NATIONAL ENERGY TECHNOLOGY LABORATORY

Advanced Research Sensors and Controls Awards Kick-off Meeting

Robert Romanosky, Technology Manager

December 15-16, 2009

U.S. DEPARTMENT OF ENERGY

National Energy Technology Laboratory

Where Energy Challenges Converge and Energy Solutions Emerge

- **Only government owned & operated DOE national lab**
- **Dedicated to energy RD&D, domestic energy resources**
- **Fundamental science through technology demonstration**
- **Unique industry–academia–government collaborations**

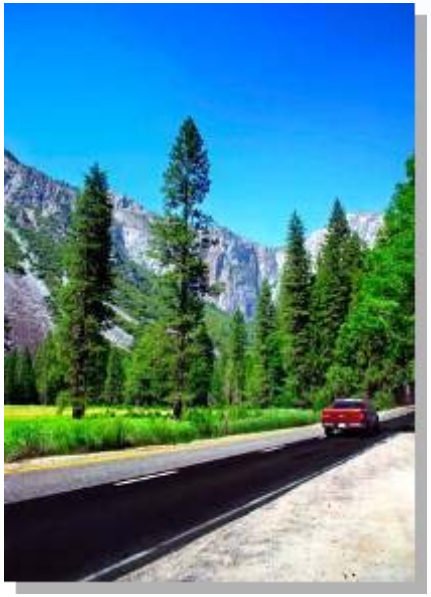
Oregon

Pennsylvania

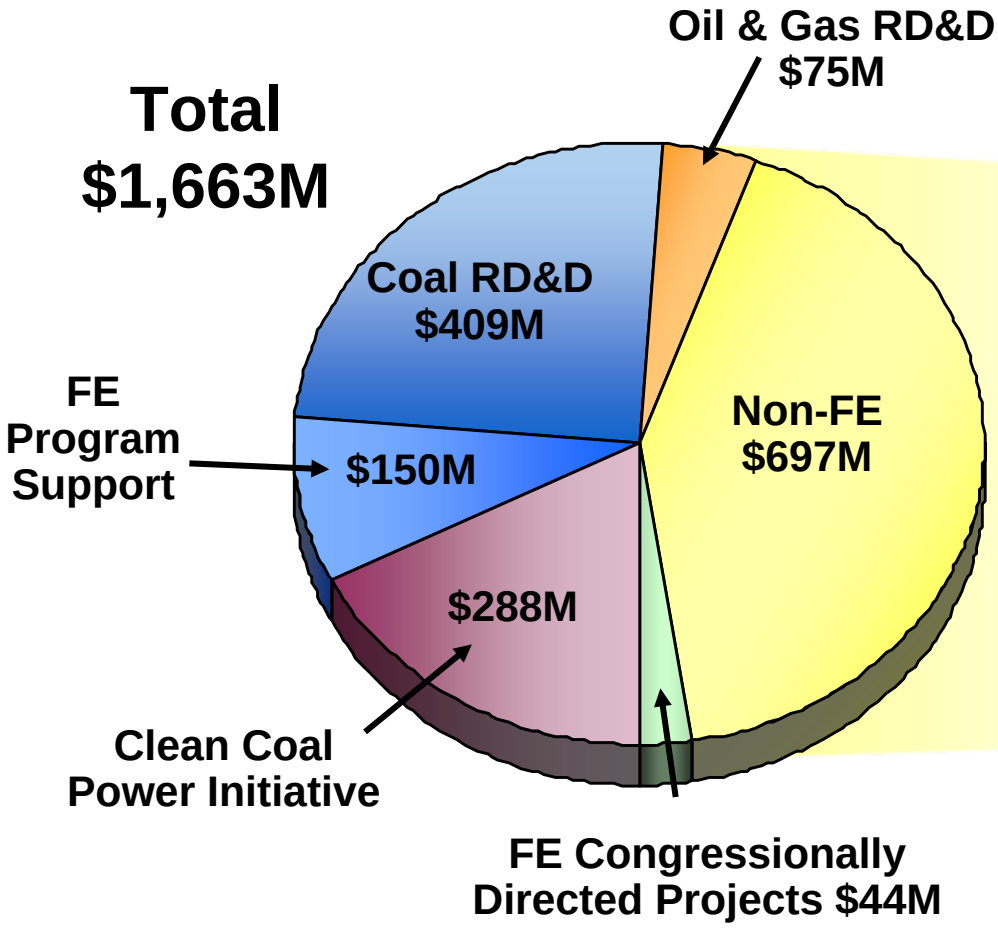
West Virginia

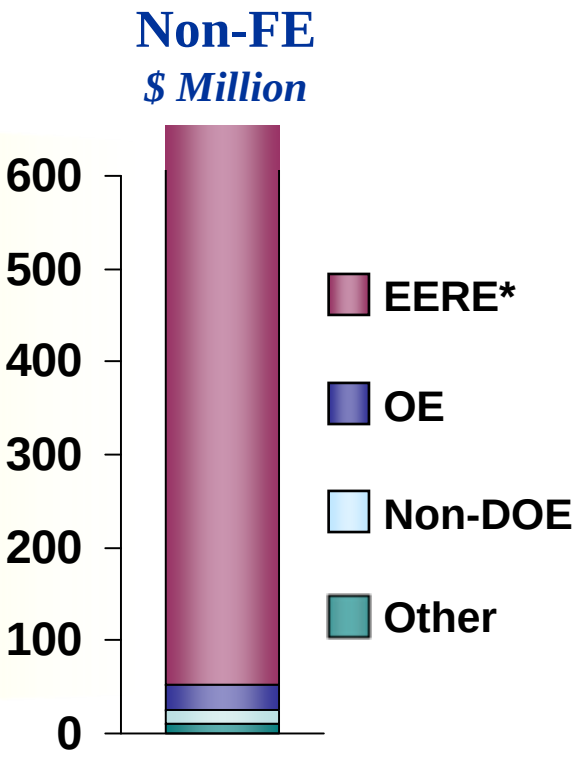
NETL Mission

Advancing energy options to fuel our economy, strengthen our security, and improve our environment



NETL FY 2009 Budget





*NETL also financially manages ~$941M for EERE's Project Management Center

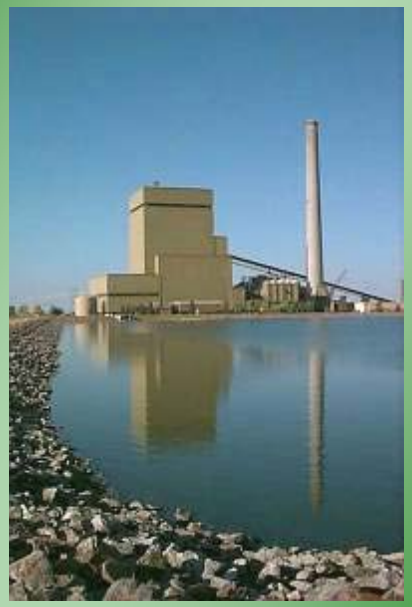
Note: In addition to NETL's FY 2009 budget of $2.6B, NETL will implement programs valued at $15.5B under the American Recovery and Reinvestment Act of 2009

Working with NETL

- **Competitive Solicitations (Open, University, Small Business)**
- **Cooperative Research and Development Agreements (CRADAs)**
- **Partnering with NETL and Industry for testing of sensors on full scale systems**

NETL Mission Areas

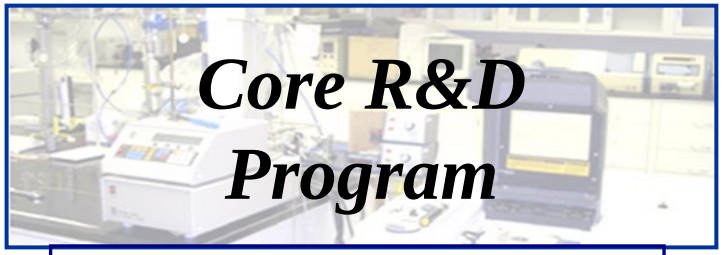
Strategic Center for Coal



Strategic Center for Natural Gas and Oil

Project Management Center

NETL's Strategic Center for Coal



Core R&D Program

Coal & Power Systems

Gasification
Advanced Turbines
Fuel Cells
Hydrogen and Clean Fuels
Innovations for Existing Plants
Carbon Sequestration

All Programs Support DOE Goals for Energy Security

- ***Energy diversity***
- ***Environmental impacts***
- ***Energy infrastructure***
- ***Energy productivity***

FutureGen

Clean coal power generation with carbon capture and storage

Demonstration Program

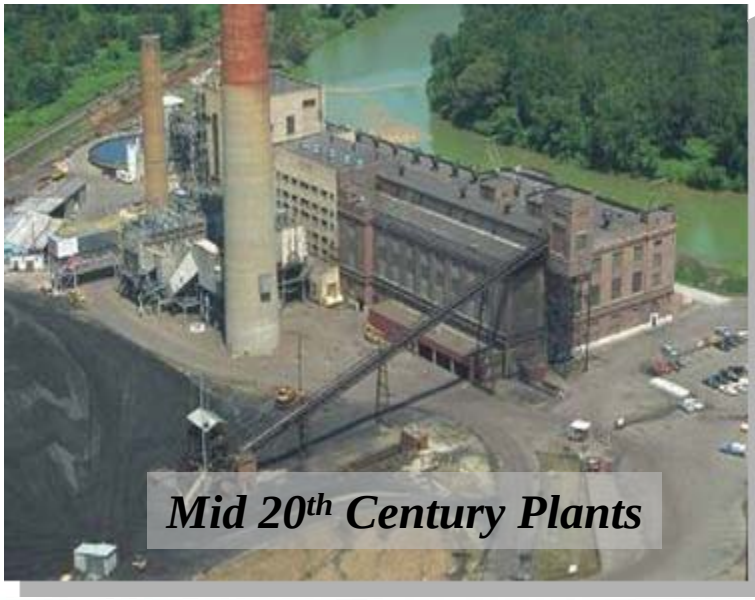
Clean Coal Power Initiative

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**

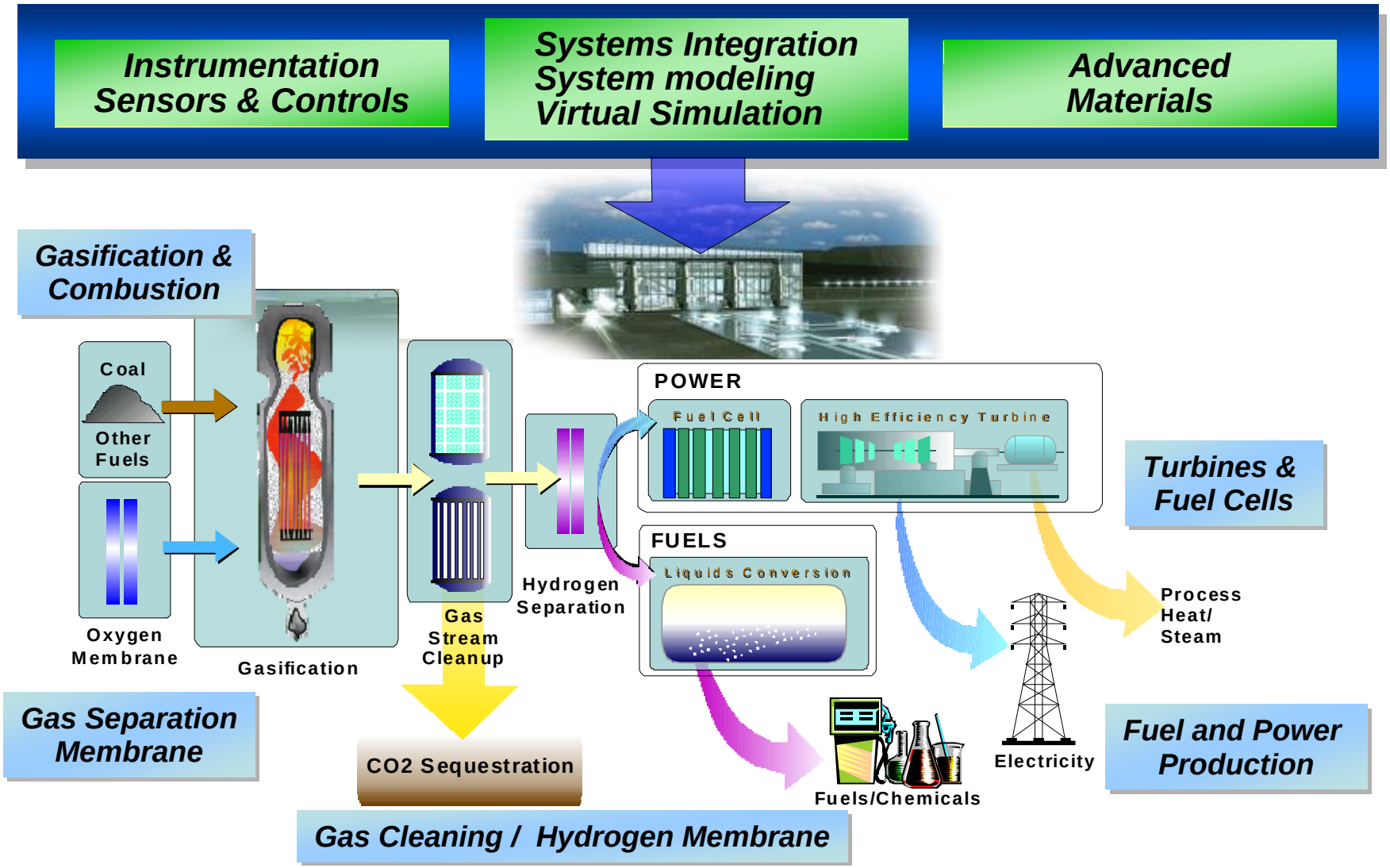
Technology Challenges
Being addressed within Advanced Research

- 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

Ultra-Clean Energy Plant



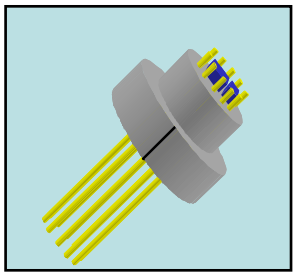
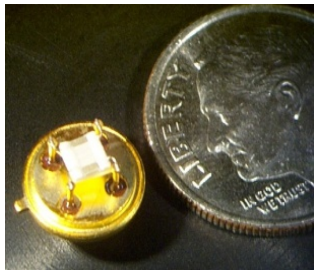
Target for Sensor and Controls

Seamless, integrated, automated, optimized, intelligent power and fuel production facilities

Identify and execute research and development for sensing and advanced process control to help ensure that key technologies will be available to meet the needs of future near zero emission power systems

Motivation for Developing New Sensors and Control Technology

- **Low cost, high benefit technology**
- **Existing technology is inadequate**
  - Advanced power systems have harsh conditions that need to be monitored with new instrumentation and sensor technology
- **Boosts efficiency and significantly contributes to high reliability**
- **Supports all power generation systems and related infrastructures**
- **Makes operation of future ultra clean energy plants possible**
- **Enables new paradigms in plant and asset management beyond traditional process control**


Driver for New Sensing Technology

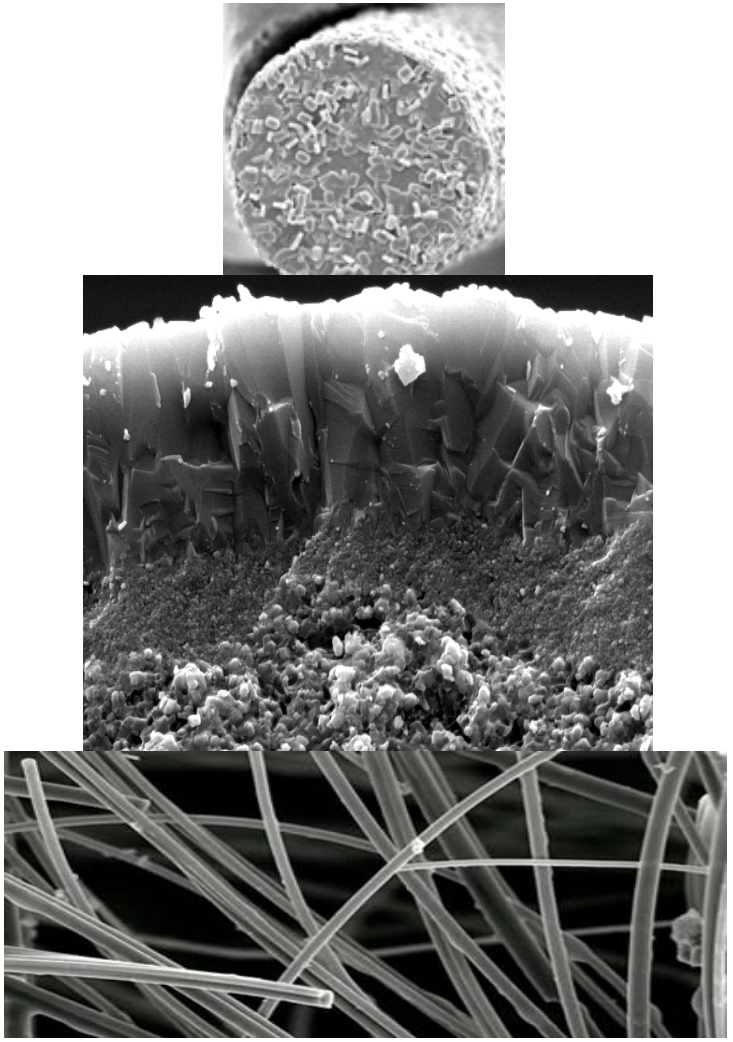
- **Advanced Power Generation:**
  - Harsh sensing conditions throughout plant
  - Monitoring needed with advanced instrumentation and sensor technology.
  - Existing instrumentation and sensing technology are inadequate

- **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.

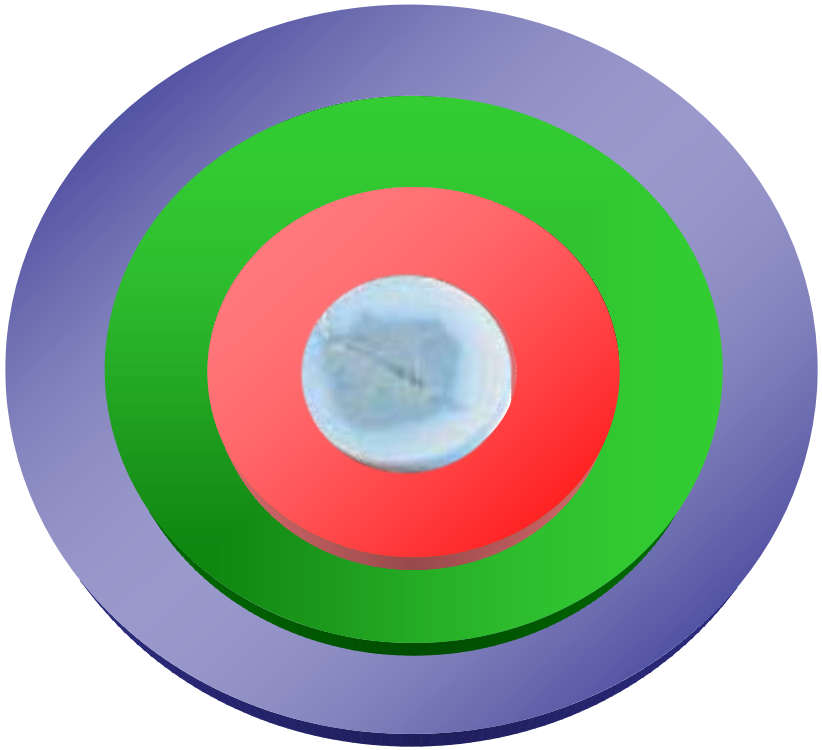
Materials for Sensing in Harsh Environments (Optical and Micro Sensors)

- **Sapphire**
- **Alumina**
- **Silicon Carbide**
- **Doped Silicon Carbide Nitride**
- **Yttria stabilized zirconia**
- **Fused/doped silica for certain conditions**
- **Interest in**
  - Active / doped coatings
  - 3D porous or “mesh” nano-derived ceramics / metal oxides



Development Target

Commercially Viable Sensor Technologies



- ***Feasibility / Proof of Concept***
  - Materials
  - Basis for sensing
  - Fabrication of device
  - Selectivity
  - Accuracy
  - Identification of failure mechanisms
- ***Demonstration of Sensor Performance***
  - Sensor design
  - Sensor packaging
  - Survivability followed by performance
  - Portability, connectivity, ease of use
- ***Technology transfer / Commercialization***
  - Commercialization plan (license vs. sell)
  - Testing
  - Ability to manufacture
  - Letting go of the technology and embracing the business

Sensor and Control Needs

Controls

- Integrated control
- Neural nets
- Predictive, adaptive control
- Modeling
- Advanced networking

Advanced Materials

- High temperature sensor materials
- Nano-derived materials
- In service monitoring of materials

Gas Purification / Separation Environmental Control

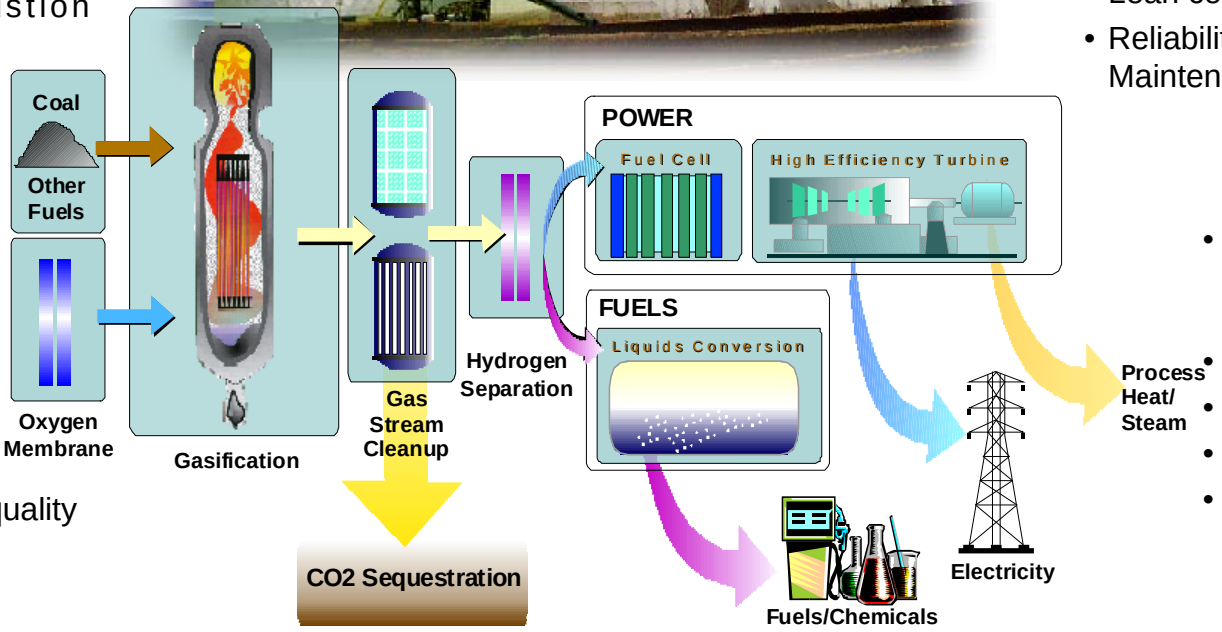
- Mercury Trace Metals
- NOx, SOx
- Ammonia
- CO_2 Monitoring

Turbines

- Temperature
- Fuel Quality
- Dynamic Pressure
- Thermal barrier coating
- Hydrogen
- Fast response
- Lean combustion control
- Reliability and Predictive Maintenance Monitoring

Gasification Chemical Looping Advanced Combustion

- Temperature
- Gas Quality
- Fuel / air ratio control
- Robust sensors
- Feed flow and Characterization
- Particle Detection
- O_2 control
- Corrosion monitor
- Steam conditions/quality



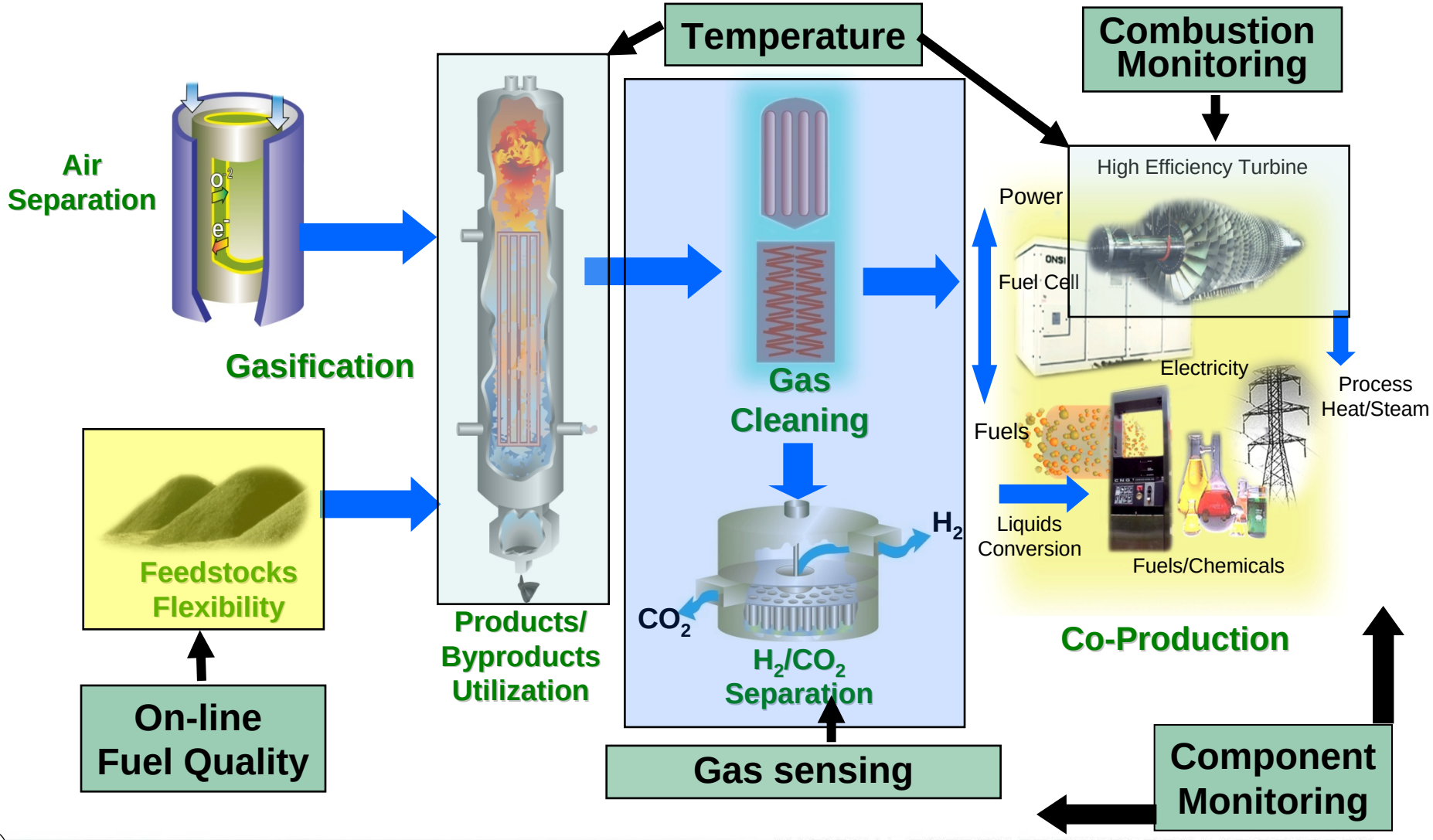
Fuel Cells

- Catalyst and electrode monitoring
- Sulfur
- Reformate Quality
- Flow & Pressure
- Diagnostic Capability

Updated November 2008

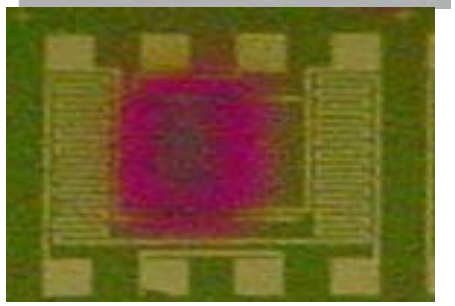
Prioritized Sensing Needs

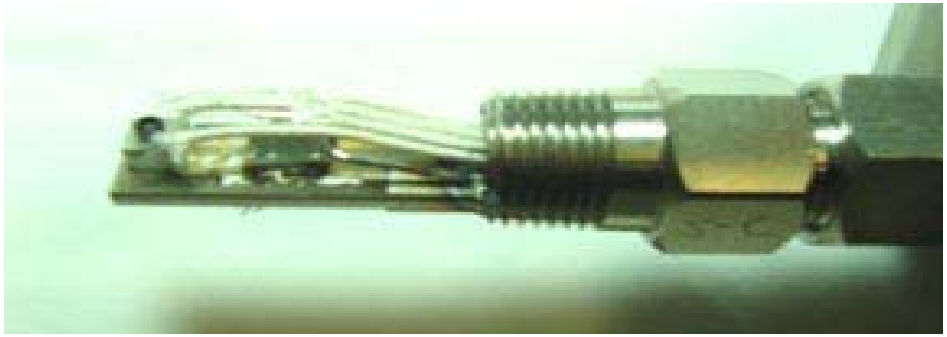
IGCC based Near Zero Emission Cogeneration Plant



High Temperature (~500 °C) Micro Sensor Development and Testing

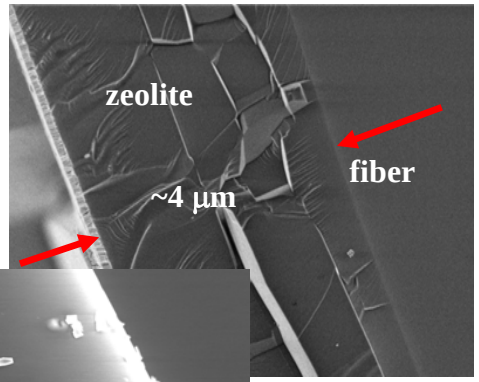
- **Ceramic and semiconductor substrate materials**
  - YSZ, Alumina, Silicon Carbide, etc
- **Multigas catalytic active sensing materials**
  - Single gas sensors and sensor arrays
  - NOx, NH_3, CO, CO_2, H_2, O_2, HCl, SO_2, H_2S, HCs
- **Key technology for pervasive sensing, sensor networking and advanced control**
- **Targeting low cost sensors**
  - Initial investment in sensor system and software (~20K)
  - Approximately $50 for replacement of sensor elements with 12 month targeted lifetime
- **Testing is critical**
  - Large amount of lab data demonstrating potential
  - Moving forward with pilot scale and full scale evaluations

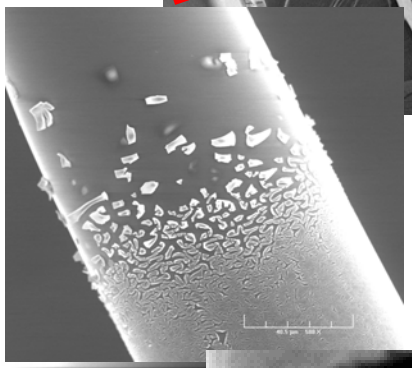


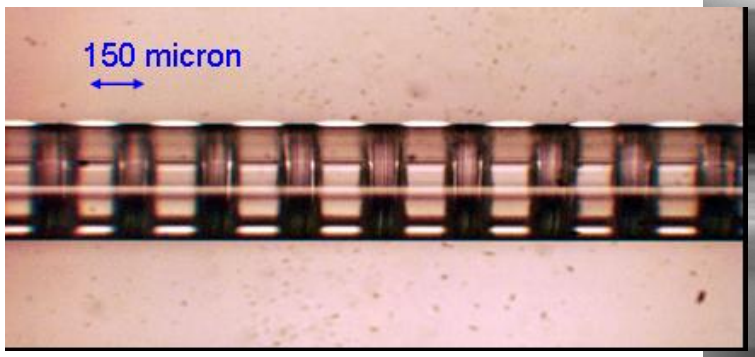


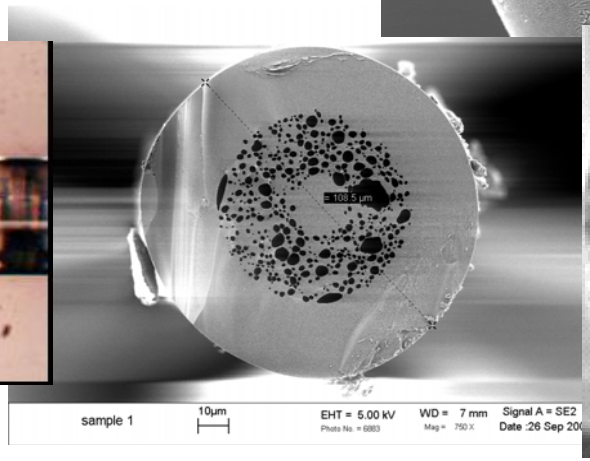
Fiber-based Gas Sensors

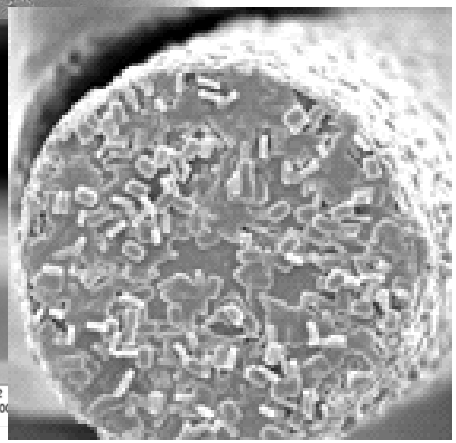
- **Silica-based fiber sensors**
  - High temperature grating development
  - Distributed and selective gas sensing
  - Active sensing layers
- **Sapphire-based fiber sensors**
  - Coating materials
  - Single & Multipoint sensing designs





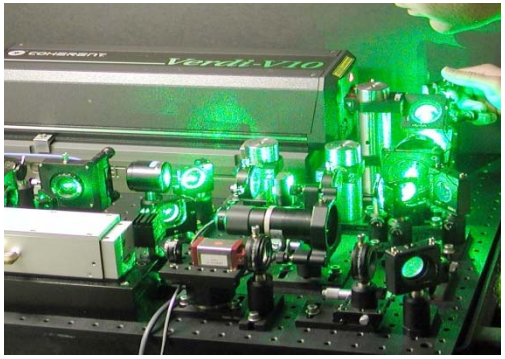




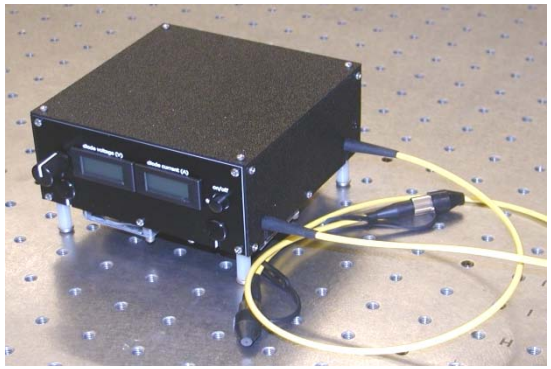


Optical and Laser Based Techniques

- **Novel approaches for temperature and gas species monitoring**
  - Optical materials, new light/laser sources
  - Detection in pressurized vessels
  - Trace level detection
  - (NO_X, SO_X, particulate, Hg, CO, CO_2, etc)

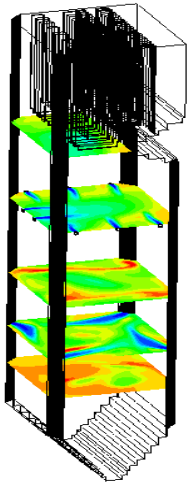


- **Advantages with these techniques**
  - Non-intrusive, rapid, continuous measurements
  - Readily adapted for regulatory monitoring
  - Relative ease in calibration
- **Challenges with these techniques**
  - Optical access
  - Rugged, compact, field ready systems
- **Testing Completed / Underway**

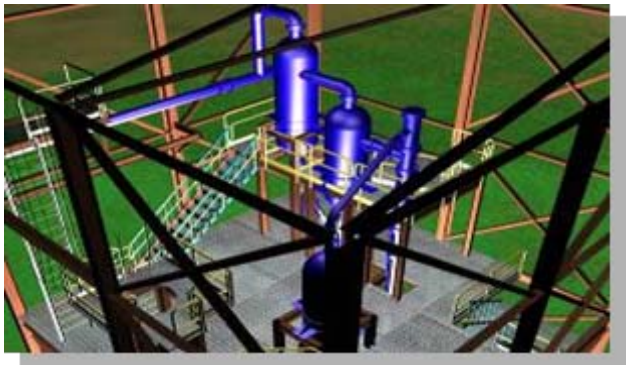


Advanced Control Development

- **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
  - Continue to examine and identify opportunities in this area Technology advancing rapidly in non FE areas



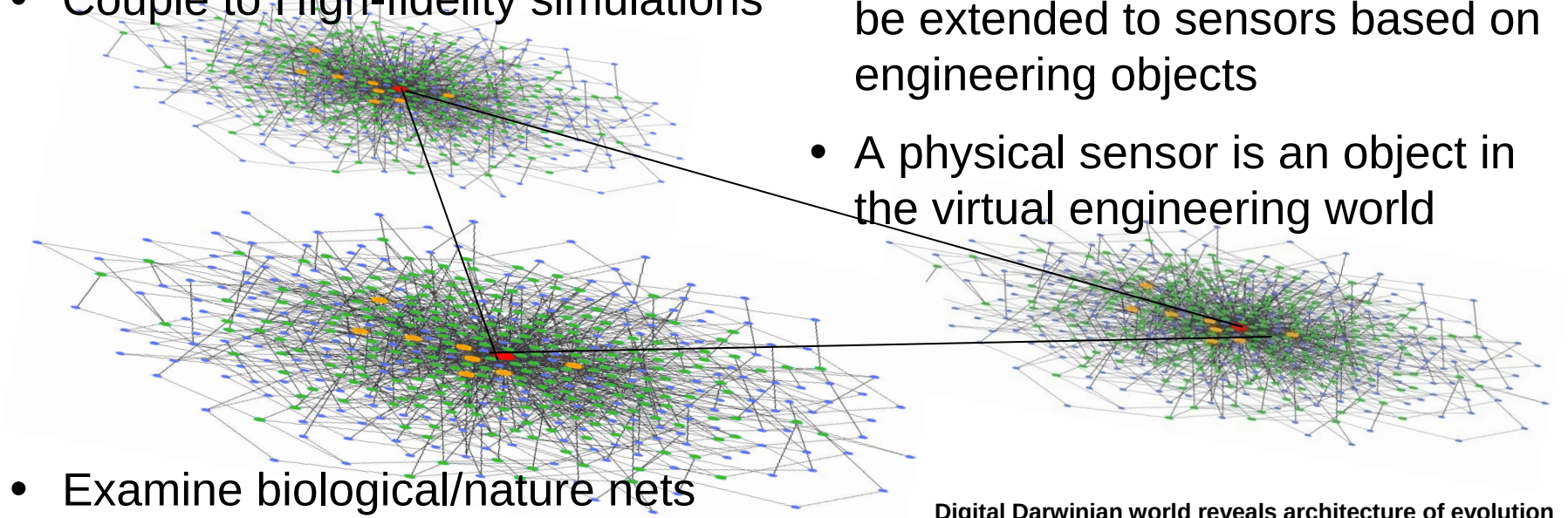
- **Advanced Control**
  - Link to process and component modeling for Model Predictive Control
  - DOE Projects focused on core control of chemical looping and gasification processes and lower level controls
  - Examining model free adaptive control for existing combustion systems and actuation control
- **Challenge**
  - What data to collect, where to send it, coordinated output….
  - Measuring, modeling, and controlling solids and multiphase reacting flows



High Density, Heterogeneous, Massive Sensor Nets for Process Systems

- Massive real time data sets
  "data storm"
- Hybrid sensor architectures
- Computing is capable & ubiquitous
- Complex systems *"are the future"*
- Couple to High-fidelity simulations

- Utilize and extend capabilities of virtual engineering
- Build and test various sensor network strategies
- Principles of model integration can be extended to sensors based on engineering objects
- A physical sensor is an object in the virtual engineering world



- Examine biological/nature nets and communication networks

Digital Darwinian world reveals architecture of evolution
(Nature Physics)

Introduction to Stigmergy

Development of representative algorithms

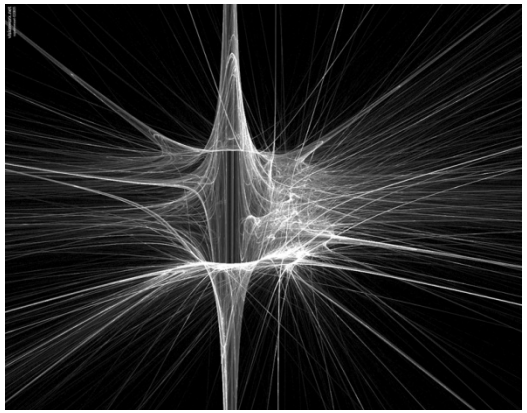
Indirect communication of multi-agent groups through environmental elements

Nature:

- Used to describe the construction of termite nests
- Information is stored implicitly within the environment

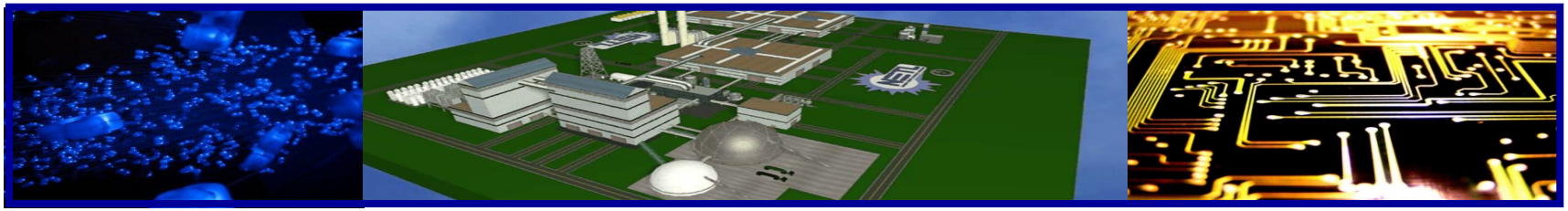
Advanced S&C:

- Potentially powerful tool for coordination of sensor data
- Makes use of a decentralized controller
- Processors are embedded in each hub
- Hubs can communicate with their neighbors
- Forms a data line within the structure
- Communicating sensor hub approach may allow the structure to enforce desired restrictions on control



Technology Gaps and Future Directions

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



Conclusions

- **Challenges require innovation at all levels**
  - Creation of low cost reliable, zero emission power and multi product large scale plants utilizing domestic resources will require advanced sensors and controls for operation and achievement of performance goals
- **Focus is on High Risk and High Reward Development**
  - Advanced power systems, including turbines, harsh environments that require monitoring and the development of sensors for these environments is the thrust of NETL's Program.
- **Value in reduction to practice**
  - Development of individual S&C technologies, including enabling technologies, are required but value is derived from integrating, adapting, networking, packaging for systems and plant level operation and control

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