Crosscutting Research Targets Support Across Multiple Program Areas

Key Technologies
- Sensors & Controls
- Simulation-Based Engineering
- High Performance Materials
- Water Management R&D

Key Drivers
- Higher Efficiency
- Process Intensification
- Improve Design Tools
- Improve Process Control
- Lower Water Use
Crosscutting Research

- Sensors and Controls
  - Advanced Sensing
  - Distributed Intelligent Control
  - High Temperature & Harsh Environment Application

- Simulation-based Engineering
  - High fidelity models of advanced power systems
  - Advanced power system simulations
  - Carbon Capture Simulation Initiative
  - National Risk Assessment Partnership

- High Performance Materials
  - Ultrasupercritical Boilers & Turbines
  - High-strength metallic & intermetallic alloys
  - Computational Material Modeling

- Water Management R&D
  - Advanced / Novel Heat Transfer and Cooling Systems
  - Water Treatment and Reuse
  - Process Efficiency and Heat Utilization
  - Data, Modeling, and Analysis
Crosscutting Research
Sensors and Controls

- Low cost, high benefit technology
- Existing technology is inadequate
  - Sensing in harsh conditions
  - Controls to manage complexities within plant and frequent changes (e.g. set point, integration with renewables)
- Boosts efficiency of existing facilities
- Contributes to higher reliability or reduction in forced outages
- Enables integration and coordination with all power generation technologies and related infrastructures
- Essential for operation of future ultra clean energy plant
Crosscutting Research
Advanced Process Controls

Targeted to be
Transformational Development
In Process Monitoring and Control

Distributed Intelligence
Computationally driven approaches for novel control architectures and logic, information generation, sensor networking & placement

Advanced Sensing
Harsh environment sensing concepts and approaches for low cost dense distribution of sensors

Value derived from an Encompassing Approach, A purposeful applied development effort, and a Clear pathway for transitioning technology
Distributed Intelligence Approach

- Computational Environments
- Mimic Experimental Facilities
- Smooth Transition
- Mitigate Risk

- Lower-Level Intelligence
- Sensor Communication
- Know When and What to Measure

Novel Control Strategies

Safe Testing Environment

Sensor Placement

Smart Sensors

Smart Actuation

Advanced Control

What location, type and number of sensors for a given unit, objective, decision and action

- Efficient Decision Making
- Actionable Information
- Decentralized Control

- Use Local Information
- Reduce Response Time to System Changes
All concepts, technologies and systems can and should be described in a computational format.
Putting All The Sensor & Control Pieces Together

• Operational and Reliability challenges at full scale…
• Start up, Shutdown, Load following and Cycling
• Integration of plant operation with grid, water, emissions, CO₂ capture and storage operations
• Competing and conflicting objectives for plant operation and control
• Complexity in plant design and control objectives is driving advancements in process control
• Harsh environments are driving advances in sensing
• Need for real time “actionable information” is driving low cost sensor networks
Crosscutting Research
Simulation-Based Engineering

Accelerated solutions for complex power system

- Technical Knowledge
- Code & Software Development
- Collaborative Partnerships
- Experimental Facilities
- Computational Power
- Data Repository
- CCSI (Carbon Capture Simulation Initiative)
- MFiX
- C3M (Carbonaceous Chemistry for Computational Modeling)
- IDAES (Institute for the Design of Advanced Energy Systems)
• Next generation modeling and optimization platform
  – Flexible and open model
  – Complete provenance information
  – Supports advanced solvers and computer architecture
  – Intrusive UQ
  – Process Synthesis, Integration, and Intensification
  – Process Control and Dynamics
• Apply to development of new & novel energy systems
  – Chemical Looping
  – Oxy-combustion
  – Transformational Carbon Capture
• Intended to be
  – National Lab and University Capability
  – Open Source
• Not intended to compete with commercial simulators
• Builds on knowledge gained from CCSI
Advanced controls testing and development conducted in-house by NETL’s Research & Innovation Center

Future research will leverage Hyper Facility, a state-of-the-art cyber-physical system, to investigate the following [D. Tucker, et. al., 2015]:

- **Novel AM concepts** (ex: embedded technology for ‘smart’ components) under harsh environment conditions
- **Rapid prototyping** of turbomachinery, compressor, and turbine component re-designs via AM technology
- Continued **simulation and advanced controls** development for FE-base hybrid systems (ex: SOFC-GT)

**Additional resource to demonstrate REMS Project objectives (CFD model validation, materials development, etc)**
High Performance Materials

- New materials are essential for advanced power generation systems with carbon capture and storage capability to achieve performance, efficiency, and cost goals.
- Materials of interest are those that enable components and equipment to perform in the harsh environments of an advanced power system.
World’s first steam oxidation/fireside corrosion test loop operating at 760°C (1400°F)

Advanced Structural Materials for Harsh Environments

Advanced manufacturing provides technologies to fabricate, assemble and join components from high performance materials for advanced FE power generation technologies.

High-Performance Materials (HPM) focuses on materials that will lower the cost and improve the performance of existing and advanced fossil-based power-generation systems. There are four (4) research areas within HPM.

Computational Based Materials Design and Performance Prediction

Computational Based Materials Design and Performance Prediction will enable rapid design of new high performance materials, and provide validated models capable of simulating and predicting long-term performance of high performance materials.

Computational Simulation of Oxidation Rate of High Temperature Alloys

Multi-scale simulation capability to solve the complex physics of the oxidation of metals transport of charged ions subject to interfacial reactions and long range electrostatic interactions.

Oxidation and Reduction cycles: Ionic Diffusion

Microscopic View of Granulation

SEM Analysis on 40 percent iron oxide loading particle

SEM Analysis on the cross-section of 40% iron loading particle.

Core-Shell Structured Oxygen Carrier for Chemical Looping Combustion

Advanced Structural Materials for Harsh Environments

Develop advanced structural materials that are needed for the harsh operating environments (e.g., high temperature and pressure) of advanced FE power generation technologies.

Functional Materials for Process Performance Improvements:

Develop functional materials such as sorbents, coatings, catalysts, Chemical Looping oxygen carriers, and high temperature thermo-electrics needed for advanced FE power generation technologies.

Advanced Manufacturing for High Performance Structural & Functional Materials

High Performance Materials (HPM) focuses on materials that will lower the cost and improve the performance of existing and advanced fossil-based power-generation systems. There are four (4) research areas within HPM.

Computational Based Materials Design and Performance Prediction

Computational Based Materials Design and Performance Prediction will enable rapid design of new high performance materials, and provide validated models capable of simulating and predicting long-term performance of high performance materials.

Computational Simulation of Oxidation Rate of High Temperature Alloys

Multi-scale simulation capability to solve the complex physics of the oxidation of metals transport of charged ions subject to interfacial reactions and long range electrostatic interactions.

Oxidation and Reduction cycles: Ionic Diffusion

Microscopic View of Granulation

SEM Analysis on 40 percent iron oxide loading particle

SEM Analysis on the cross-section of 40% iron loading particle.

Core-Shell Structured Oxygen Carrier for Chemical Looping Combustion

Advanced Structural Materials for Harsh Environments

Develop advanced structural materials that are needed for the harsh operating environments (e.g., high temperature and pressure) of advanced FE power generation technologies.

Functional Materials for Process Performance Improvements:

Develop functional materials such as sorbents, coatings, catalysts, Chemical Looping oxygen carriers, and high temperature thermo-electrics needed for advanced FE power generation technologies.

Advanced Manufacturing for High Performance Structural & Functional Materials

High Temperature Oxidation/Corrosion Test Loop for Advanced Structural Alloys

Materials included: weld overlays, H282,740H, CCA617, HR6W, Super 304H

• Operated for over 5,000 hours above 760°C
• Initial evaluations of test samples show little to no metal oxidation or corrosion loss.
What’s Next in Materials?

- Supply chain development of materials with greatest market value potential
- High temperature, high cycle materials for fast ramping
- Structured performance evaluation program of materials
- Optimization of Advanced Manufacturing for functional and structural materials
  - Rapid prototyping to support evaluation and design
- Transformational engineering of ceramics for high temperature functional applications
- Magneto Hydrodynamic & Rare Earth Materials
Why Water Management R&D?

Public Issue: Water Withdrawals and Consumptive Use
Thermo-electric Power Large User of Water, Relatively Small Consumer

New & Existing Power Plants Must Optimize Water Use

- Optimize the freshwater efficiency of energy production, electricity generation, and end use systems for Today’s and Tomorrow’s Power Plant Systems
- Optimize the energy efficiency of water management, treatment, distribution, and end use systems
- Enhance the reliability and resilience of energy and water systems
- Increase safe and productive use of nontraditional water sources (e.g., municipal wastewater treatment, extracted or produced waters, power plant effluent waste streams)
- Promote responsible energy operations with respect to water quality, ecosystem, and seismic impacts
- Exploit productive synergies among water and energy systems

2010 Thermoelectric
Freshwater Requirements:
Withdrawal: ~ 117 BGD
Consumption: ~ 4 BGD

80% Increase in water consumption for CO₂ Capture & Storage

Sources: ¹USGS, Estimated Use of Water in the United States in 2010, USGS Circular 1405, 2014
Water Management Research
Focus Areas

• Advanced/Novel Heat Transfer and Cooling Systems
  – Wet, Dry, Hybrid
  – Incremental & Step Change Improvements
  – Advanced Manufacturing of Recuperators for Combustion Turbines

• Water Treatment and Reuse
  – Sensors for water quality measurement
  – Economic Pathways for Zero Liquid Discharge
  – Characterization and treatment of power plant effluent discharge streams
  – Treatment of high TDS Waters (promote greater Water Reuse – collaboration with CS)

• Process Efficiency and Heat Utilization
  – Pathways for produce more power per unit of water withdrawn, consumed, and treated
  – Utilization of Low-Grade Heat
  – Bottoming Cycles

• Develop a National Water for Energy Atlas
  – Tools to enable regional and plant level decision making
  – Develop a National Water Atlas

• Breakthrough or Out of the Box
  – Low/No water FE based Systems, Distributed Generation, Grid Upgrades
University Training & Research

University Coal Research

Started in 1979, the program was designed to raise the level of competitiveness of universities in fossil energy research committed to improving the scientific understanding and environmental acceptability of coal while training new generations of research scientists and engineers.

- Students are expected to present project progress at annual review meetings.
- Over 2500 students are estimated to have received degrees while conducting research under the program.

Historically Black Colleges & Universities

Started in 1984, the program was designed to raise the level of competitiveness of HBCU/OMIs in fossil energy research and tap an under-utilized resource by increasing opportunities in the areas of science, engineering, and technical management.

- Each grant typically involves 3-5 students throughout the duration of the project.
- Students are expected to present project progress at annual review meetings.

Grants Awarded – By State Period FY95 to FY14

UCR Program Results:
- 1000+ Technical Papers
- 10+ Technical Awards
- 7 Patents Issued to Date

HBCU Program Results:
- 500+ Technical Papers
- 5+ Technical Awards
- 2 Patents Issued to Date
Innovative Energy Concepts
Incubator to Enable Advanced Transformative Technologies

• Transformative improvements in Electricity Generation and Delivery
• System Studies to validate concepts and understand economics of the technologies
• Recent Studies:
  – Direct Power Extraction
  – Thermoelectric Materials
  – Pulse Detonation/Pressure Wave Combustion
  – Plant Flexibility Concepts
• Conduct basic research to develop & validate computational tools
• Expand basic research to improve critical components for technology to reach potential

DPE – Plasma passing through a magnetic field generates electricity, high temperature heat recovered in traditional power cycles

Rotating Wave
Detonation concept for improving fuel and cycle efficiency

Pulse Detonation concept for improving fuel and cycle efficiency
Conclusions

• The U.S. power generation industry is at a critical juncture
  – Demand, resources, workforce, reliability, regulation, grid integrity, transmission, etc.

• Competing demands for reliable, low-cost energy and climate change mitigation appear incongruent

• Uncertainty of regulatory outcomes and rising costs impact industry’s willingness to commit capital investment

• The U.S. must foster new processes that address conflicting energy objectives simultaneously