NATIONAL ENERGY TECHNOLOGY LABORATORY

2010 UCR/HBCU Annual Review Meeting

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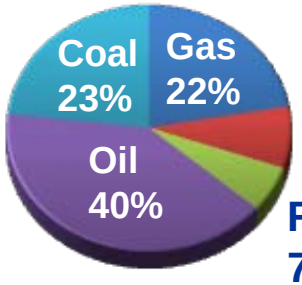
June 2, 2010

Energy Demand 2006-2030
Why is this Important?

100 QBtu / Year
85% Fossil Energy



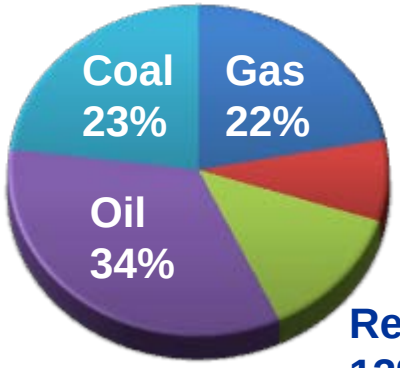
Nuclear 8%

Renewables 7%

+ 13%

United States

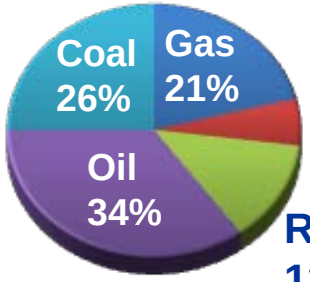
113 QBtu / Year
79% Fossil Energy



Nuclear 8%

Renewables 13%

465 QBtu / Year
81% Fossil Energy



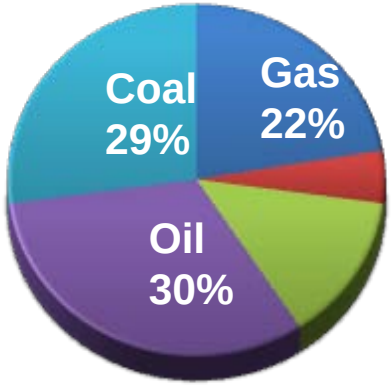
Nuclear 6%

Renewables 13%

+ 45%

World

675 QBtu / Year
81% Fossil Energy



Nuclear 5%

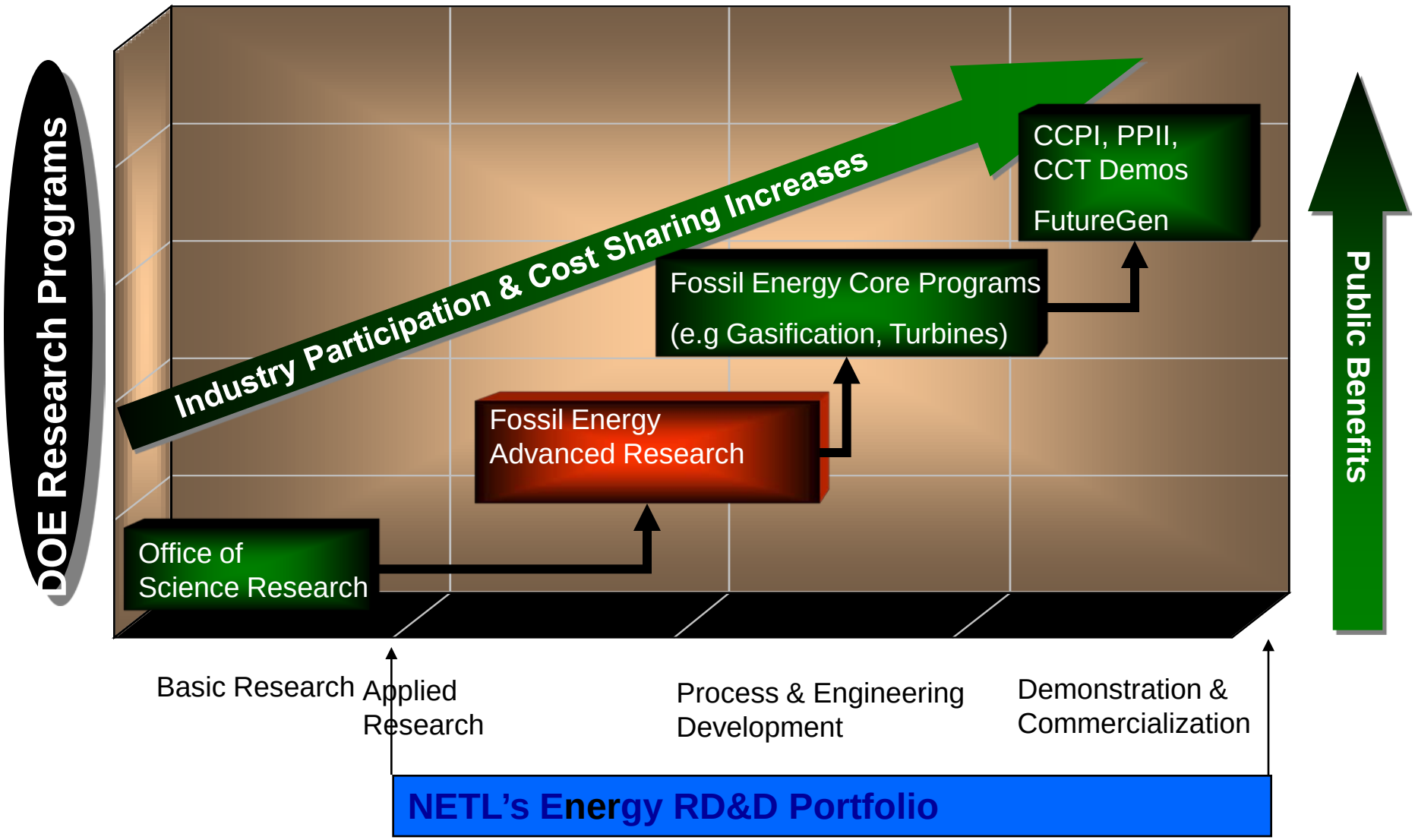
Renewables 14%

U.S. data from EIA, Annual Energy Outlook 2009 early release ; world data from IEA, World Energy Outlook 2008

Point of Reference

- **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, endangering near-term production capacity**
- **The U.S. must foster new processes that address conflicting energy objectives simultaneously**
- **Our nation's dependence on liquid fuel from foreign resources will continue to remain high for the near term**

Fossil Energy Program Outline



Advanced Research UCR/HBCU

Fiscal Year Activity

Program Funding ($K)

Program	FY08	FY09	FY10	FY11
UCR	2,434	2,413	2,400	2,400
HBCU	805	813	850	850

Projects Awarded

Projects	FY08	FY09	FY10	FY11
UCR	2	6	7	est 7
HBCU	4	4	4	est 4

Ultra-Clean Energy Plant

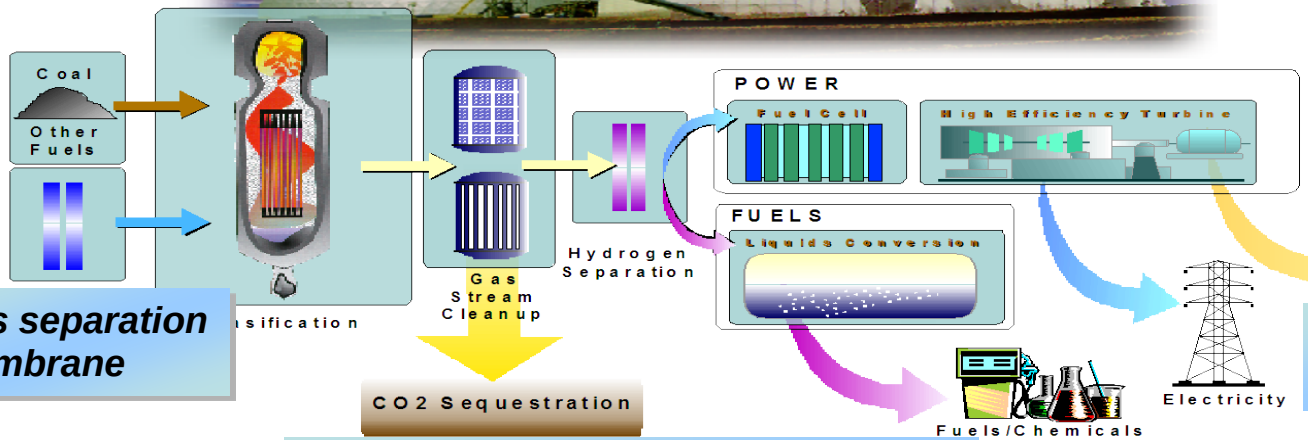
Instrumentation Sensors & Controls

Systems Integration System modeling Virtual Simulation

Advanced Materials

Gasification & Combustion

Turbines & Fuel Cells



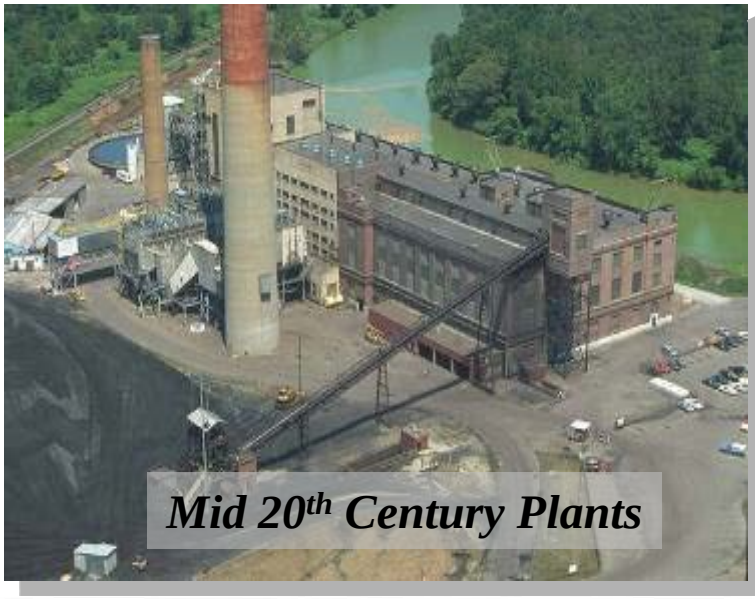
Gas separation Membrane

Fuel and Power Production

Gas Cleaning / Hydrogen Membrane

Technology Challenges
Being addressed within Advanced Research

- Zero emissions
- Integrated systems
- Controllable and reliable designs
- Tight tolerances & operating margins
- High temperatures & pressures



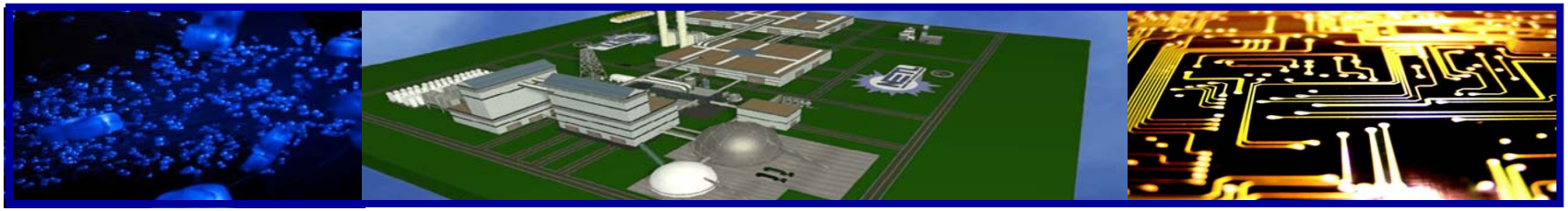
- Plant design
- Process modeling and control
- Operations monitoring
  (efficiency, emission, equipment)
- Dynamic & transient mode management
- Materials for harsh environments

Driver for New Sensing Technology

- **Advanced Power Generation:**
  - Harsh sensing conditions throughout plant
  - Monitoring needed with advanced instrumentation and sensor technology.
  - Existing instrumentation and sensing technology are inadequate
- **Coal Gasifiers and Combustions Turbines:**
  - have the most extreme conditions
    - Gasifier temperatures may extend to 1600 C and pressures above 800 psi. Slagging coal gasifiers are highly reducing, highly erosive and corrosive.
    - Combustion turbines have a highly oxidizing combustion atmosphere.
- **Targeting development of critical on line measurements**
  - Sensor materials and designs are aimed at up to 1600 C for temperature measurement and near 500 C for micro gas sensors.
  - Goal is to enable the coordinated control of advanced power plants followed by improvement of a system's reliability and availability and on line optimization of plant performance.

Technology Gaps and Future Directions

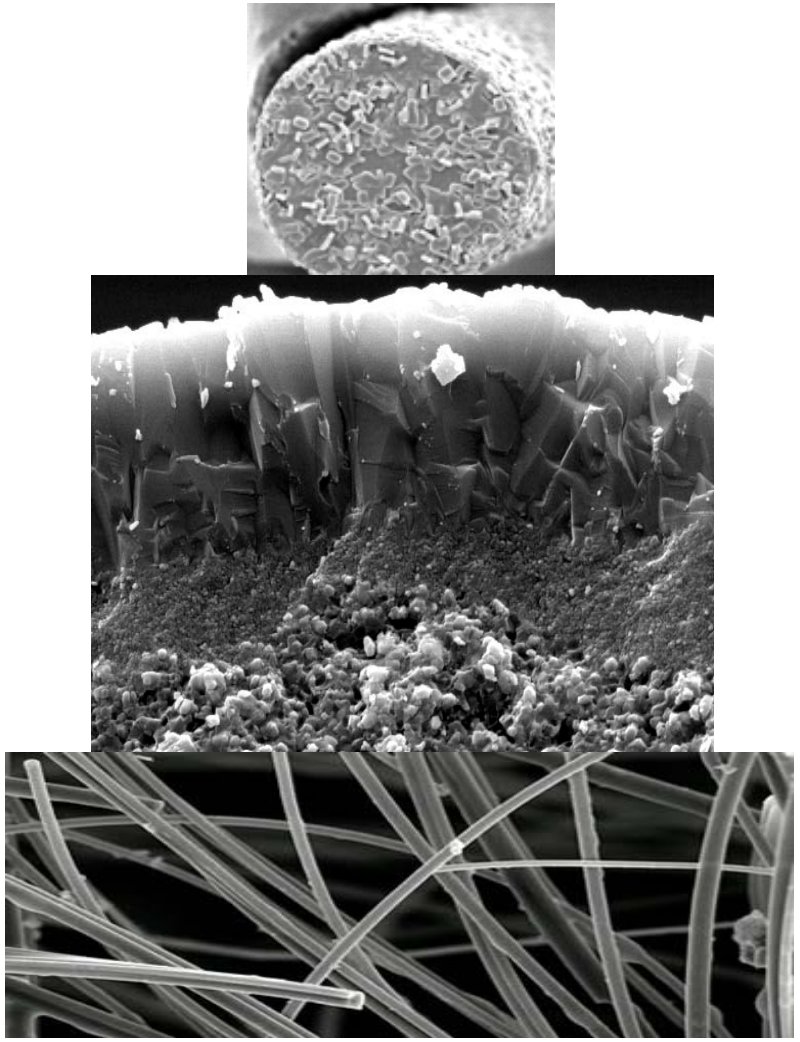
- **Sensor Packaging and Testing**
- **Application of computational intelligence for sensing and control**
- **Utilization of sensor networks**
- **Integration with models**



Materials for Sensing in Harsh Environments

Optical and Micro Sensors

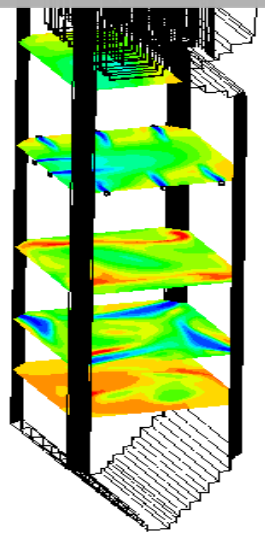
- **Sapphire**
- **Alumina**
- **Silicon Carbide**
- **Doped Silicon Carbide Nitride**
- **Yttria stabilized zirconia**
- **Fused/doped silica for certain process conditions**
- **Active/doped coatings**
- **Nano derived high temperature materials and structures**
- **Novel materials for high temperatures (1000 C)**



Advanced Control Development

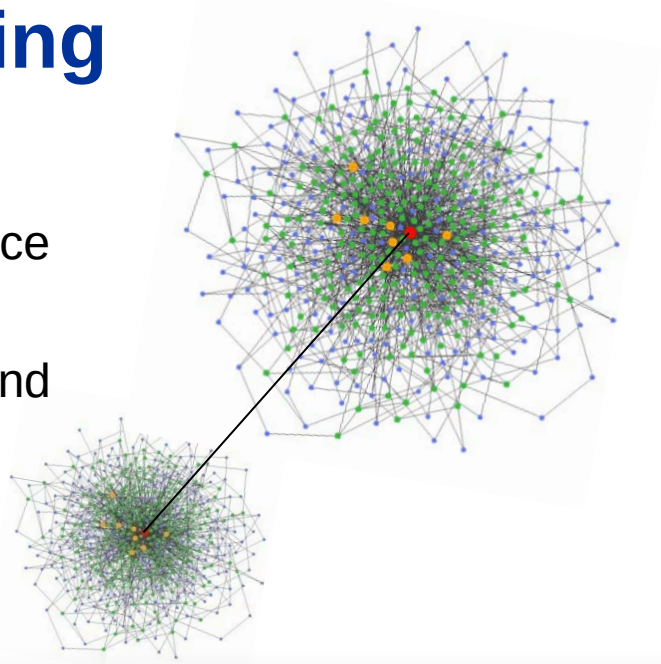
- **Advanced Control**
  - Link to process and component modeling for Model Predictive Control
  - Focus on core control advanced technologies
  - Examine adaptive control for existing combustion and actuation systems
  - Examine novel control architectures

- **Sensor Networks**
  - Pervasive low cost networked sensing for condition monitoring and control including wireless/less wires
  - Permit capture and manipulation of data for process improvement (via advanced control) and enable novel approaches to system integration
  - Explore novel constructs and application to generate and control power

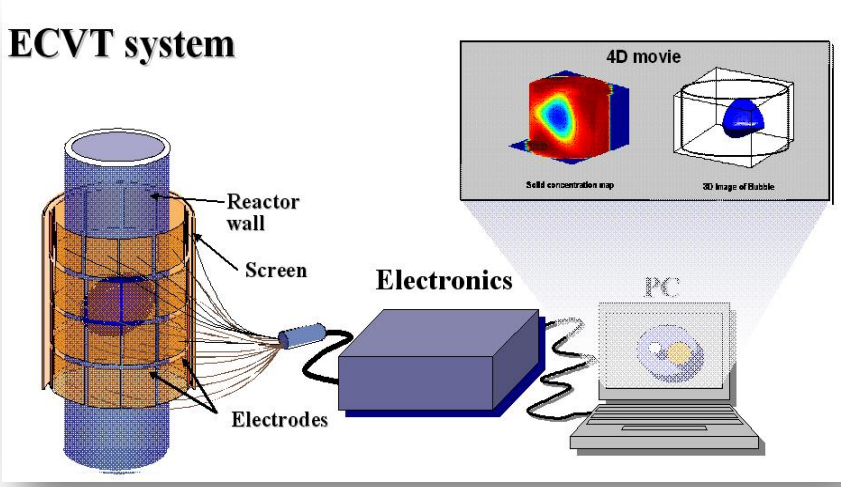


- **Challenge**
  - What data to collect, where to send it, coordinated output….
  - Measuring, modeling, and controlling solids and multiphase reacting flows

Sensor Technology for Control and Condition Monitoring



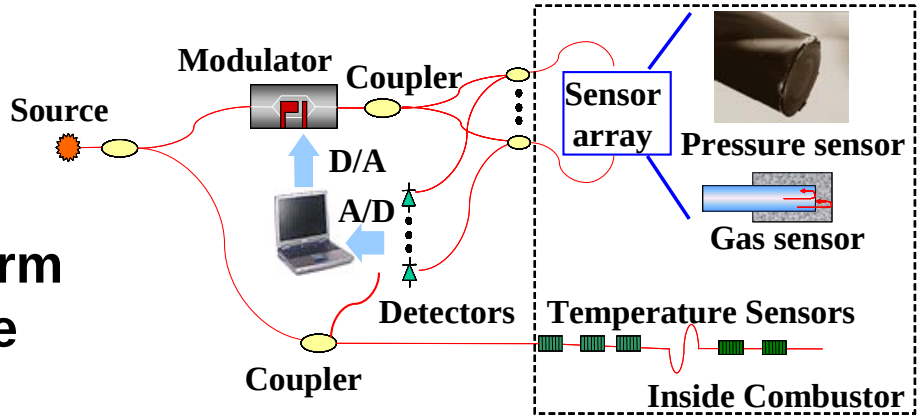
- **Sensor Networking**
  - Heterogeneous networks with “node” intelligence
- **Understand placement and sensor density**
  - Tailored to system size, physics, complexity, and role in plant
- **Integrated with Control Hardware**
  - Linked to device(s) role, value, priority, and overall capability
- **Provides information (not data) models and plant staff for component health, materials degradation, life prediction, and maintenance**
- **Model development is key for supporting and implementing networks and controls**

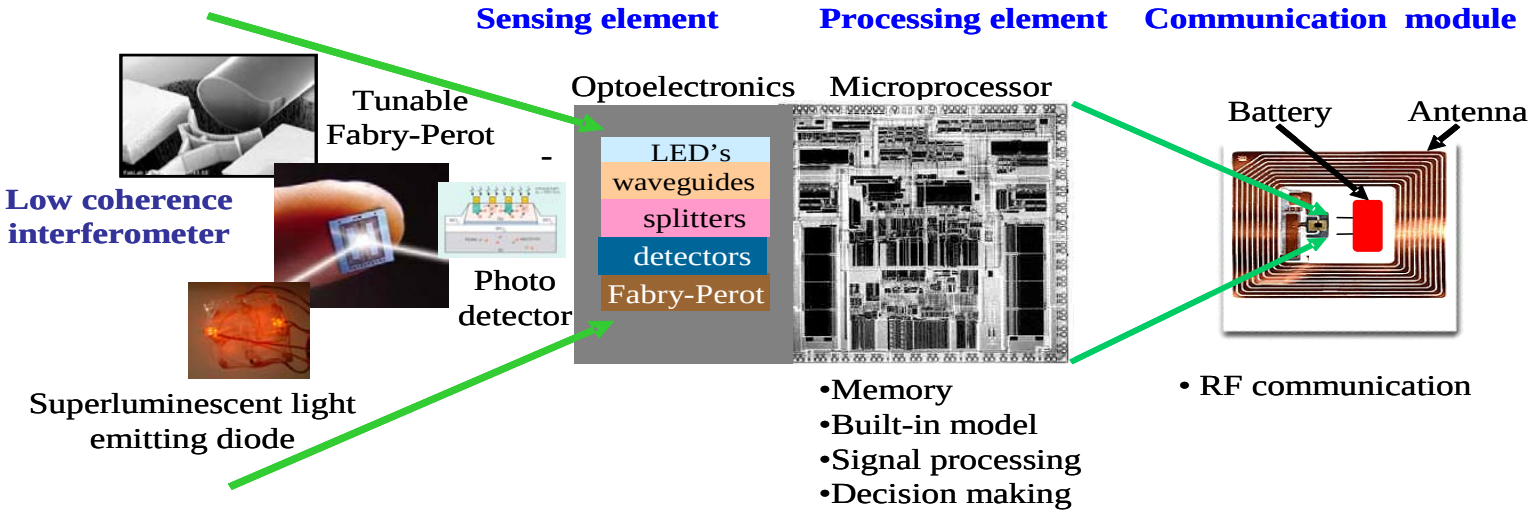


Sensor Networking

Optical Device Development for Sensor Networking

- **Development of fiber optic devices and micromechanical systems for dense sensor networking.**
- **Silica and silicon based platform for miniaturization of the entire sensor system.**
- **University of Maryland, Ames NL**

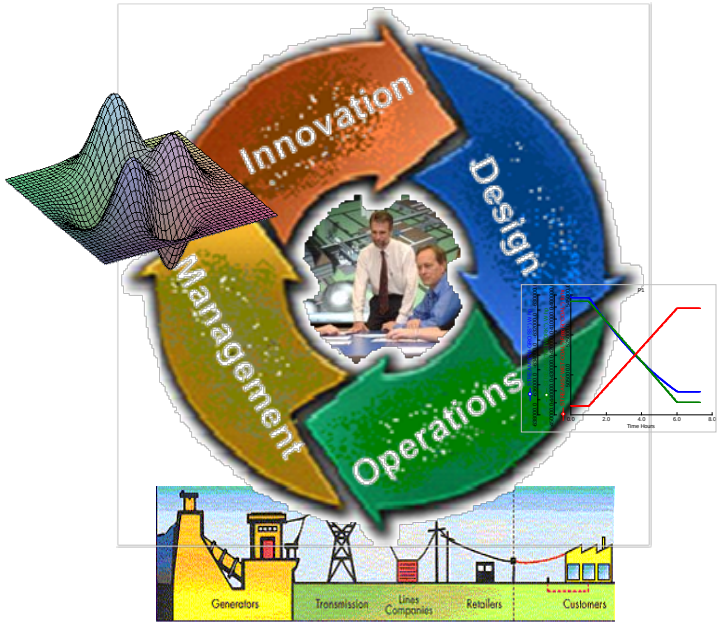




NETL Collaboratory
Process & Dynamic Systems Research

R&D Areas

- **Innovation**
  - Process Synthesis
  - Heat Exchanger/Water Networks
- **Design**
  - Process/Equipment Co-Simulation
  - Virtual Plant Simulation
  - Plant-wide Optimization
  - Risk and Uncertainty Analysis
  - Cost Estimation
- **Operations**
  - Dynamic Simulation and Control
  - Real-time Applications
- **Management**
  - Planning and Scheduling
  - Supply Chain Management
  - Enterprise-Wide Optimization

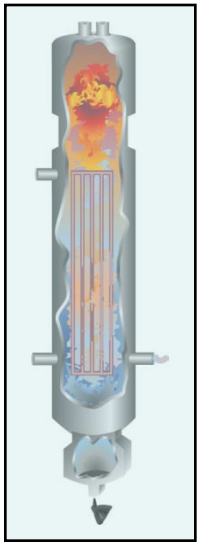


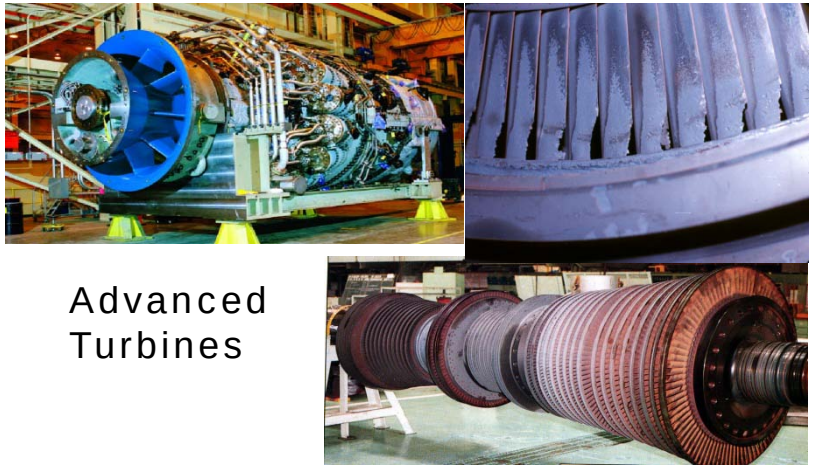
Power Plant Lifecycle

Fossil Energy Key Material Research Areas

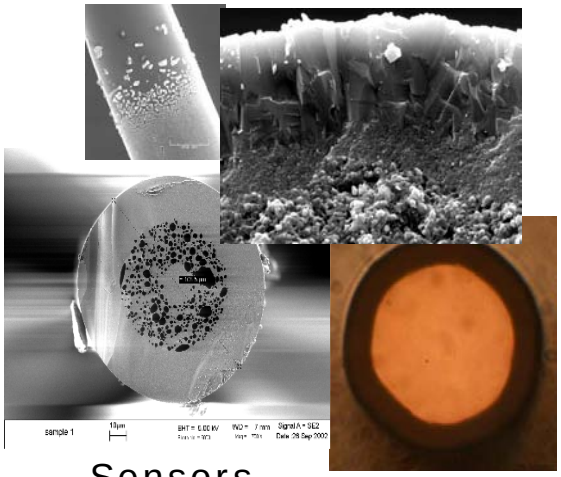
USC Boilers/Turbines

Gasifier

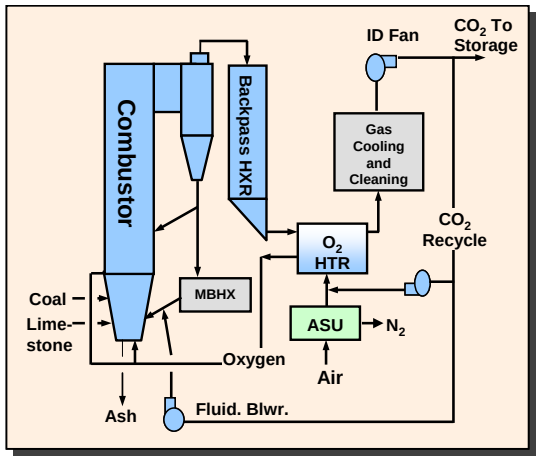




Advanced Turbines



Sensors



Oxy-Firing

Fuel Cells

Advanced Research Materials Program
HIGH TEMPERATURE APPLICATIONS

New Alloys

To increase the temperature capability of alloys for use in specific components required for advanced power plants by understanding the relationships among composition, microstructure, and properties.

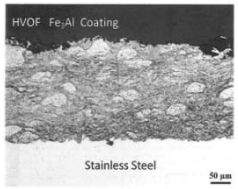
Breakthrough Materials

To explore routes for the development of materials with temperature/strength capabilities beyond those currently available.

UltraSupercritical Materials

To evaluate and develop materials technologies that allow the use of advanced steam cycles in coal-based power plants to operate at steam conditions of up to 760 C (1400 F) and 5,000 psi

Coatings and Protection of Materials



To develop the design, application, and performance criteria for coatings intended to protect materials from the high-temperature corrosive environments encountered in advanced fossil energy plants.

Functional Materials

To understand the special requirements of materials intended to perform specific functions, such as energy storage systems.

US A-USC Materials Programs

- Identify and evaluate **advanced materials** that help achieve highly efficient, cost competitive, and environmentally acceptable pulverized coal combustion based electric power generation (A-USC)
  - Steam conditions of 760 °C (1400 °F) and 5000 psi
  - Plant efficiency increases to 45 -47%
- Primarily a Materials Technology Evaluation Program
  - Focus on **nickel-based alloys** including gamma prime (age-hardenable) strengthened alloys for highest temperature regions of the boiler and steam turbine
  - Develop fabrication and joining technology for new alloys
  - Continue research on stainless and ferritic steels for economy of new plant
- Unique Conditions for US Program
  - Higher-temperatures than European Program (760 C versus 700 C) means **different alloys** are being evaluated
  - High Cr Alloys and extensive testing of coatings and surface modification for **US coals**
  - Data for **ASME code** acceptance of new materials
  - Phase II Boiler work includes focus on **Oxycombustion**

Gasification Technology

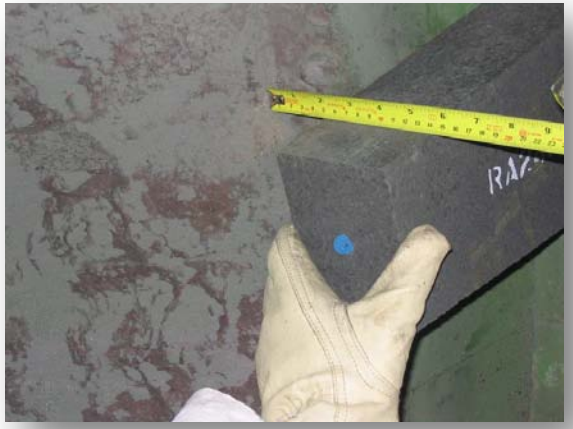
Advanced Refractories for Gasifiers

Office of Research and Development

Enhancing reliability, performance, and on-line availability of gasification systems

Project Objectives:

- Develop refractories with improved performance longer and predictable service life
- Develop refractories that are environmentally friendly and cost effective low/no chrome, minimize Cr+6 formation
- Develop refractories with carbon feedstock flexibility
  - model gasifier slag predict chemistry, viscosity, and phases formed
  - control slag/refractory interactions and slag viscosity
  - design slag to increase refractory service life
- Develop reliable sensors to accurately monitor gasification temperature



Failed refractory material

Failed thermocouple

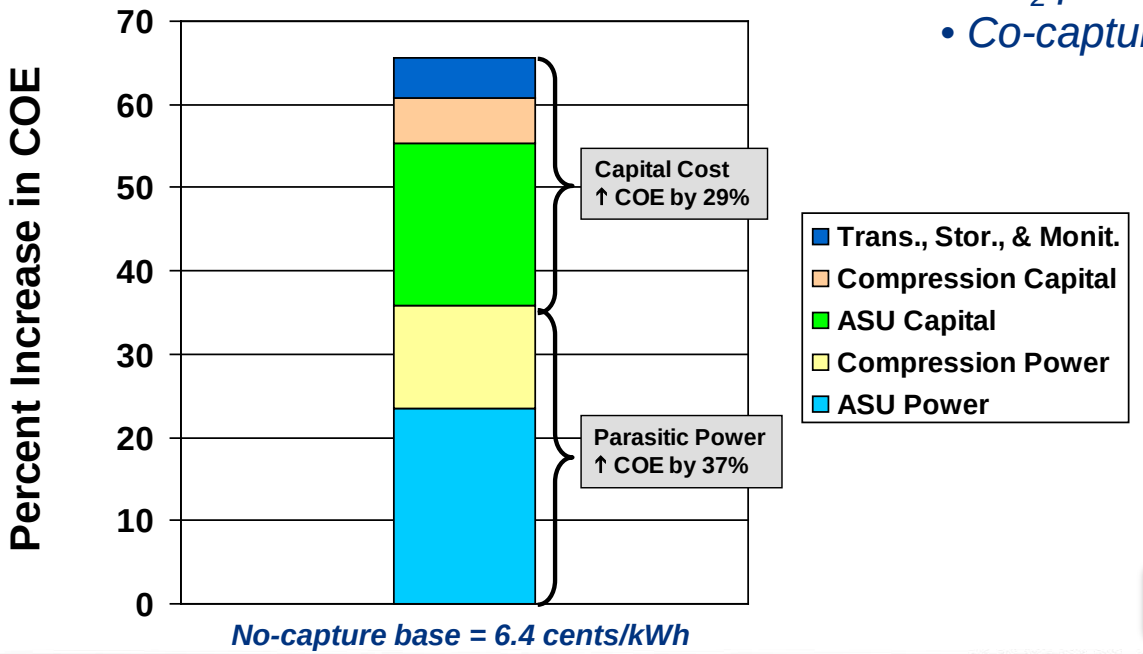
Innovations for Existing Plants
Pulverized Coal Oxy-combustion

Challenges

- *Cryogenic ASUs are capital and energy intensive*
- *Existing boiler air infiltration*
- *Corrosion and process control*
- *Excess O_2 and inerts (N_2, Ar) ↑ CO_2 purification cost*

Advanced Oxy-combustion R&D Focus

- *New oxyfuel boilers*
  - *Advanced materials and burners*
  - *Corrosion*
- *Retrofit existing air boilers*
  - *Air leakage, heat transfer, corrosion*
  - *Process control*
- *Low-cost oxygen*
- *CO_2 purification*
- *Co-capture (CO_2 + SOx, NOx, O_2)*



No-capture base = 6.4 cents/kWh

Laboratory to 5 MWe Pilot-scale

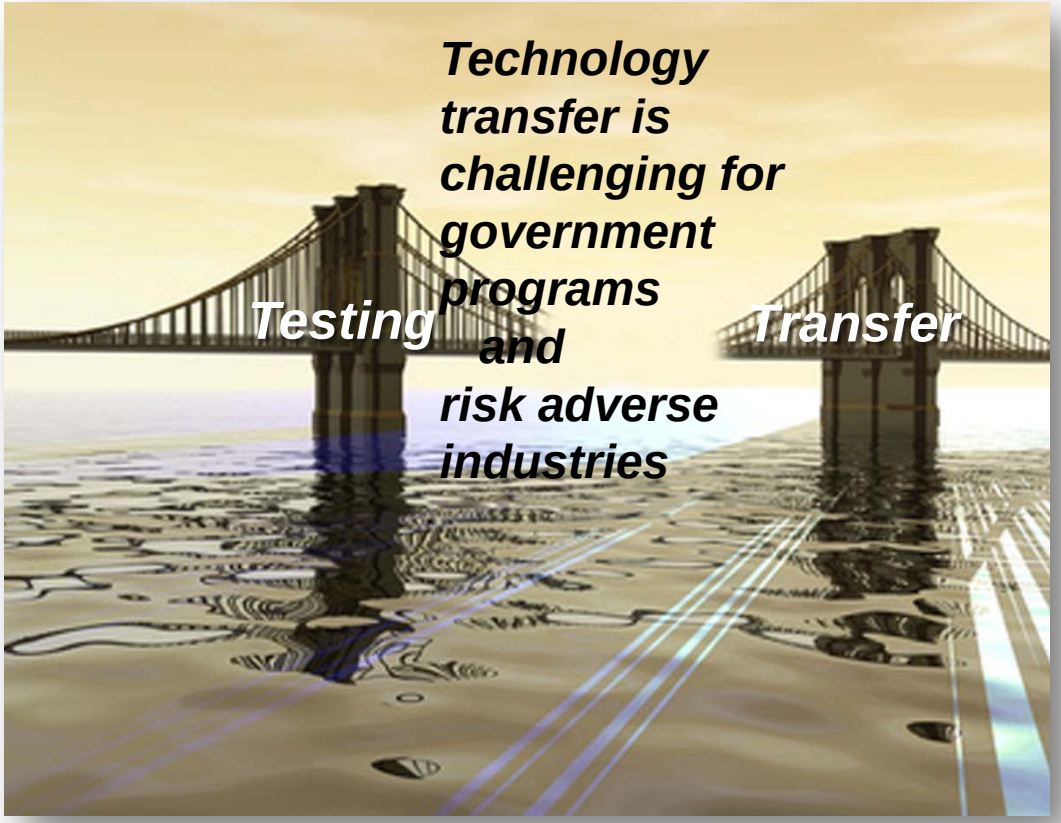
Partners (11 projects): Praxair, Air Products, Jupiter, Alstom, B&W, Foster Wheeler, REI, SRI

Technology Testing and Transfer

The Advanced Research Program's primary role is to support innovation and transformation of concepts into working technologies

Measures of success tie back to testing, patents/ licensing, and commercialization

- **Opportunities within AR to assist with technology maturation**
  - Sensor testing at bench scale
  - Sensor packaging for large scale testing efforts
  - Application knowledge to improve designs for industrial use
  - Partnering for multidisciplinary approach to productize a technology



What Does the Future Look Like?

- **The USA and the world will face great energy challenges with ever increasing environmental constraints**
- **Advanced fossil energy power systems will be needed**
- **The Advanced Research Materials Program is poised to have even greater impacts on future energy systems**
  - Novel materials for high temperature applications
  - Next generation stainless steels with higher strength and better oxidation resistance
  - Advanced coatings
  - Prescriptive materials design and lifetime prediction for extreme environments

Contact Information

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