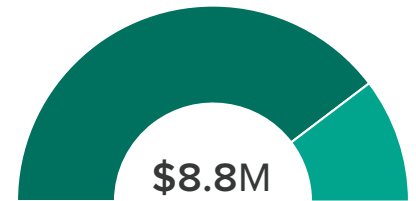


Rare earth extraction technologies are being developed to provide a domestic supply of rare earth oxides and provide additional economic opportunities to coal mining communities.

AWARD NUMBER  
**DE-FE0027035**

### PROJECT BUDGET

FY19 FUNDING



- DOE ..... \$6,999,797
- PERFORMER ..... \$1,820,212

### CONTACTS

- HQ PROGRAM MANAGER  
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- TECHNOLOGY MANAGER  
**MARY ANNE ALVIN**
- FEDERAL PROJECT MANAGER  
**CHARLES E. MILLER**
- PRINCIPAL INVESTIGATOR  
**RICK HONAKER**
- CONTRACT SPECIALIST  
**PATRICK MAYLE**
- CONTRACTING OFFICER  
**ANGELA HARSHMAN**

### PARTNERS



### CORE COMPETENCIES



FE ROADMAP OBJECTIVE: 1.2

# ECONOMICS IMPROVED FOR RARE EARTH PRODUCTS FROM COAL

PRESENTER: **CHARLES MILLER**

The University of Kentucky reduces cost for pilot-scale extraction of rare earth elements (REEs) by roasting coal-based feedstocks upstream of an acid leaching process. Roasting drives off volatile materials, which increases the interior surface area of coal particles and allows a one-order-of-magnitude reduction in the concentration of acid. University of Kentucky's innovative process and facility consistently produces more than 80% concentration of mixed rare earths on an elemental basis (98% on an oxide basis) – among the highest quality REE product generated to date by external participants.

Recent advancements in REE technologies accelerate growth of our nation's economy and strengthen national security by reducing dependence on foreign supplies of REE and providing additional economic opportunities to coal mining communities.

CORE COMPETENCIES:



MATERIALS ENGINEERING  
and MANUFACTURING



PROGRAM EXECUTION  
and INTEGRATION

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

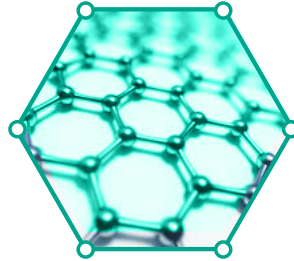


# NETL PARTNERS WITH RAMACO CARBON TO COMMERCIALIZE GRAPHENE FROM COAL

NETL's patent-pending technology converts coal into high-value carbon materials that expand its commercial use beyond traditional power and heat applications

## USING COAL FEEDSTOCKS TO MANUFACTURE HIGH-TECH MATERIALS AND CONSUMER PRODUCTS

NETL's patent-pending technology converts coal into various single-atom-thick carbon materials such as graphene. Graphene is a high-tech material with unprecedented electrical conductivity, strength, and optical properties. Graphene can be used in composites and building materials to create new consumer products with better performance and lower cost.



## PARTNERING WITH INDUSTRY TO COMMERCIALIZE GRAPHENE PRODUCTION

Graphene Quantum Dots Produced from Coal



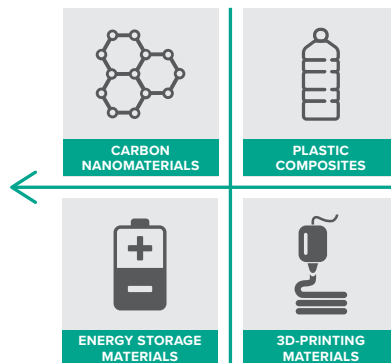
Further Processing Highlights Remarkable Optical Properties



NETL is partnering with Ramaco Carbon to assess the commercial potential of this technology and evaluate pathways for commercial-scale production. This partnership will also evaluate using graphene in a range of life science and medical imaging applications.

## CREATING NEW MARKETS FOR COAL WITH GRAPHENE

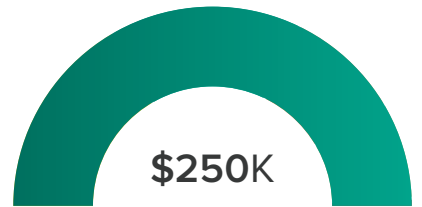
Researchers have successfully processed anthracite, bituminous, and sub-bituminous coal samples from regional partners in Wyoming, Kentucky, Virginia, and Pennsylvania to manufacture graphene quantum dots. Coal enables the low-cost production of graphene and other high-tech carbon materials. Graphene is a critical enabling technology for many emerging applications, such as construction materials, carbon fiber, battery and electrode materials, water purification sorbents, and 3D-printing materials.



AWARD NUMBER  
**FWP-1022432**

### PROJECT BUDGET

FY19 FUNDING



● DOE SHARE ..... \$250,000

### CONTACTS

HQ PROGRAM MANAGER  
**TRACI RODOSTA**

TECHNOLOGY MANAGER  
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TECHNICAL PORTFOLIO LEAD  
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PRINCIPAL INVESTIGATORS  
**FAN SHI**  
**MCMAHAN GRAY**  
**CONGJUN WANG**

### PARTNERS



RESEARCH & INNOVATION CENTER



CORE COMPETENCY



FE ROADMAP OBJECTIVE: 1.2



# NETL PARTNERS WITH RAMACO CARBON TO COMMERCIALIZE GRAPHENE FROM COAL

PRESENTER: **CHRIS MATRANGA**

NETL's patent-pending technology converts coal into high-value carbon materials, increasing markets for coal. Converting coal into single-atom-thick carbon materials such as graphene enables unprecedented electrical, mechanical, and optical properties. In partnership with Ramaco Carbon, NETL leverages those unique properties to evaluate commercial life science and medical imaging applications for coal-based materials.

NETL's expertise in low-cost production of graphene and other high-value carbon materials from coal is a critical enabling technology for emerging applications such as construction materials, carbon fiber, and battery and electrode materials. These applications represent new commercial uses for coal beyond traditional power and heat applications.

CORE COMPETENCY:



MATERIALS ENGINEERING  
and MANUFACTURING

CREATING NEW JOBS, PRODUCTS,  
AND MARKETS FOR COAL



# PROCESS IMPROVEMENTS, COST REDUCTIONS BY AUTOMATION OF RARE EARTHS EXTRACTION

Developing cost-effective and environmentally friendly automated processes for recovering domestic rare earth elements from acid coal mine drainage paves the way for industrial-scale applications

## AUTOMATION ESSENTIAL FOR RARE EARTH EXTRACTION FACILITY

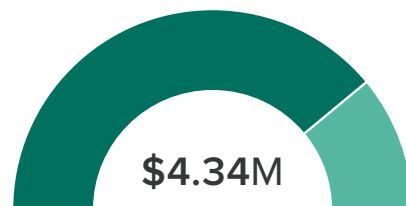
Incorporating instrumentation and controls to automate WVU's rare earth element (REE) extraction system provides real-time process measurements, precisely controls reagent flows, and ensures steady-state operation. The knowledge gained through automation is essential to jump-start the control scheme as the process grows toward an industrial-scale application.



AWARD NUMBER  
**DE-FE0026927**

## PROJECT BUDGET

FY19 FUNDING



- DOE ..... \$3,411,874
- WVU ..... \$928,915

## PRODUCT CONCENTRATE EXCEEDS EXPECTATIONS



A new, cost-effective refining step incorporated into the precipitation circuit after solvent extraction **increases the total REE concentration from approximately 40% to more than 93%**, greatly exceeding the initial goals of the project.

## CONTACTS

HQ PROGRAM MANAGER  
**TRACI RODOSTA**

TECHNOLOGY MANAGER  
**MARY ANNE ALVIN**

FEDERAL PROJECT MANAGER  
**JESSICA MULLEN**

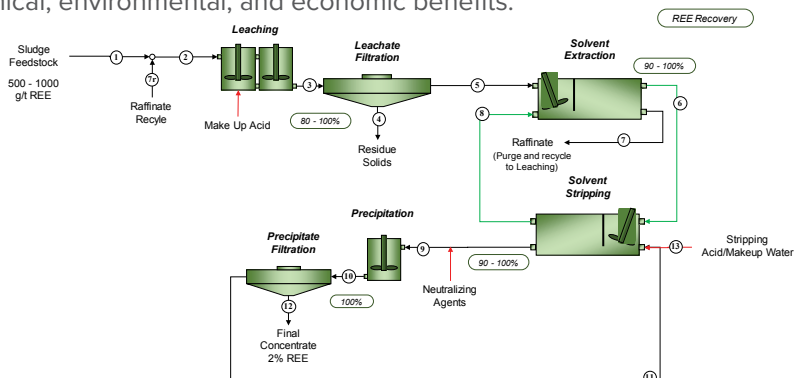
PRINCIPAL INVESTIGATOR  
**PAUL ZIEMKIEWICZ**

CONTRACT SPECIALIST  
**RAELYNN HONKUS**

CONTRACTING OFFICER  
**ANGELA BOSLEY**

## DEVELOPING AN INNOVATIVE REE EXTRACTION PROCESS

WVU's innovative process for extracting REEs from acid coal mine drainage provides many technical, environmental, and economic benefits.



The automation, design, and testing of REE extraction facilities identifies process improvements, reducing REE extraction costs.

## PARTNERS



## CORE COMPETENCIES



FE ROADMAP OBJECTIVE: **1.2**

# PROCESS IMPROVEMENTS, COST REDUCTIONS BY AUTOMATION OF RARE EARTHS EXTRACTION

PRESENTER: **JESSICA MULLEN**

West Virginia University enhanced their rare earth extraction capabilities by incorporating instrumentation and controls to automate their rare earth element (REE) extraction system. Automation provides critical real-time process measurements, precisely controls reagent flows, and ensures steady-state operation – providing essential process control information needed for moving the technology to industrial scale.

Additionally, the state-of-the-art facility incorporated a new cost-effective refining step, more than doubling the final total REE concentration to 93%. Automation and innovative processing steps enable production of highly concentrated rare earths, moving the United States closer to a cost-effective and environmentally benign domestic supply of REEs from acid coal mine drainage.

CORE COMPETENCIES:



MATERIALS ENGINEERING  
and MANUFACTURING



PROGRAM EXECUTION  
and INTEGRATION

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

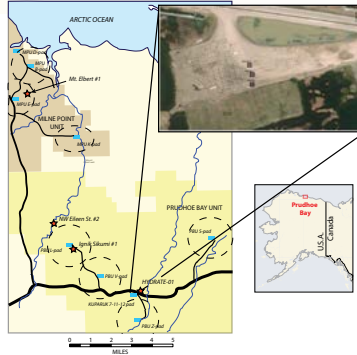


# CONFIRMATION OF ALASKA NORTH SLOPE GAS HYDRATE SITE FOR LONG-TERM TESTING

Reservoirs saturated with gas hydrate in Alaska are confirmed as suitable for extended-duration testing – offering the only viable global option to assess production potential

## ACCOMPLISHMENTS: CONTINUED PROGRESS TOWARD ESTABLISHING A VIABLE FIELD LABORATORY IN ALASKA

- FY19 drilling program designed and executed by NETL, JOGMEC, USGS, PRA, and BPXA
- Hydrate-01 well confirmed geologic viability of site with available surface infrastructure
- Program structure as defined by NETL-JOGMEC CRADA working effectively
- Steering Committee approval gained to advance project toward testing phase

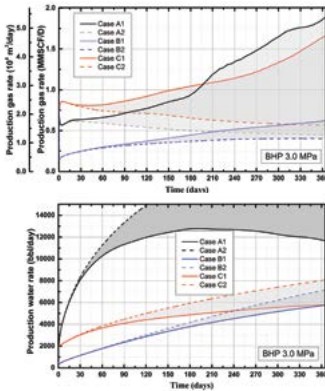


## PROBLEM: FINALIZE DESIGN FOR TEST WELLS

- 2D geo model finalized
- 3D-VSP acquired and interpreted
- Gas and water predictions agreed
- Data acquisition plans finalized
- Evaluating designs for test wells

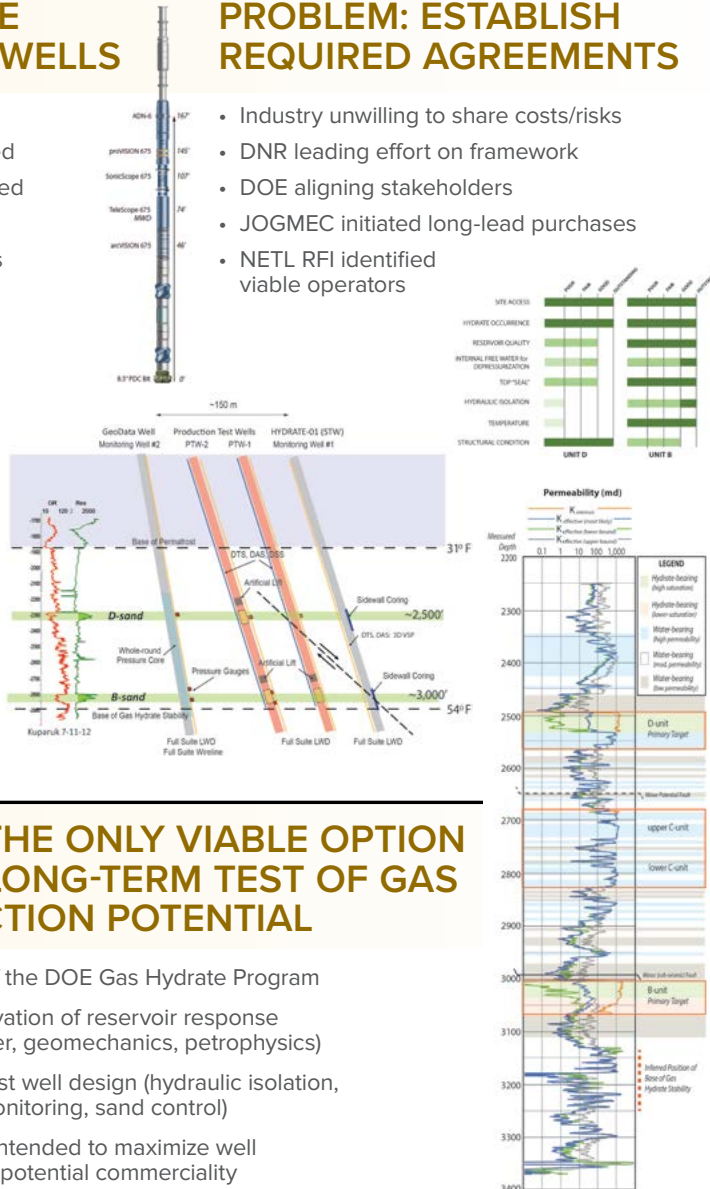
### NETL Gas and Water Rate Predictions (B-sand, 1-yr test)

A – Optimistic; B – Conservative; C – Most Likely  
1 – Confined Model; 2 – Unconfined Model



## PROBLEM: ESTABLISH REQUIRED AGREEMENTS

- Industry unwilling to share costs/risks
- DNR leading effort on framework
- DOE aligning stakeholders
- JOGMEC initiated long-lead purchases
- NETL RFI identified viable operators



## IMPACTS: THIS IS THE ONLY VIABLE OPTION GLOBALLY FOR A LONG-TERM TEST OF GAS HYDRATE PRODUCTION POTENTIAL

- A long-standing primary goal of the DOE Gas Hydrate Program
- Test design will focus on observation of reservoir response to depressurization (heat transfer, geomechanics, petrophysics)
- Test will enable evaluation of test well design (hydraulic isolation, flow assurance, intervention, monitoring, sand control)
- Test will inform follow-on tests intended to maximize well and stimulation to demonstrate potential commerciality

## PROJECT BUDGET

• PETROTECH RESOURCES ALASKA	..... \$5.9M
(planning support; end 3/19)	
• BPXA	..... \$13.0M
(Drilling Services thru PRA: 12/18-1/19)	
• NETL	..... \$1.0M
(modeling/engineering) (EY19 & EY20)	
• LBNL	..... \$503K
(modeling) (FY19+)	
• USGS	..... \$134K
(science) (FY17+)	

## CONTACTS

- HQ PROGRAM MANAGER  
**GABBY INTIHAR**
- STEERING COMMITTEE (DOE)  
**TIM REINHARDT, BRIAN ANDERSON**
- TECHNOLOGY MANAGER  
**JOSEPH STOFFA**
- PRINCIPAL INVESTIGATOR  
**RAY BOSWELL**
- CONTRACT SPECIALIST  
**JEFF KOOSER**
- CONTRACTING OFFICER  
**DON HAFER**
- NETL WORKING GROUP  
**MARIA VARGAS, LEAH BOWER, JESSICA LAMP, DON REMSON, YONGKOO SEOL, EUGENE MYSHAKIN, SKIP PRATT, RICK BAKER, TOM MCGUIRE, ALANA SHERIFF, LISA BAKER**

## PARTNERS

The MH21-S Consortium (JAPAN)



## STAKEHOLDERS



Alaska Dept. of Natural Resources  
Prudhoe Bay Unit Working Interest Owners

## CORE COMPETENCIES



GEOLOGICAL and ENVIRONMENTAL SYSTEMS



PROGRAM EXECUTION and INTEGRATION

FE ROADMAP OBJECTIVE: 1.3

# CONFIRMATION OF ALASKA NORTH SLOPE GAS HYDRATE SITE FOR LONG-TERM TESTING

PRESENTER: **RAY BOSWELL**

DOE/NETL, in collaboration with JOGMEC, USGS, PRA, and BPXA, has taken critical steps toward establishing a long-term methane hydrate production test site on the North Slope of Alaska. The site represents the only location in the world where gas hydrate recoverability can be viably tested and monitored over the desired time frames. A stratigraphic test well, Hydrate-01, was drilled in December 2018 as the initial phase of the program. The well confirmed the presence of two high-quality, hydrate-saturated reservoirs.

Subsurface data were acquired during drilling, logging, and coring operations, including a full suite of geophysical measurements and 34 sidewall pressure cores. In addition, a 2D geological model was finalized, and 3D-VSP subsurface imaging data were acquired, processed, and interpreted. The long-term goal of the project is to test and monitor the response of the gas hydrate-bearing reservoirs to controlled depressurization. The project fulfills a long-standing goal of NETL's Methane Hydrate Program.

CORE COMPETENCIES:



GEOLOGICAL and ENVIRONMENTAL SYSTEMS



PROGRAM EXECUTION and INTEGRATION

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



# CRUCIAL TOOL FOR GAS HYDRATE PRODUCTION RESEARCH READY FOR FIRST USE

World's first specialized pressure core characterization and X-ray CT visualization tools (PCXT) will inform future best practices for methane hydrate production

## NEW SUITE OF TOOLS FOR ANALYZING AND IMAGING HYDRATE-BEARING SAMPLES AT RESERVOIR PRESSURES

### World's first laboratory tool with these capabilities:

- Manipulating hydrate-bearing pressure cores and drilling subsamples at high pressure
- Core-scale and pore-scale physical property measurements at high pressure
- Core-scale and pore-scale X-ray CT scanning at high pressure



Transport Storage Chamber



Anisotropic Permeability Cell



Sample Cutter and Manipulator



CT Scanning Chamber



Effective Stress Chamber

AWARD NUMBER

**FWP-1022410**

## PROJECT BUDGET

**\$626,000**

## CONTACTS

HQ PROGRAM MANAGER

**GABBY INTIHAR**

TECHNOLOGY MANAGER

**JOSEPH STOFFA**

FEDERAL PROJECT MANAGER

**SANDRA BOREK**

PRINCIPAL INVESTIGATOR

**YONGKOO SEOL**

## PRESSURE CORES ARE RARE AND EASILY DESTROYED

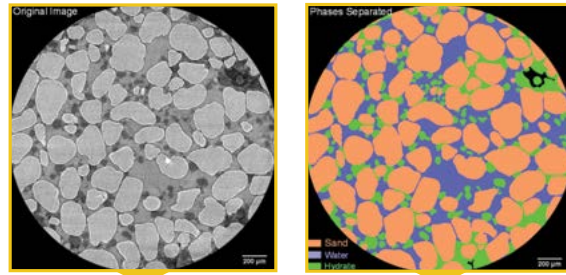
### AND VALUABLE WINDOW INTO HYDRATE RESERVOIR BEHAVIOR

Conventional sample handling does not:

- Maintain sample at *in-situ* reservoir pressures
- Allow for sub-sampling without destruction of hydrate material
- Bridge the gap between core-scale and pore-scale observations



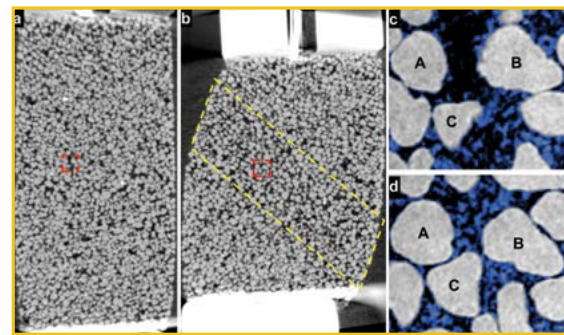
Sub-Coring Tool



Pore-Scale Imaging and Visualization

## NEW *IN-SITU* MEASUREMENTS WILL IMPROVE HYDRATE PRODUCTION STRATEGIES

- Functionality of PCXT tested successfully on synthetic cores
- Nearly ready for natural pressure cores from the Gulf of Mexico
- Results will be projected to reservoir scale to inform best practices for methane hydrate production



Hydrate-Bearing Sediment Behavior Under Loading

## PARTNERS



**Rensselaer**



**West Virginia University**

## CORE COMPETENCY



GEOLOGICAL and ENVIRONMENTAL SYSTEMS

FE ROADMAP OBJECTIVE: **1.3**

# CRUCIAL TOOL FOR GAS HYDRATE PRODUCTION RESEARCH READY FOR FIRST USE

PRESENTER: **YONGKOO SEOL**

NETL's RIC has developed the world's first specialized Pressure Core Characterization and X-Ray Visualization Tools (PCXT) for analyzing and imaging hydrate-bearing samples at in situ reservoir conditions. The tools are designed to manipulate hydrate-bearing pressure cores, drill subsamples, measure core- and pore-scale physical properties, and perform X-ray CT scanning – all while maintaining high-pressure/ low-temperature conditions. Pressure cores, obtained from natural hydrate-bearing reservoirs, are rare and easily destroyed, yet they provide a precious window into hydrate reservoir behavior.

Conventional laboratory testing equipment does not maintain in situ reservoir conditions. This tool suite combines sample handling, measurement, analysis, and imaging capabilities precisely for optimizing information gleaned from pressurized samples. Results will help bridge the gap between pore-scale and core-scale observations and will be used to improve methane hydrate production strategies.

CORE COMPETENCY:



GEOLOGICAL and  
ENVIRONMENTAL SYSTEMS

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



# DRONE-MOUNTED AUTONOMOUS SMART METHANE EMISSION DETECTION SYSTEM REDUCES FALSE POSITIVES

Technology for improved detection of methane emissions employing machine learning

## REAL-TIME METHANE LEAK DETECTION

The Smart Methane Emission Detection System (SLED/M):

- Utilizes machine learning techniques and commercial off-the-shelf optical sensors to enable early leak detection
- Advances the technology to perform autonomously from drones for commercial aerial inspections

SwRI developed a system to reliably, accurately, and identify methane leaks at critical midstream sections of the natural gas distribution network in real time for the purpose of mitigating methane emissions.



Drone with the optical gas imaging (OGI) camera for data collection.

## IDENTIFYING LEAKS ACCURATELY IN A TIME- AND COST-EFFECTIVE MANNER



Ronin Gimbal outfitted with an OGI camera; the gimbal allows for controlled omnidirectional pointing of the camera

Conventional detection systems, designed to locate larger leaks, suffer from false positives and missed detections, which hamper effectiveness and utilization by industry.

SwRI designed SLED/M to **identify methane leaks that typically go unnoticed along pipelines and storage facilities.**

By optimizing algorithms to reliably detect leaks under a variety of environmental conditions, this technology **substantially reduces false positives (<2.25%; # of events classified as leaks).**



## CAN YOU SPOT THE METHANE?

The system detects and pinpoints methane leaks, known as fugitive emissions, by pairing passive optical sensing data with artificial intelligence algorithms.

The integration of SLED/M with a drone has **generated a more precise and efficiently deployed leak detection technology.**

By optimizing and enhancing the algorithms and inspection method, the technology is expected to lead to reduced methane emissions and associated environmental impacts of natural gas production, processing, and transmission.

AWARD NUMBER  
**DE-FE0029020**

## PROJECT BUDGET

TOTAL AWARD VALUE  
**\$1,147,319**

## CONTACTS

HQ PROGRAM MANAGER  
**TIMOTHY REINHARDT**

TECHNOLOGY MANAGER  
**JARED CIFERNO**

FEDERAL PROJECT MANAGER  
**JOSEPH RENK**

PRINCIPAL INVESTIGATOR  
**HEATH SPIDLE**

CONTRACT SPECIALIST  
**CARLA WINAUGHT**

CONTRACTING OFFICER  
**ANGELA HARSHMAN**

## PARTNERS



**IRCameras**



## CORE COMPETENCY



PROGRAM EXECUTION  
and INTEGRATION

FE ROADMAP OBJECTIVE: **1.4**



# DRONE-MOUNTED AUTONOMOUS SMART METHANE EMISSION DETECTION SYSTEM REDUCES FALSE POSITIVES

PRESENTER: **JOSEPH RENK**

Conventional methane detection systems, designed to locate larger leaks, suffer from false positives and missed detections, which hamper effectiveness and utilization by industry. Southwest Research Institute's (SwRI) Smart Methane Emission Detection System (SLED/M) identifies small methane leaks, known as fugitive emissions, that typically go unnoticed along pipelines and storage facilities with a substantial reduction in false positives due to the use of algorithms optimized under a variety of environmental conditions.

The system detects and pinpoints these fugitive emissions by pairing passive optical sensing data with artificial intelligence algorithms and embedded edge computing. The integration of SLED/M into an autonomous drone will enable a more precise and efficiently deployed leak detection method. By optimizing and enhancing the algorithms and inspection method, the autonomous technology in SLED/M will reduce methane emissions and reduce the environmental impact of natural gas transportation.

CORE COMPETENCY:



PROGRAM EXECUTION  
and INTEGRATION

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



# INNOVATION IN ENERGY AWARD TO GLOBAL OIL AND GAS INFRASTRUCTURE DATABASE

The Global Oil and Gas Infrastructure (GOGI) database is an invaluable resource to identify and evaluate global methane emissions from O&G infrastructure. This open-source, big-data-driven platform can be applied to assess hydrocarbon infrastructure needs, economic costs, and support a range of critical decision-making needs.

## HARNESSING THE DATA DELUGE

### Broad Challenge

- **Reliable, accessible data** is the foundation of **scientific inquiry** and **empirical discovery**
- Growing public data contains huge potential to implement big data analytics and resolve **energy-related** and **economic challenges**



### The Task

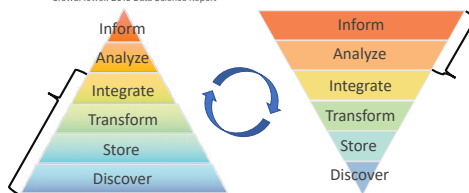
EDF, with support from 10 oil and gas supermajors, wanted to use big data to mitigate fugitive methane emissions from oil and gas infrastructure. They needed an open-source global infrastructure database fast (~four months) and asked NETL's GAIA Group to use our advanced data tools and expertise to respond to this need.

### OUR SOLUTION

- NETL researchers have developed and utilized advanced data-science tools to expedite data discovery, accessibility, and processing times for utilizing new data – creating time for analyzing informing
- We used our custom big data, machine learning, data-science tools and capabilities to rapidly (~four months) integrate publicly available oil and gas infrastructure data across the globe
- Resulted in GOGI v1, the first open-source global oil and gas infrastructure database

Scientists 80% time spent acquiring, cleaning, and organizing data  
– CrowdFlower, 2016 Data Science Report

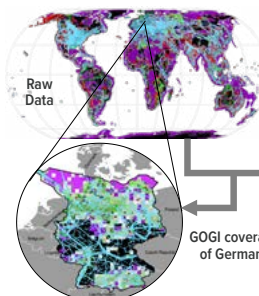
Substantial time saved for analyzing and informing as NETL solutions mature



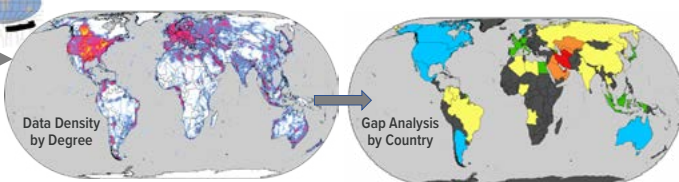
## RAPIDLY REFINING DATA RESOURCES: GOGI v1

- Includes >6 million features from more than 1,000 sources and more than 380 data sets spanning 194 countries
- Researchers used **expert-driven** and **machine learning strategies** for data acquisition

**DEVELOPMENT WORKFLOW:** Converted search terms and phrases into an Open O&G Spatial Database



Categorical Terms = 500  
Geographic Terms = 5,151  
Spatial/Non-Spatial = 380  
Validation Sources = 6



GOGI v1 enables analytics on a per-country, regional, and global basis to assess data quality, identify gaps, mitigate risk, and inform decision-making

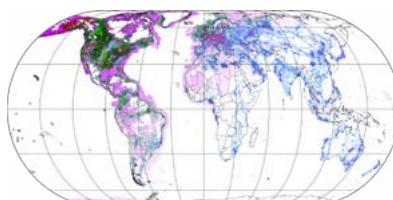
## APPLICATIONS AND RECOGNITION

- Applied by **Environmental Defense Fund** to quantify methane emissions across global oil and gas supply chain
- GOGI used in **Harvard study** on methane emissions, manuscript for **Earth System Science Data journal** (Scarpelli et al., below)
- NETL **Technical Report** includes data quality assessment and gap analysis by country, region, and at the global scale (Rose et al., 2018)
- Database touted by **Buzzfeed's Data Editor** who broadcast it through his data analytics feed
- GOGI v1 **downloaded** from EDX more than 900 times
- **GOGI v2** discussions ongoing now with EDF for potential machine learning/artificial intelligence-driven Phase II study to support their MethaneSAT work

GOGI Team Received 2019 Carnegie Science Award for Innovation in Energy



Access and visualize GOGI through GeoCube – NETL's interactive web mapping platform



Rose, K., Bauer, J., Baker, V., Bean, A., DiGiulio, J., Jones, K., Justman, D., Miller, R. M., Romeo, L., Sabbatino, M., Tong, A. Development of an Open Global Oil and Gas Infrastructure Inventory and Geodatabase: NETL-TRS-6-2018; NETL Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory; Albany, OR, 2018; p 594; DOI: 10.18141/1427573.  
Sabbatino, M., Romeo, L., Baker, V., Bauer, J., Barkhurst, A., Bean, A., DiGiulio, J., Jones, K., Jones, T.J., Justman, D., Miller III, R., Rose, K., and Tong, A. 2017. Global Oil & Gas Features Database. Submitted 2017-12-12. Available at: <https://edx.netl.doe.gov/dataset/global-oil-gas-features-database>. DOI: 10.18141/1427300  
Scarpelli, T., Jacob, D., Maasackers, J., Sulprizio, M., Sheng, J., Rose, K., Romeo, L., Worden, J., Janssens-Maenhout, G. In review. A global gridded (0.1° x 0.1°) inventory of methane emissions from oil, gas, and coal exploitation based on national reports to the United Nations Framework Convention on Climate Change. Earth System Science Data (In press).

CRADA NUMBER  
**#0693**

### PROJECT BUDGET

**\$160,873**

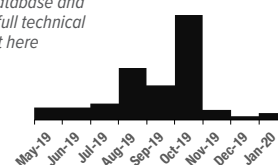
### ACCESS TO GOGI

GOGI database and technical report available for download on NETL's Energy Data eXchange (EDX)



- Data and information available globally, regionally, and by country
- Downloaded more than 900 times from EDX\*

Download GOGI geodatabase and view full technical report here



### CONTACTS

NETL WORKING GROUP  
**KELLY ROSE**  
**JENNIFER BAUER**  
**LUCY ROMEO**  
**AARON BARKHURST**  
**DEVIN JUSTMAN**  
**VIC BAKER**  
**ANDREW BEAN**  
**MICHAEL SABBATINO**

### PARTNERS



CARBON LIMITS

HARVARD UNIVERSITY



### CORE COMPETENCY



FE ROADMAP OBJECTIVES: **1.3, 1.4**

# INNOVATION IN ENERGY AWARD TO GLOBAL OIL AND GAS INFRASTRUCTURE DATABASE

PRESENTERS: **KELLY ROSE** and **CHAD ROWAN**

The award-winning Global Oil and Gas Infrastructure (GOGI) database is the first open-source database of oil and natural gas infrastructure information that offers insights into each country's hydrocarbon footprint. This groundbreaking achievement provides an invaluable technological tool for: predicting and assessing global methane emissions risks; providing a big-data platform to assess local hydrocarbon infrastructure needs; identifying information gaps; evaluating economic costs; and supporting a range of critical decision-making needs.

Research teams from throughout the world can access authoritative information needed to make critical decisions when developing oil and gas infrastructure and take energy-saving action to reduce methane leaks.

CORE COMPETENCY:



GEOLOGICAL and  
ENVIRONMENTAL SYSTEMS

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



# SHALE GAS PRODUCTION IMPROVED AT WEST VIRGINIA FIELD SITE

Unraveling the Marcellus Shale to maximize resource recovery

## OPTIMIZING PRODUCTION EFFICIENCY AND OVERALL HYDROCARBON RECOVERY

One of the most advanced field laboratory test sites in the Nation to test innovative and environmentally sustainable approaches for the development of shale gas, supporting DOE's mission of energy independence.

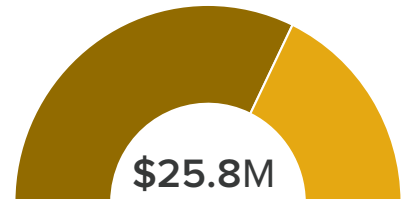
Development/validation of new knowledge and technologies have led to reserve increases of up to 20% and contributed to best practices incorporated into drilling, completion, and stimulation (DCS) operations.



AWARD NUMBER  
**DE-FE0024297**

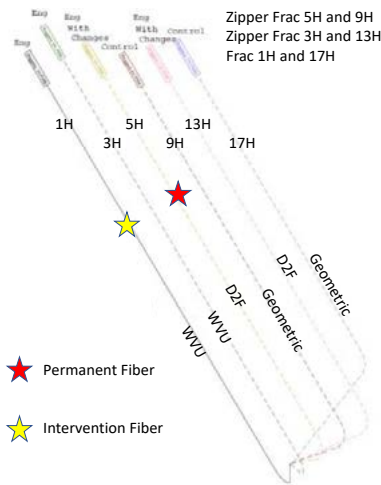
## PROJECT BUDGET

FY19 FUNDING



- DOE SHARE .....\$16,608,355
- PERFORMER .....\$9,180,952

## ADVANCED GEOMECHANICAL MODELING



- Computed tomography imaging and logging 250 feet of 4-inch whole core and over 125 sidewall cores retrieved from the initial Northeast Natural Energy Morgantown Industrial Park and subsequent Boggess sites. Core has been distributed to scientists at multiple institutions to expand our fundamental understanding of gas-bearing shales
- Development of a high-resolution geomechanical model of the Marcellus to yield insights to improve production efficiency and environmental performance throughout the Marcellus Shale region – the largest natural gas play in the United States

## CONTACTS

- HQ PROGRAM MANAGER  
**ELENA MELCHERT**
- TECHNOLOGY MANAGER  
**JARED CIFERNO**
- FEDERAL PROJECT MANAGER  
**ROB VAGNETTI**
- PRINCIPAL INVESTIGATOR  
**TIM CARR, WVU**
- CONTRACT SPECIALIST  
**ANGELA BOSLEY**
- CONTRACTING OFFICER  
**SUE MILTENBERGER**

## BIG DATA ACQUISITION AND MACHINE LEARNING

- Multi-scale modeling approaches and advanced data collection from dedicated downhole fiber optic sensors improving the understanding of hydraulic fracturing response and stimulated rock volume (SRV)
- More cost-effective data acquisition and coupled modeling approaches for adoption by operators throughout the Marcellus Shale region
- Data integration leading to engineered completion designs, which optimize spacing between laterals, stage length, and perforation clusters



## PARTNERS



## CORE COMPETENCIES



FE ROADMAP OBJECTIVE: **1.3**

# SHALE GAS PRODUCTION IMPROVED AT WEST VIRGINIA FIELD SITE

PRESENTER: **ROB VAGNETTI**

The largest improvements in unconventional oil and gas development are expected through optimized well completion and stimulation strategies aimed at maximizing well productivity and overall hydrocarbon recovery. The data obtained from a suite of innovative behind-the-bit tools deployed at the Marcellus Shale Energy and Environmental Laboratory, together with data from 130 feet of core collected by NETL's CT Imaging Lab, have been integrated into advanced reservoir models supported by machine learning algorithms to optimize cluster and stage designs at a 6-well pad near Core, West Virginia. This field laboratory represents one of the most advanced oil and gas test sites in the nation, supporting the DOE mission of energy independence.

CORE COMPETENCIES:



GEOLOGICAL and  
ENVIRONMENTAL SYSTEMS



PROGRAM EXECUTION  
and INTEGRATION



SYSTEMS ENGINEERING  
and ANALYSIS

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



# WELL BLOWOUT PREVENTION ADVANCED BY DOWNHOLE KICK DETECTION TECHNOLOGY

Award-winning downhole sensor-based kick detection system provides real-time notification of fluid influxes during drilling operations to prevent loss of well control – improving safety and reducing operating costs

## MOTIVATION

- Late kick detection is cited as one of the primary causes of well control failures
- Blowouts can result in loss of human life, catastrophic environmental damage, and substantial economic losses
- A method for early kick detection is needed



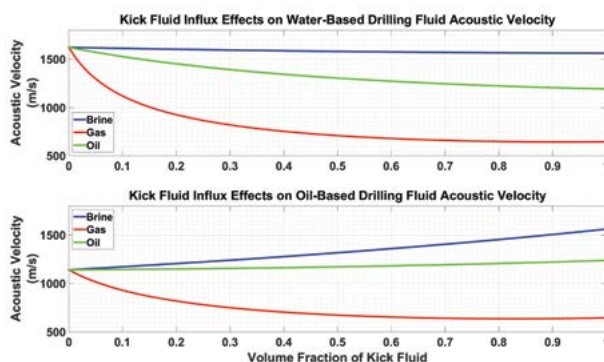
# 44%

## OF NON-PRODUCTIVE TIME IS ASSOCIATED WITH KICK/WELLBORE INSTABILITY-RELATED PROBLEMS

## ACCOMPLISHMENTS

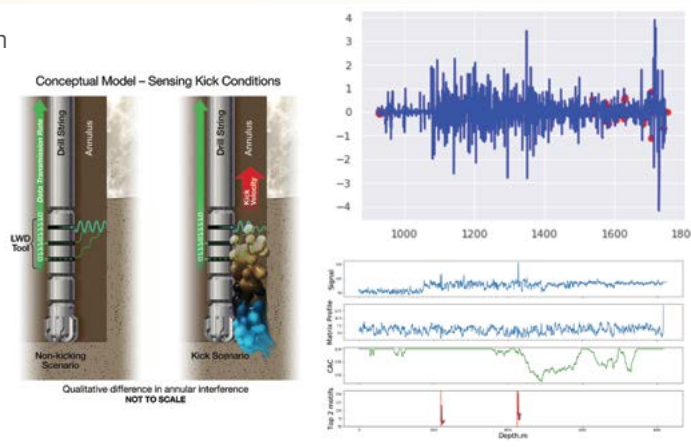
- Completed the Proof-of-Concept work that predicts that kicks can be detected downhole, and estimates substantial warning time for the driller
- Awarded Technology Commercialization Fund (TCF) award with Saudi Aramco
- CRADA signed with Saudi Aramco
- Received a U.S. Patent in April 2019

FORMATION FLUID	WATER-BASED DRILLING FLUID		
	EFFECT ON MIXTURE PROPERTY		
	ELECTRICAL RESISTIVITY	BULK DENSITY	ACOUSTIC VELOCITY
BRINE	DECREASES	DECREASES	VARIABLE
PETROLEUM	INCREASES	VARIABLE	VARIABLE
NATURAL GAS	INCREASES	DECREASES	DECREASES



## NEXT STEPS

- On path to commercialization
- Exploring other industry interest (e.g., TOTAL, CT4, Petrobras, etc.)
- Validating, through TCF project, the technology using field data from industry partners and experimental data
- Developing a kick fingerprinting algorithm to predict kick fluid composition and volume



AWARD NUMBER  
**FWP-1022409**

U.S. PATENT NUMBER  
**10253620**

## PROJECT BUDGET

TOTAL AWARD VALUE  
**\$3,555,181**

## CONTACTS

HQ PROGRAM MANAGER  
**ELENA MELCHERT**

TECHNOLOGY MANAGER  
**ROY LONG**

TECHNICAL PORTFOLIO LEAD  
**KELLY ROSE**

CONTRACT SPECIALIST  
**MAUREEN DAVISON**

CONTRACTING OFFICER  
**JEFF KOOSER**

## EXTERNAL INTEREST



**ExxonMobil**

**BOEM**  
BUREAU OF OCEAN ENERGY MANAGEMENT

**LSU** UNIVERSITY OF HOUSTON



ارامكو السعودية  
**Saudi Aramco**



**CT4**



## CORE COMPETENCIES



GEOLOGICAL and ENVIRONMENTAL SYSTEMS



PROGRAM EXECUTION and INTEGRATION

FE ROADMAP OBJECTIVE: **1.3**

# WELL BLOWOUT PREVENTION ADVANCED BY DOWNHOLE KICK DETECTION TECHNOLOGY

PRESENTER: **KELLY ROSE**

NETL's patented cost-effective and near real-time early kick detection system uses downhole measurements to provide data on the wellbore condition of onshore and offshore subsurface drilling operations. If a kick has occurred, it will be reflected in measurements that are made available to the driller much faster than the kick fluid can travel, allowing the driller to take necessary action to regain well control before the kick strengthens. Shutdown costs, time, personnel safety, and ecosystem damage associated with wellbore loss-of-control events are of significant concern in the drilling industry. The use of this technology will improve safety, reduce operational costs, and reduce the likelihood of a loss-control event during drilling operations.

CORE COMPETENCIES:



GEOLOGICAL and  
ENVIRONMENTAL SYSTEMS



PROGRAM EXECUTION  
and INTEGRATION

**LEVERAGING BIG DATA AND MACHINE  
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NATURAL GAS RESOURCES**





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**Pittsburgh, PA** 15236  
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Program staff are also located in  
**Houston, TX** and **Anchorage, AK**

**CUSTOMER SERVICE**  
1-800-553-7681

[www.NETL.DOE.gov](http://www.NETL.DOE.gov)