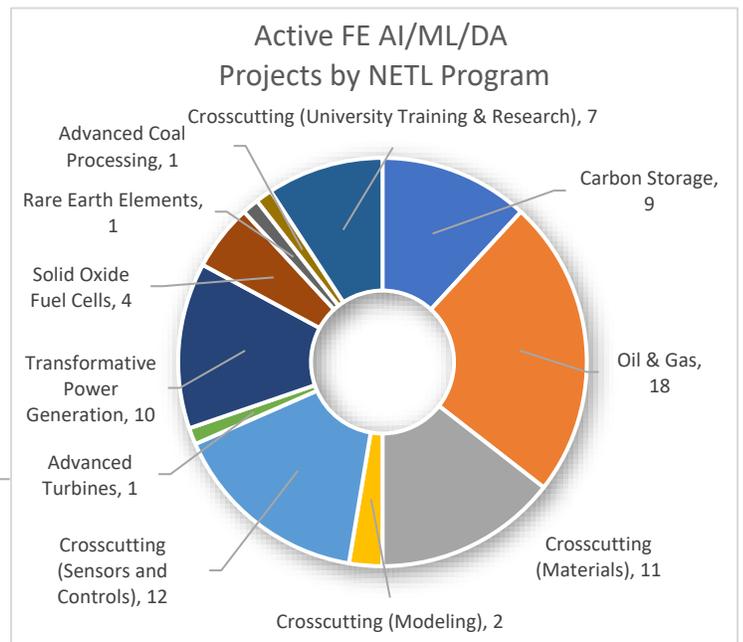


Artificial Intelligence, Machine Learning, and Data Analytics at NETL

Artificial intelligence (AI) refers to machines that can – for a given set of human-defined objectives – learn, predict, and make decisions, significantly increasing the speed and efficacy of decision making. Most AI applications use algorithms known as machine learning (ML) to find patterns in massive amounts of data. The patterns are then used for making predictions. The automated methods capturing, organizing, and processing the massive amounts of data used by ML are known as data analytics (DA). At the National Energy Technology Laboratory (NETL), these tools are used to accelerate numerous areas of energy technology development.

Energy applications for artificial intelligence (AI), machine learning (ML), and data analytics (DA) provide innovative ways to augment the National Energy Technology Laboratory’s (NETL) ongoing mission for the U.S. Department of Energy/Office of Fossil Energy (DOE/FE) to find more efficient methods to use the nation’s abundant energy resources for a thriving economy, a cleaner environment, and continued energy security.

76 FE R&D projects with total funding of more than \$250 million currently utilize AI, ML, or DA (see chart), including 64 extramural FE projects and 12 internal NETL projects. In addition, there are 22 Office of Electricity and Office of Cybersecurity, Energy Security, and Emergency Response projects managed by NETL.



Transforming Subsurface Science AI/ML/DA can:

- Analyze large geologic datasets efficiently
- Improve understanding of geophysical conditions and reactions to injection/recovery
- Improve subsurface visualization for enhanced characterization
- Improve well integrity and completion design
- Increase hydrocarbon recovery
- Reduce environmental impacts
- Improve dynamic forecasting of reservoir response
- Improve autonomous monitoring and control of injection and production operations

Transforming Fossil Energy Plants AI/ML/DA can:

- Improve maintenance
- Diagnose problems early
- Reduce outages and downtime
- Prevent and detect damage
- Improve flexible operation
- Reduce emissions
- Increase efficiency
- Reduce cost of energy
- Improve cybersecurity

Applying AI/ML/DA techniques and science-based models helps NETL scientists and projects achieve breakthroughs in meeting the needs of existing U.S. electric power plants, next-generation advanced energy systems, and subsurface operations involving oil and gas operations and carbon storage.

NETL R&D Applications in AI/ML/DA

DOE's fossil energy research and development (R&D) programs are taking advantage of *new opportunities over a broad range of potential applications for AI, ML, and DA techniques. These techniques help researchers ask more relevant questions and design better experiments to reach development goals at a faster pace. With continued growth in the speed and computational power of supercomputers, these tools are becoming increasingly useful to the energy research landscape.*

The table below shows the AI/ML/DA applications being investigated under fossil energy R&D programs.

AI/ML/DA Application	Fossil Energy R&D Programs										
	Carbon Storage	Oil & Gas	High-Performance Materials	Modeling and Simulation	Sensors and Controls	University Training and Research	Advanced Turbines	Trans. Power Gen.	Solid Oxide Fuel Cells	Rare Earth Elements	Advanced Coal Processing
Predictive Maintenance								X			
Digital Twins				X							
Agent-Based Controls/Online System Identification					X						
Power Plant Components			X				X		X		
Condition-Based Monitoring					X		X	X	X		
Materials Development			X	X					X		
Cybersecurity					X	X					
Damage Detection						X		X			
Process Optimization and Control			X	X	X	X	X	X	X		
Data Characterization	X	X									X
Predictive Methods	X	X								X	

NETL Predictive Modeling Tools that Leverage AI/ML/DA

NETL utilizes an extensive suite of predictive modeling tools that leverage AI/ML/DA in support of the DOE/FE mission.

The Institute for the Design of Advanced Energy Systems (IDAES)

The Institute for the Design of Advanced Energy Systems (IDAES) is a resource for developing and optimizing innovative advanced energy systems via process systems engineering tools and approaches. The open-source IDAES computational framework supports developing new concepts for energy systems. Due to the complexity of energy systems and an increasing need to operate dynamically, IDAES models support tightly coupled multi-scale optimization of processes with the bulk power system, while incorporating uncertainty quantification techniques. This includes a process model library and optimization-based ML tools for creating thermophysical property models, reaction models, and general surrogate models.

Offshore Risk Modeling (ORM) Suite

NETL's Offshore Risk Modeling (ORM) suite supports DOE goals for offshore spill prevention and data-driven risk assessments for oil and natural gas industry activities. ORM improves offshore oil and gas operational strategies and resource assessments using novel DA, ML, and advanced visualization techniques optimized for the offshore. ORM can be used in daily operations as well as long-term planning to improve decision making, and it helps ensure that the United States is prepared for future rapid response needs (e.g., hurricane impacts, oil spill scenario planning).

Global Oil and Gas Infrastructure (GOGI) Database

The Global Oil and Gas Infrastructure (GOGI) database demonstrates novel DA and ML methods and tools developed by NETL to rapidly and efficiently find, access, integrate, and use internet data to map and assess global oil and gas infrastructure. The GOGI database is funded by the United Nations Environment Programme (UNEP) and 10 of the world's largest oil and gas companies to improve infrastructure maintenance and reduce their environmental footprint.

Multiphase Flow Science Tools (MFiX)

NETL's suite of multiphase computational fluid dynamics (CFD) code, called Multiphase Flow with Interphase eXchanges (MFiX), is developed for modeling reacting multiphase systems. This open-source suite of software tools has more than three decades of development history and more than 5,000 registered users worldwide. The software is the standard testbed for comparing, implementing, and evaluating multiphase flow constitutive models. In a project called "CFD for Advanced Reactor Design (CARD)," NETL's in-house MFiX group uses AI to accelerate CFD codes.

Carbon Capture Simulation for Industry Impact (CCSI²)

The Carbon Capture Simulation for Industry Impact (CCSI²) is a partnership among national laboratories, industry, and academic institutions that develops, deploys, and utilizes state-of-the-art computational modeling and simulation tools. CCSI²'s open-source, R&D 100 award-winning computational toolset provides end users in industry with a comprehensive, integrated suite of scientifically validated models with uncertainty quantification, optimization, risk analysis, and intelligent decision-making capabilities. CCSI² utilizes a variety of ML methods within its Framework for Quantification of Uncertainty and Surrogates (FOQUS), helping generate optimal experimental designs that maximize the learning from costly laboratory- and pilot-scale experiments, reducing technical risk. CCSI² also employs DA and ML to accelerate the solution of complex models for the detailed design of novel carbon capture devices and components that utilize advanced manufacturing to enable process intensification.

NETL Capability Centers for AI/ML/Data Analytics

NETL established and leads the Science-Based Artificial Intelligence/Machine Learning Institute (SAMI), a joint institute for AI and ML. NETL has created SAMI's required computational infrastructure, including the Joule 2.0 supercomputer, the Watt computer for data analysis, and the Energy Data eXchange (EDX), supporting the entire life cycle of data with secure, private, collaborative workspaces for research projects. NETL also is investing in new infrastructure to support SAMI, including the Center for Artificial Intelligence and Machine Learning (CAML) at NETL-Pittsburgh and a Computational Science and Engineering (CSE) Center at NETL-Morgantown.



Science-Based Artificial Intelligence/Machine Learning Institute (SAMI)

The Science-Based Artificial Intelligence/Machine Learning Institute (SAMI) combines the strengths of NETL's fossil energy subject matter experts, computational scientists, and data scientists with experts in AI/ML at external institutions. SAMI is supported by NETL's supercomputer and AI/ML computer hardware. SAMI accumulates ML knowledge in analytical projects; enhances data handling functions, including curation, management, and data transformation; and combines physics-based modeling and AI/ML to address previously unanswerable problems. SAMI supports lab initiatives in fossil energy integration, optimization, and resiliency and real-time decision science for the subsurface, as well as NETL's effort to develop and screen materials for carbon capture.



Center for Artificial Intelligence and Machine Learning (CAML)

NETL's Center for Artificial Intelligence and Machine Learning (CAML) houses computer hardware and software allowing researchers to explore problems using AI and ML. The center features a machine designed to house, transport, and process up to 19 petabytes of data using cutting-edge algorithms developed by NETL and external collaborators.



Center for Computational Science and Engineering (CSE)

NETL is home to Joule 2.0, which is among the fastest, largest, and most energy-efficient supercomputers in the United States. The powerful 4-petaflop system allows researchers to simulate energy technologies at various scales with the help of physics-based models, such as density functional theory, molecular dynamics, Monte Carlo simulations, microkinetic models, phase-field models, CFD, and others. Most of the research projects at NETL use such simulations to save time and resources in support of successful technology development.



Appendix: Active NETL AI/ML/DA Projects

Project Number	Performer	Project Title	Program	NETL Technology Manager
FWP-1022432	NETL	Task 6: COAL DATA	Advanced Coal Processing	Joseph Stoffa
FE0026515	University of Texas at Austin	Development of a Framework for Data Integration, Assimilation, and Learning for Geological Carbon Sequestration	Carbon Storage	Mark McKoy
FE0031684	New Mexico Institute of Mining and Technology	Improving Subsurface Stress Characterization for Carbon Dioxide Storage Projects by Incorporating Machine Learning Techniques	Carbon Storage	Mark McKoy
FWP-18-021006	Sandia National Laboratories (SNL)	FWP Support for: Identification of Faults Susceptible to Induced Seismicity: Integration of Forward and Joint Inversion Modeling, Machine Learning, and Field Calibrated Geologic Models	Carbon Storage	Mark McKoy
FWP-FE-1142-19-FY20	Los Alamos National Laboratory (LANL)	Support for Regional Initiative to Accelerate CCUS Deployment in Midwestern and Northeastern USA	Carbon Storage	Mark McKoy
FWP-FE-1143-19-FY20	Los Alamos National Laboratory (LANL)	Southeast Regional Carbon Storage Partnership: Phase IV	Carbon Storage	Mark McKoy
FWP-FE-853-17-FY17	LANL - Los Alamos National Laboratory	Autonomous Monitoring of Wellbore Integrity Applying Time Reverse Nonlinear Elastic Wave Spectroscopy (TR NEWS) and Fiber Optic Sensing and Communication	Carbon Storage	Mark McKoy
FE0031685	University of Illinois at Urbana-Champaign	Identification of Faults Susceptible to Induced Seismicity	Carbon Storage	Mark McKoy
FE0031544	Pennsylvania State University	Integration of Seismic-Pressure-Petrophysics Inversion of Continuous Active-Seismic Monitoring Data for Monitoring and Quantifying CO2 Plume	Carbon Storage	Mark McKoy
FWP-1022465	National Energy Technology Laboratory (NETL)	Carbon Storage Data	Carbon Storage	Mark McKoy
FWP-FEAA134	Oak Ridge National Laboratory (ORNL)	ExtremEMat: Accelerated Design and Manufacture of Next-Generation for Extreme Environment Materials	Crosscutting (High Performance Materials)	Briggs White
FE0031553	Pennsylvania State University	High Throughput Computational Framework of Materials Properties for Extreme Environments	Crosscutting (High Performance Materials)	Briggs White

Project Number	Performer	Project Title	Program	NETL Technology Manager
FE0031554	Missouri State University	Multi-modal Approach to Modeling Creep Deformation In Ni-Base Superalloys	Crosscutting (High Performance Materials)	Briggs White
FWP-FEAA128	Oak Ridge National Laboratory (ORNL)	Components Fabricated by Additive Manufacturing	Crosscutting (High Performance Materials)	Briggs White
FWP-1022433	National Energy Technology Laboratory (NETL)	eXtremeMAT - Accelerated Design and Manufacture of Next Generation Extreme Environment Materials	Crosscutting (High Performance Materials)	Briggs White
FWP-71133	NETL; PNNL	ExtremEMat: Extreme Environment Materials	Crosscutting (High Performance Materials)	Briggs White
FWP-B000-17016	Idaho National Laboratory (INL)	ExtremEMat: Extreme Environment Materials	Crosscutting (High Performance Materials)	Briggs White
FWP-FE-850-17-FY17	Los Alamos National Laboratory (LANL)	ExtremEMat: Extreme Environment Materials	Crosscutting (High Performance Materials)	Briggs White
FE0031559	University of Maine	Ultrasonic Measurements of Temperature Profile and Heat Fluxes in Coal-Fired Power Plants	Crosscutting (High Performance Materials)	Briggs White
FWP-1022406	NETL	Advanced Alloy Development	Crosscutting (High Performance Materials)	Briggs White
UCFER-04-20	Carnegie Mellon University	Computer vision and machine learning making the processing-microstructure- property connection in heat resistant alloys	Crosscutting (High Performance Materials)	Sydni Credle
FWP-1022423	NETL, CMU, SNL, WVU, LBNL	IDAES - Institute for the Design of Advanced Energy Systems	Crosscutting (Modeling, Simulation, and Analysis)	Sydni Credle
FE0031644	Southwest Research Institute	Digital Twin Model for Advanced Manufacture of a Rotating Detonation Engine Injector	Crosscutting (Modeling, Simulation, and Analysis)	Sydni Credle

Project Number	Performer	Project Title	Program	NETL Technology Manager
FE0031753	Expert Microsystems	Hybrid Analytics Solution to Improve Coal Power Plant Operations	Crosscutting (Sensors and Controls)	Sydni Credle
SC0018729	Sonalysts, Inc.	Metaphortress: A Situational Awareness Platform	Crosscutting (Sensors and Controls)	Sydni Credle
FE0031288	Georgia Tech Research Corporation	Real-Time Health Monitoring for Gas Turbine Components using Online Learning and High Dimensional Data	Crosscutting (Sensors and Controls)	Sydni Credle
FE0031641	General Electric (GE) Company	Physical Domain Approaches to Reduce Cybersecurity Risks Associated with Control Systems	Crosscutting (Sensors and Controls)	Sydni Credle
FE0031640	Southern Company Services, Inc.	Operational Technology Behavioral Analytics	Crosscutting (Sensors and Controls)	Sydni Credle
FE0031768	West Virginia University Research Corporation	Boiler Health Monitoring using a Hybrid First Principles-Artificial Intelligence Model	Crosscutting (Sensors and Controls)	Sydni Credle
FE0031763	General Electric (GE) Company	Deep Analysis Net with Casual Embedding for Coal Fired Power Plant Fault Detection and Diagnosis	Crosscutting (Sensors and Controls)	Sydni Credle
FWP-1022427	NETL	Advanced Sensors and Controls: Task 5.1 - Development and Testing of Agent Based Controls for Power Systems	Crosscutting (Sensors and Controls)	Sydni Credle
FE0031751	National Rural Electric Cooperative Association	Generation Plant Cost of Operations and Cycle Optimization Model	Crosscutting (Sensors and Controls)	Sydni Credle
FE0031666	Siemens Corporation	Cyber Secure Sensor Network for Fossil Fuel Power Generation Assets Monitoring	Crosscutting (Sensors and Controls)	Sydni Credle
FE0026348	Siemens Corporation	Novel Temperature Sensors and Wireless Telemetry for Active Condition Monitoring of Advanced Gas Turbines	Crosscutting (Sensors and Controls)	Sydni Credle
SC0020797	Sporian Microsystems, Inc.	A Spectroscopy-Based, Online, Real-time Monitoring System with Integrated Machine Learning for Liquid Phase Selenium in Coal Power Plant Effluent Streams	Crosscutting (Sensors and Controls)	Sydni Credle

Project Number	Performer	Project Title	Program	NETL Technology Manager
FE0031645	University of Missouri	A Robotics Enabled Eddy Current Testing System for Autonomous Inspection of Heat Exchanger Tubes	Crosscutting (University Training & Research)	Sydni Credle
FE0031650	Colorado School of Mines	AI Enabled Robots for Automated Nondestructive Evaluation and Repair of Power Plant Boilers	Crosscutting (University Training & Research)	Sydni Credle
FE0031745	Florida International University	Secure Data Logging and Processing with Blockchain and Machine Learning	Crosscutting (University Training & Research)	Sydni Credle
FE0031651	Florida International University	Development of a Pipe Crawler Inspection Tool for Fossil Energy Power Plants	Crosscutting (University Training & Research)	Sydni Credle
FE0031655	University of Texas at El Paso	Autonomous Aerial Power Plant Inspection in GPS-Denied Environments	Crosscutting (University Training & Research)	Sydni Credle
FE0031649	New Mexico State University	A Lizard-Inspired Tube Inspector (LTI) Robot	Crosscutting (University Training & Research)	Sydni Credle
FE0031904	Florida International University	Development and Evaluation of a General Drag Model for Gas-Solid Flows Via Physics-Informed Deep Machine Learning	Crosscutting (University Training & Research)	Sydni Credle
M617000257	Sandia National Laboratories (SNL)	Survivable Industrial Control Systems (ICS)	Cybersecurity for Energy Delivery Systems	Eddie Christy
M614000328	Sandia National Laboratories (SNL)	Artificial Diversity and Defense Security (ADDSec)	Cybersecurity for Energy Delivery Systems	Eddie Christy

Project Number	Performer	Project Title	Program	NETL Technology Manager
OE0000833	General Electric	Cyber Attack Detection and Accommodation for Energy Delivery Systems	Cybersecurity for Energy Delivery Systems	Eddie Christy
M617000247	Lawrence Berkeley National Laboratory (LBNL)	Cybersecurity via Inverter-Grid Automatic Reconfiguration (CIGAR)	Cybersecurity for Energy Delivery Systems	Eddie Christy
OE0000902	General Electric (GE) Company	Cyber-Physical Resilience for Wind Power Generation	Cybersecurity for Energy Delivery Systems	Eddie Christy
OE0000903	General Electric (GE) Company	Cyber-Physical Protection for Natural Gas Compression	Cybersecurity for Energy Delivery Systems	Eddie Christy
M619000162	National Renewable Energy Laboratory (NREL)	Situational Awareness of Grid Anomalies (SAGA) for Visual Analytics: Near Real-Time Cyber-Physical Resiliency through Machine Learning	Cybersecurity for Energy Delivery Systems	Eddie Christy
M619000156	Idaho National Laboratory (INL)	Geo Threat Observables	Cybersecurity for Energy Delivery Systems	Eddie Christy
M619000158	Pacific Northwest National Laboratory (PNNL)	Analytic Integration Framework for the Big Data Platform	Cybersecurity for Energy Delivery Systems	Eddie Christy
M617000255	Pacific Northwest National Laboratory (PNNL)	SDN4EDS	Cybersecurity for Energy Delivery Systems	Eddie Christy
CR0000001	Southern Company Services, Inc.	Cybersecurity for the Operational Technology Environment Pilot Participant	Cybersecurity for Energy Delivery Systems	Eddie Christy
OE0000876	Iowa State University	Sensor enabled data driven predictive analytics for modeling and control with high penetration of DERs in distribution systems	Electricity	Eddie Christy
OE0000875	Iowa State University	Robust Real-Time Modeling of Distribution Systems with Data-Driven Grid-Wise Observability	Electricity	Eddie Christy
OE0000877	Georgia Tech Research Corporation	Sensing Electrical Networks Securely and Economically (SENSE)	Electricity	Eddie Christy

Project Number	Performer	Project Title	Program	NETL Technology Manager
OE0000911	Nevada System of Higher Education	A Robust Event Diagnostics Platform: Integrating Tensor Analytics and Machinelearning into Real-Time Grid Monitoring	Electricity	Eddie Christy
OE0000917	Siemens Corporation	Mindsynchro	Electricity	Eddie Christy
OE0000912	Schweitzer Engineering Laboratories (SEL), Inc.	Machine Learning Guided Operational Intelligence from Synchrophasors	Electricity	Eddie Christy
OE0000915	General Electric (GE) Company	Phasor Measurement Unit Based Data Analytics using Digital Twin and Phasor Analytics Software	Electricity	Eddie Christy
OE0000910	Iowa State University	Robust Learning of Dynamic Interactions for Enhancing Power System Resilience	Electricity	Eddie Christy
OE0000913	Texas A&M Engineering Experiment Station	Big Data Synchrophasor Monitoring and Analytics for Reliability Tracking (BDSMART)	Electricity	Eddie Christy
OE0000916	University of California - Riverside	Discovery of Signatures, Anomalies, and Precursors in Synchrophasor Data with Matrix Profile and Deep Recurrent Neural Networks	Electricity	Eddie Christy
M620000069	Oak Ridge National Laboratory (ORNL)	Situation-Temporal Awareness for Integrated Oil and Natural Gas Systems (STATIONS)	Electricity	Eddie Christy
FWP-1022409	NETL	Offshore Research: Task 3.0 Assessing Current and Future Infrastructure Hazards	Oil & Gas	Roy Long
FWP-1022424	NETL	Natural Gas Infrastructure: Task 2.0 Sensor Devices and Enabling Technologies	Oil & Gas	Jared Ciferno
FWP-72954	Pacific Northwest National Laboratory (PNNL)	Novel Signatures from Deployed Sensors for Natural Gas Transmission Pipelines	Oil & Gas	Jared Ciferno
FE0031790	University of North Dakota Energy and Environmental Research Center (UNDEERC)	Improving Enhanced Oil Recovery Performance Through Data Analytics and Next-Generation Controllable Completions	Oil & Gas	Jared Ciferno
FE0031792	Battelle Memorial Institute	Chemically Enabled Carbon Dioxide Enhanced Oil Recovery in Multi-Porosity, Hydrothermally Altered Carbonates in the Southern Michigan Basin	Oil & Gas	Jared Ciferno
FWP-FEW0250	LLNL, LBNL, SLAC, NETL	A New Framework for Microscopic to Reservoir-Scale Simulation of Hydraulic Fracturing and Production	Oil & Gas	Jared Ciferno
FWP-1022415	NETL	Onshore Unconventional Resources	Oil & Gas	Jared Ciferno

Project Number	Performer	Project Title	Program	NETL Technology Manager
FE0024297	WVU	Marcellus Shale Energy and Environment Laboratory (MSEEL)	Oil & Gas	Jared Ciferno
FE0031775	University of Utah	Improving Production in the Emerging Paradox Oil Play	Oil & Gas	Jared Ciferno
FE0031779	University of Wyoming	Unlocking the Tight Oil Reservoirs of the Powder River Basin, Wyoming	Oil & Gas	Jared Ciferno
FE0031781	Clemson University	All-digital Sensor System for Distributed Downhole Pressure Monitoring in Unconventional Fields	Oil & Gas	Jared Ciferno
FE0031782	Battelle Memorial Institute	Using Natural Gas Liquids to Recover Unconventional Oil and Gas Resources	Oil & Gas	Jared Ciferno
FE0031783	University of Kentucky	Conasauga Shale Research Consortium	Oil & Gas	Jared Ciferno
FE0031784	University of Kansas Center for Research, Inc.	A Novel "Smart Microchip Proppants" Technology for Precision Diagnostics of Hydraulic Fracture Networks	Oil & Gas	Jared Ciferno
FE0031789	University of North Dakota Energy and Environmental Research Center (UNDEERC)	Carbon Dioxide Enhanced Oil Recovery Improvement In Conventional Fields Using Rich Gas	Oil & Gas	Jared Ciferno
FE0031791	University of Texas at Austin	Engineered Water for Improved Oil Recovery from Fractured Reservoirs	Oil & Gas	Jared Ciferno
SC0020468	PetroLern, LLC	Early Prediction and Prevention of Frac Screen-Out using Deep Reinforcement Learning	Oil & Gas	Jared Ciferno
FE0031864	University of New Mexico	Solid State Mixed-Potential Electrochemical Sensors for Natural Gas Leak Detection and Quality Control	Oil & Gas	Jared Ciferno
FWP-1022420	NETL RIC	Rare Earth Elements from Coal and Coal By-Products Task 9.0: Sedimentary REE Resource Assessment Method	Rare Earth Elements	M.A. Alvin
FWP-FEAA121	Oak Ridge National Laboratory	Reliability of Materials and Components for Solid Oxide Fuel Cells - Task 5: Non-Conventional SOFC Geometries; Task 4: Advanced Manufacturing of SOFC	Solid Oxide Fuel Cells	Shailesh Vora
FWP-66841	Pacific Northwest National Laboratory	SECA Core Technology Program - PNNL - Task 2: SOFC Modeling	Solid Oxide Fuel Cells	Shailesh Vora
FE0031653	General Electric	Multi-Gas Sensors for Enhanced Reliability of Solid Oxide Fuel Cell Operation	Solid Oxide Fuel Cells	Shailesh Vora

Project Number	Performer	Project Title	Program	NETL Technology Manager
FWP-1022411	NETL RIC	Solid Oxide Fuel Cells Task 2: Cell and Stack Degradation Evaluation and Modeling	Solid Oxide Fuel Cells	Shailesh Vora
FE0031754	University of Utah	Deployment of Dynamic Neural Network Optimization to Minimize Heat Rate During Ramping for Coal	Transformative Power Generation	John Rockey
FWP-1022461	NETL/RIC	Transformational Technologies for New and Existing Plants (TTNEP) Task 3.0: Optimizing Dynamics for Performance and Reliability; Task 4.0: Sensors, Diagnostics, and Control for Performance and Reliability; Task 6.0: CFD-Based Reduced Order Model	Transformative Power Generation	John Rockey
FE0031765	Clemson University	Test and Validate Distributed Coaxial Cable Sensors for In Situ Condition Monitoring of Coal-Fired Boiler Tubes	Transformative Power Generation	John Rockey
FE0031750	Microbeam Technologies, Inc.	Demonstration of Multi-Gamma Based Sensor Technology for As-Fired Coal Property Measurement	Transformative Power Generation	John Rockey
FE0031683	Electric Power Research Institute, Inc.	Integrated Boiler Management through Advanced Condition Monitoring and Component Assessment	Transformative Power Generation	John Rockey
FE0031682	Reaction Engineering International	Development of Miniaturized High-Temperature Multi-Process Monitoring System	Transformative Power Generation	John Rockey
FE0031680	Reaction Engineering International	Combustion Performance and Emissions Optimization Through Integration of a Miniaturized High-Temperature Multi Process Monitoring System	Transformative Power Generation	John Rockey
FE0031548	West Virginia University Research Corporation	High Temperature Electrochemical Sensors for In-Situ Corrosion Monitoring in Coal-Based Power Generation Boilers	Transformative Power Generation	John Rockey
FE0031547	Microbeam Technologies, Inc.	Improving Coal Fired Plant Performance through Integrated Predictive and Condition-Based Monitoring Tools	Transformative Power Generation	John Rockey
FE0031546	GE Steam Power, Inc.	Extended Low Load Boiler Operation to Improve Performance and Economics of an Existing Coal Fired Power Plant	Transformative Power Generation	John Rockey
FE0031774	University of Pittsburgh	An Effective Quality Assurance Method For Additively Manufactured Gas Turbine Metallic Components Via Machine Learning From In-Situ Monitoring, Part-Scale Modeling, and Ex-Situ Characterization Data	Turbines	Richard Dennis