NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL Sensors and Controls Program Overview

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Crosscutting Research Technology Manager

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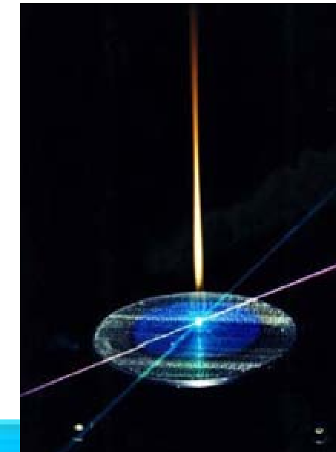
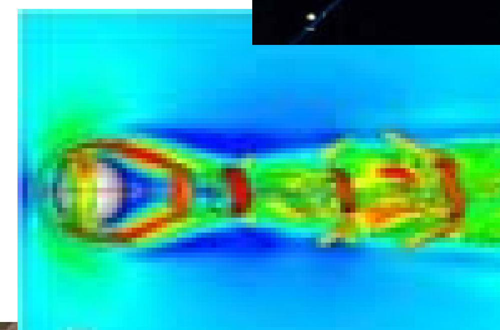
U.S. DEPARTMENT OF ENERGY

Overall Objective

- **Drivers for Advancing Sensor and Control Technology**
- **Sensor Research and Development**
  - Materials
  - Devices
  - Utilization and Networking
- **Novel Control Architectures using Networked Sensors**
- **Stakeholder Opportunities**
- **Conclusions**

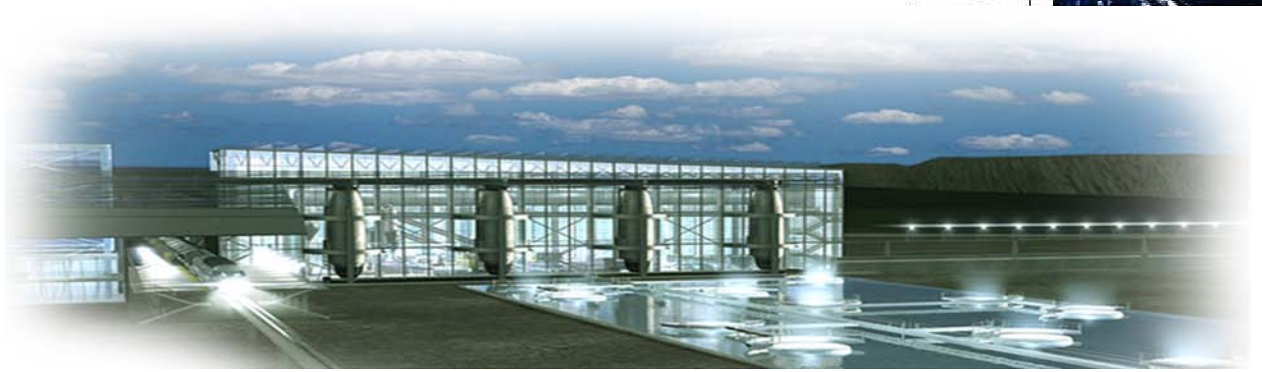




Target for Sensor and Controls

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

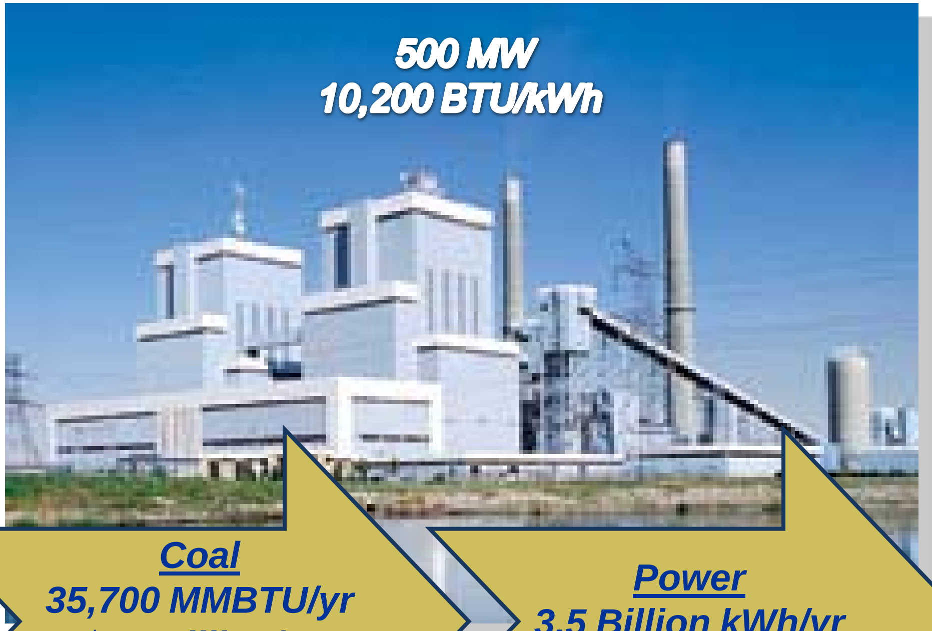
- **Low cost, high benefit technology**
- **Existing technology is inadequate**
- **Boosts efficiency of existing facilities and significantly contributes to high reliability**
- **Supports all other power generation technologies and related infrastructures**
- **Makes operation of future ultra clean energy plants possible**
- **Enables new paradigms in plant and asset management beyond traditional process control**

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



1% Improvements/increases are easily achievable. Sensors and Controls can enable improvements to be maintained for long term.

Coal
35,700 MMBTU/yr
$70 Million/yr
@ $2/MMBTU

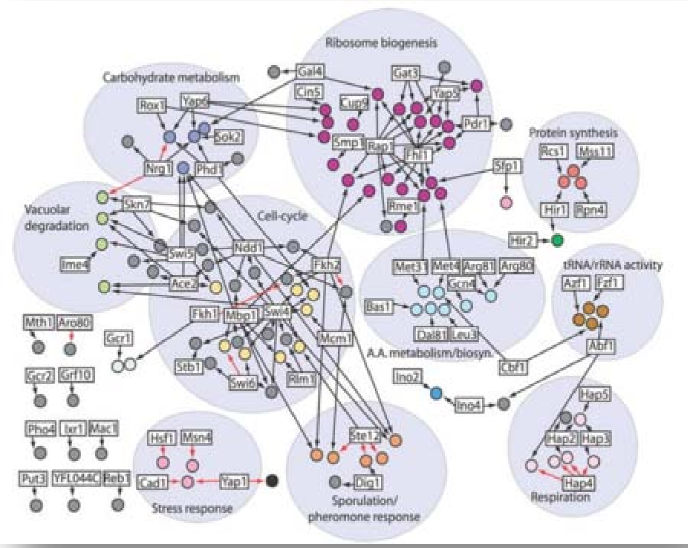
Power
3.5 Billion kWh/yr
@ 80% capacity factor

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

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

Sensors and Controls
Planned Activities and Summary



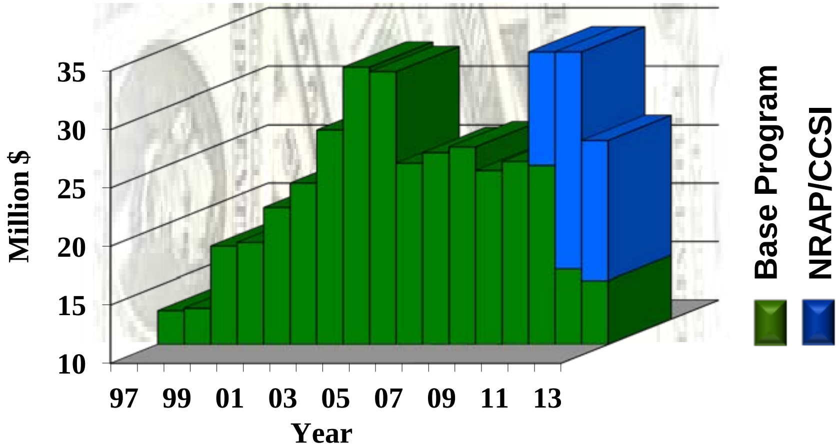
- Target initial demonstration of distributed intelligent sensor nodes
- Complete bench-scale testing of novel wireless sensing concepts
- Continue pilot & full scale testing to develop industrially viable sensor technology.
- Continue long term plan development for novel control strategies and network architecture to manage complexity associated with a fully integrated zero emission plant.
- Hold Industrial Stakeholder Workshops to help shape program (June 4-7, ISA POWID, Austin TX)
- **2014 Target** – Testing of integrated networking of smart sensors
- **2018 Target** – Test of advanced controls for optimized plant operations

Crosscutting Research Program

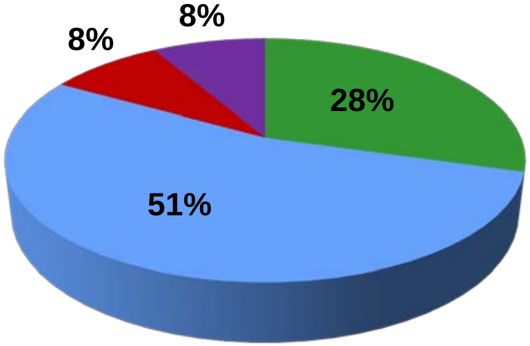
Key Activity / Component	FY11 Actual Budget	FY12 House Budget	FY13 President Budget
Plant Optimization Technologies	8,000	13,663	7,000
Computational System Dynamics	12,758	11,800	7,800
Computational Energy Science	12,235	13,371	9,400
System Analysis Product Integration	0	4,000	0
University Training & Research	2,395	3,000	2,400
Historically Black Colleges & Universities	848	1,000	850
Crosscutting Research TOTAL	**36,236**	**46,834**	**27,450**
Advanced Materials (ACS)	**9,082**	**5,000**	**0**

Dollars $K

Crosscutting Research Program Budgets 1997-2012



FY12 Budget Distribution among Crosscutting Research Program Elements



NETL Managed = $46,834

- Plant Optimization Technologies ($13,663)
- Coal Utilization Sciences ($25,171)
- System Analysis Product Integration ($4000)
- Historically Black Colleges and Universities, University Training and Research ($4,000)

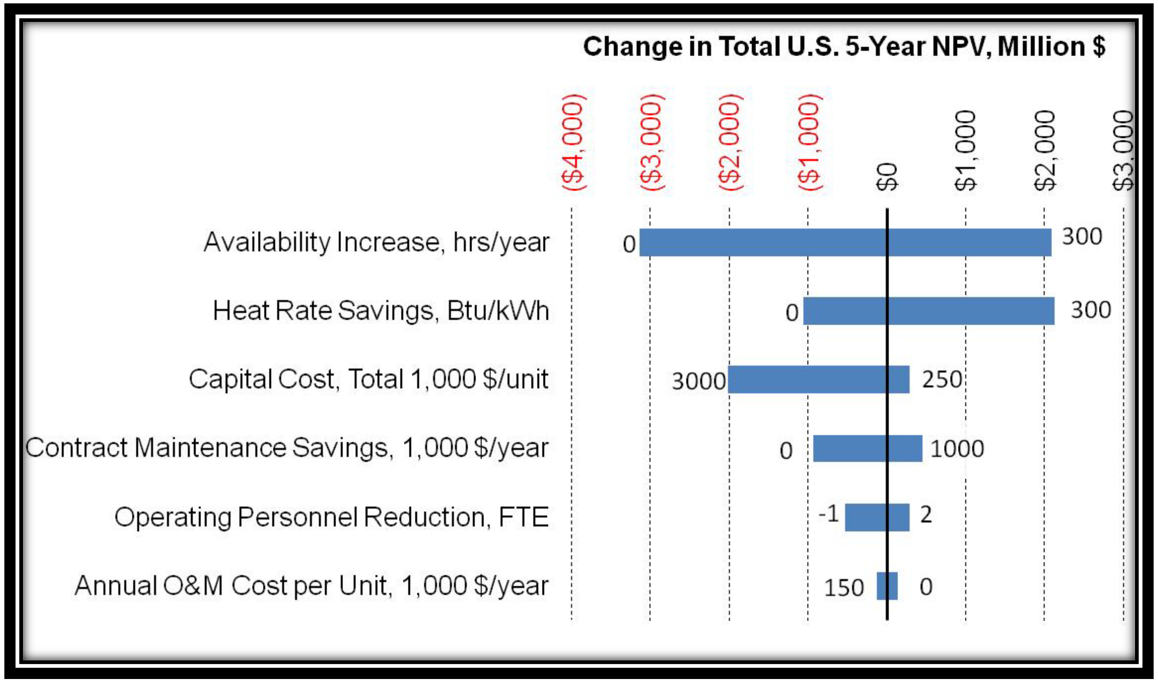
Research in Sensors and Controls

Stakeholder Input

Optical Sensors	• *Spectroscopic / Non contact* • *Fiber based*	*Optical Access, Interference management* *Single Point, Distributed and Multiplexed Sensors, Coatings for sensing, protection, and attachment*
Micro Sensors	• *Single point* • *Array based*	*Active sensing layers and protection materials, Algorithms for Gas Identification and Quantification, Packaging of sensors, lead wire and connector improvements*
Other	• *Embedded sensors* • *Imaging*	*Active films, direct write sensors, Metamaterials, Capacitance Imaging, Algorithms for image reconstruction*
Enabling Technologies	• *Wireless* • *Energy Harvesting*	*Passive Wireless, Active Wireless communication, Thermoelectric and vibration energy harvesting approaches, Sensor Networking*

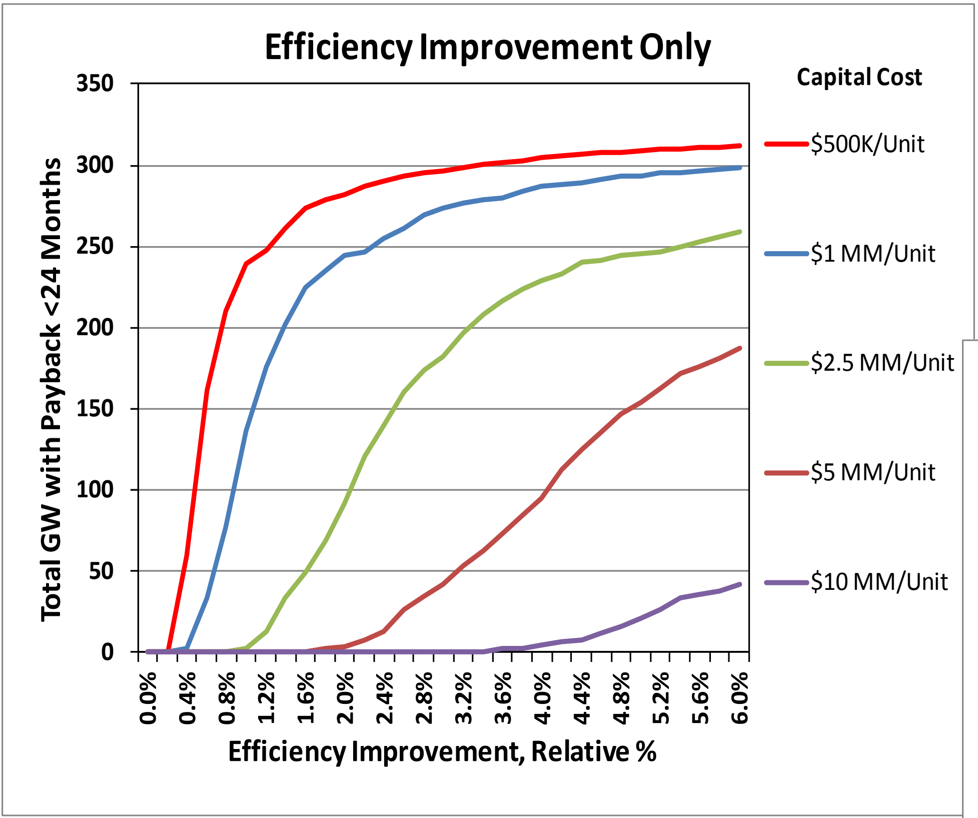
Net Present Value Analysis (NPV) for Sensor and Control Benefit

- **Established input ranges to determine which plants would benefit economically from a Sensors and Controls refurbishment project.**
- **Obtained Unit level data from the EV database including:**
  - Electric price, Fuel price, Emissions
  - Current heat rate, and
  - Capacity factor
- **Built an NPV tool to model the business case decision of each unit**
- **Assumed units would only refurbish if they could payback in 2 years**

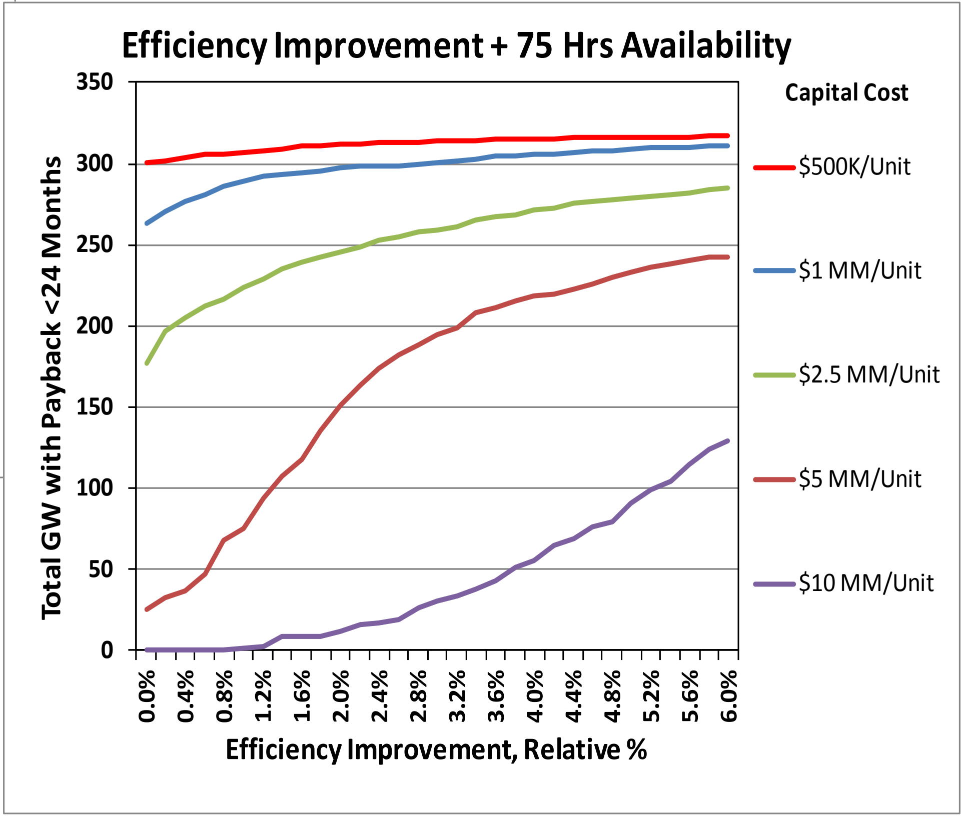


Source: Results based on unit by unit discounted cash flow model. Unit level data taken from 2010 EV database. Cost and performance based on NETL survey of previous sensors and controls projects.

Net Present Value Analysis – Results



More analysis underway to expand and understand S&C impact



A $5M project would be economically feasible for 150GW of the fleet, roughly half, if it can increase availability 75hrs/yr and improve relative efficiency 2%.

Source: Results based on unit by unit discounted cash flow model. Unit level data taken from 2010 EV database.
Cost and performance based on NETL survey of previous sensors and controls projects.

Technical and Operational Drivers for Advanced Sensing and Control Technology

- **Advanced power generation has harsh conditions throughout a plant that need to be monitored**
  - Existing instrument may not be available for certain process conditions
- **On line and in situ measurements enable real time operation**
  - Better faster and cheaper cannot reasonably be done with lab samples and data sheets
  - Optimizing efficiency or environmental performance are difficult to achieve during load changes and fuel switching/blending
- **Inherent complexity of advanced plants drive need for actionable information with embedded cause & effect logic**
  - Too much data, fast dynamics, and challenge to understand economic, emission, and availability impact of open loop control are concerns

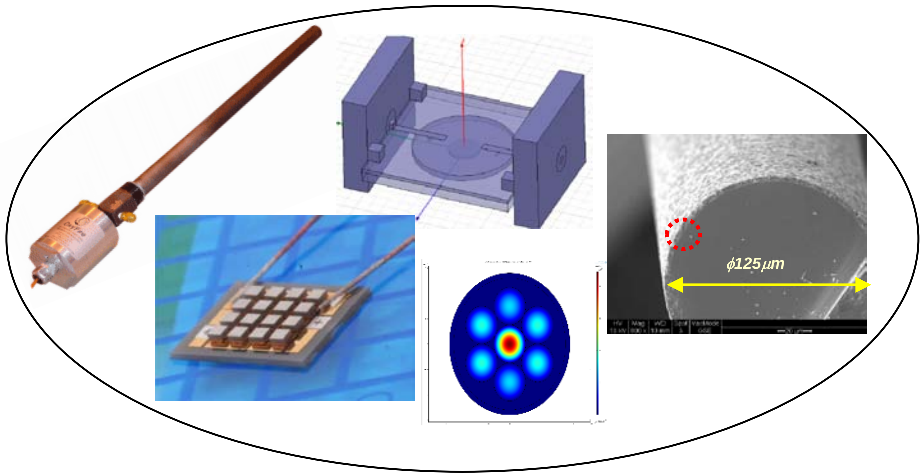
Harsh Environments

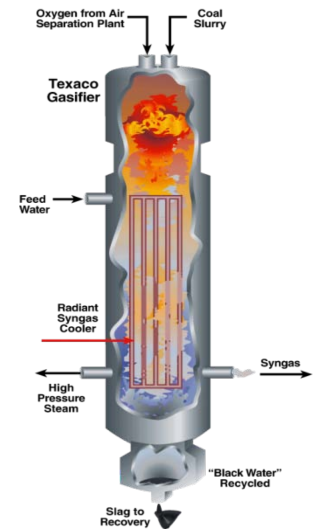
Solid Oxide Fuel Cells

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

Advanced Combustion Turbines

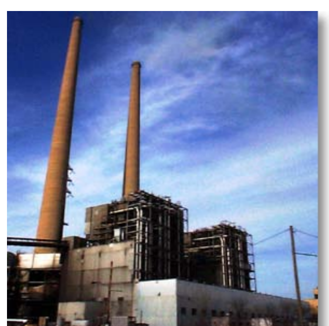
- Gaseous Fuel (Natural Gas to High Hydrogen Fuels)
- Up to 1300 °C combustion temperatures
- Pressure ratios of 30:1





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

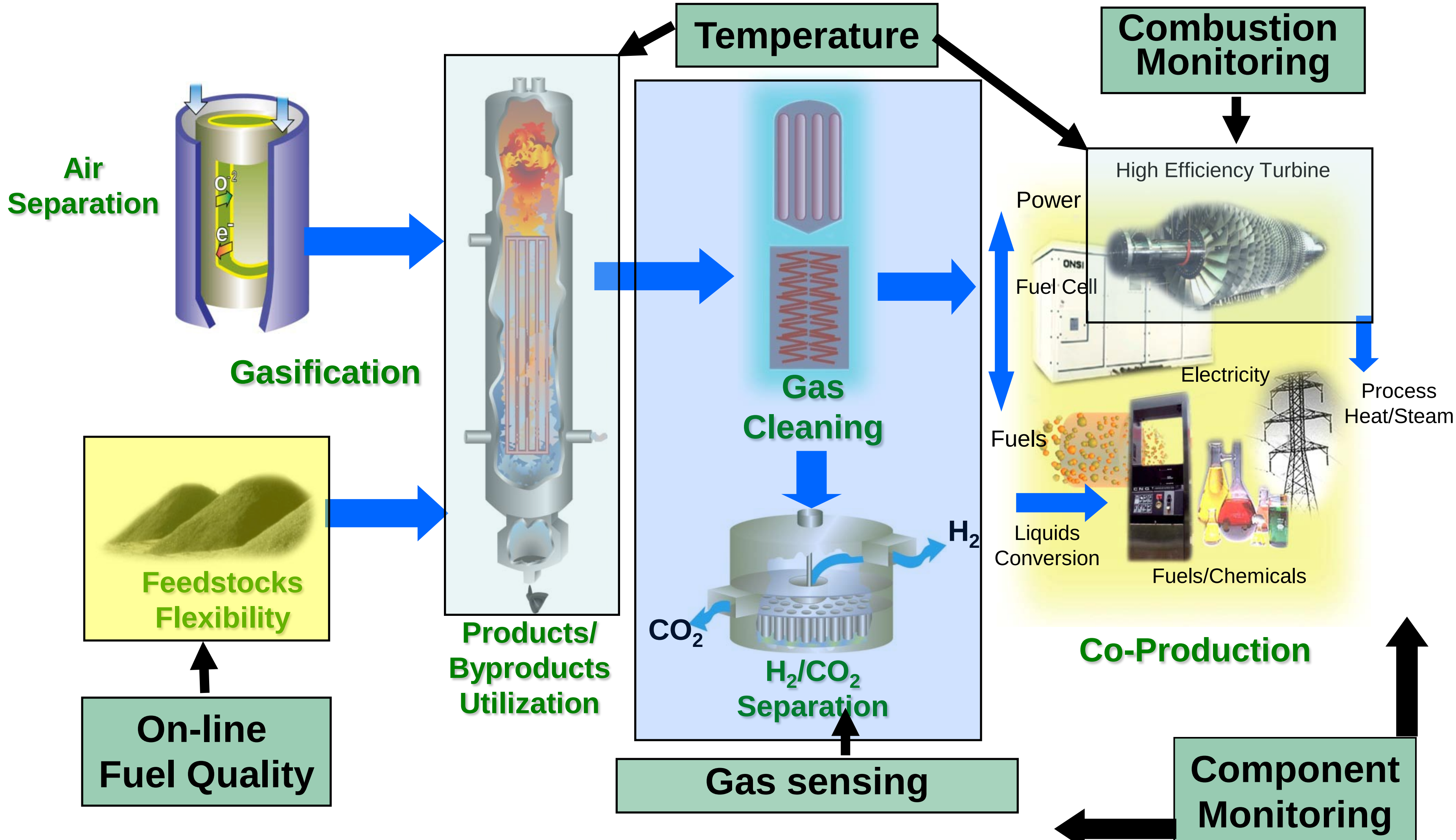
- *Up to 1600 C, and 1000 PSI (slagging gasifiers)*
- *Erosive, corrosive, highly reducing environment*
- *Physical shifting of refractory brick, vibration, shifting "hot zones"*

General Sensor Requirements

Fuel Quality	**Coal – Heating Value (C,H, O), Minerals and ash**
Fuel Quality	**Natural Gas – CH_4, other hydrocarbons, include LNG** **Synthesis Gas – H_2 (~26%), CO (~37%), CO_2 & H_2S** **Conditions near 500 C & up to 800 psi, Fast response**
Exhaust Gas	**NOx – 2-5,000 ppm, SOx 3-5,000 ppm,** **Particulate, Mercury (ppb), CO (ppm-%), CO_2 (%)**
Temperature	**1000-1600 C, highly erosive and corrosive** **Packaging for extreme conditions**
Pressure	**Up to 1000 psi, high temperature, erosive & corrosive** **Dynamic pressure for turbine applications**
Materials Assessment	**Refractory Life, Thermal Barrier Coating Life** **Piping and tubes for stress/strain, corrosion, cracking**

Prioritized Sensing Needs

IGCC based Near Zero Emission CoGeneration Plant



Research in Sensors and Controls

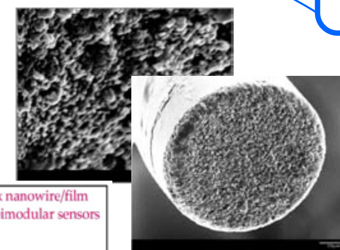
Stakeholder Input

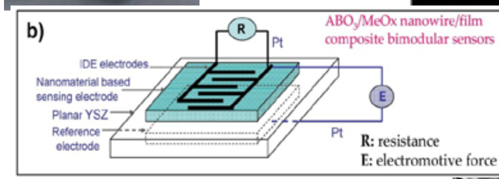
Industrial On Line Measurement Needs

Sensors Materials

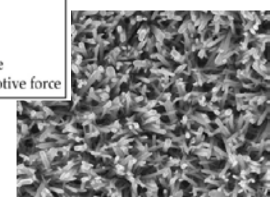
For High Temperatures & Harsh Environments

Fiber optical Materials, Coatings and Devices



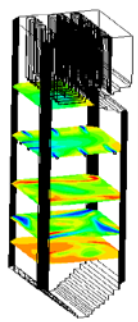


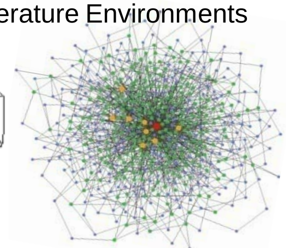
Micro Sensor Materials for High Temperature Environments



Integration with Process Control and Monitoring

Sensor Designs





Networking, Node Intelligence, Condition Based Maintenance Process Control

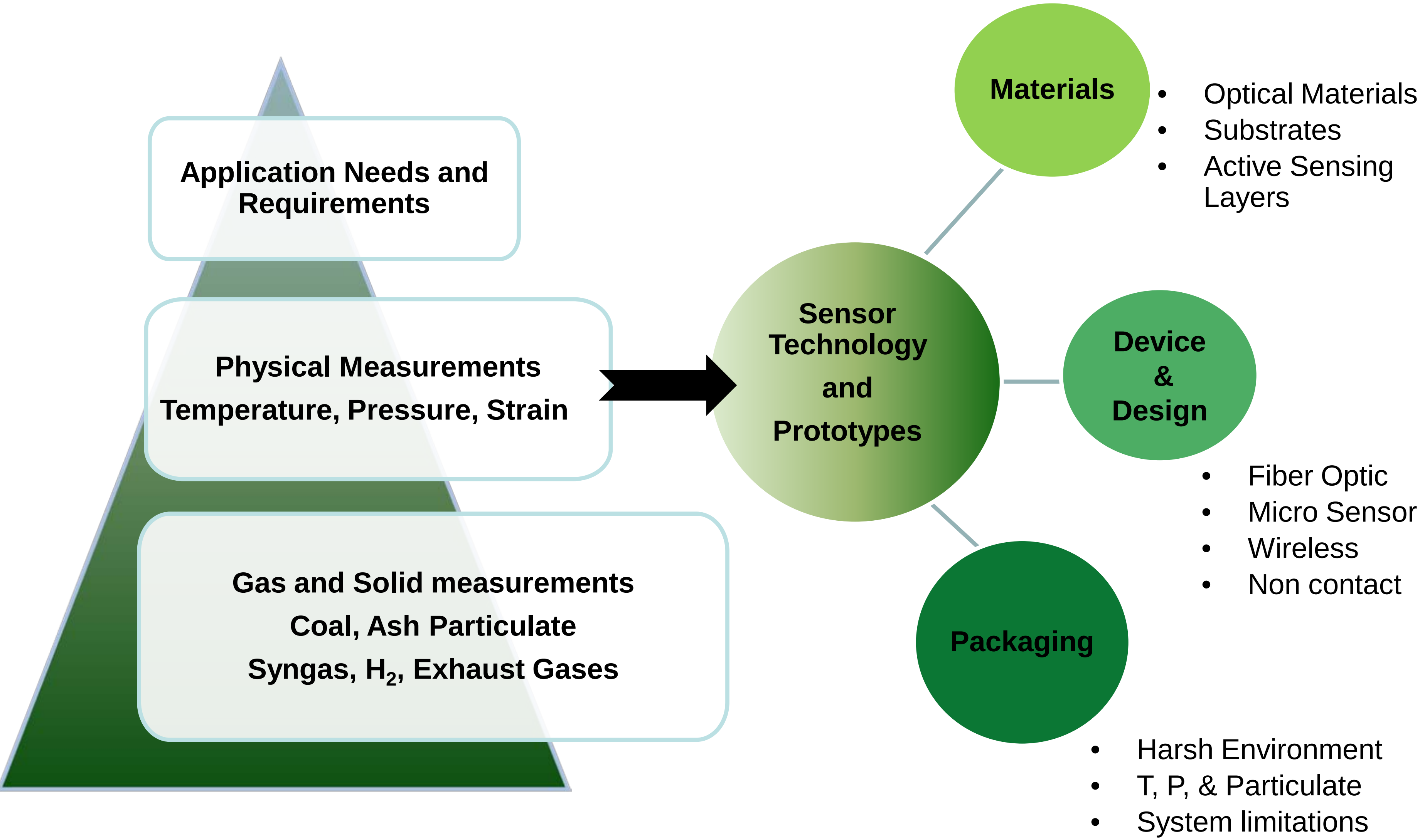
Sensor Packaging

Novel Control Architectures
Distributed Intelligence
Heterogeneous Dense Sensor Networks
Self Organization
Wireless

Sensor Placement and Networking

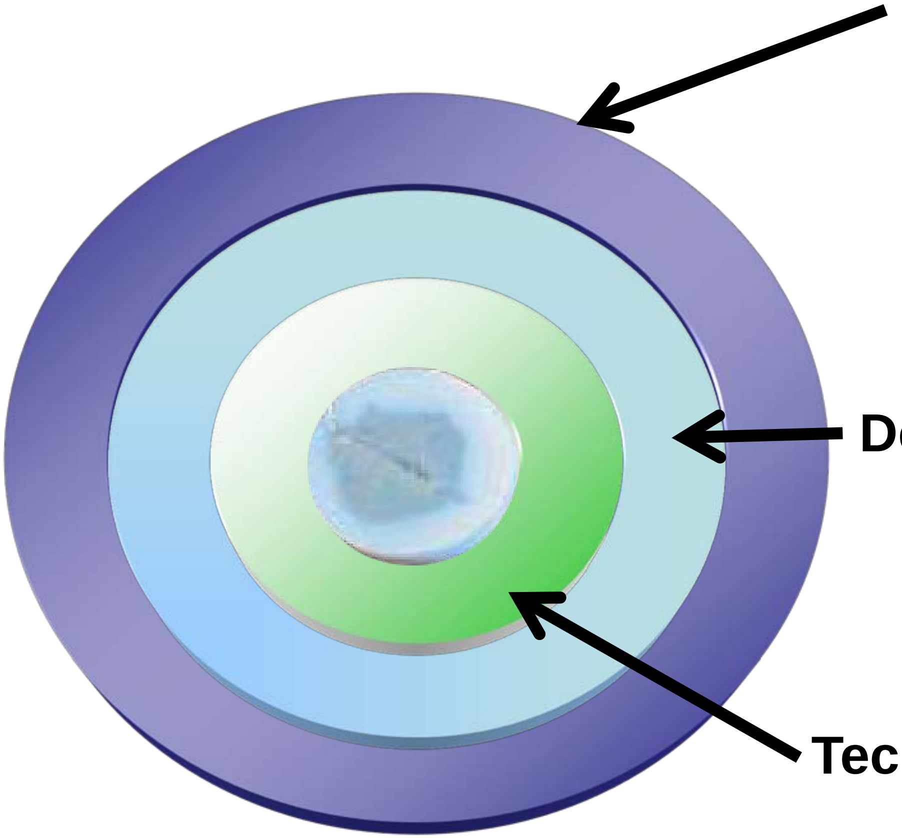
Prototyping and Testing

Delineation of Sensor Development



Sensor Development

Targeting Development of 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 and packaging
- –Survivability followed by performance
- –Portability, connectivity, ease of use

Technology transfer / Commercialization

- –Commercialization plan (license vs. sell)
- –Testing
- –Ability to manufacture
- –Let go of technology / embrace business

Research in Sensors and Controls

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Sensors Materials

For High Temperatures & Harsh Environments

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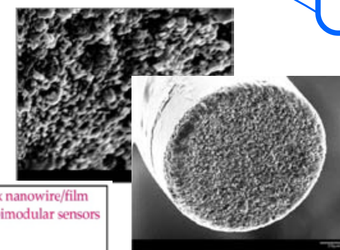
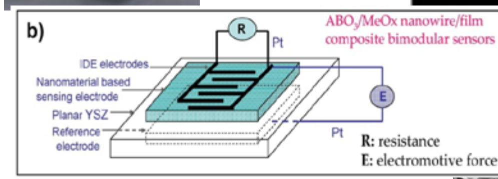
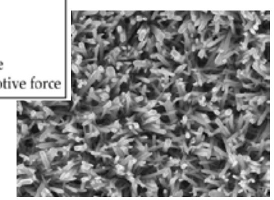


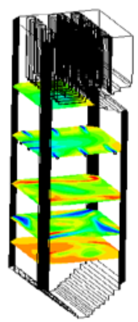


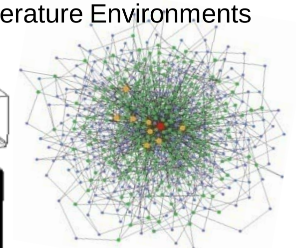
Micro Sensor Materials for High Temperature Environments



Integration with Process Control and Monitoring

Sensor Designs





Networking, Node Intelligence, Condition Based Maintenance Process Control

Sensor Packaging

Novel Control Architectures
Distributed Intelligence
Heterogeneous Dense Sensor Networks
Self Organization
Wireless

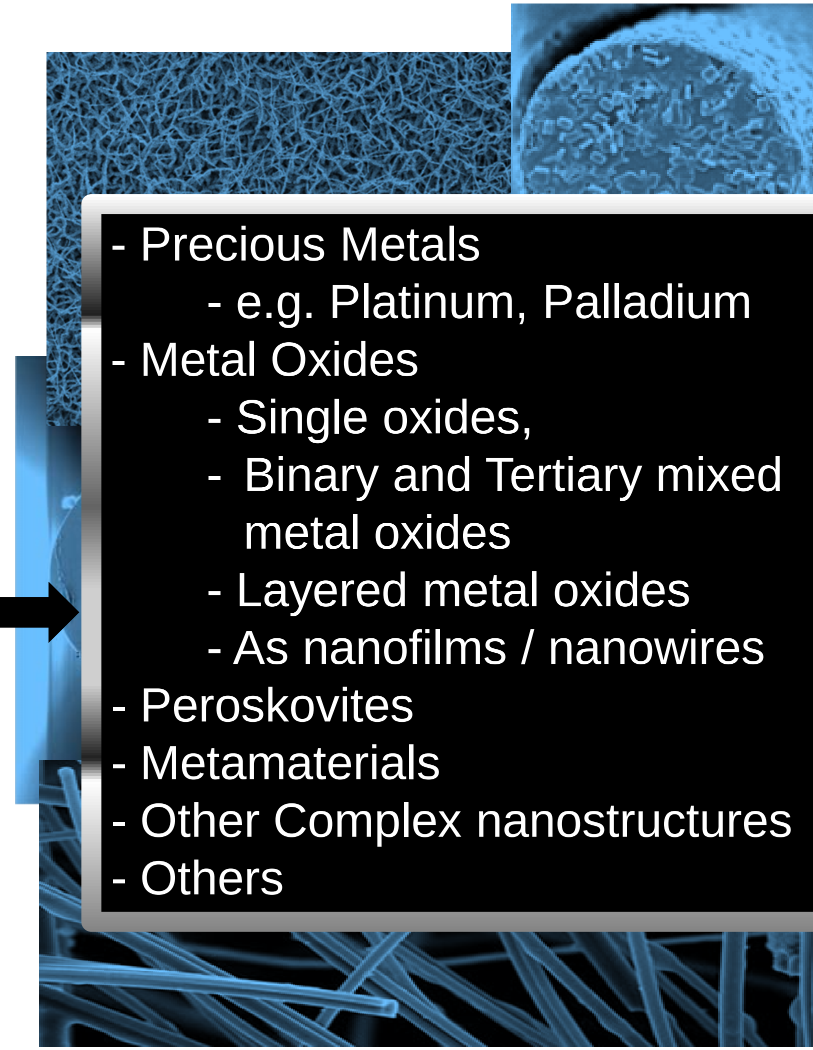
Sensor Placement and Networking

Prototyping and Testing

Materials for Sensing in Harsh Environments

Optical and Micro Sensors

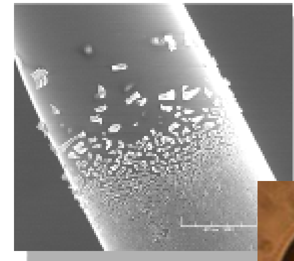
- **Sapphire**
- **Alumina**
- **Silicon Carbide**
- **Doped Silicon Carbide Nitride**
- **Yttria-Stabilized Zirconia**
- **Fused/doped Silica for certain process conditions**
- **Active/doped materials**
- **Nano derived high temperature materials and structures**
- **Novel materials for high temperatures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



- Precious Metals
  - e.g. Platinum, Palladium
- Metal Oxides
  - Single oxides,
  - Binary and Tertiary mixed metal oxides
  - Layered metal oxides
  - As nanofilms / nanowires
- Peroskovites
- Metamaterials
- Other Complex nanostructures
- Others

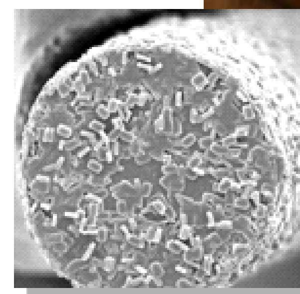
Fiber-based Sensor Material Development

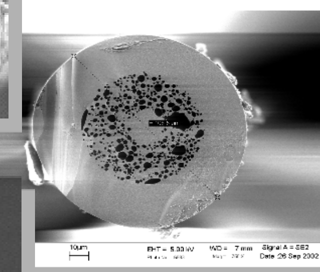
- **Using silica-based fiber sensors to develop distributed and selective gas sensing by depositing active sensing layers onto novel gratings**
- **Driving sapphire materials development for single and multipoint sensing**
  - Targeting coating materials to improve wave guide properties
  - Developing techniques for creation of Bragg and Long period gratings onto sapphire fiber
- **Using silica and sapphire to create radially directed holey fibers for gas sensing**
- **Program participants include VT, Prime Research, UMiss, NMT, UMR, UC, ASU and GE**



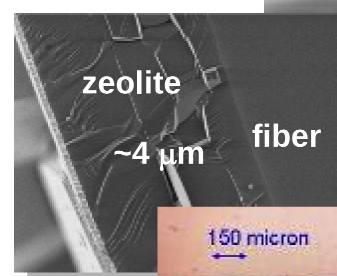
Coated Silica fiber (NMT, UMR, ASU, UC)

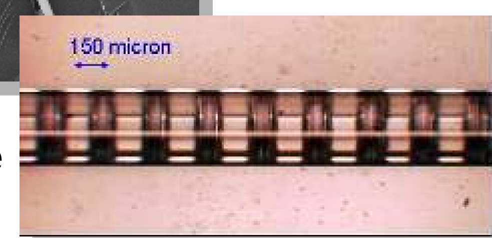
Coated Sapphire Fiber (Prime)





Holey Fiber (VT)

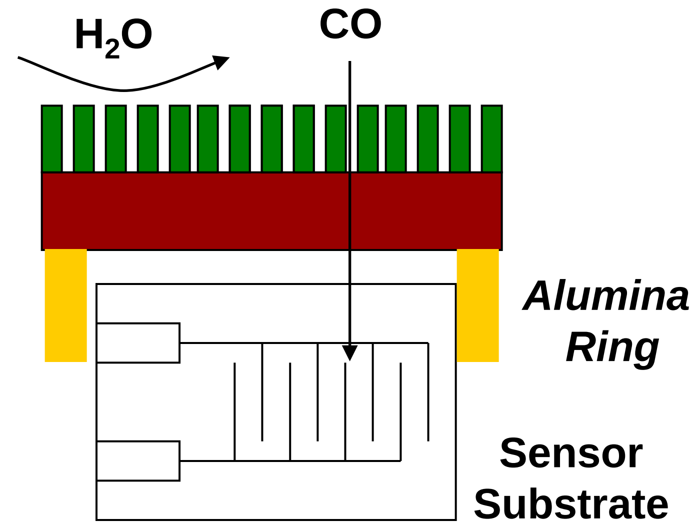


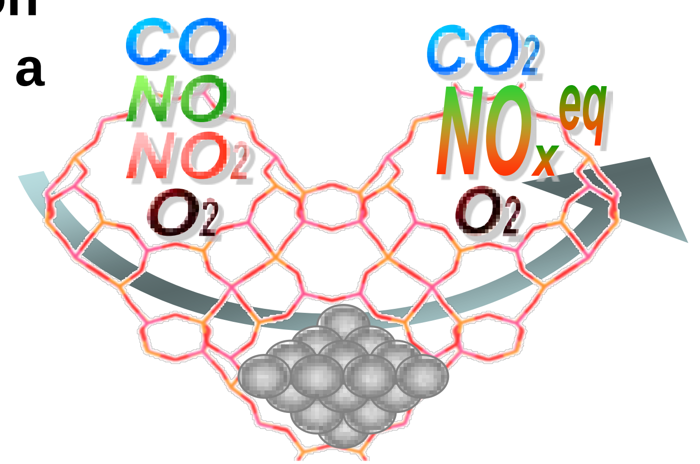


Grating in Sapphire Fiber (PSU)

Development of Active Sensing Materials

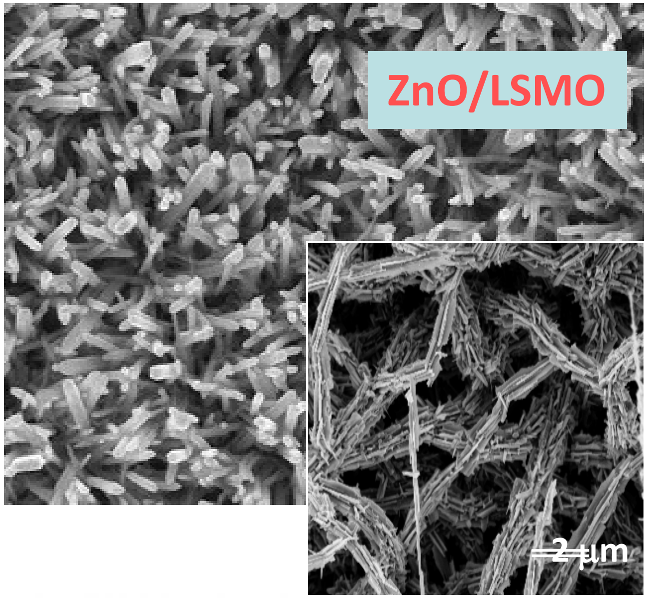
- **Enhance selective gas sensing through use of nano derived materials**
- **Charge exclusion**
- **Size exclusion**
- **Layering of materials**
- **Application of fundamental understanding of material/gas interaction**
- **Success is in the application of forming a complete sensor structure and the demonstration of the sensor’s performance over time**
- **Nano derived material applications by OSU, UMR, ASU, UC, and GE**

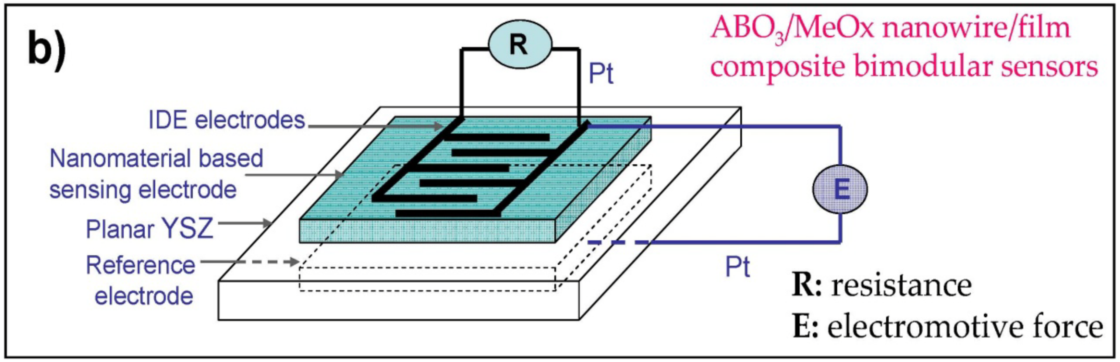


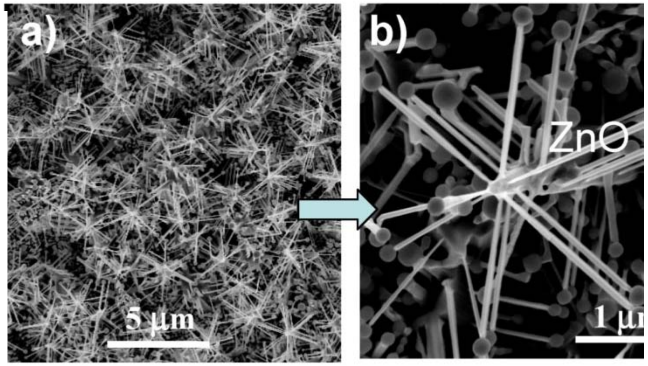


Multifunctional Nanowire/Film Composite-based Bimodular Sensors High Temperature Gas Detection

- **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**







Research in Sensors and Controls

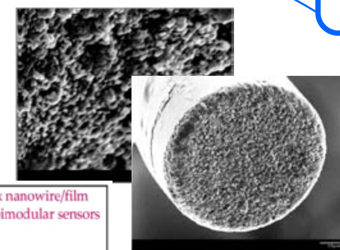
Stakeholder Input

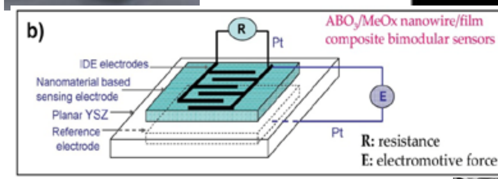
Industrial On Line Measurement Needs

Sensors Materials

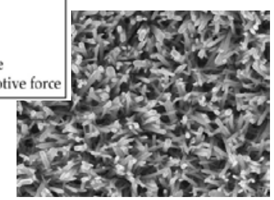
For High Temperatures & Harsh Environments

Fiber optical Materials, Coatings and Devices



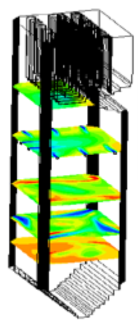


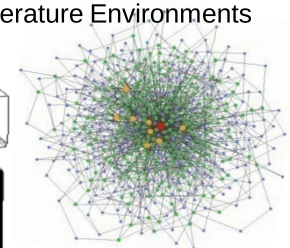
Micro Sensor Materials for High Temperature Environments



Sensor Designs

Integration with Process Control and Monitoring





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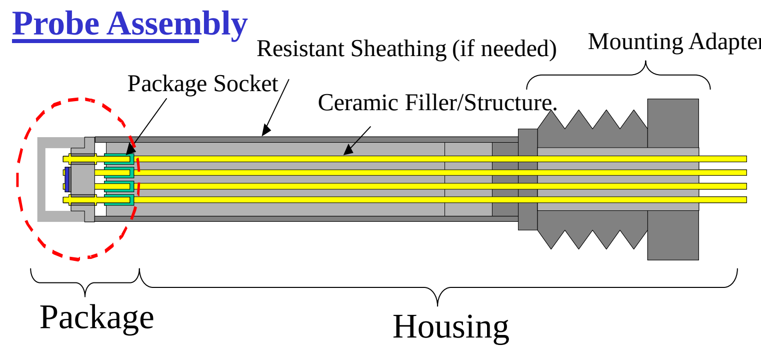
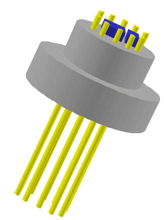
Sensor Placement and Networking

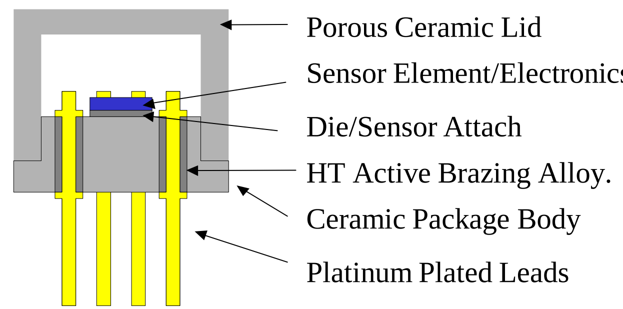
Prototyping and Testing

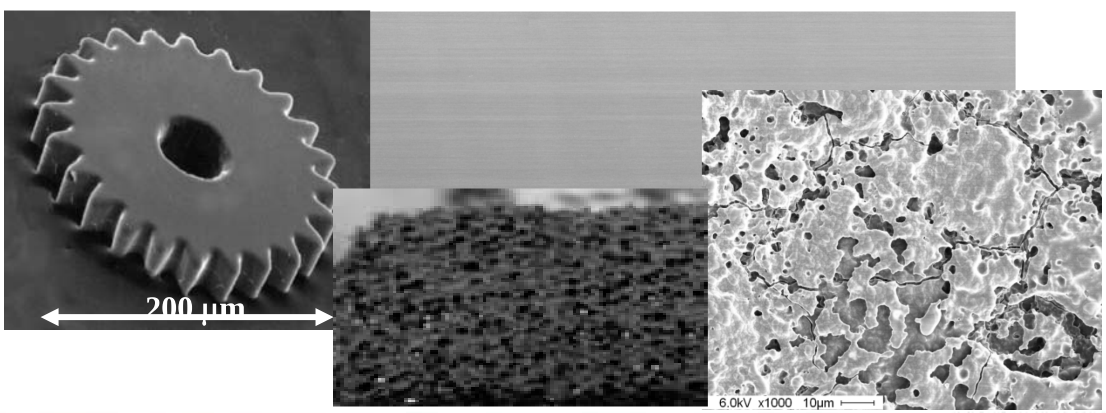
Integrated Micro Sensor
(Temperature and Pressure)

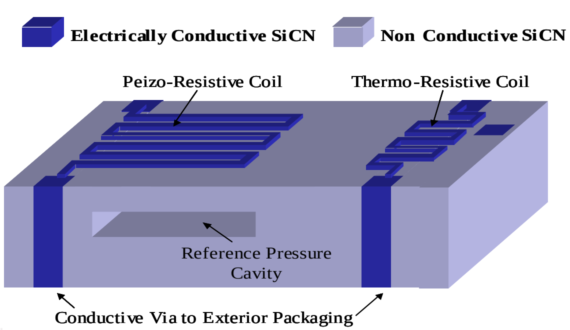
- **Developed conductive/ non-conductive SiCN sensor element for integrated T&P measurement up to 1000 ºC and 1000 psi**
- **Material shows high temperature stability and corrosion resistance**
- **Capitalizes on mature MEMS sensor concepts**
- **First to make SiCN-x Ceramic Foam**





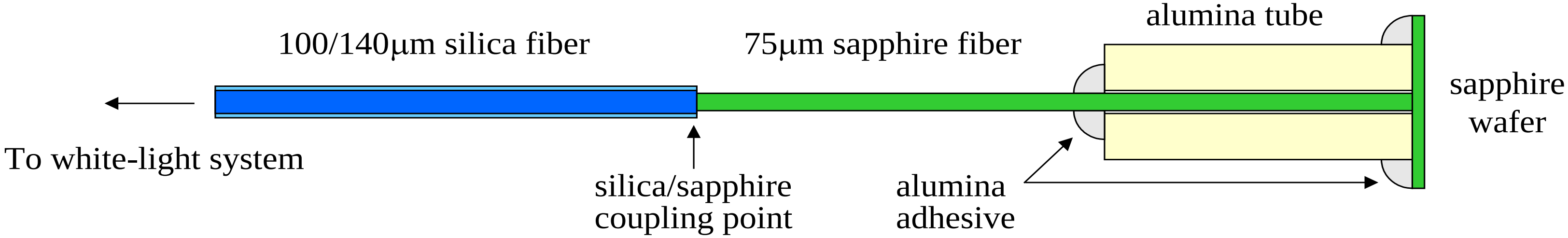




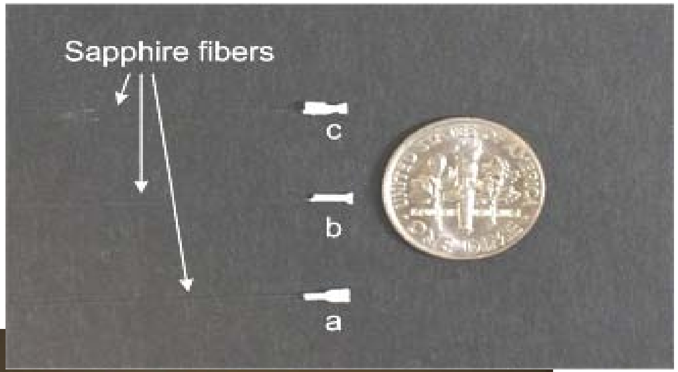


Single Point Sapphire Temperature Sensor

Fabry Perot Sensor System



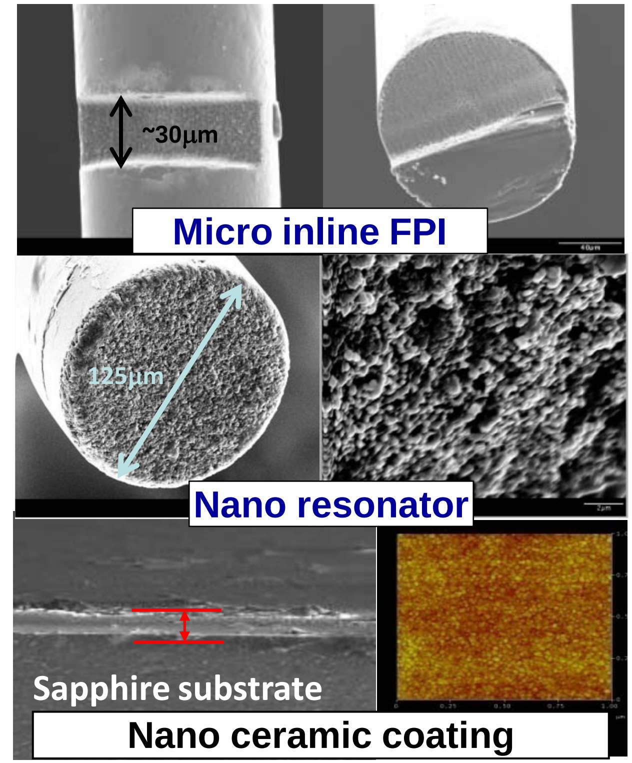
- **Measures temperature up to 1600 ºC**
- **Methods, fabrication, designs, packaging under development since 1999**
- **Full scale testing at TECO**
  - 7 months of operation
- **IP and licensing being evaluated by Virginia Tech**
- **Considering testing on turbines (combustor section)**

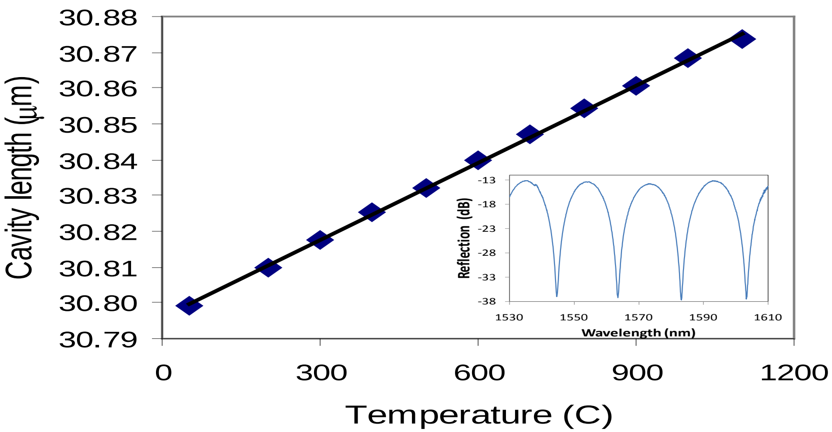


Micro-Structured Sapphire Fiber Sensors

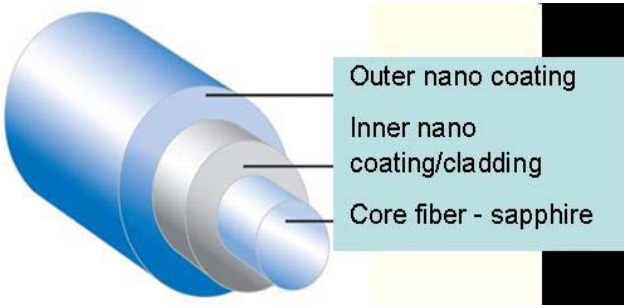
- Support new designs for high temperature fiber based sensing
- Target simultaneous measurements temperature (up to 1600°C) and pressure.
- Micro-machined sensor elements
- Cladding sapphire fiber with nano coatings
- Novel ceramic nano thin film coatings as double-layer cladding for protection in harsh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

Fs laser micro/nano machining





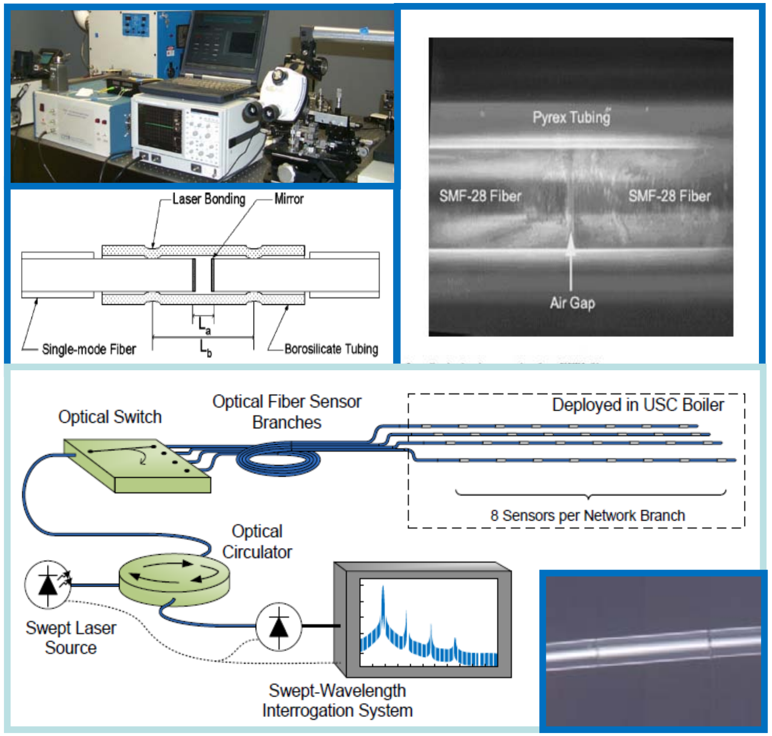
Temperature measurement up to 1100 C



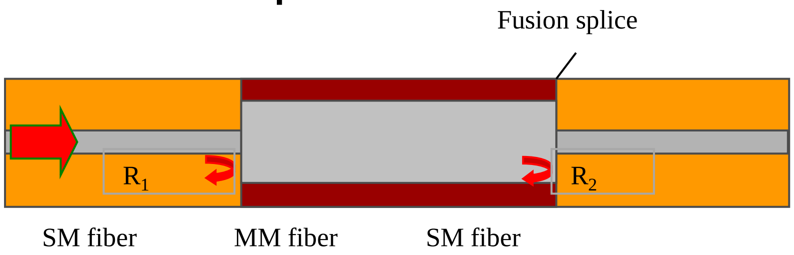
Multiplexed Sensing System

Temperature and Strain Measurement

- **Multiplexed sensors for massive distribution and data collection efforts**
- **Silica fibers using single mode / multimode interferometers for high temperature operation**
- **Targeting**
  - High temperature operation (up to 800 °C)
  - Up to 8 sensors per fiber
  - With high resolution (0.1 °C)
- **Numerous applications**
  - Initial application to advanced boiler systems and new boiler materials
- **Virginia Tech CPT**

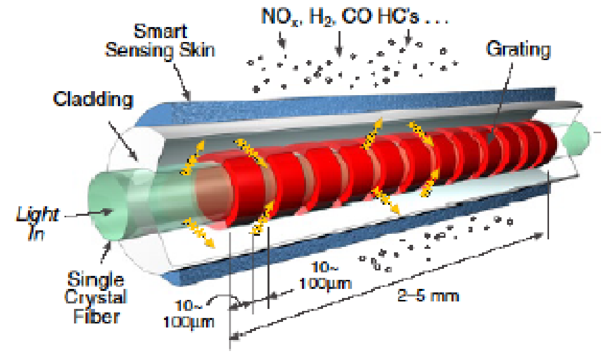


Interrogator with multiple fibers and multiple sensor elements

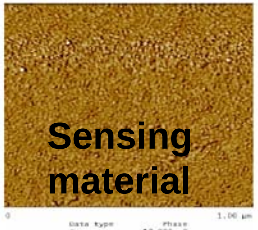


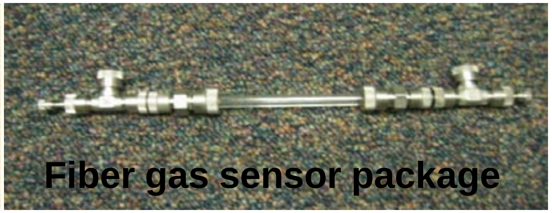
Coated Fiber Gratings for Distributed Gas Sensing

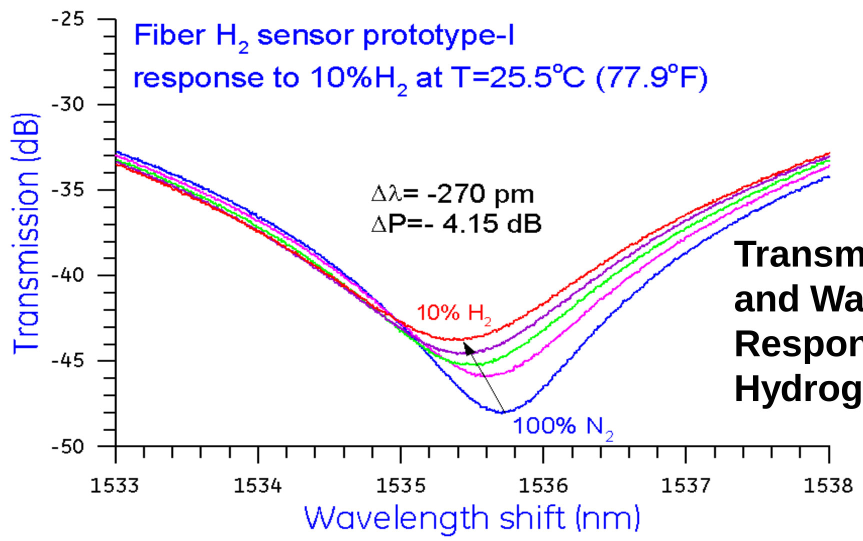
- Demonstrate ability to fabricate coated fiber gas sensors and selectively respond to gases near 500°C
- Silica fiber and nanoscale materials for detection of Hydrogen & Carbon Monoxide
- Grating development, materials selection, fabrication process
- GE Global Research



Fiber Gas Sensor Concept

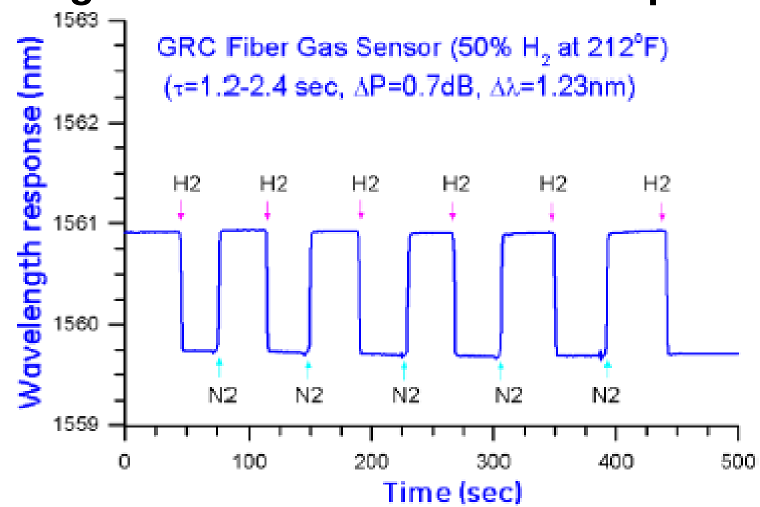






Transmission and Wavelength Response to Hydrogen

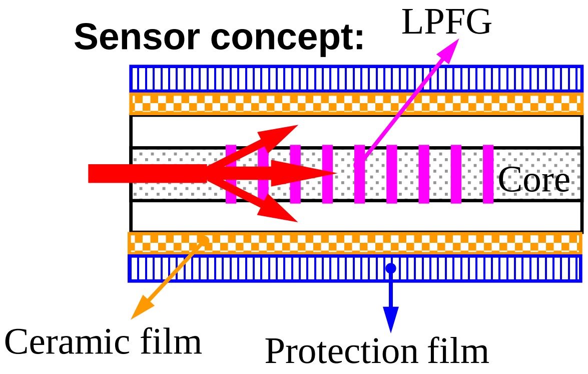
Fiber gas sensor transmission response

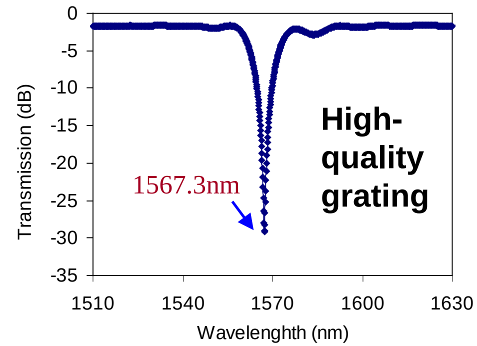


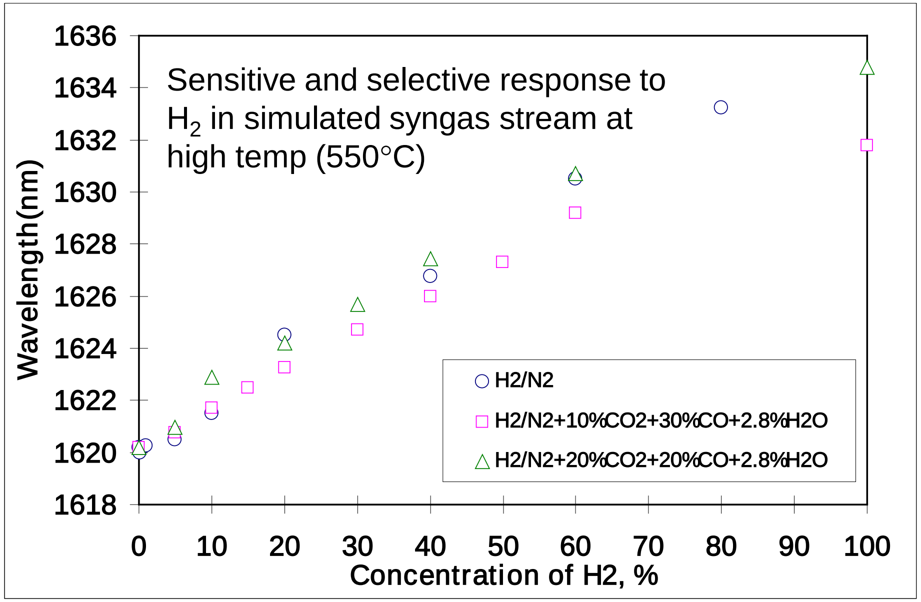
Coated Fiber for High Temperature Gas Sensing

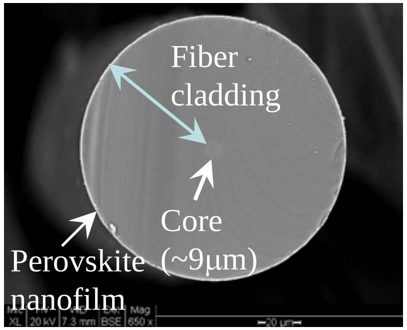
- **Feasibility to fabricate and sense at 500°C**
- **Silica fiber and nanocrystalline doped ceramics for detection of H_2, CO, CO_2, & H_2S**
- **Grating development, materials selection, & fabrication process**
- **Highly sensitive, large dynamic range**
- **NMT, UCinn, MST, ASU**

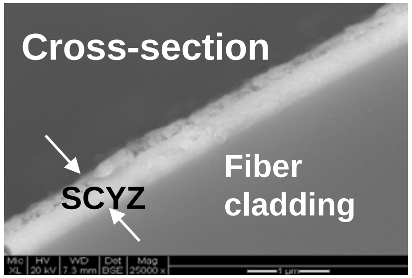
Sensor concept:

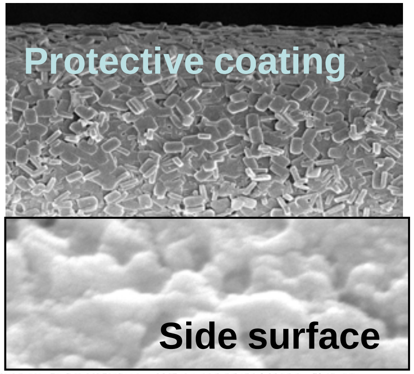




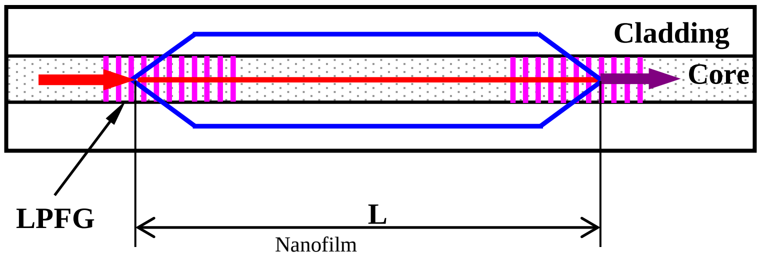


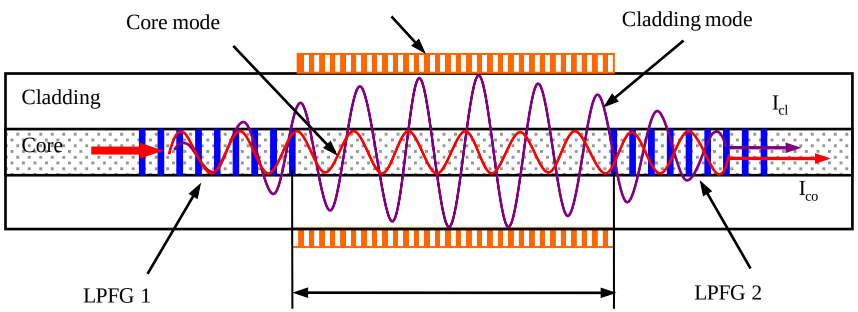


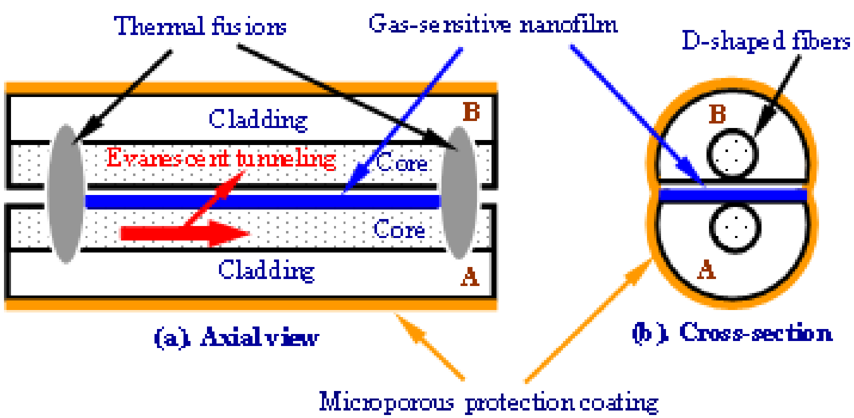




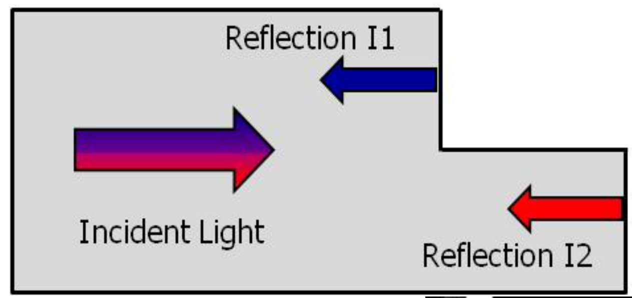
Fiber Optic Sensor Designs



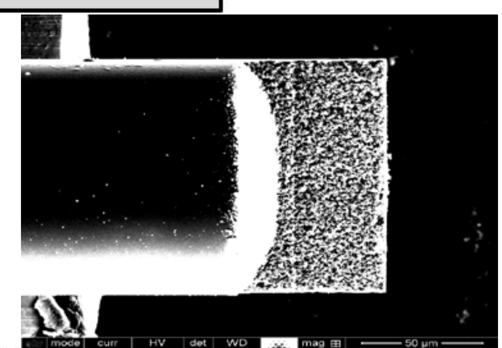




- **Mach-Zehnder interferometer (MZI) and Michelson interferometer (MI) formed by a pair of LPFGs** (left)
- **Cladding Tunneling LPFG** (bottom left)
- **Michelson Interferometer** (below)

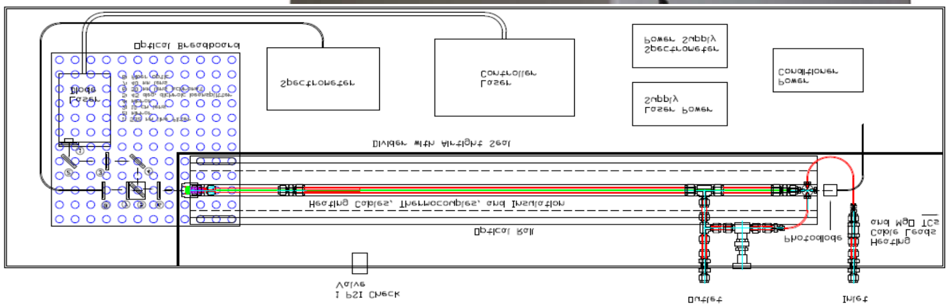


MST and UC Sensor Designs



Real-time Raman Gas Composition Monitor

- **Rapid gas analysis for on line monitoring and control**
  - **N_2, O_2, H_2, CO, CO_2, and H_2O**
  - **Full suite of hydrocarbons**
  - **Rapid analysis of other gases under study**
  - **Fast (<1-second) continuous measurements**
- **Analysis in the lab or at pipeline pressure and temperature**
- **Extensive lab testing, prototype development**
- **Completed 3rd party bench scale testing and turbine test cell evaluation**
- **Targeting other proofs of concept related to commercial applications**
- **May lead to protection of assets from non spec gaseous fuel, aid in performance monitoring of turbomachinery, help relationship between gas composition and component life (e.g. high H2 fuels)**



Research in Sensors and Controls

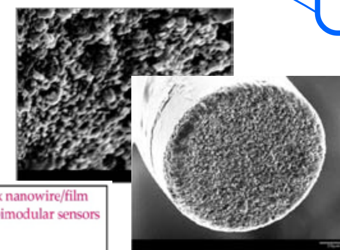
Stakeholder Input

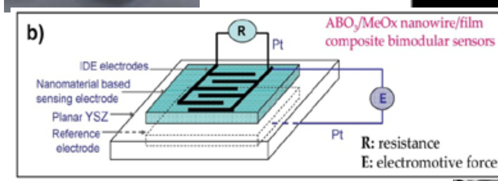
Industrial On Line Measurement Needs

Sensors Materials

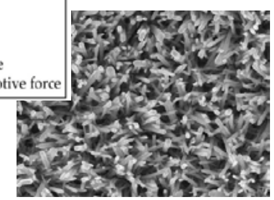
For High Temperatures & Harsh Environments

Fiber optical Materials, Coatings and Devices



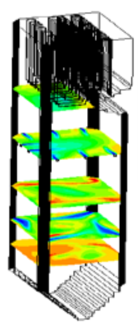


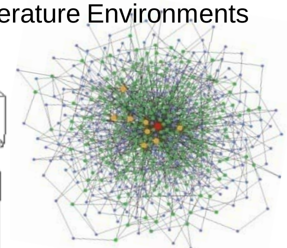
Micro Sensor Materials for High Temperature Environments



Integration with Process Control and Monitoring

Sensor Designs





Networking, Node Intelligence, Condition Based Maintenance Process Control

Sensor Packaging

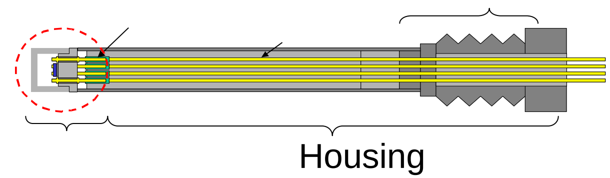
Novel Control Architectures
Distributed Intelligence
Heterogeneous Dense Sensor Networks
Self Organization
Wireless

Sensor Placement and Networking

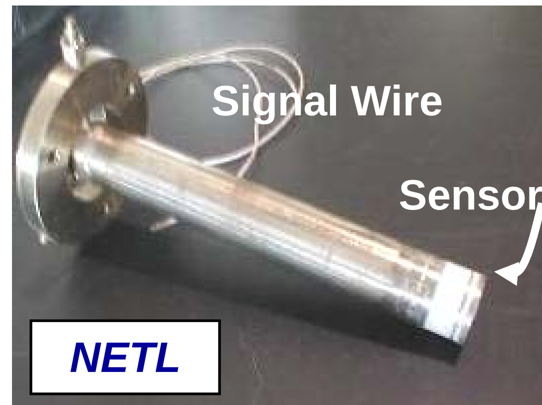
Prototyping and Testing

Sensor Packaging
(Design, Materials, Technology Transfer)

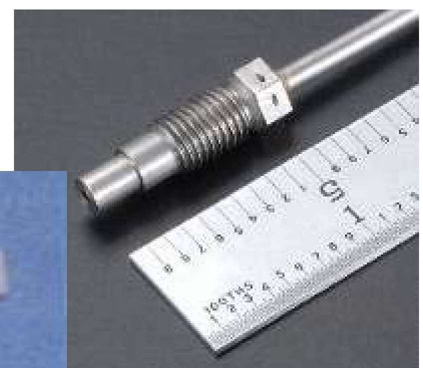
- **Package sensor to enable exposure to environment but protect for adequate performance**
  - Chemical exposure, electrical lead failure, mechanical thermal expansion considerations
- **Ease in handling, installation, replacement**
- **Barrier for technology transfer**



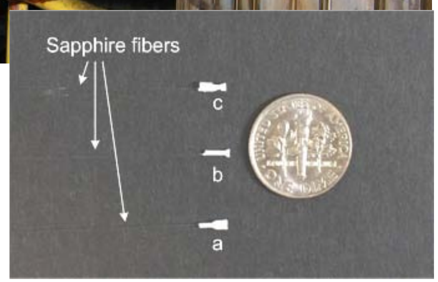
Sporian



Prime
OSU



Better Sensing / Harsh Environment Sensing



Sapphire Based Optical Sensor

- Longevity Low drift
- Functionality in Extreme Environments
- Retrofit for TC Ports
- Analyze purchase via replacement costs
- Numerous Emerging Optical Technologies easily deployable in Boilers

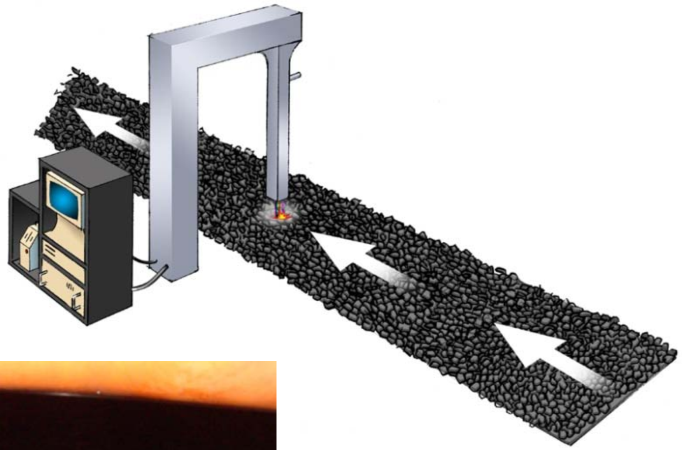
Oxygen Micro Sensor

- Internal Self Referencing
- Functional in 600C boiler environment
- Value is strategically placed sensor
- Better value in self powered wireless O_2 sensor for rapid low cost deployment. (Note: not yet developed)

Interest in quantifying value of "placed" temperature and O_2 sensors for boiler management

On line Coal Analysis

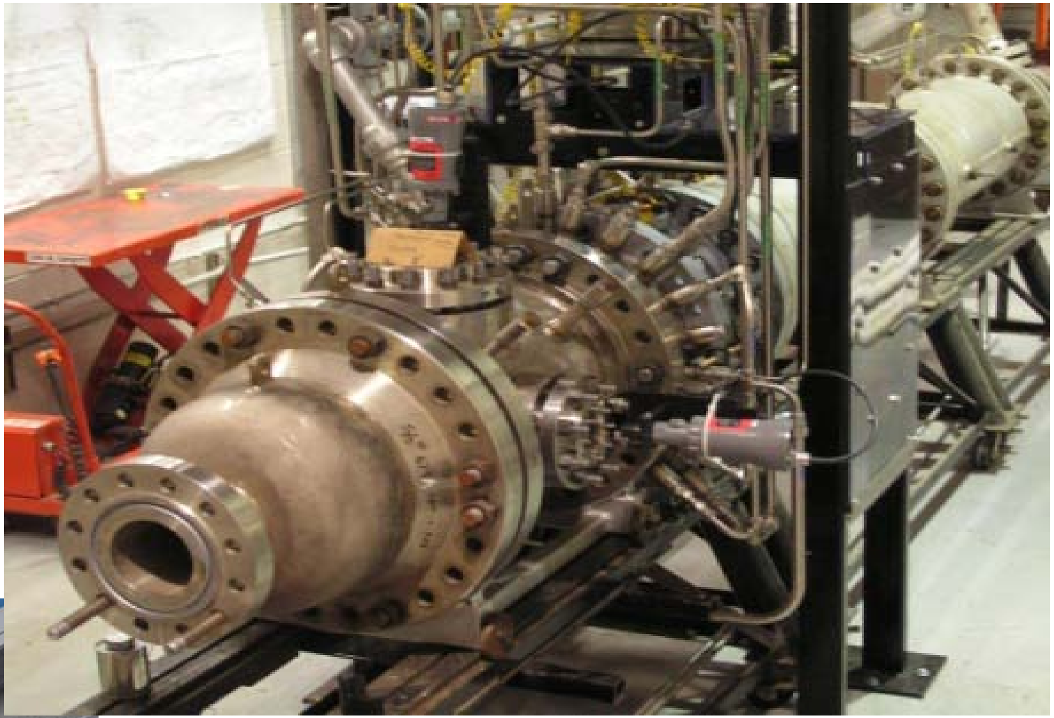
- Laser Induced Breakdown Spectroscopy
- On line elemental analysis
- Relational heating value and ash fusion temperature measurement
- Successful full scale testing on a coal belt
- Can be used for other solids and fuels with appropriate adaptation
- More testing desired to refine commercial design
- Significant potential for coal blending, boiler management, slag prediction, etc
- May benefit soot blowing schedules and aid in boiler tube wastage/management with potential to impact forced outages.

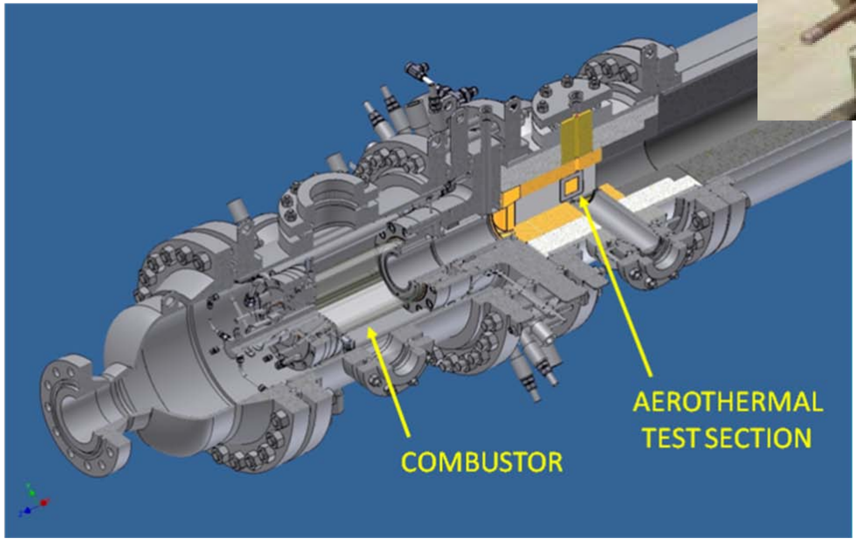


Facilitated Testing at NETL

Aerothermal rig

- Temperatures up to 1300 C
- Pressures up to 10 Atm
- Fuel flexibly
  (NG Propane & H_2 mixes)
  (liquid fuel capability)
- Multiple ports from ¾” - 1 ½”
- Optical access and ability to affix a part (e.g. airfoil parts)
- 5-6 hours of run time per day





Viewpoint

- Ability to advance sensor technology through to a TRL level 4/5
- Lower cost option for this level of testing
- Buys down risk for OEMS
- Potential to improve success rate for sensor technologies moving to spinning rig type testing

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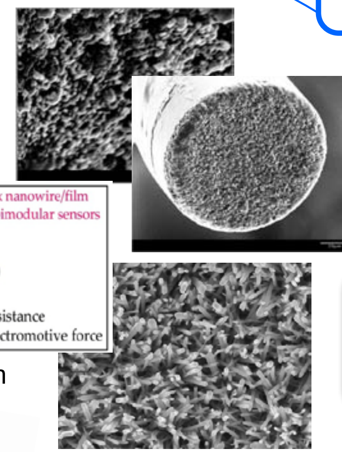
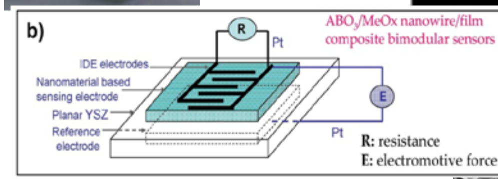
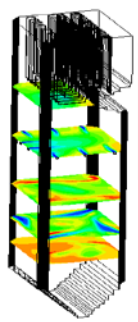


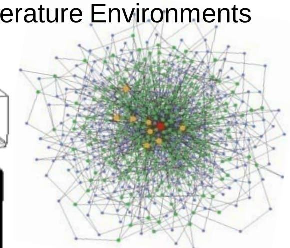


Micro Sensor Materials for High Temperature Environments

Integration with Process Control and Monitoring

Sensor Designs





Networking, Node Intelligence, Condition Based Maintenance Process Control

Novel Control Architectures
Distributed Intelligence
Heterogeneous Dense Sensor Networks
Self Organization
Wireless

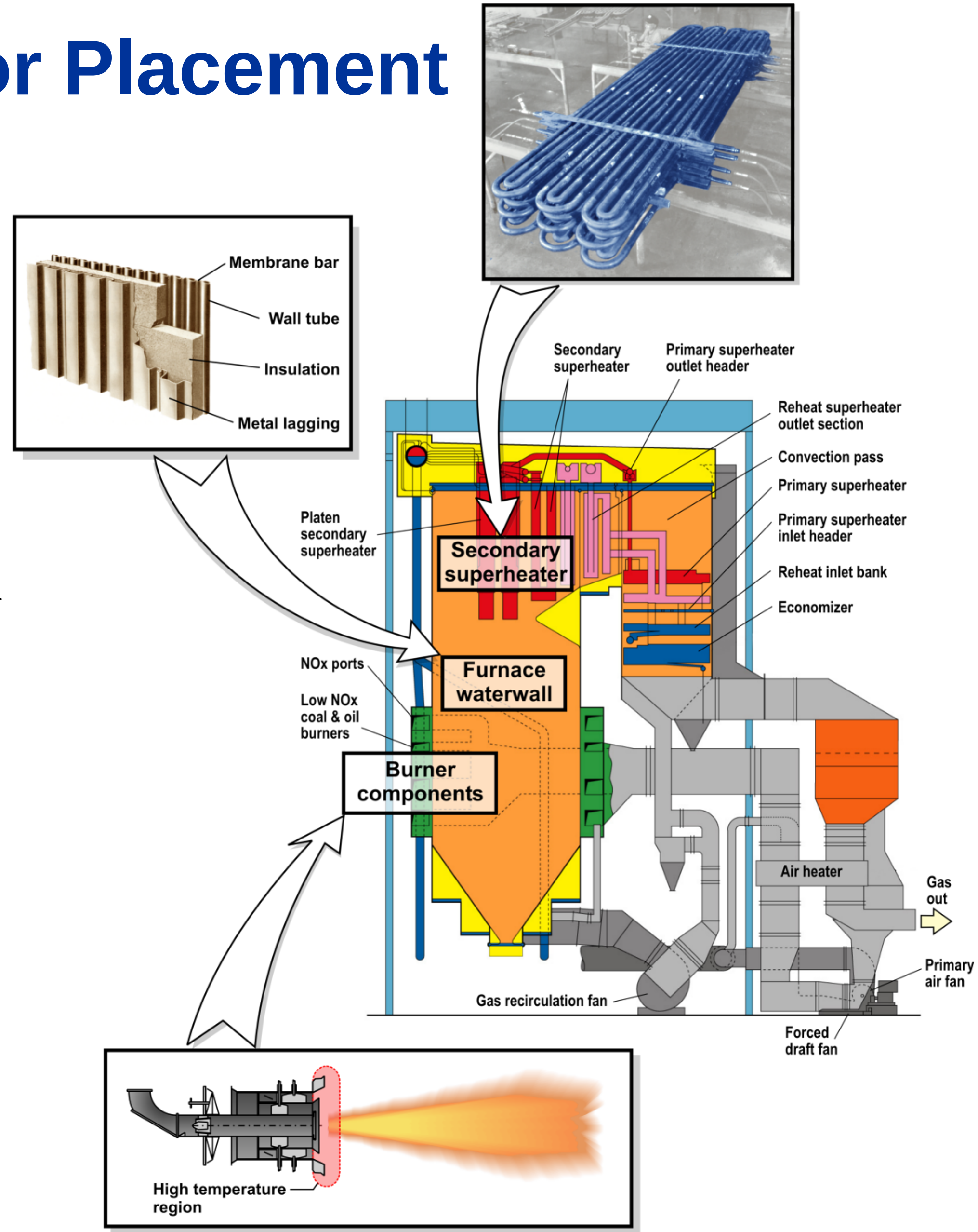
Sensor Placement and Networking

Prototyping and Testing

Sensor Packaging

Sensor Placement

- **Use computational approaches to determine where, type, and number of sensors to optimize parameters, enable fault tolerance, etc**
- **Verify with experimental work**
- **Useful for component system and eventually plant level**
- **Seek relationship for number of sensors to "value" based on**….(size of component, conditions, #of parameters, challenges with changing system operation, etc)

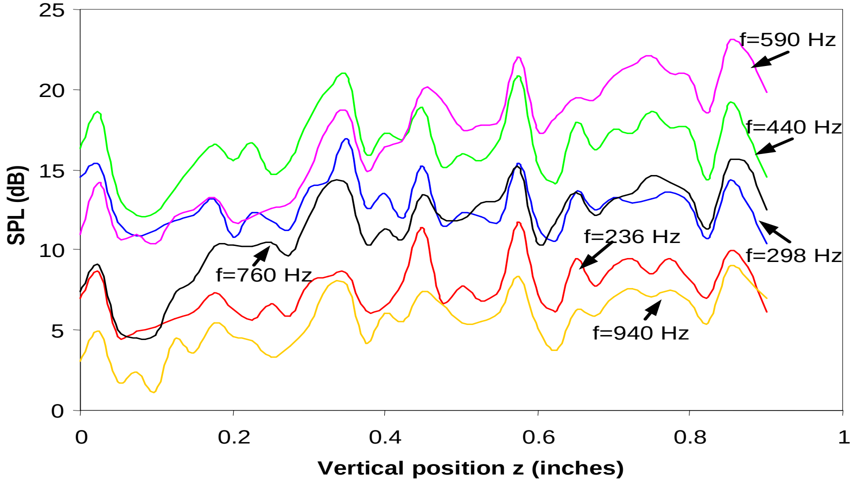


Sensor Placement

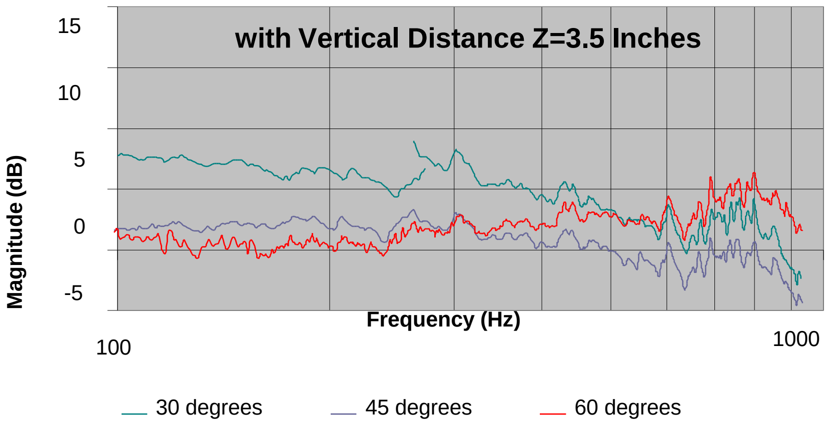
Experimental Investigation

- Investigate sensor placement and number of sensors under controlled combustion conditions
- Support theoretical pursuits for sensor networking, self organization, and sensor placement based on system models
- Determine how many sensors and where the sensors should be placed to ensure a defined degree of convergence and confidence
- A single sensor is inadequate, particularly when variations are large-scale temporal and spatial
- Multiple sensors implies more information, but… can it lead to better control and performance
- UMD & Ames NL

Single sensor placed at different vertical locations



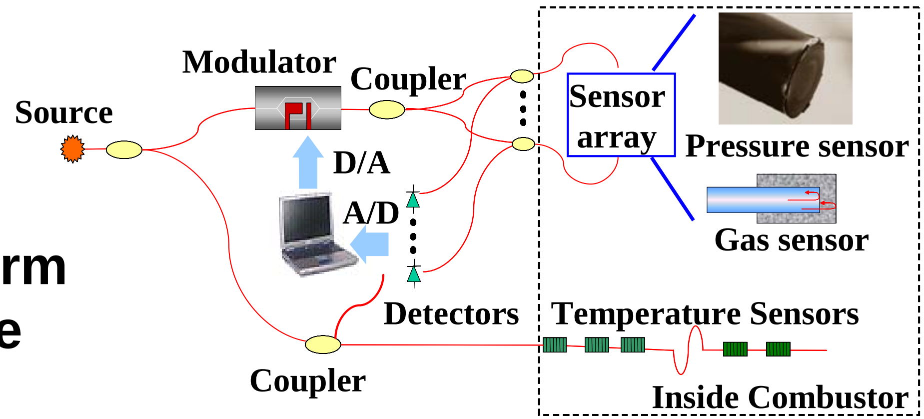
Multiple Sensors at different circumferential locations

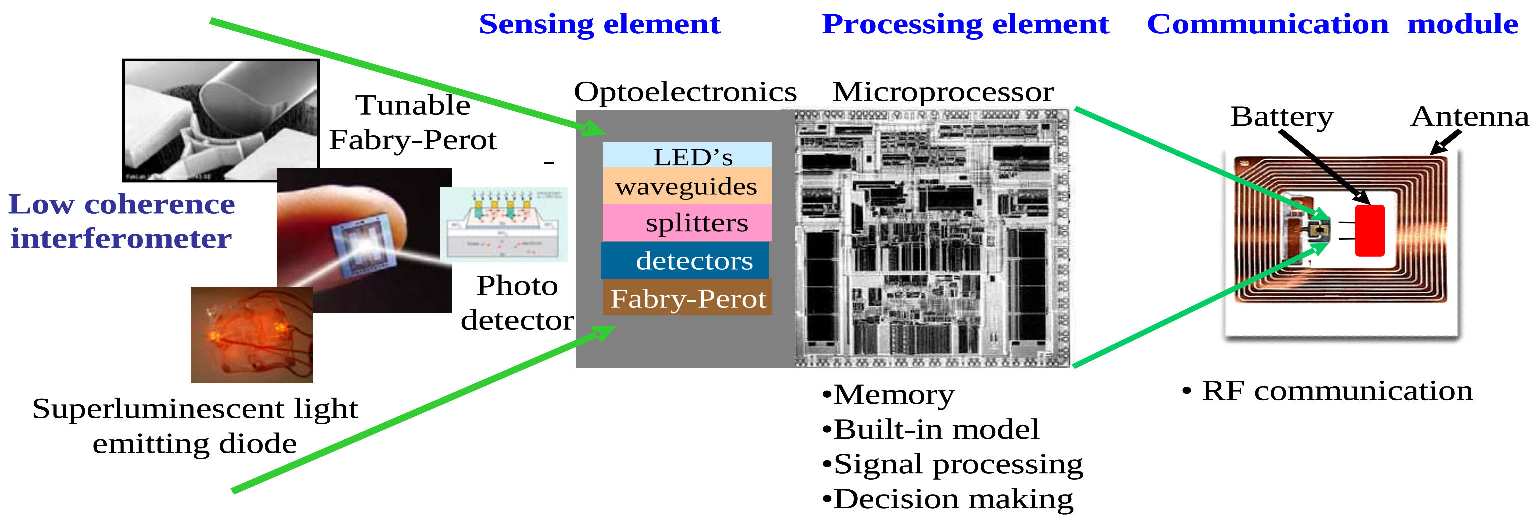


Sensor Networking

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**



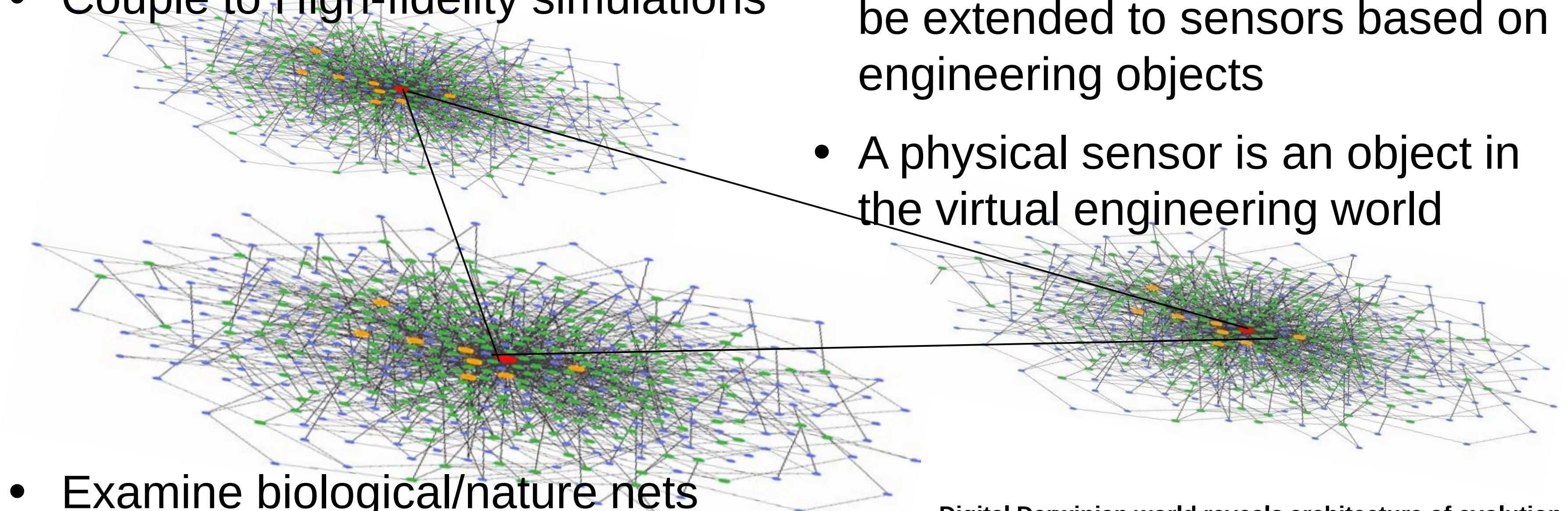


High Density, Heterogeneous, Massive Sensor Nets for Process Systems

- 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*)

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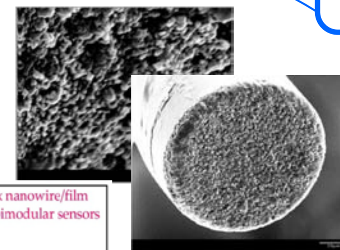

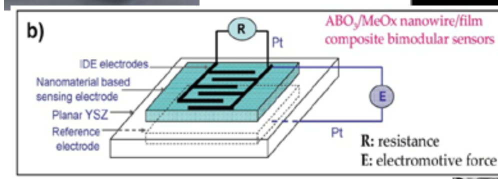

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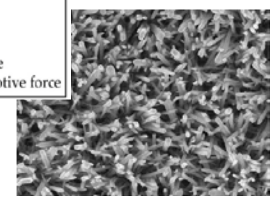
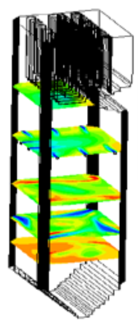
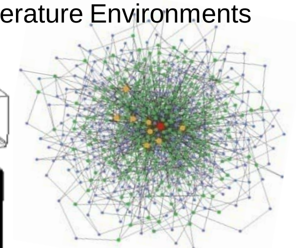


Integration with Process Control and Monitoring

Sensor Designs





Networking, Node Intelligence, Condition Based Maintenance Process Control

Novel Control Architectures
Distributed Intelligence
Heterogeneous
Dense Sensor Networks
Self Organization
Wireless

Sensor Packaging

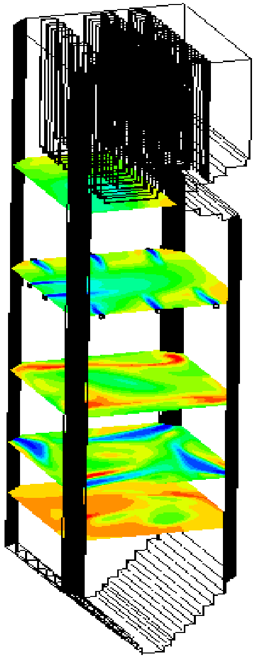
Sensor Placement and Networking

Prototyping and Testing

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

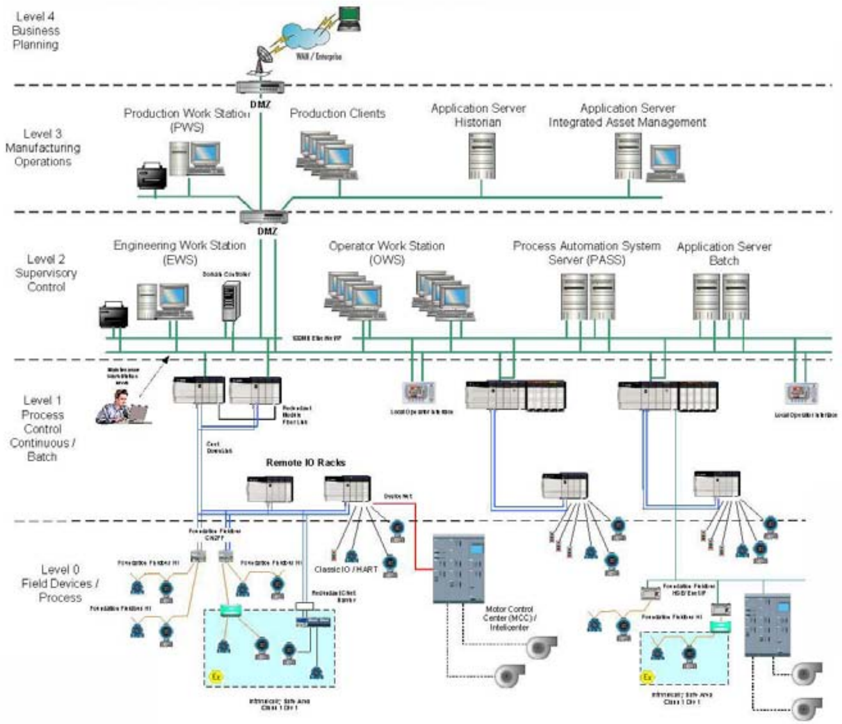
- **Sensor Networks**
  - Pervasive low cost networked sensing for condition monitoring and control including wireless/less wires
  - Permit capture and manipulation of data for process improvement (via advanced control) and enable novel approaches to system integration
  - Explore novel constructs and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

Evolutionary vs Revolutionary

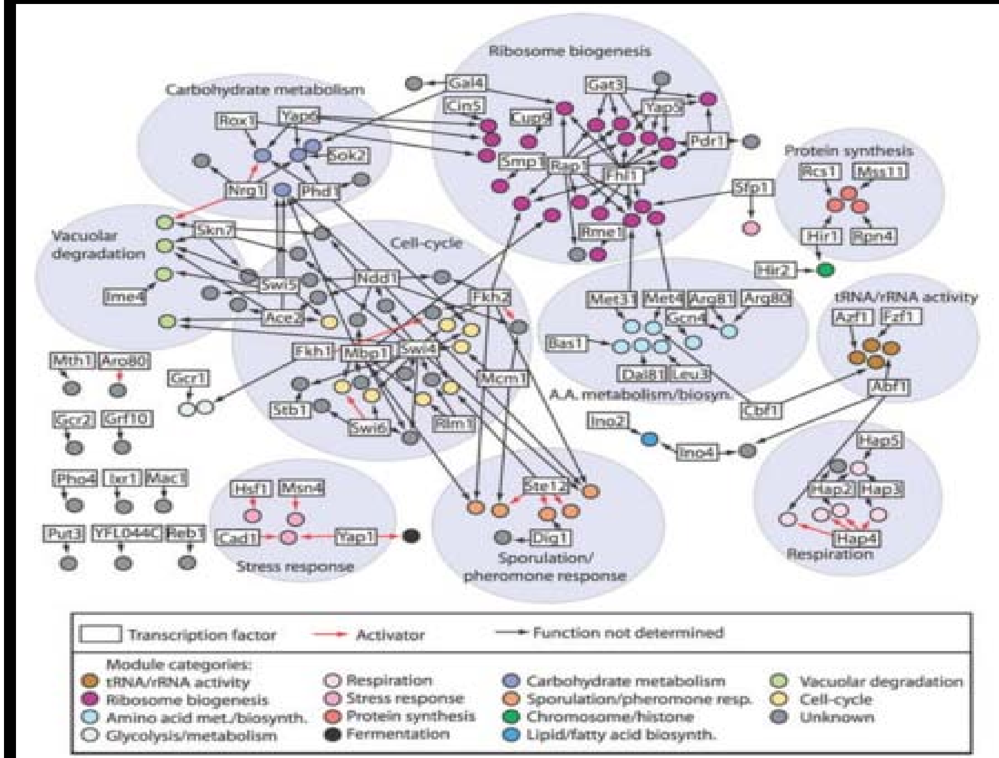
Challenging conventional architectures to
support advancements in computational intelligence



Traditional Control Architecture
For Distributed Control Systems (DCS)

- Linear and based on minimization
  of error and set points

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



Stigmergy

Development of Representative Algorithms

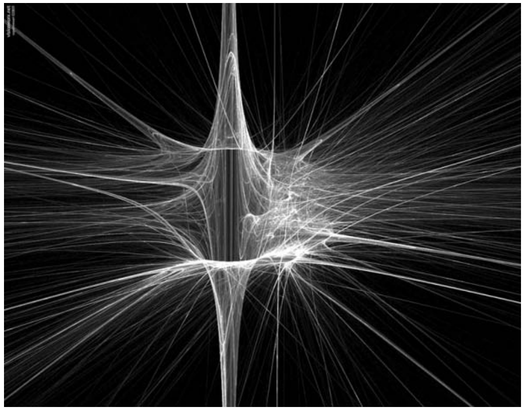
Indirect communication of multi-agent groups through environmental elements

Nature:

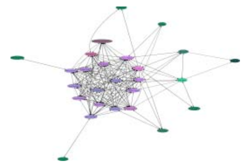
- Used to describe the construction of termite nests
- Information is stored implicitly within the environment

Advanced S&C:

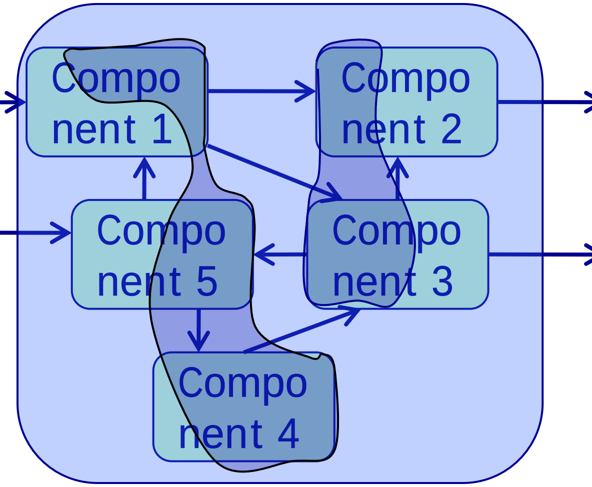
- Potentially powerful tool for coordination of sensor data
- Makes use of decentralized control
- Processors are embedded at sensor level
- Sensor-coordinated communication
- Data transfer determined through sensor communication
- Novel approach to managing complexity and dynamics associated with advanced power systems.

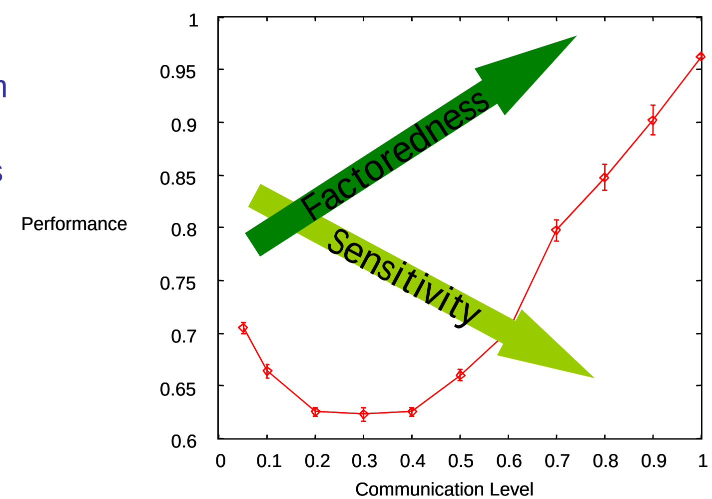


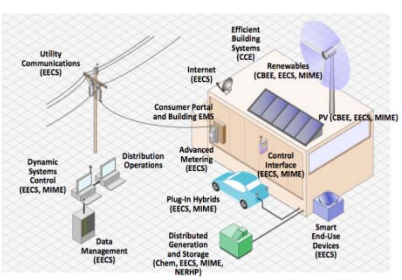
Distributed Sensor Coordination for Advanced Energy Systems

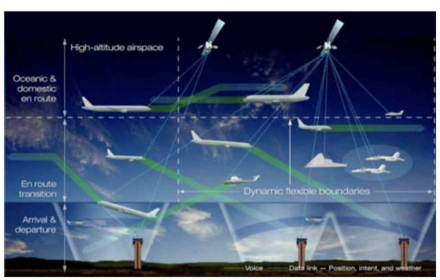


- **Motivation:**
  - Advanced energy systems are becoming more interconnected
  - Computation pushed down to sensors
    - » *How do we control and coordinate such systems?*
- **Objectives:**
  - Derive criteria for assessing sensor effectiveness and system impact
  - Demonstrate effectiveness and reconfigurability of sensors to changes in system
- **Concept:**
  - Focus on *what* to control, *what* to optimize (not *how* to control):
    - » Improved objective functions for each subsystem
    - » Improved 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





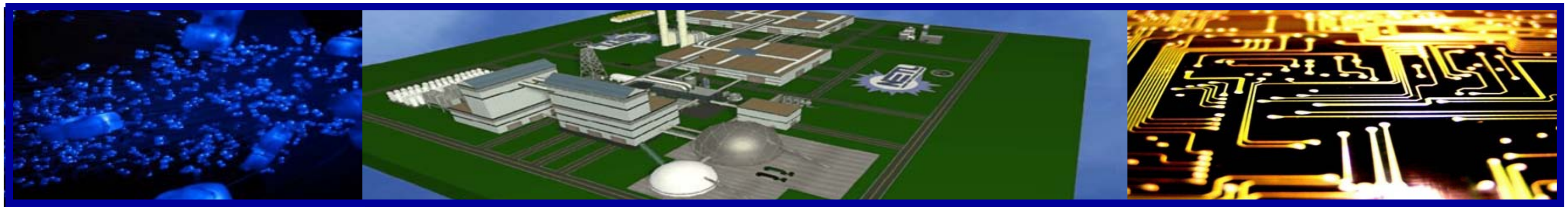




Technology Gaps and Vision

- **Near Term Technology Gaps**
  - Sensor Packaging and Prototype Testing
  - Demonstration of low cost sensor network

- **Long Term Vision**
  - Rapid low cost sensor deployment
  - Demonstration of Stimergic-based information management and Decentralized Autonomous Operation

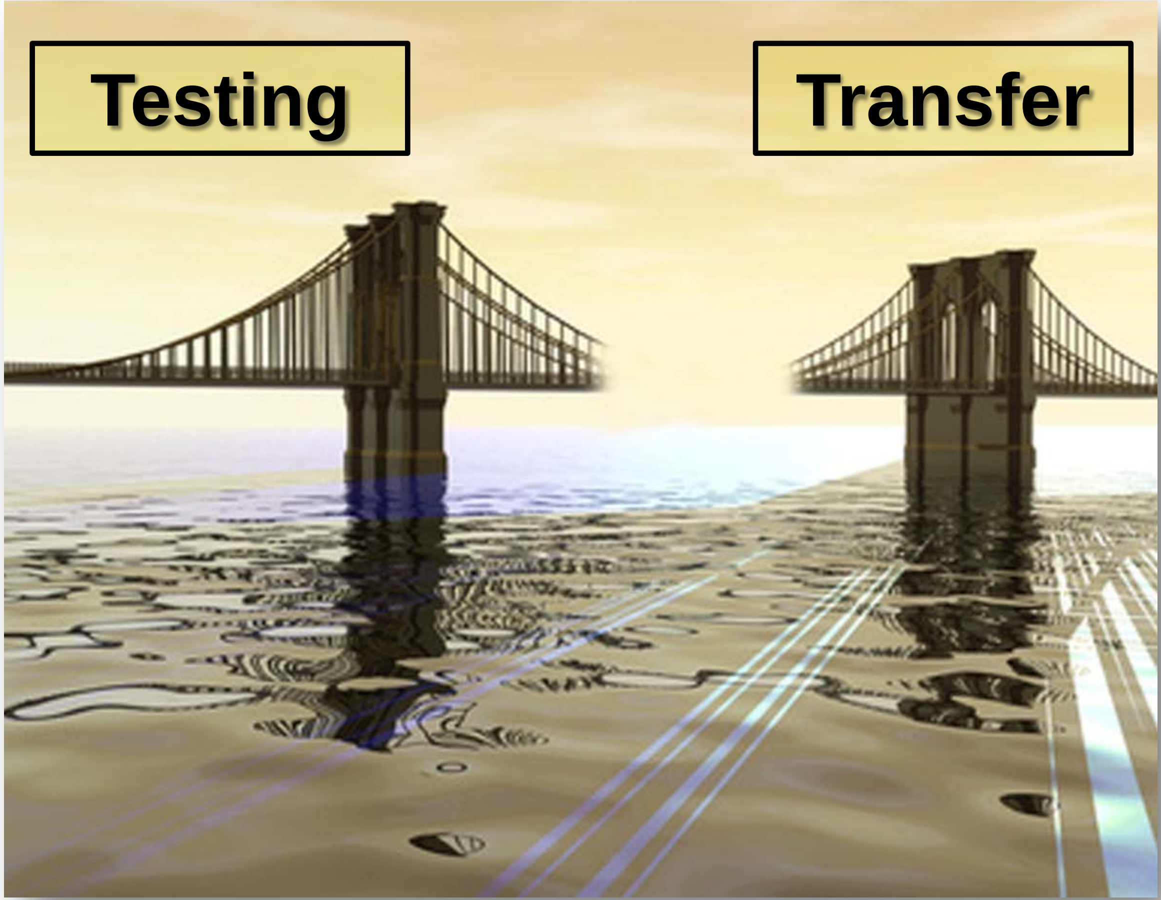


Technology Testing and Transfer

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

- The Program's measures of success tie back to testing, patents/ licensing, and commercialization

- Technology transfer is challenging for government programs and risk adverse industries



Stakeholder Opportunities

- **Programmatic Input**
  - Value Proposition for Utilization of New Technology
  - Viable Deployment Scenarios for New Technology
  - Emerging Measurement and Control Needs
  - Benefits from employing S&C Technology
- **Partnering with Developer or NETL for Testing**
- **NETL S&C Workshop Participation**
  - Industry input
  - Industry perspective to the developer
- **Participation in funded Research, Development, and Demonstration though DOE NETL**

Sensor & Controls Portfolio Handbook

Handbook provides a summary of the on-going research under the Advanced Research Program

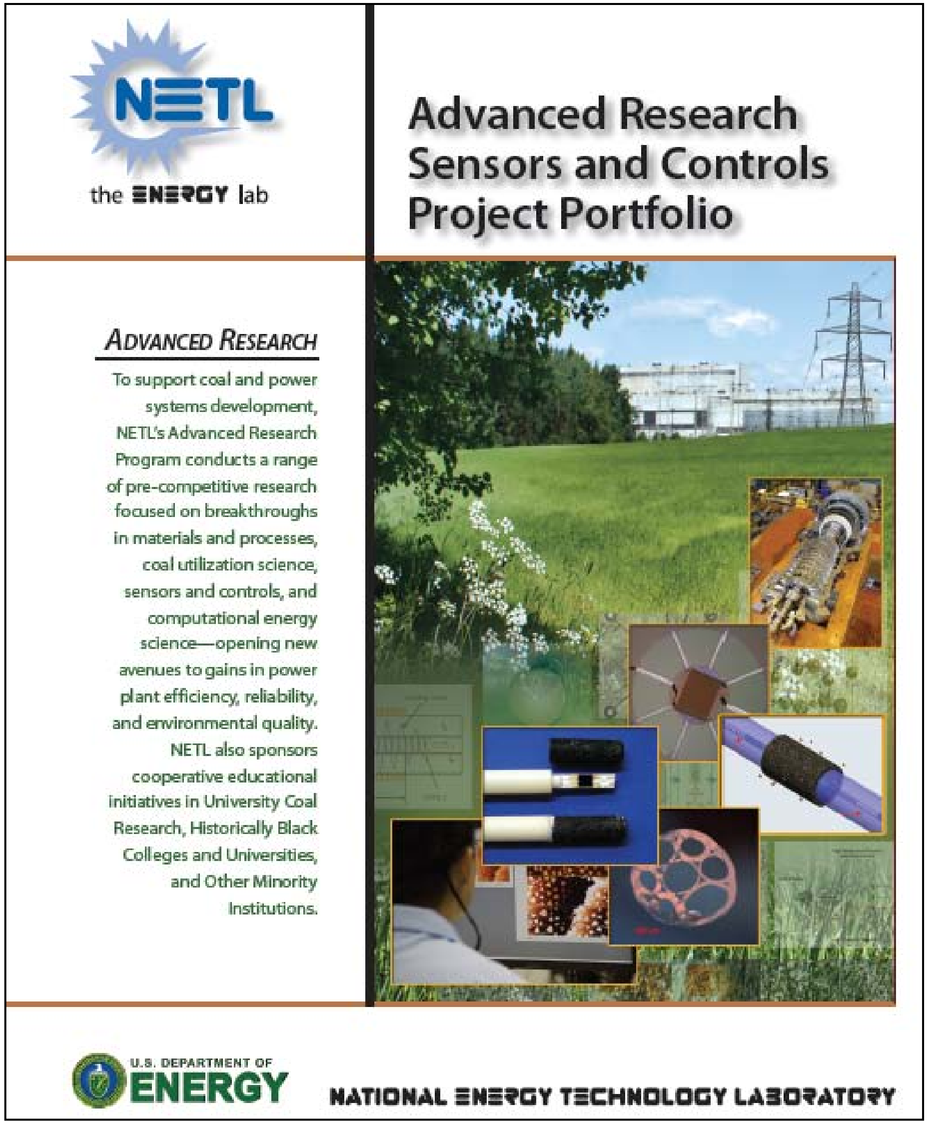
Released: May 2011

Addresses research areas:

- **optical sensing, microsensors,**
- **advanced process control**
- **wireless communications, energy harvesting devices, and**
- **imaging systems.**

Document located at:

http://www.netl.doe.gov/technologies/coalpower/advresearch/pubs/Sensors_Portfolio_2011_Book.pdf



Summary

- **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 have harsh environments that require monitoring and the development of sensors for these environments is a focus of NETL's sensors 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 system operation and control.

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Backup Slides

Sensor Designs

Optical Sensors
- Spectroscopic / Non contact
- Fiber based

Optical Access, Interference management

Single Point, Distributed and Multiplexed Sensors, Coatings for sensing, protection, and attachment

Micro Sensors
- Single point
- Array based

Active sensing layers and protection materials, Algorithms for Gas Identification and Quantification, Packaging of sensors, lead wire and connector improvements

Other
- Embedded sensors
- Imaging

Active films, direct write sensors, Metamaterials, Capacitance Imaging, Algorithms for image reconstruction

Enabling Technologies
- Wireless
- Energy Harvesting

Passive Wireless, Active Wireless communication, Thermoelectric and vibration energy harvesting approaches, Sensor Networking