Crosscutting Research

Program Overview

NATIONAL ENERGY TECHNOLOGY LABORATORY

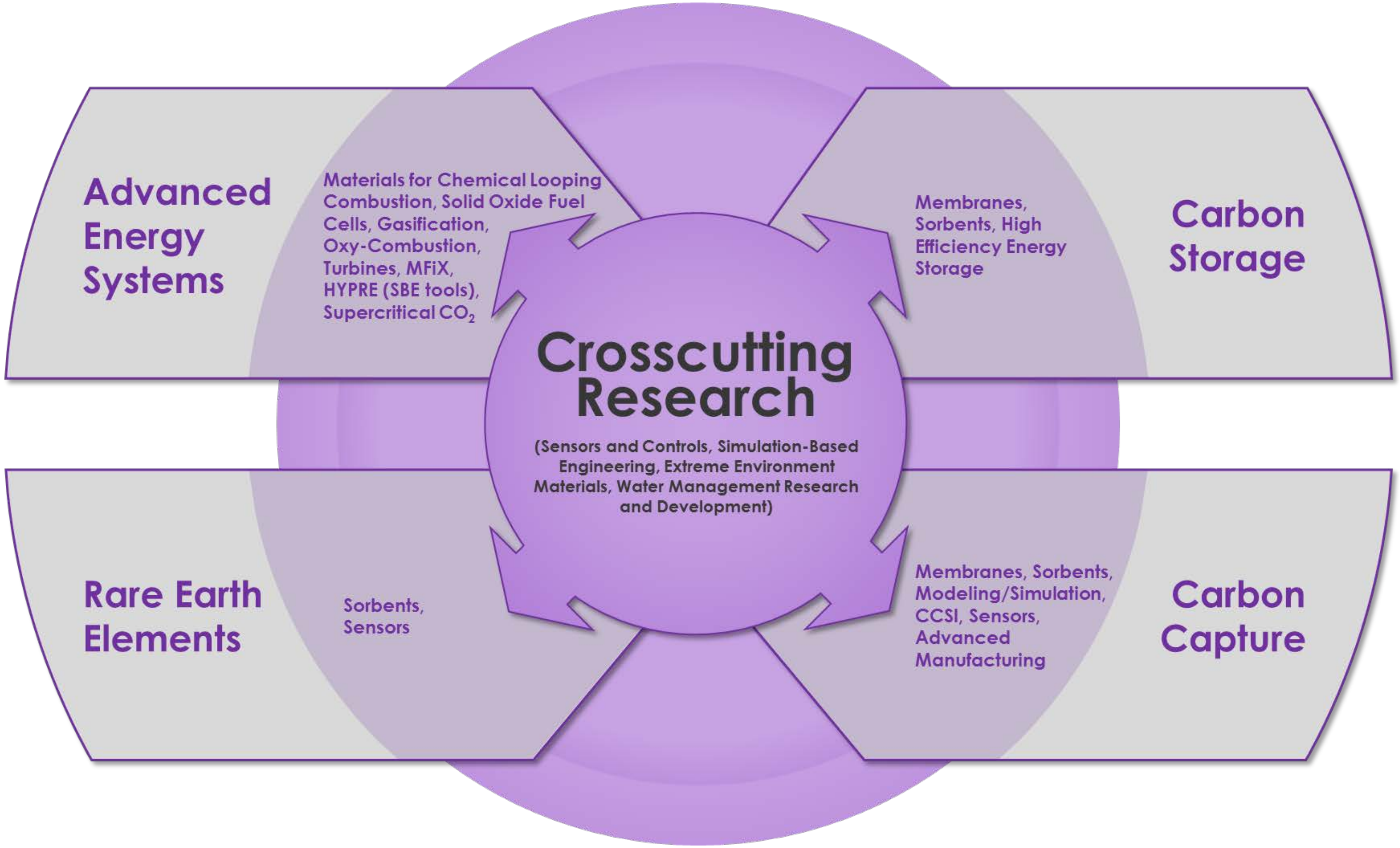
March 20, 2017

Robert Romanosky, Ph.D.
Acting Technology Manager
National Energy Technology Laboratory

Solutions for Today | Options for Tomorrow

U.S. DEPARTMENT OF ENERGY

Crosscutting Research
Targets Support Across Multiple Program Areas



Key Technologies

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

Key Drivers

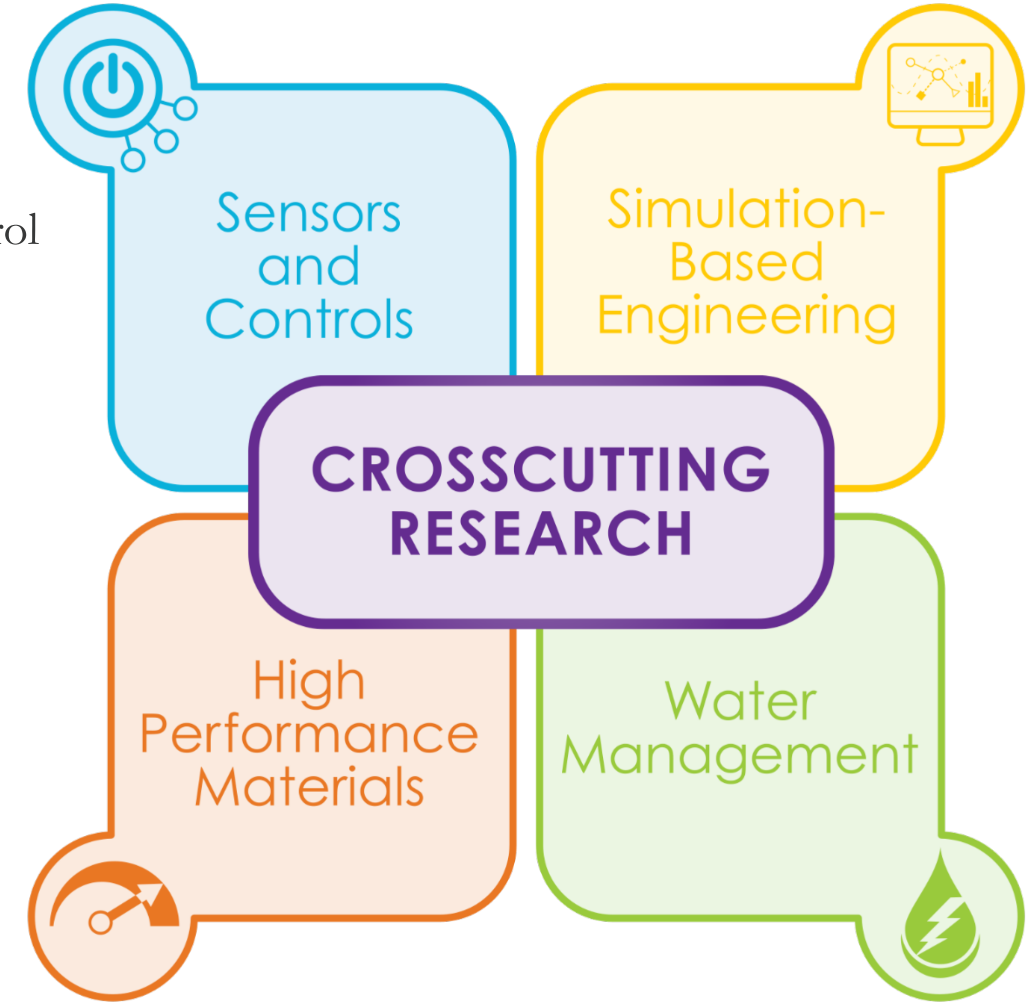
- Higher Efficiency
- Process Intensification
- Improve Design Tools
- Improve Process Control
- Lower Water Use

Crosscutting Research

NATIONAL ENERGY TECHNOLOGY LABORATORY

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

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

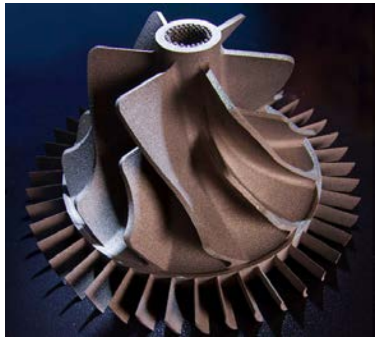


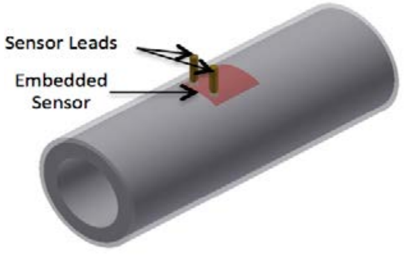
❑Simulation-based Engineering
- High fidelity models of advanced power systems
- Advanced power system simulations
- Carbon Capture Simulation Initiative
- National Risk Assessment Partnership

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

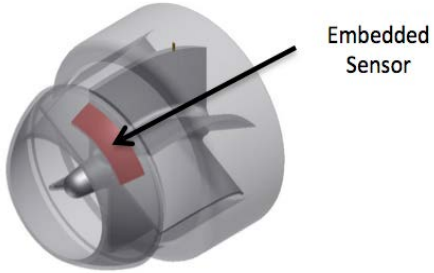
Crosscutting Research
Sensors and Controls

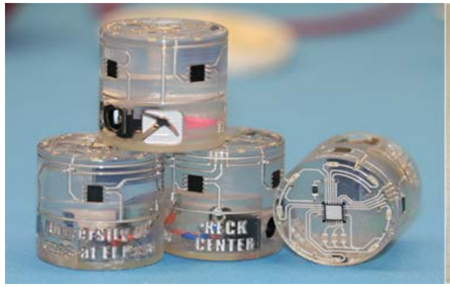
- **Low cost, high benefit technology**
- **Existing technology is inadequate**
  - Sensing in harsh conditions
  - Controls to manage complexities within plant and frequent changes (e.g. set point, integration with renewables)
- **Boosts efficiency of existing facilities**
- **Contributes to higher 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**

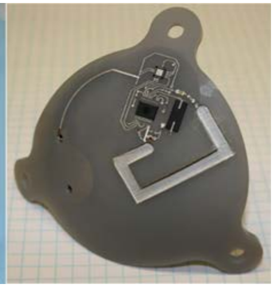




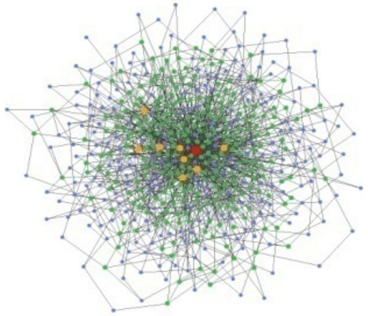
Smart tube with embedded sensor







Crosscutting Research
Advanced Process Controls



Targeted to be
Transformational Development
In Process Monitoring and Control

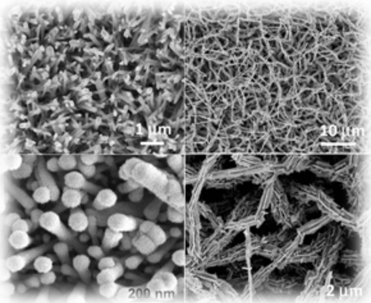
Distributed Intelligence

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

NATIONAL ENERGY TECHNOLOGY LABORATORY

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

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

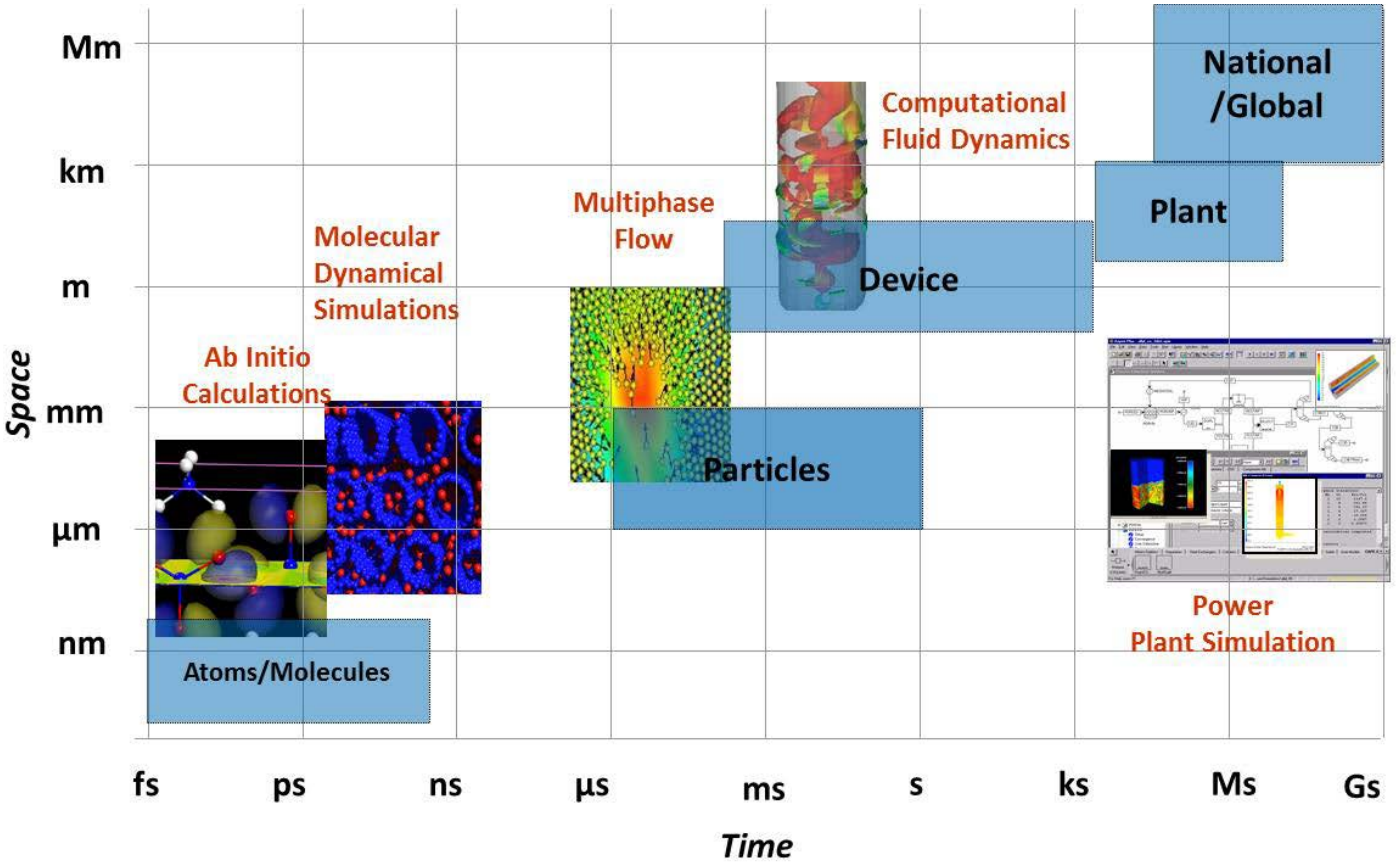
- Efficient Decision Making
- Actionable Information
- Decentralized Control

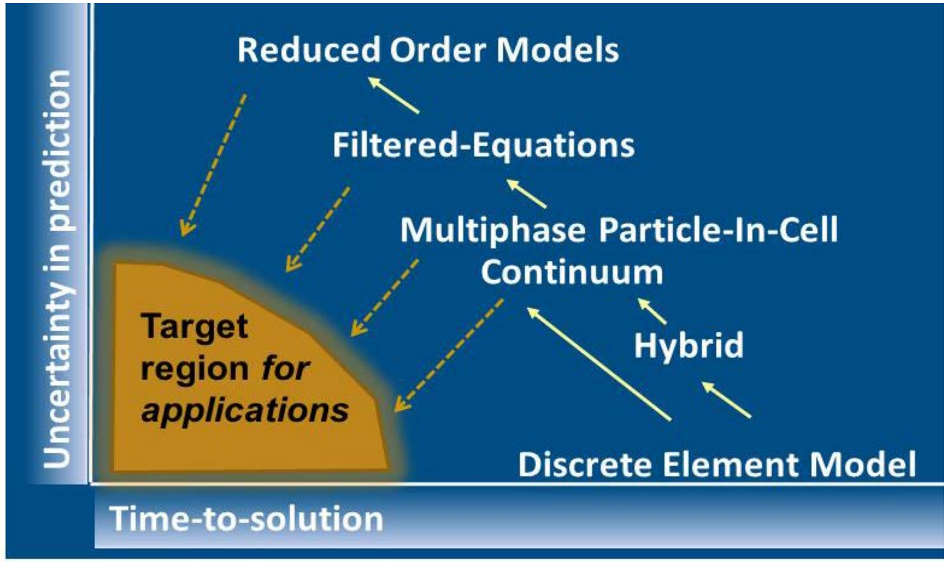
What location, type and number of sensors for a given unit, objective, decision and action

- Use Local Information
- Reduce Response Time to System Changes

Computational Modeling: Scale Comparison

All concepts, technologies and systems can and should be described in a computational format.





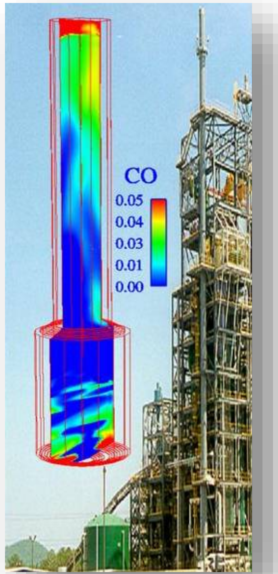
Computational Tools and Analysis for a Broad Set of Applications

Putting All The Sensor & Control Pieces Together

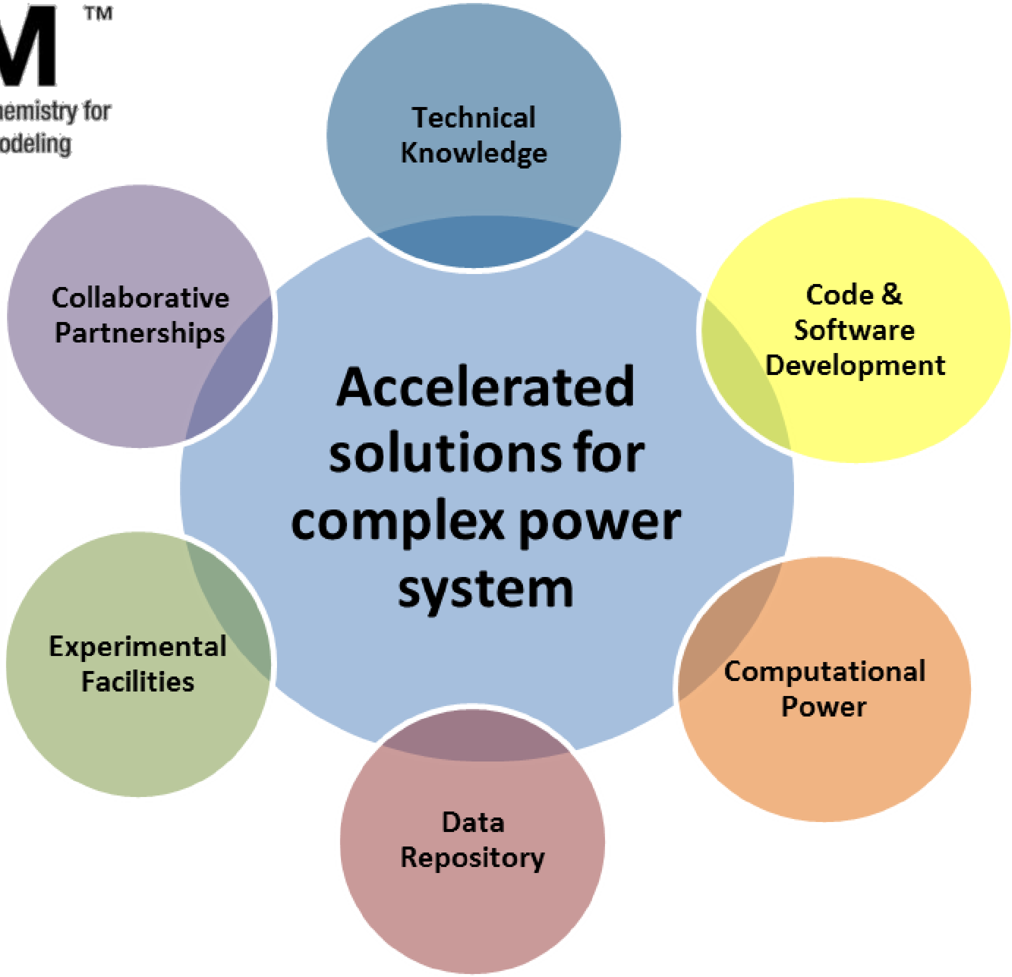
- Operational and Reliability challenges at full scale…
- Start up, Shutdown, Load following and Cycling
- Integration of plant operation with grid, water, emissions, CO_2 capture and storage operations
- Competing and conflicting objectives for plant operation and control
- Complexity in plant design 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

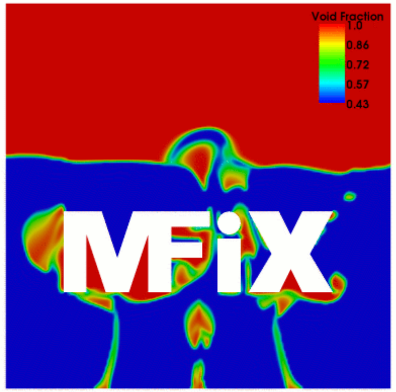
Crosscutting Research
Simulation-Based Engineering

NATIONAL ENERGY TECHNOLOGY LABORATORY



C3M™
Carbonaceous Chemistry for Computational Modeling



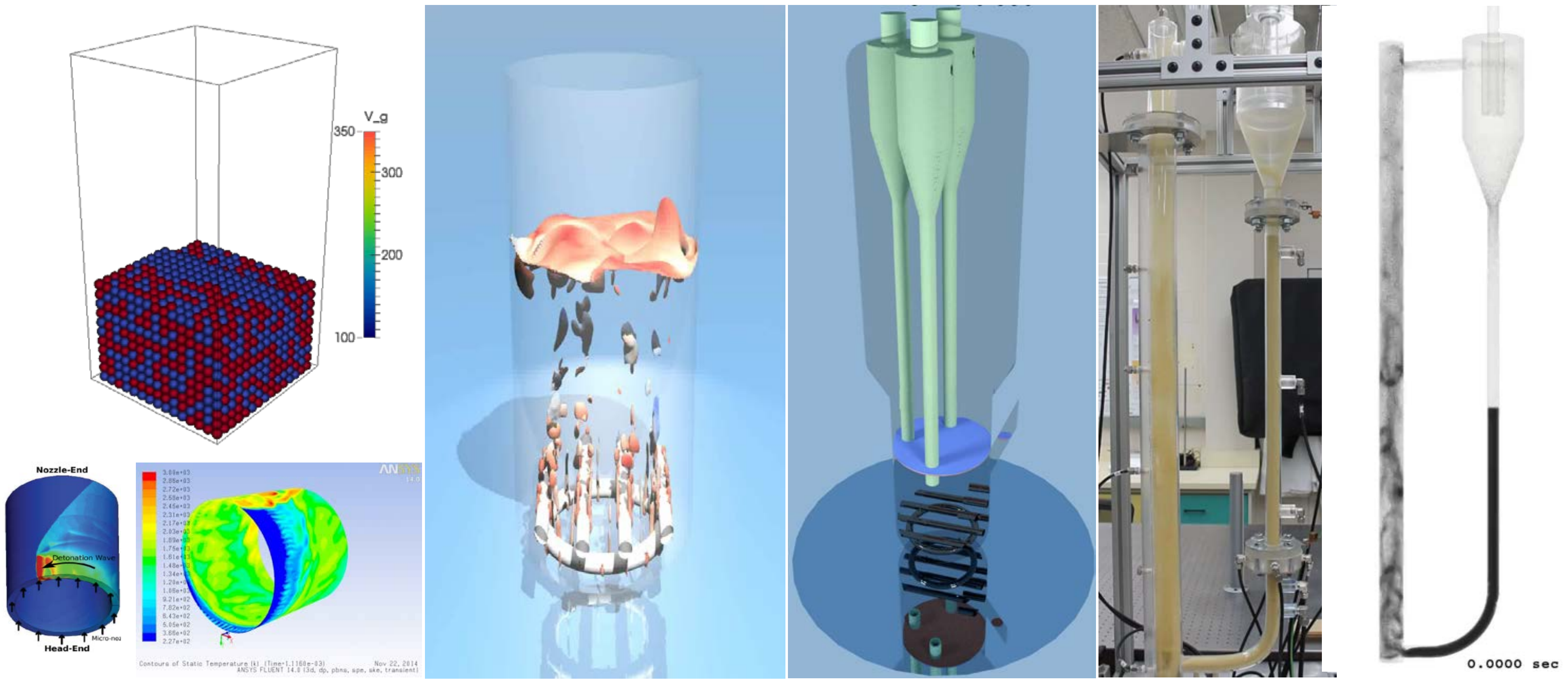


CCSI
Carbon Capture Simulation Initiative

IDAES
Institute for the Design of Advanced Energy Systems

NETL Multiphase Flow Science
From Fundamentals to Cutting Edge

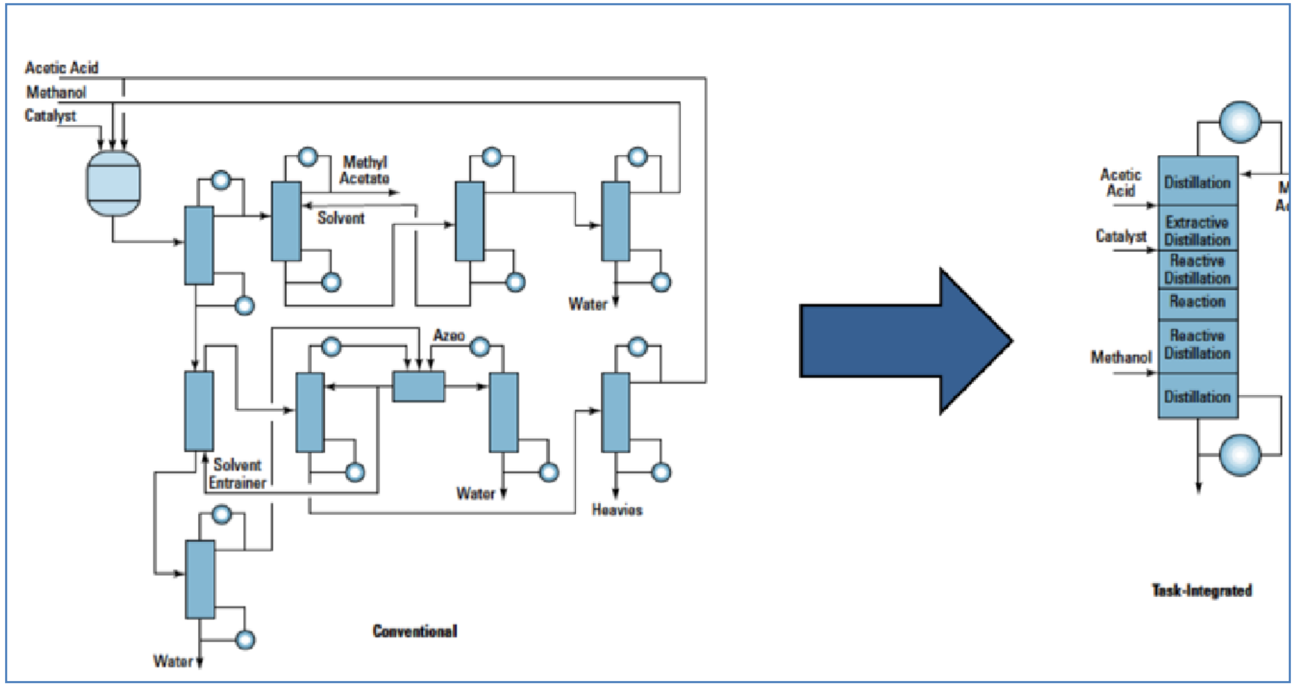
NATIONAL ENERGY TECHNOLOGY LABORATORY



IDAES
Institute for the Design of Advanced Energy Systems

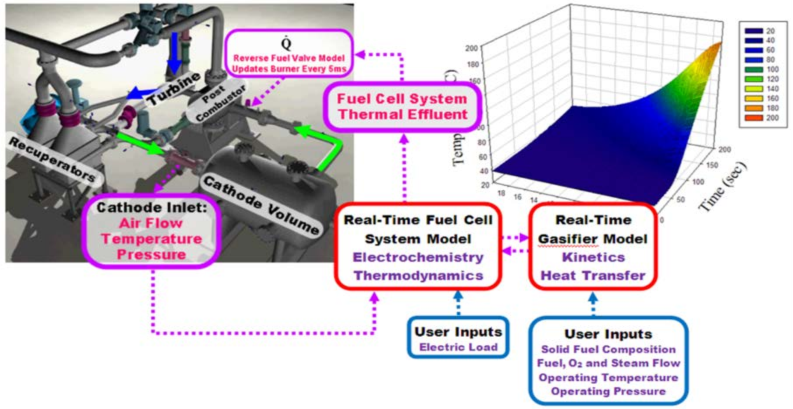
- **Next generation modeling and optimization platform**
  - Flexible and open model
  - Complete provenance information
  - Supports advanced solvers and computer architecture
  - Intrusive UQ
  - Process Synthesis, Integration, and Intensification
  - Process Control and Dynamics
- **Apply to development 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**

Development Of Innovative Advanced Energy Systems Through Advanced Process Systems Engineering



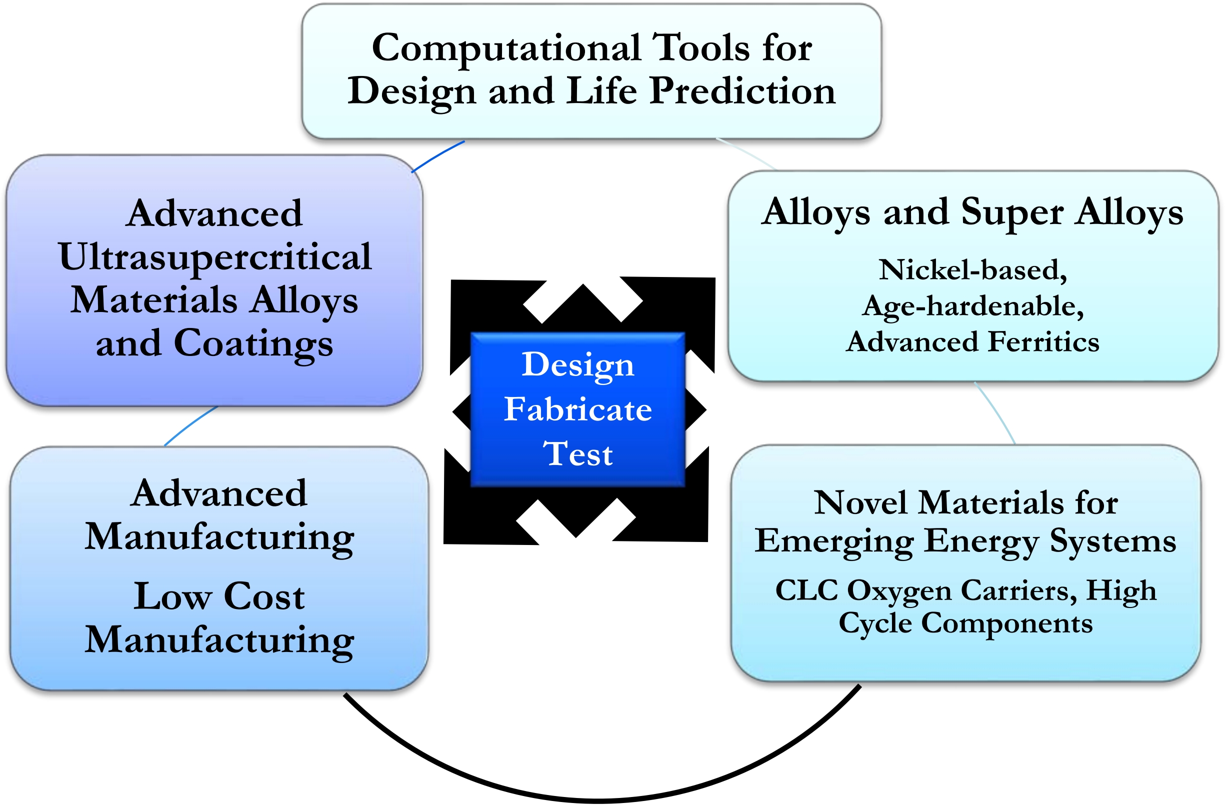
NETL – HYPER Performance Facility

Advanced Controls Testing and Development

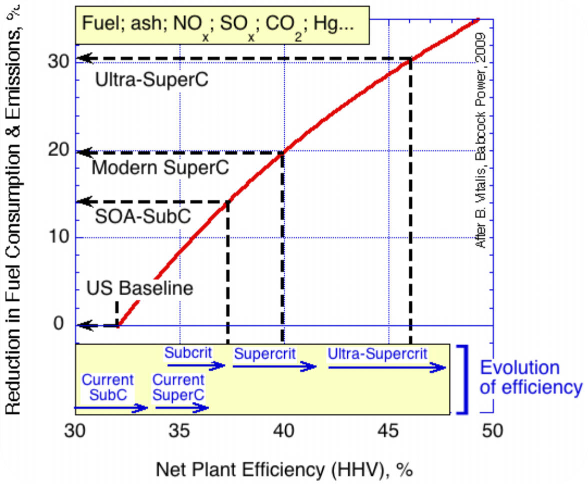


- Advanced controls testing and development conducted in-house by NETL's Research & Innovation Center
- Future research will leverage Hyper Facility, a state-of-the-art cyber-physical system, to investigate the following [D. Tucker, et. al., 2015]:
  - **Novel AM concepts** (ex: embedded technology for '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)

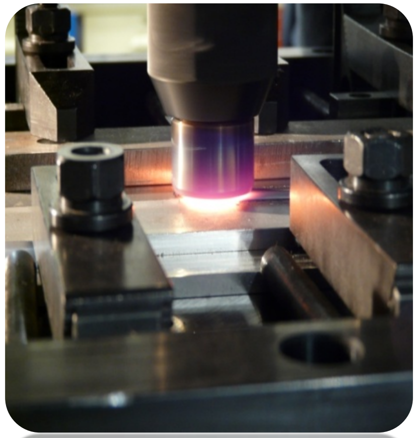
High Performance Materials



- 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.



Advanced Manufacturing for High Performance Structural & Functional Materials

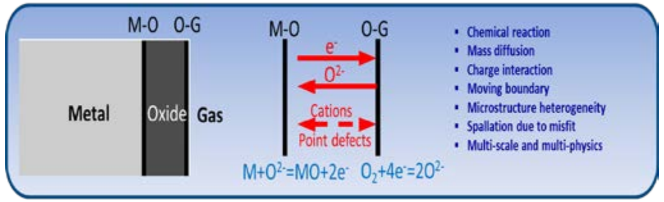


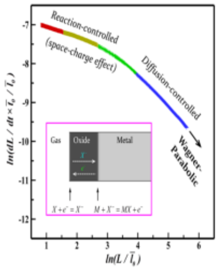
Advanced Manufacturing for High Performance Structural and Functional Materials: Advanced manufacturing provides technologies to fabricate, assemble and join components from high performance materials for advanced FE power generation technologies.

Friction stir welding of ¼" thick dispersion strengthened Sandvik APMT plate

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.





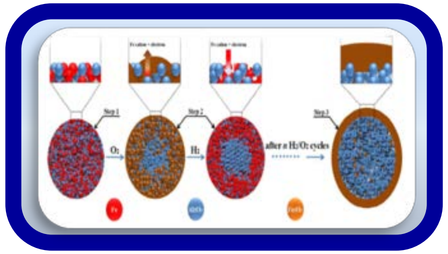
Computational Simulation of Oxidation Rate of High Temperature Alloys

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

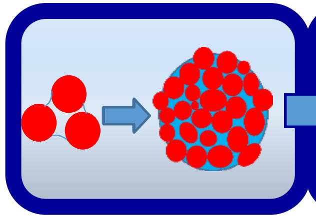
High-Performance Materials (HPM) focuses on materials that will lower the cost and improve the performance of existing and advanced fossil-based power-generation systems. There are four (4) research areas within HPM.

Functional Materials for Process Performance Improvements

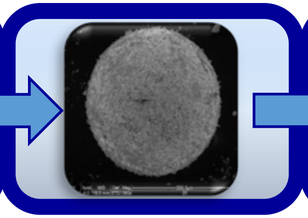
Functional Materials for Process Performance Improvements:
Develop functional materials such as sorbents, coatings, catalysts, Chemical- Looping oxygen carriers, and high temperature thermo-electrics needed for advanced FE power generation technologies.



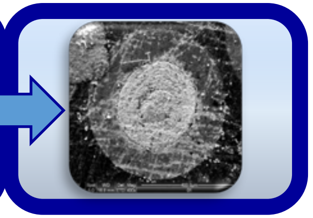
Oxidation and Reduction cycles: Ionic Diffusion



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

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.

Fabrication of the test loop

World's first steam oxidation /fireside corrosion test loop operating at 760°C (1400°F)

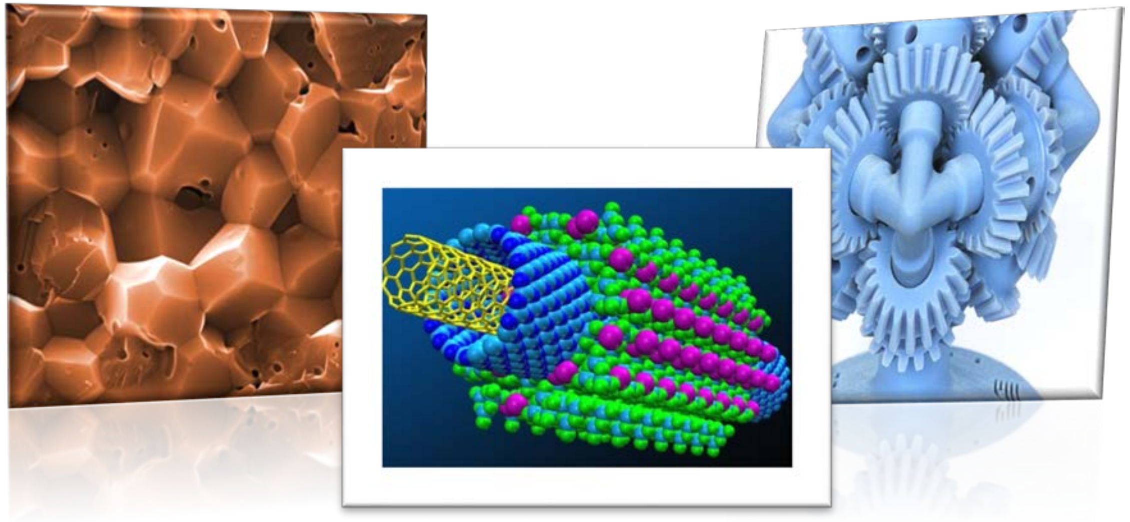
Installed

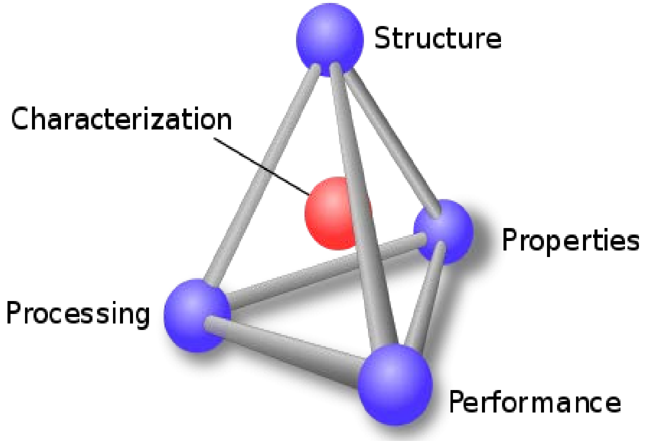
Materials included: weld overlays, H282,740H, CCA617, HR6W, Super 304H

- Operated for over 5,000 hours above 760°C
- Initial evaluations of test samples show little to no metal oxidation or corrosion loss.

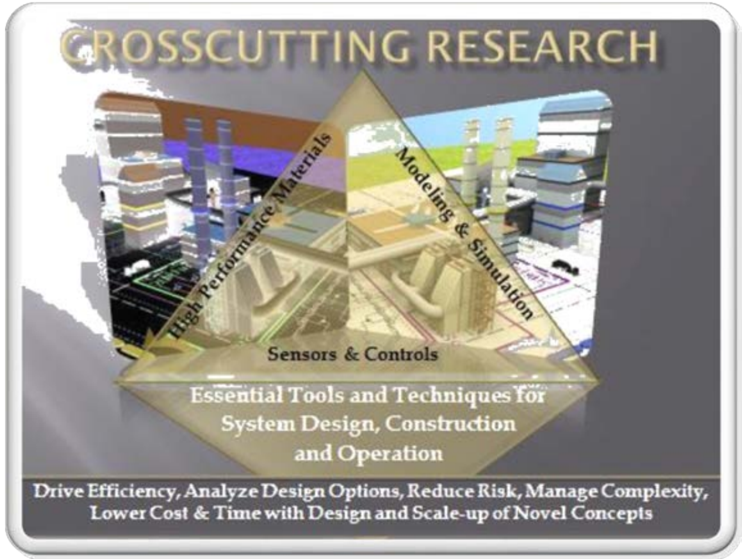
High Temperature Oxidation/Corrosion Test Loop for Advanced Structural Alloys

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

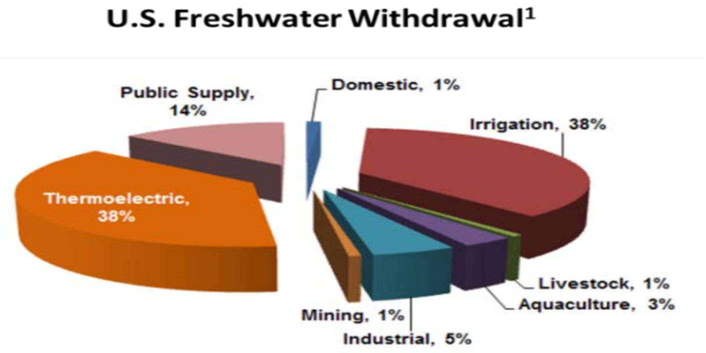


Why Water Management R&D?

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

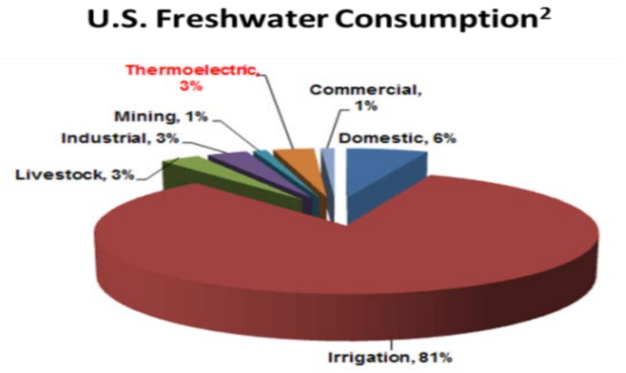
New & Existing Power Plants Must Optimize Water Use

- 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 CO_2 Capture & Storage



Sources: [1]USGS, Estimated Use of Water in the United States in 2010, USGS Circular 1405, 2014
[2]USGS, Estimated Use of Water in the United States in 1995, USGS Circular 1200, 1998

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.**

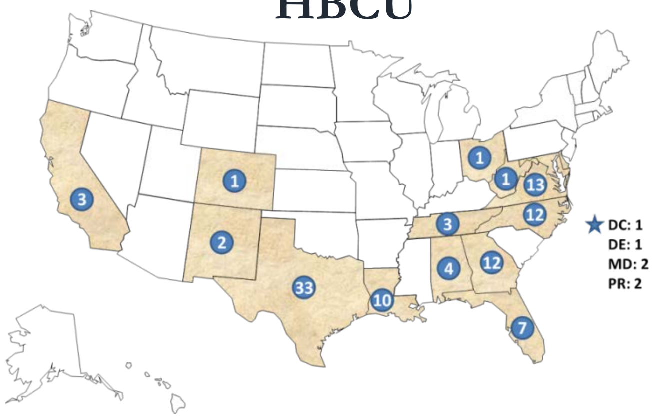
UCR

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

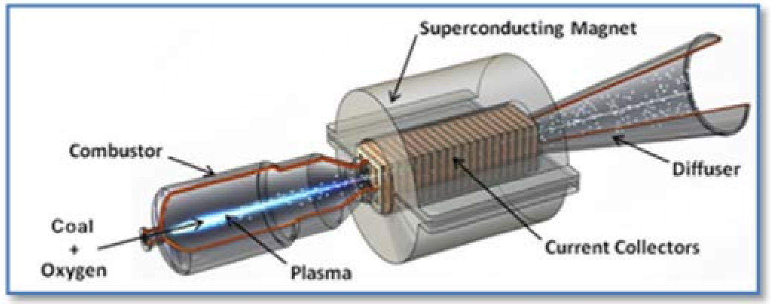
HBCU



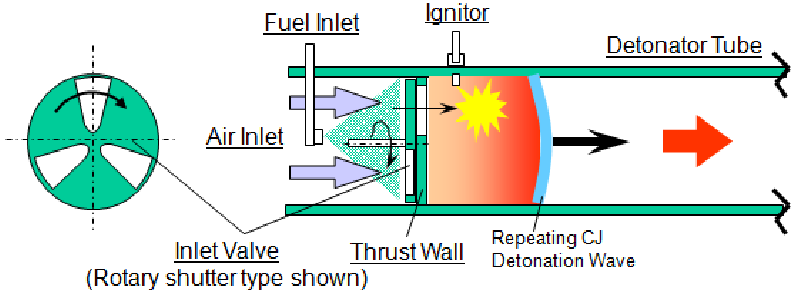
Innovative Energy Concepts

Incubator to Enable Advanced Transformative Technologies

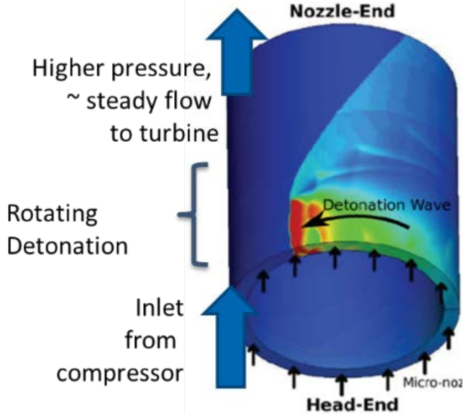
- Transformative improvements in Electricity Generation and Delivery
- System Studies to validate concepts and understand economics of the technologies
- Recent Studies:
  - Direct Power Extraction
  - Thermoelectric Materials
  - Pulse Detonation/Pressure Wave Combustion
  - Plant Flexibility Concepts
- 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



Pulse Detonation concept for improving fuel and cycle efficiency



Rotating Wave Detonation concept for improving fuel and cycle efficiency

Crosscutting Research Project Map

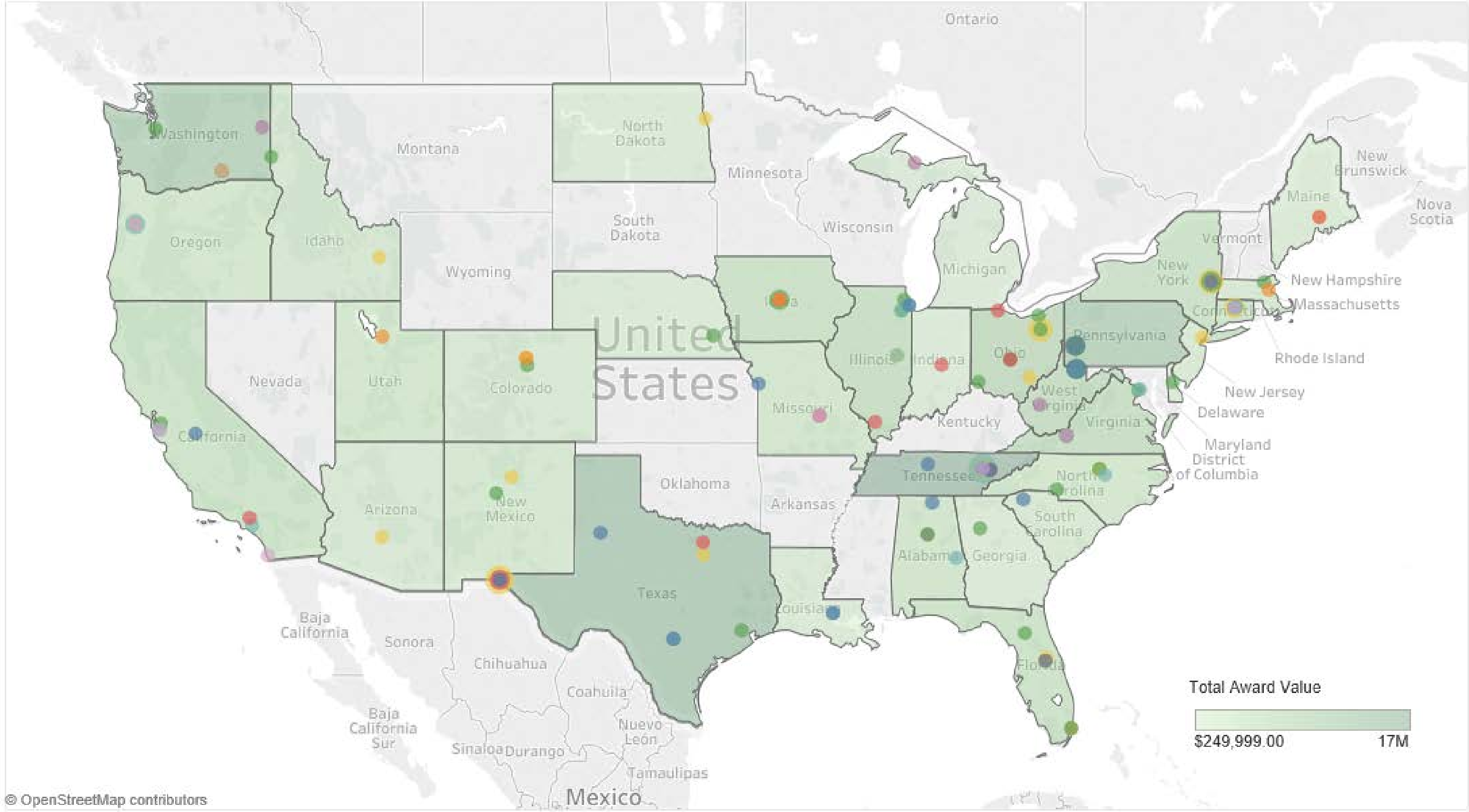
NATIONAL ENERGY TECHNOLOGY LABORATORY

Project Status
- (All)
- Active
- Inactive

Awa
- ☑ (All)
- ☑ FOA
- ☑ FWP

Key Technology
- ☑ (All)
- ☑ High Performance Materials
- ☑ Sensors and Controls
- ☑ Simulation-Based Engineering
- ☑ Water Management R&D

2009 2010 2011 2012 2013 2014 2015 2016



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**