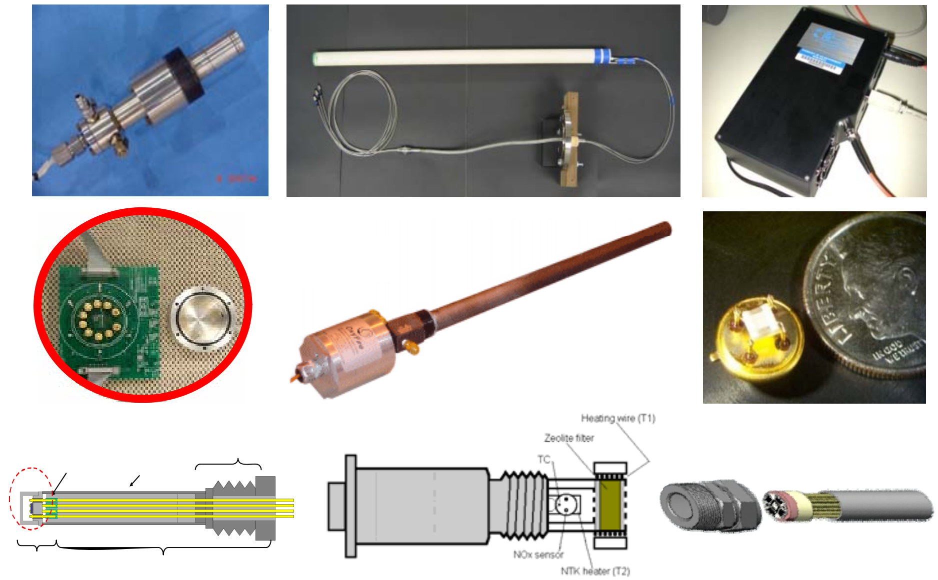
Advanced Research



Stakeholder Workshop for Advanced Sensing In Fossil Energy Applications

Robert R. Romanosky

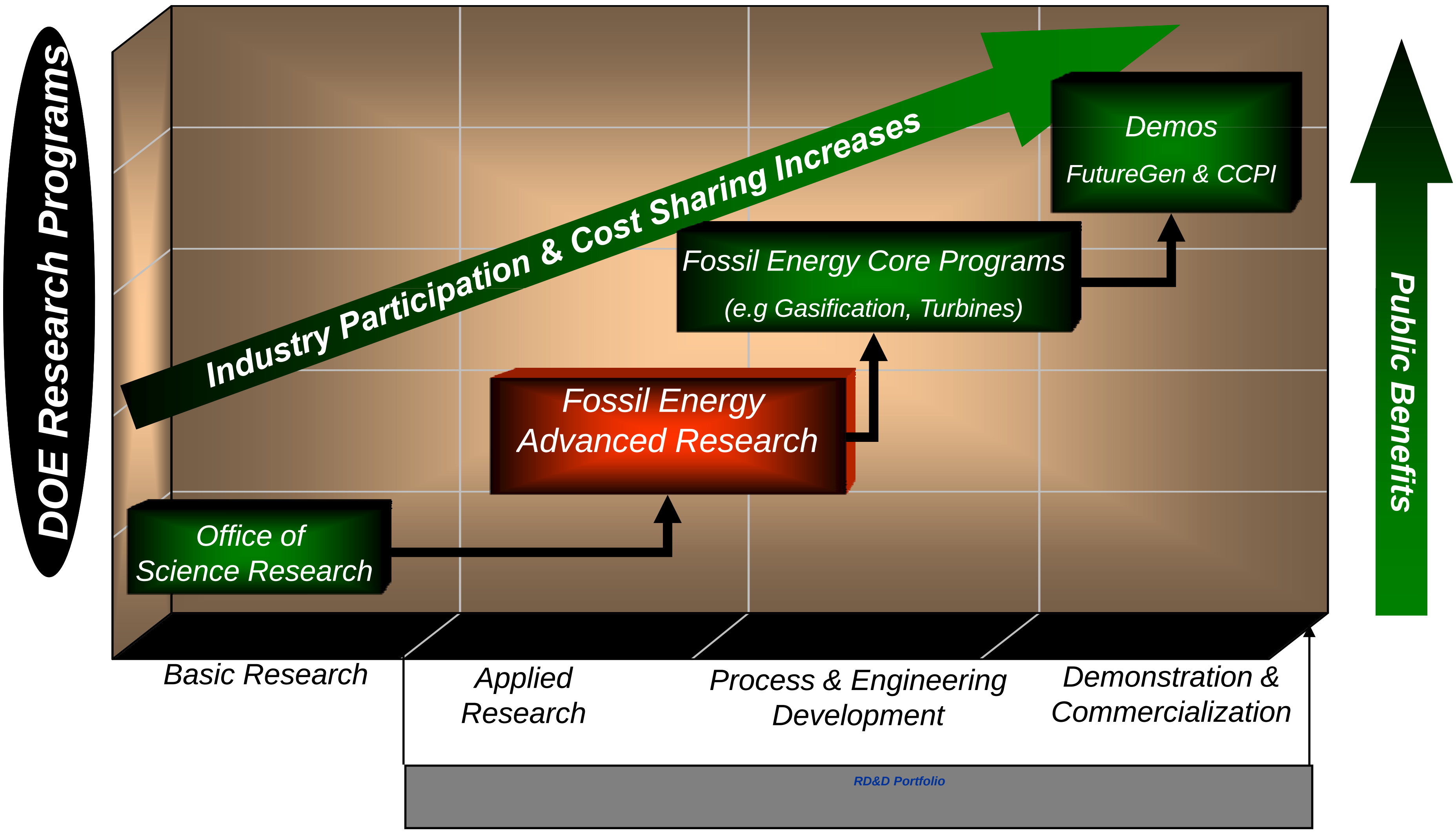
Advanced Research Technology Manager

8 April 2010

Overall Objective

- Fundamental R&D on New Sensor Materials
- Design of Advanced Sensors
- Testing of Sensors
- Algorithms Development for sensor placement
- Research and Development of Advanced Control systems
- Scheme for Integration of Advanced Sensors and Controls

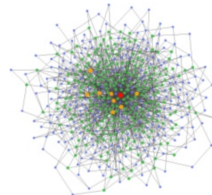
Advanced Research



Advanced Research

Gasification Refractory Materials

Ultrasupercritical Tubing



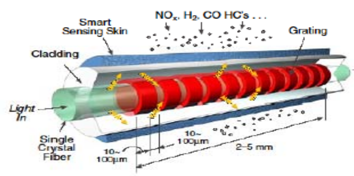
Integrated networking of Smart Sensors

Full-scale Power Plant Model validated using Advanced Power Systems

Adv Materials for Near Zero Emission Power Plants

2005 ***2010*** ***2012*** ***2015*** ***2020***

Fiber-based sensors commercialized



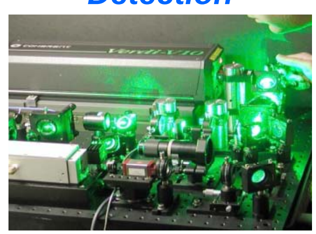
Materials for Ultrasupercritical component testing

Demonstrate Novel Control Architectures for Plant Operation

Transfer of Advanced Sensing Platform

Initial Model Capability
- ***Transport Gasifier***
- ***Gas Turbine***
- ***Heat Recovery Steam Generator***
- ***Solid-Oxide Fuel Cell***

Transition Laser Based Sensors for On line Detection



Adv Power Plant Simulations and Models for Advanced Power Systems Design

Advanced Research

NETL

- **Robert Romanosky**,
  Technology Manager
- **Susan Maley**
  Project Manager Sensors & Controls

Identify and execute R&D in sensing and advanced process control to enable advancement and availability of key technologies for near zero emission power systems

Sensors and Controls

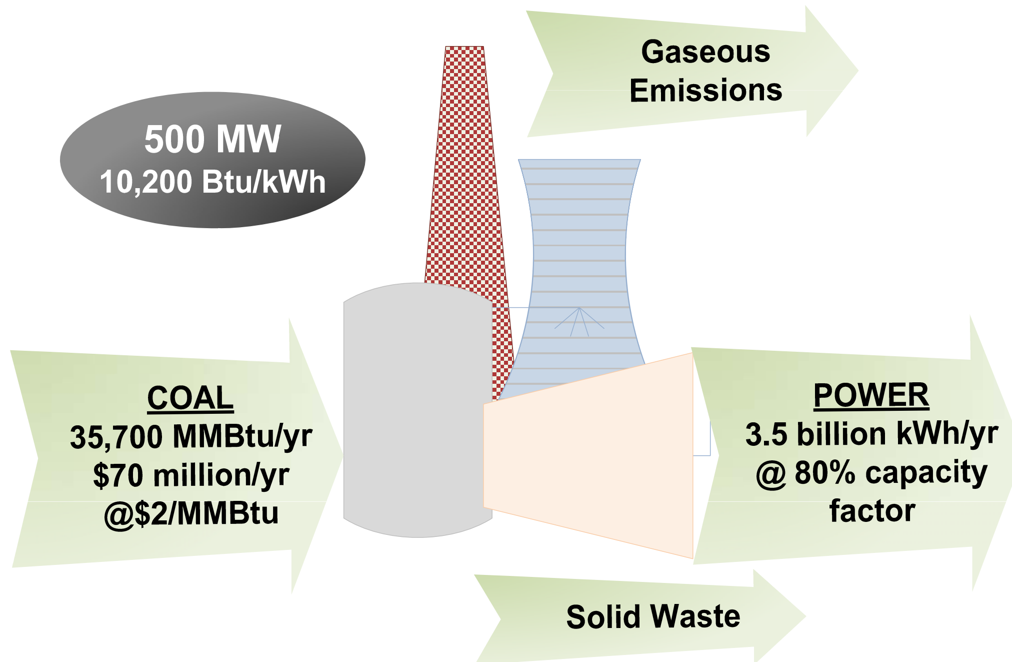
Shaped by	⇨	• **goals of efficient integrated plant operation with near zero emissions including carbon capture**
Influenced by	⇨	• **stakeholder involvement**
Motivated by	⇨	• **advancements in the basic sciences and fundamental research and engineering**
Intended to	⇨	• **have practical benefit and value to commercial operations**
Enhanced by	⇨	• **efforts in the AR Computational Energy Sciences and Materials Areas**
Encompasses	⇨	• **on-line and in-situ sensing and computational intelligent process control development**

Contribution from Sensors and Controls

Value Derived for an Existing Coal Fired Power Plant

1% HEAT RATE improvement

- 500 MW net capacity unit
  - $700,000/yr coal cost savings
  - 1% reduction in gaseous and solid emissions
- Entire coal-fired fleet
  - $300 million/yr coal cost savings
  - Reduction of 14.5 million metric tons CO_2 per year



Analysis based on 2008 coal costs and 2008 coal-fired power plant fleet (units greater than 300 MW)

1% increase in AVAILABILITY

- 500 MW net capacity unit
  - 35 million kWh/yr added generation
  - Approximately $2 million/yr in sales (@ 6 cents/kWh)
- Entire coal-fired fleet
  - More than 2 GW of additional power from existing fleet

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 above 800 psi. Slagging coal gasifiers are highly reducing, highly erosive and corrosive.
    - Combustion turbines are highly oxidizing atmospheres.

- **Reduce Total Cost of Ownership of plants / systems by developing and supporting control algorithms and condition monitoring technologies**
  - Focus on improving the reliability, availability and maintainability of existing and future power systems
  - Enable coordinated control for advanced power plants including carbon capture

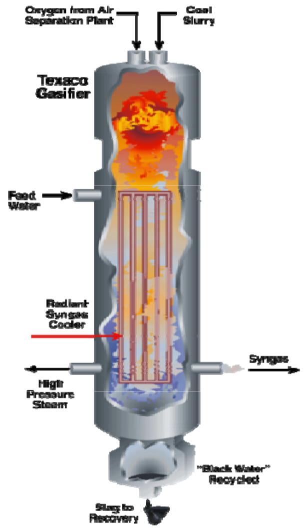
Harsh Environments

Solid Oxide Fuel Cells

- Utilizes Hydrogen from gaseous fuels and Oxygen from air
- 650 – 1000 °C temperature
- Atmospheric pressure

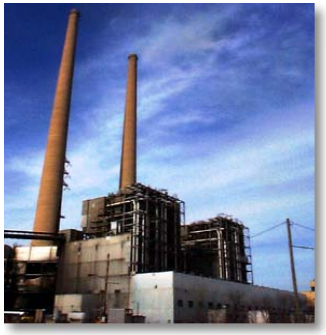
Advanced Combustion Turbines

- Gaseous Fuel (Natural Gas to High Hydrogen Fuels)
- Up to 1300 °C combustion temperatures
- Pressure ratios of 30:1



UltraSupercritical Boilers

- Development of ferritic, austenitic, and nickel-based alloy materials for USC boiler conditions
- Up to 760 °C temperature
- Up to 5000 PSI pressure

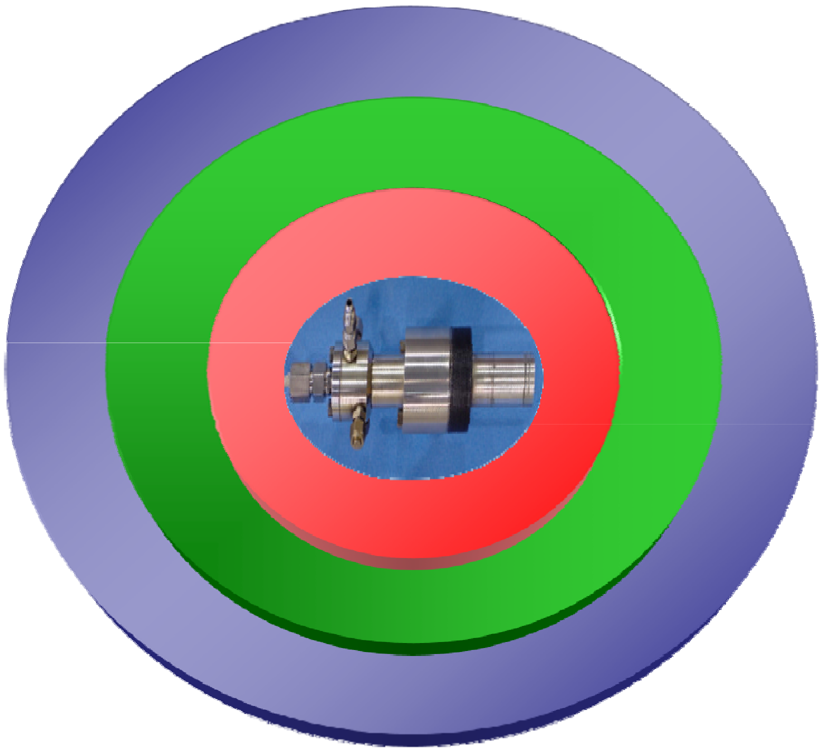


Gasifiers

- Up to 1600 -C, and 1000 PSI (slagging gasifiers)
- Erosive, corrosive, highly reducing environment
- Physical shifting of refractory brick, vibration, shifting "hot zones"

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

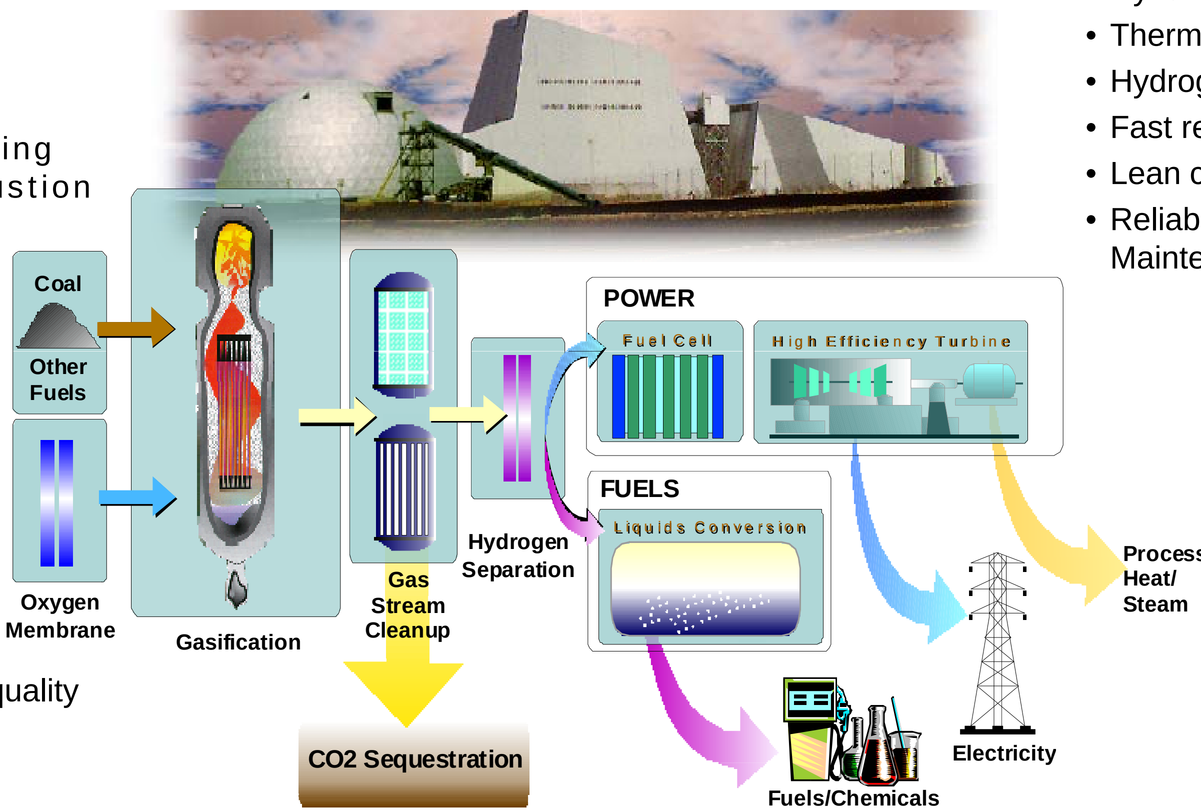
- Mercury Trace Metals
- NOx, SOx
- Ammonia
- CO_2 Monitoring

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



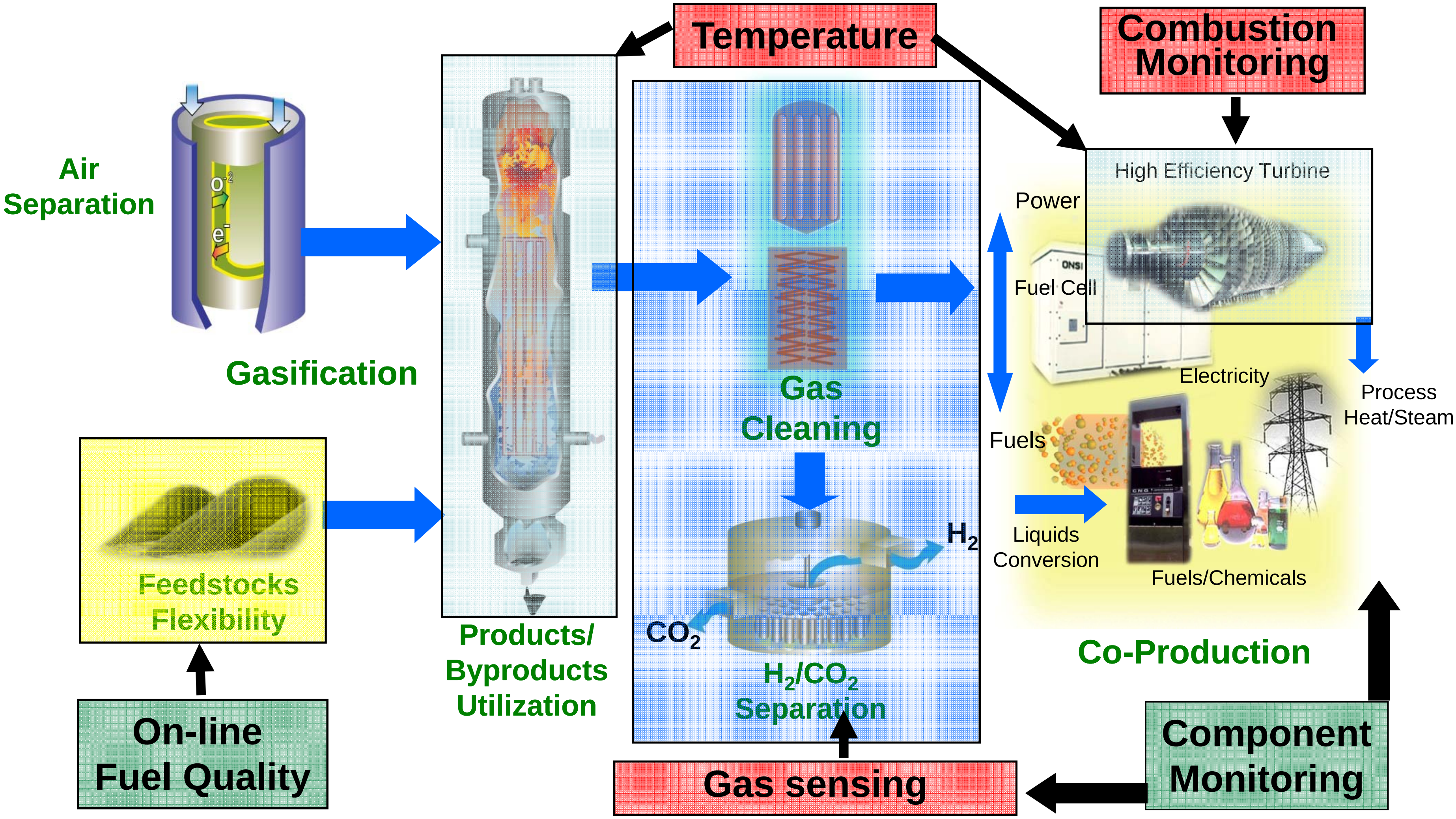
Fuel Cells

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

Updated November 2008

Prioritized Sensing Needs

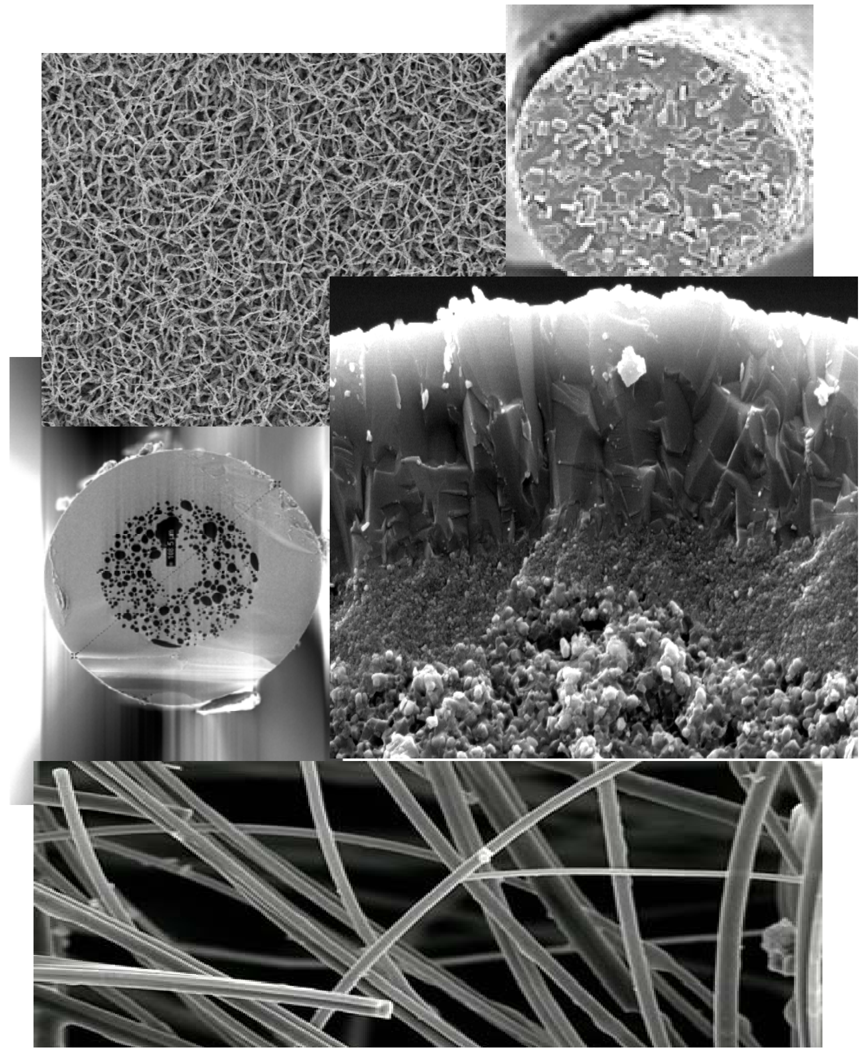
IGCC based Near Zero Emission Cogeneration Plant



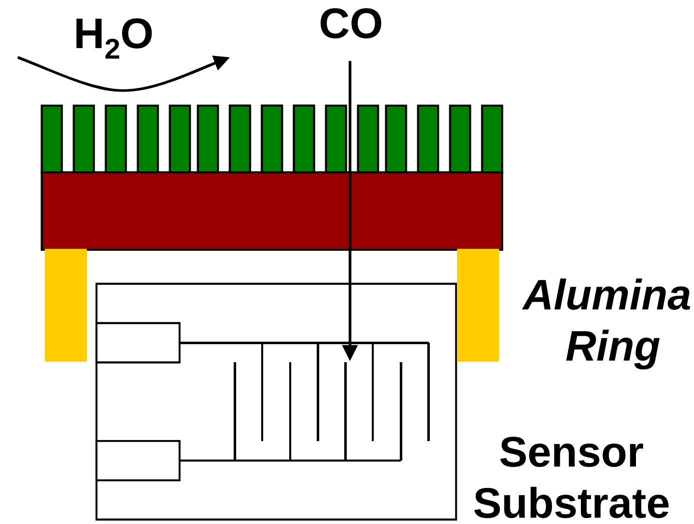
Materials for Sensing in Harsh Environments

Optical and Micro Sensors

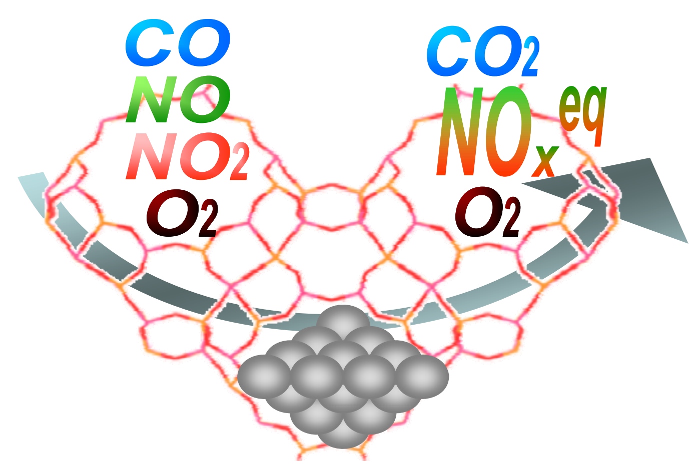
- **Sapphire**
- **Alumina**
- **Silicon Carbide**
- **Doped Silicon Carbide Nitride**
- **Yttria stabilized zirconia**
- **Fused/doped silica for certain process conditions**
- **Active/doped coatings**
- **Nano derived high temperature materials and structures**
- **Novel materials for high temperatures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



Development of Active Sensing Materials



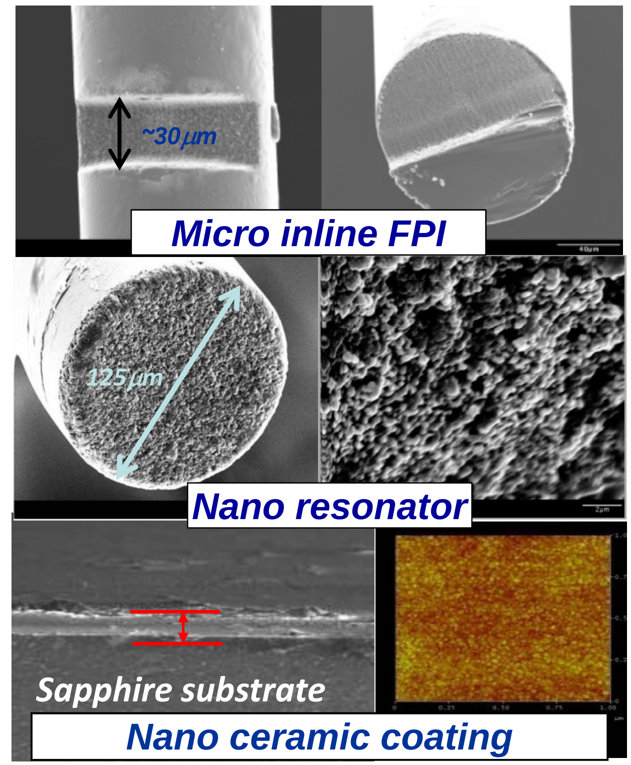
- **Enhance selective gas sensing through use of nano derived materials**
- **Application of fundamental understanding of material / gas interaction**
  - Charge and/or size exclusion
  - Selective reaction and sorption
  - Layering of materials
- **Success is in formation of a complete sensor structure followed by demonstration of the sensor's performance over time**
- **Initial evaluation**
  - Binary gas testing at temperature
- **Performance evaluation**
  - Mixed gas (4+ components) at temperature

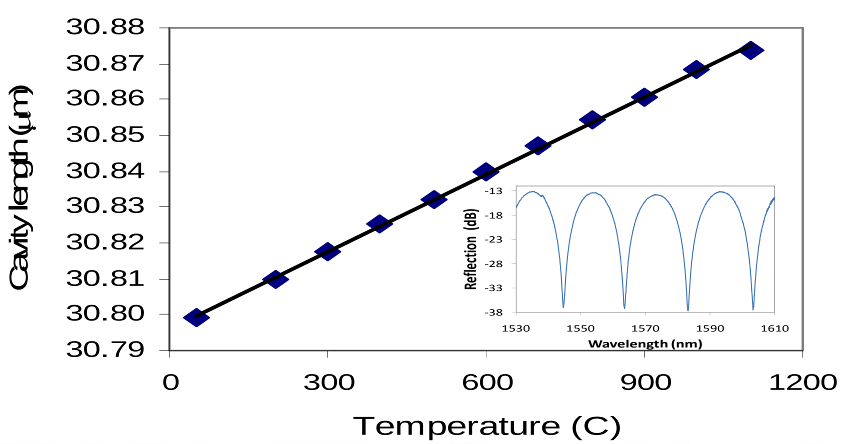


Micro-Structured Sapphire Fiber Sensors

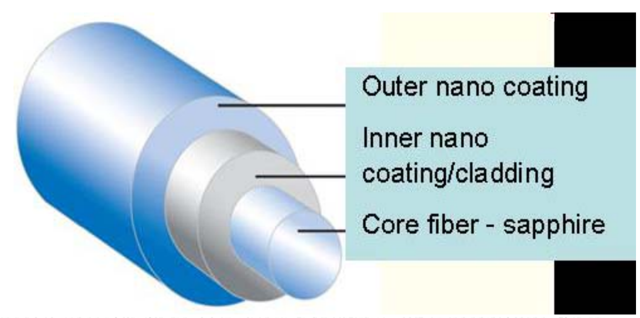
- **Support new designs for high temperature fiber based sensing**
- **Target simultaneous measurements temperature (up to 1600°C) and pressure.**
- **Micro-machined sensor elements**
- **Cladding sapphire fiber with nano coatings**
- **Novel ceramic nano thin film coatings as double-layer cladding for protection in harsh environment.**
- **Preliminary work with silica fiber**
- **MST and UCinn – newly awarded**

Fs laser micro/nano machining



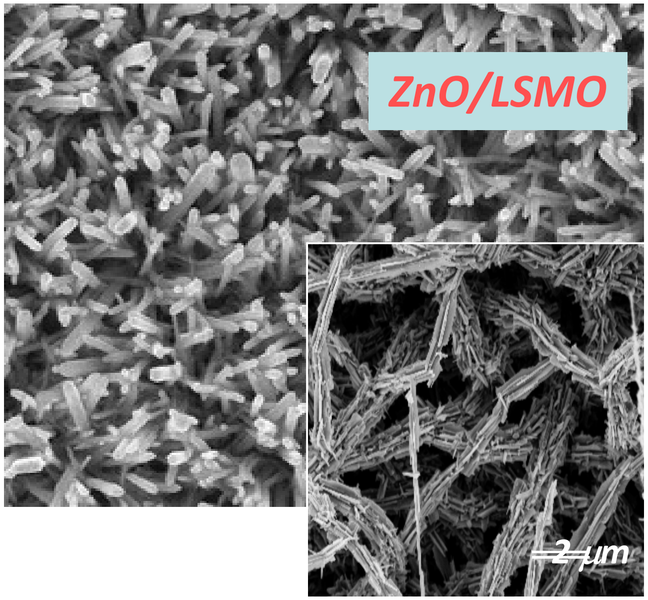


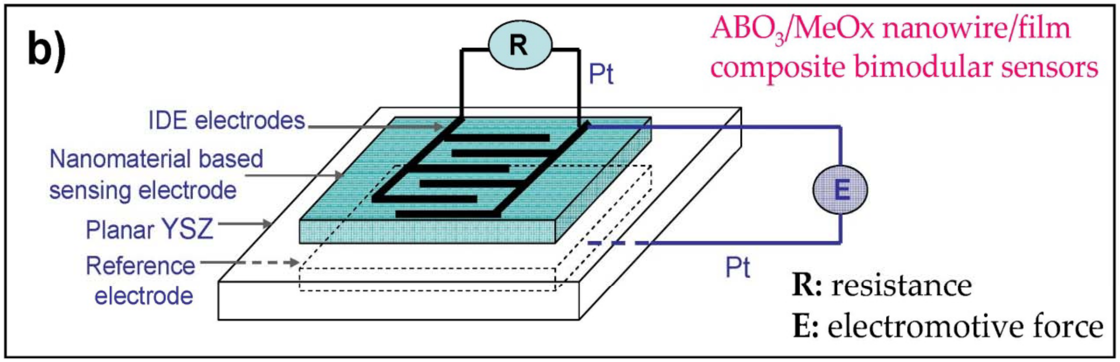
Temperature measurement up to 1100°C

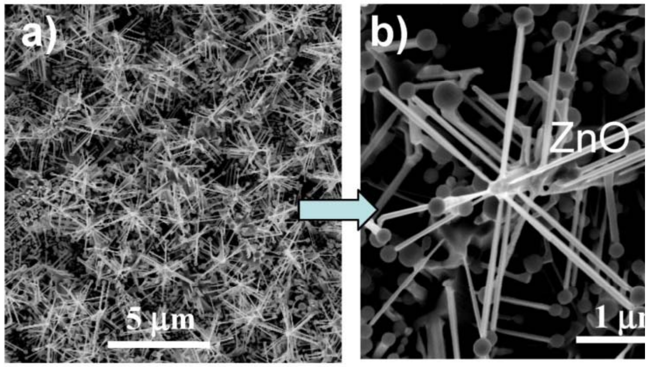


Multifunctional Nanowire/Film Composite-based Bimodular Sensors High Temperature Gas Detection

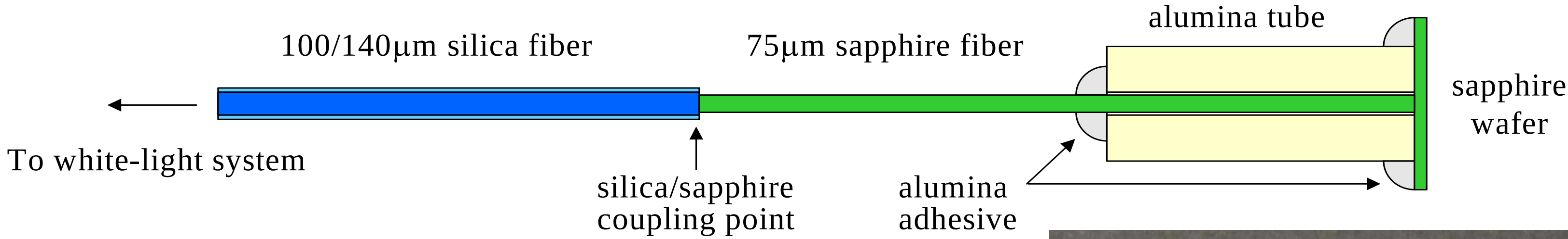
- **Newly awarded project**
- **Develop a unique class of multifunctional metal oxide/perovskite based composite nanosensors for gas detection at high temperature (700 °C-1300 °C).**
- **Combination of wet chemistry and vapor deposition to form nanowire / nanodendrite, nanofibrous films and perovskite nanofilms**
- **University of Connecticut**



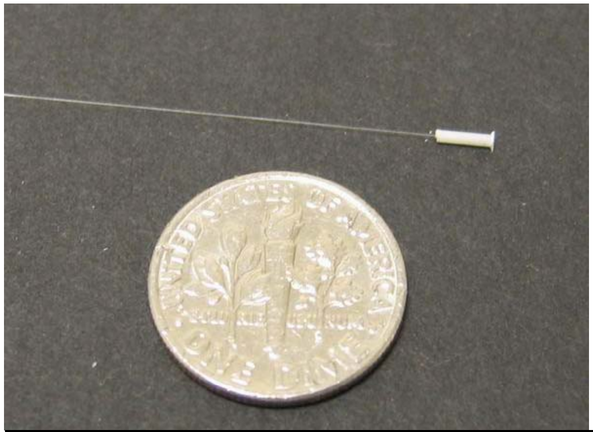


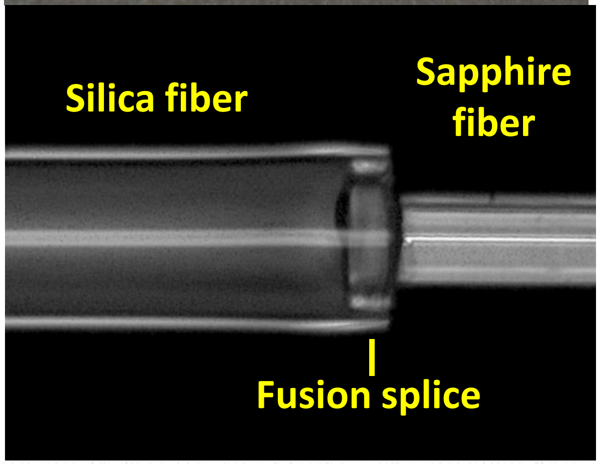


Single Point Sapphire Temperature Sensor



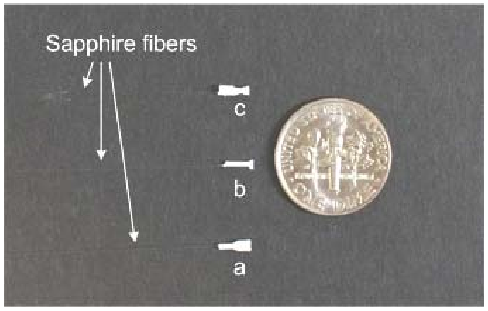
- **Fabry Perot Sensor**
- **Sapphire has desirable optical, high temperature and corrosion resistance properties**
- **Temperature measurement up to 1600°C with ~1°C resolution (0.1°C in lab)**
- **Methods, fabrication, designs, and packaging development since 1999**
- **Full scale testing – 7 months**
  - Additional testing planned
- **IP and licensing being evaluated**
- **Virginia Tech CPT**

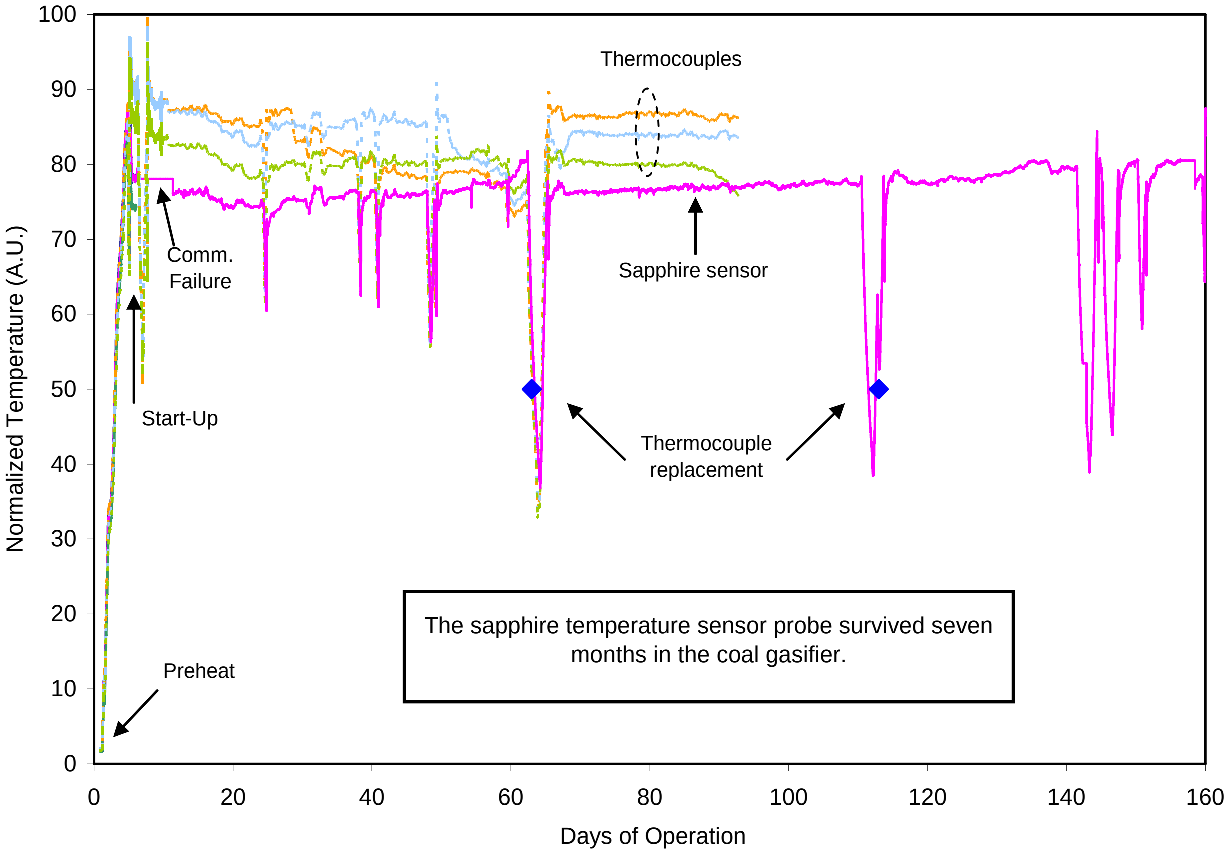




Sapphire Fiber Temperature Sensor

Full Scale Testing on a Coal Gasifier

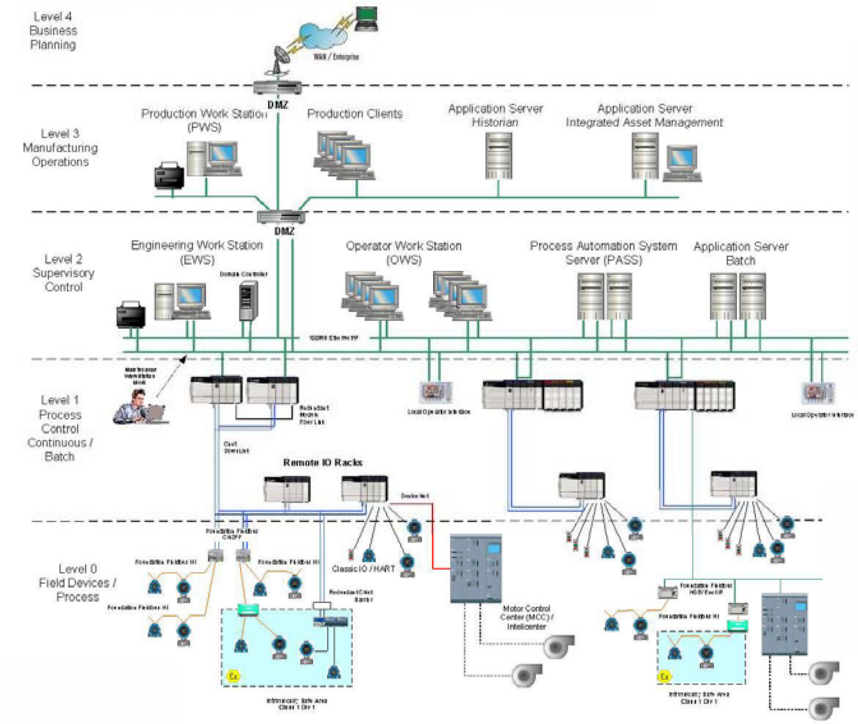




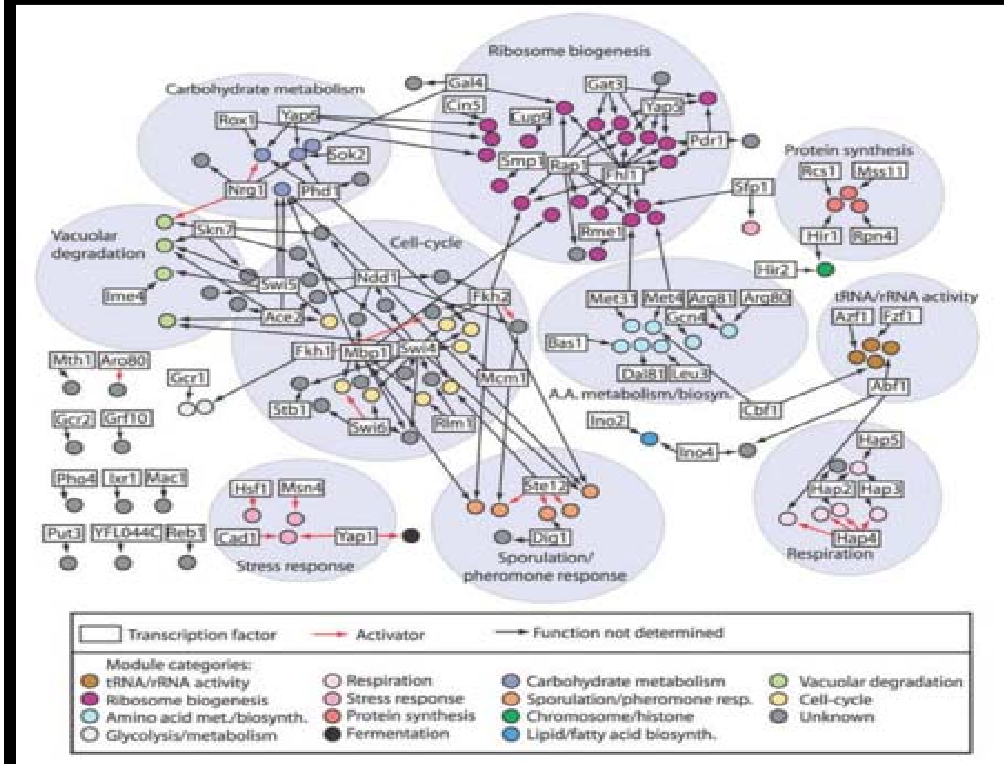
NATIONAL ENERGY TECHNOLOGY LABORATORY

Evolutionary vs Revolutionary

Challenging conventional architectures to
support advancements in computational intelligence



New approaches mimic biological systems, utilize distributed intelligence, and designed to handle complexity



Traditional Control Architecture
for
Distributed Control Systems (DCS)

- Linear and based on minimization of error and set points

Introduction to Stigmergy

Development of representative algorithms

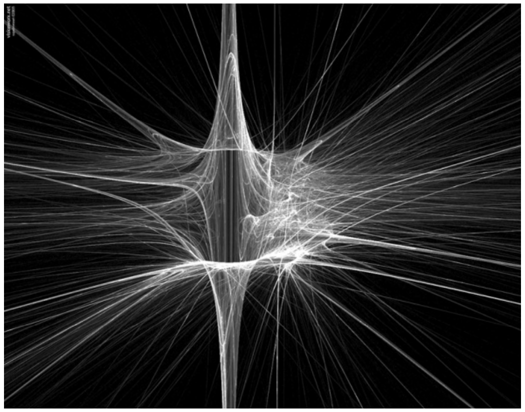
Indirect communication of multi-agent groups through environmental elements

Nature:

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

Advanced S&C:

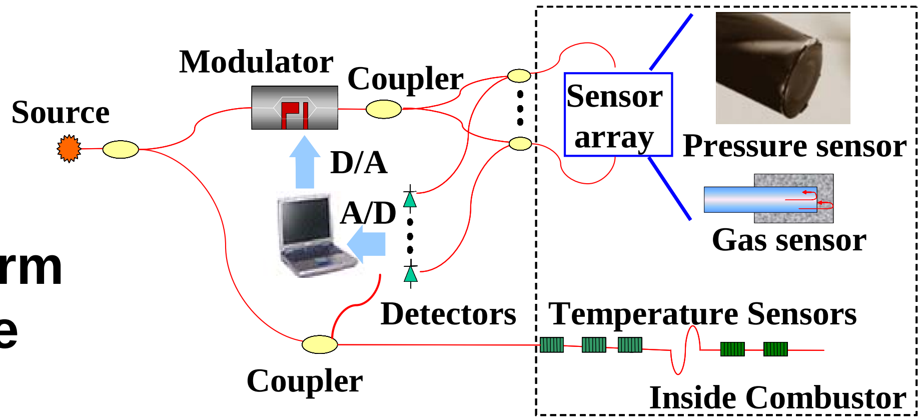
- Potentially powerful tool for coordination of sensor data
- Makes use of a decentralized controller
- Processors are embedded in each hub
- Hubs can communicate with their neighbors
- Forms a data line within the structure
- Communicating sensor hub approach may allow the structure to enforce desired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

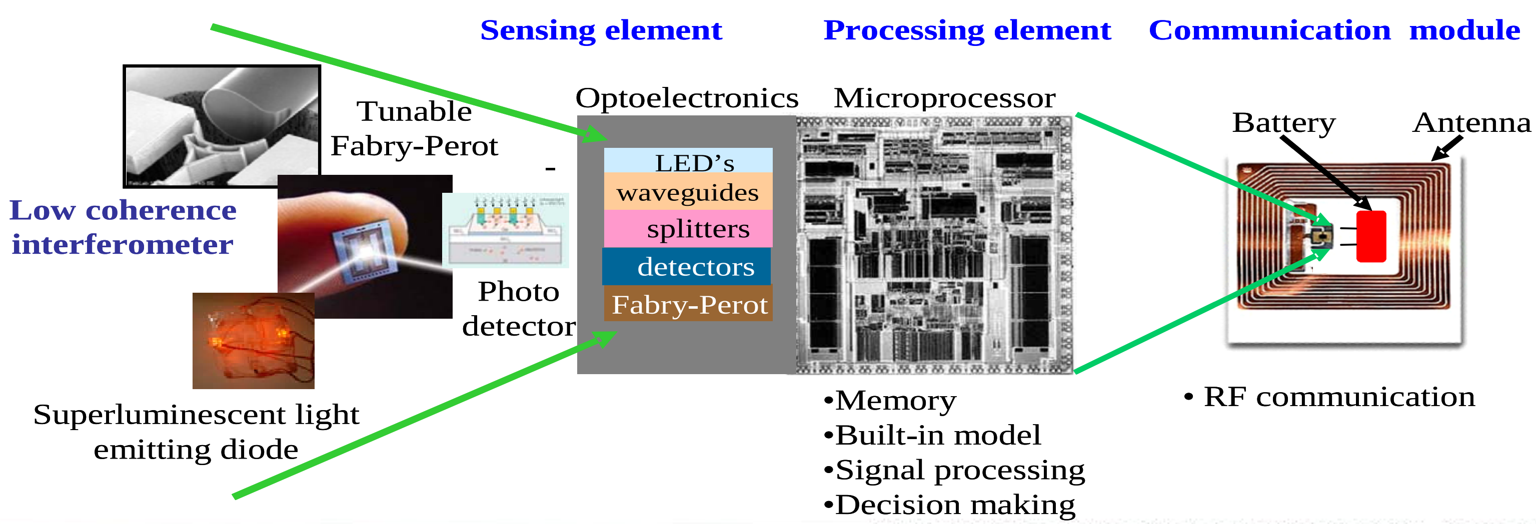


Sensor Networking

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**

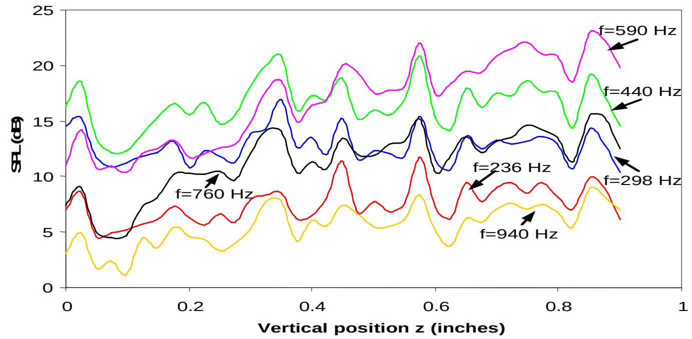




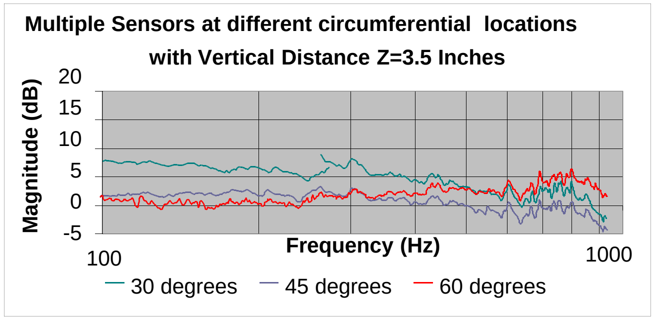
Sensor Networking and Placement

Computational and Experimental

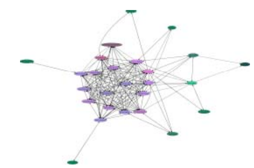
- **Network architecture to accommodate the heterogeneity of a large number of sensors**
- **Determine how many sensors and where the sensors should be placed to ensure a defined degree of convergence and confidence**
- **Define self-organization subsystems to handle of complex adaptive systems with limited external direction and how the sensors in each subsystem interact with each other**
- **A single sensor is inadequate, particularly when variations are large-scale temporal and spatial**
- **Multiple sensors = more information, but..**
- **A designed sensor network can allow for better control to achieve higher efficiency and performance.**
- **Ames NL & UMD**



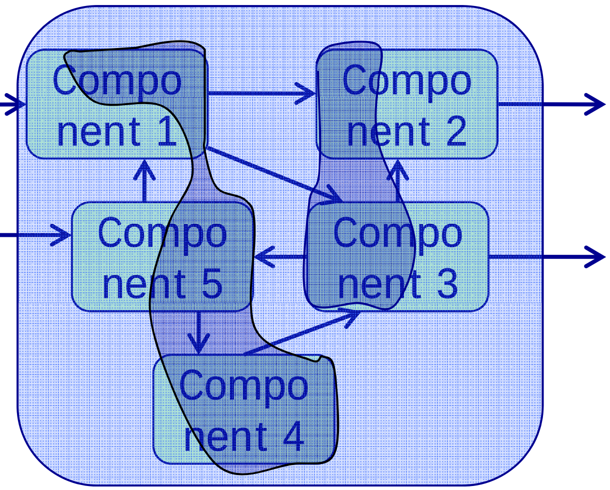
Single sensor placed at different vertical locations

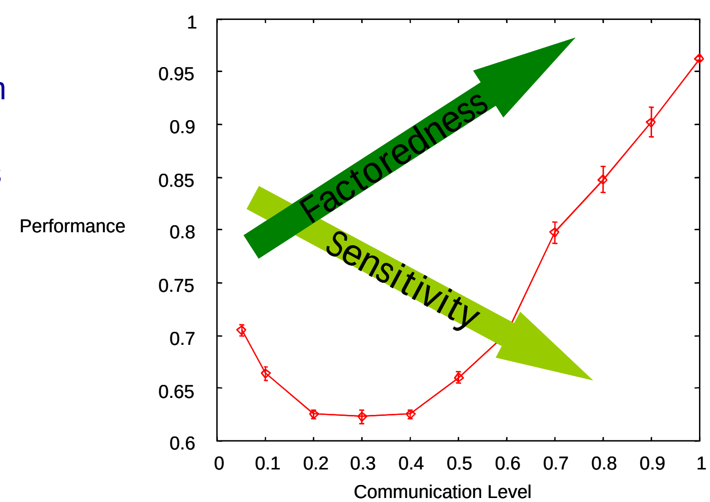


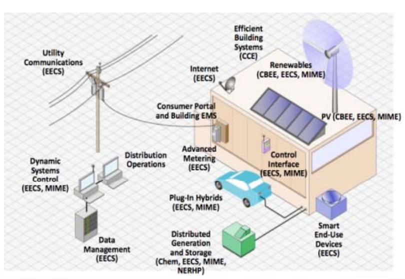
Distributed Sensor Coordination for Advanced Energy Systems

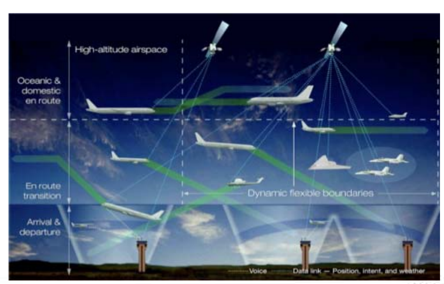


- **Motivation:**
  - Advanced energy systems are becoming more interconnected
  - Computation pushed down to sensors
    - » *How do we control and coordinate such systems?*
- **Objectives:**
  - Derive criteria for assessing sensor effectiveness and system impact
  - Demonstrate effectiveness and reconfigurability of sensors to changes in system
- **Concept:**
  - Focus on *what* to control, *what* to optimize (not *how* to control):
    - » Get better objective functions for each subsystem
    - » Get better system decomposition
- **Benefits:**
  - To Advanced Energy Systems: Response to sudden changes / System reconfiguration
  - To the Department of Energy: Smart power grid / Safe energy systems
  - To the US public: Smart House / Smart airports









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

Contact Information

Robert R. Romanosky
304-285-4721
Robert.romanosky@netl.doe.gov

NETL
www.netl.doe.gov

Office of Fossil Energy
www.fe.doe.gov

Susan M. Maley
304-285-1321
Susan.maley@netl.doe.gov