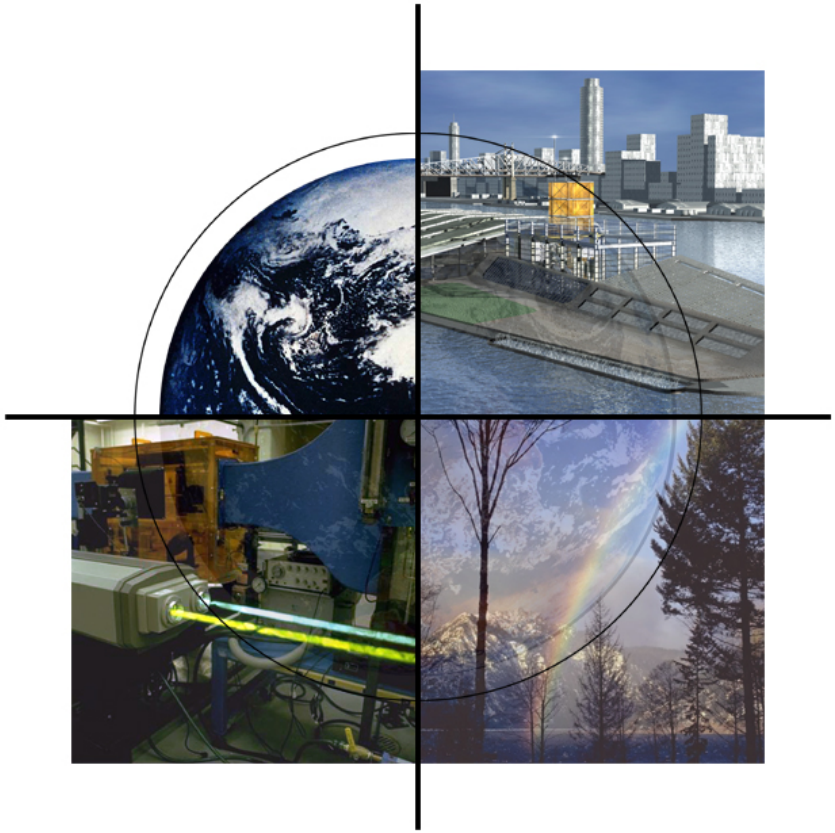
Advanced Research Program



Sensors and Control Program Overview

February, 2008

Susan Maley, Project Manager
National Energy Technology Laboratory

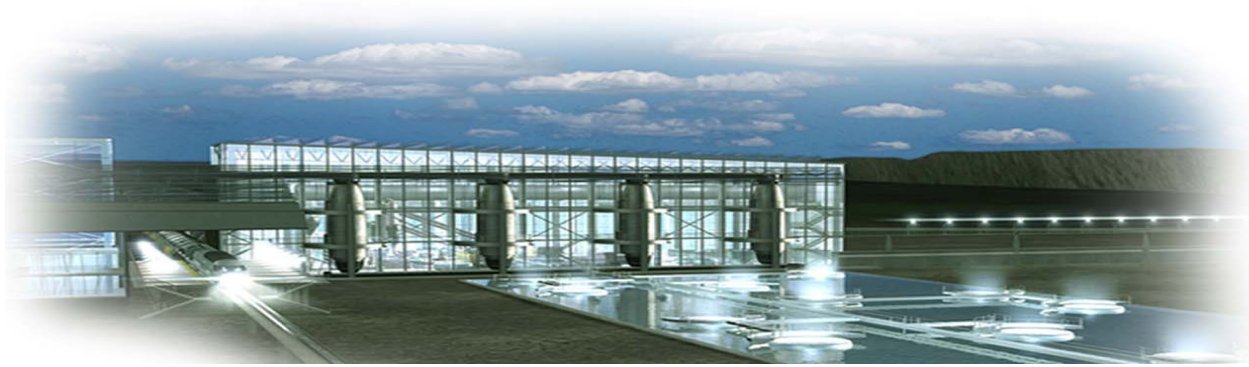
Outline

- **Program Goals**
  - Drivers, Motivation, Benefits
- **Program Structure**
  - R&D emphasis
  - Project Execution
- **Overview of R&D Emphasis**
- **Program Contacts**

Goal /Target

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



High Level Drivers for Utilizing Advanced Sensors and Control Technology

- **"More with the same"**
  - Demands associated with deregulation
  - Strengthening environmental regulation
  - Aged power infrastructure
- **"Juggling while holding hands"**
  - Growing demand of fuel and energy
  - Protection of interdependent infrastructures
  - Grid management concerns
  - Fuel and operational flexibility
- **Achieving DOE FE Goals**
  - Low RAM for recently demonstrated power technologies
  - Tight operating envelope for advanced power technologies
  - High degree of system integration needed

Drivers for New Sensing Technology

- **Advanced Power Generation has harsh conditions through out a plant that need to be monitored with new instrumentation and sensor technology.**
  - Existing instrumentation and sensing technology are inadequate
  - Coal Gasifiers and Combustions Turbines have the highest and most extreme conditions. Temperatures for these system may extend to 1600 °C and pressures near 800 psi. Slagging coal gasifiers are highly reducing, highly erosive and corrosive. Combustion turbines have a highly oxidizing combustion atmosphere.
- **Target 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.
- **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.
  - Goal of enabling the coordinated control for advanced power plants including coordinated operation carbon capture and injection

Motivation for Developing New Sensors and Control Technology

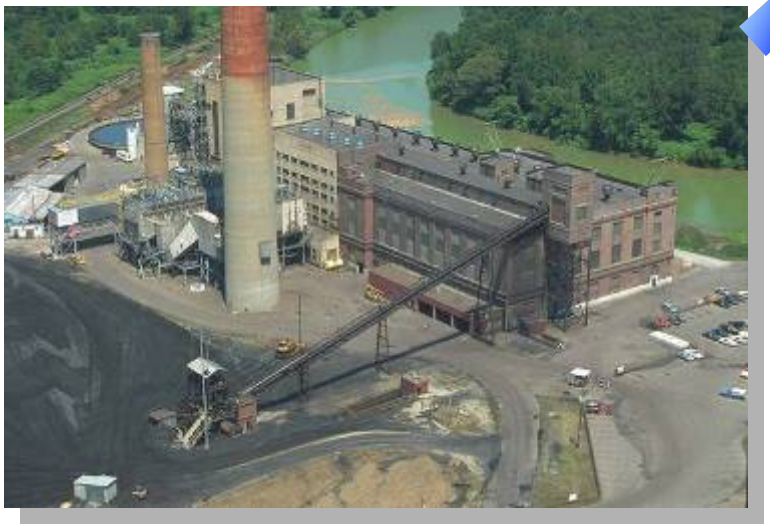
- **Low cost, high benefit technology**
- **Existing technology is inadequate**
- **Boosts efficiency of existing facilities and significantly contributes to high reliability**

- **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**

Fossil Energy Technology Challenges

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

Near/Zero Emission Advanced Power Generation System



Mid 20th Century Plants

Sensor & Control Contribution

- Process modeling and control
- Operations monitoring (efficiency, emission, equipment)
- Dynamic and transient mode management
- Sensing materials for harsh environmental

Sensors and Controls Needs

Controls

- Supervisory control
- Integrated control
- Neural nets
- Predictive, adaptive control
- Modeling

Advanced Materials

- High temperature Micro sensor materials
- Nano-derived materials

Gas Purification / Separation Environmental Control

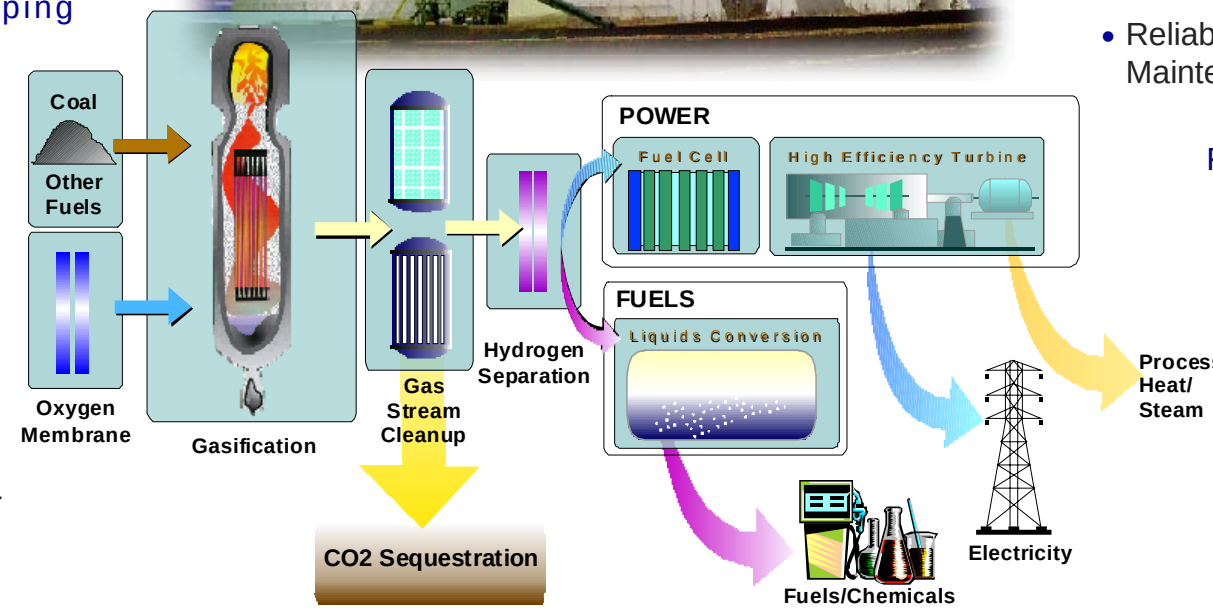
- Mercury Trace Metals
- NOx, SOx
- Ammonia
- CO2 Monitoring

Turbines

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

Gasification Chemical Looping

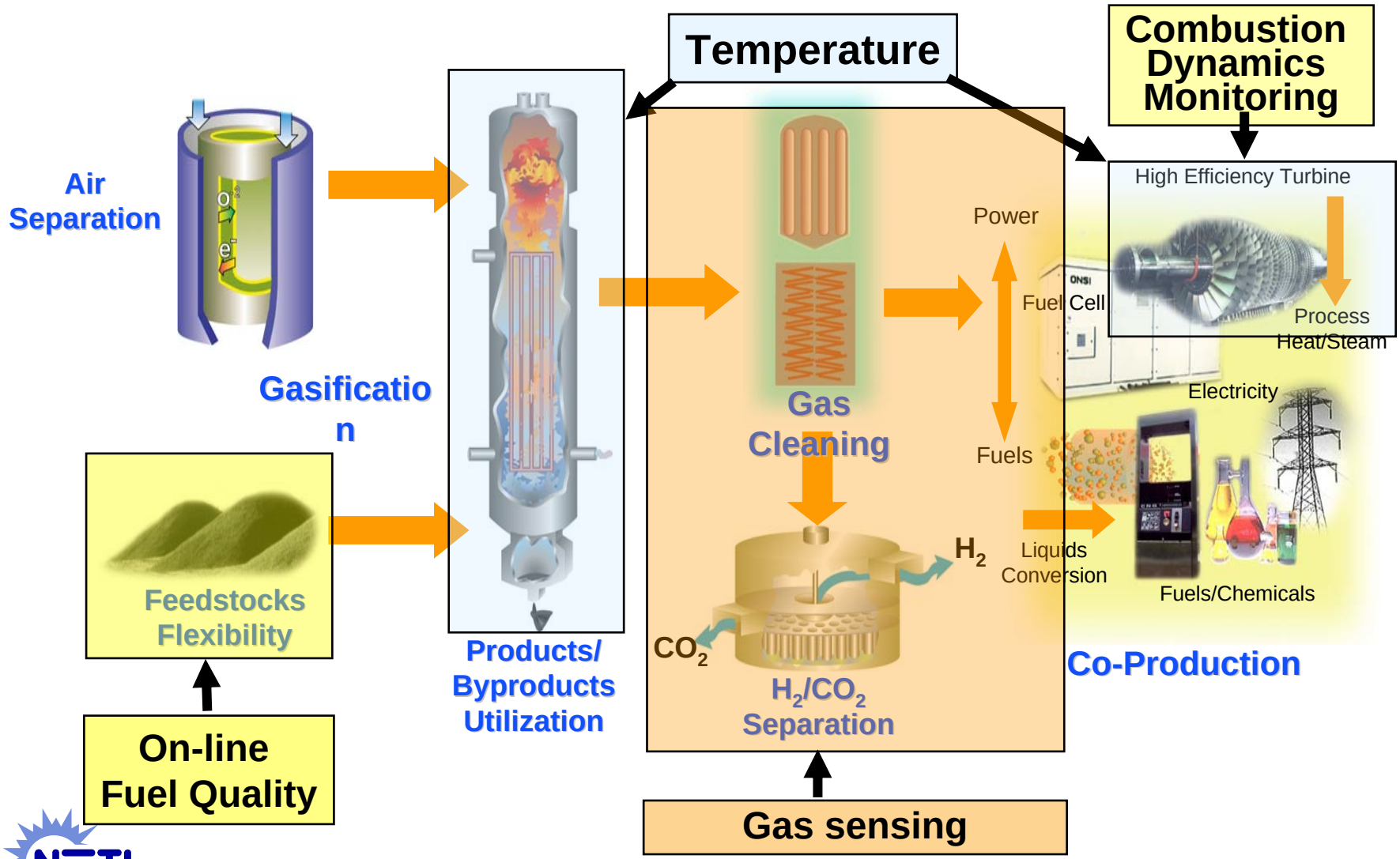
- Temperature
- Gas Quality
- Fuel / air ratio control
- Robust sensors
- Feed flow and Characterization
- Particle Detection
- Standardized signaling
- Corrosion monitor
- O_2 control



Fuel Cells

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

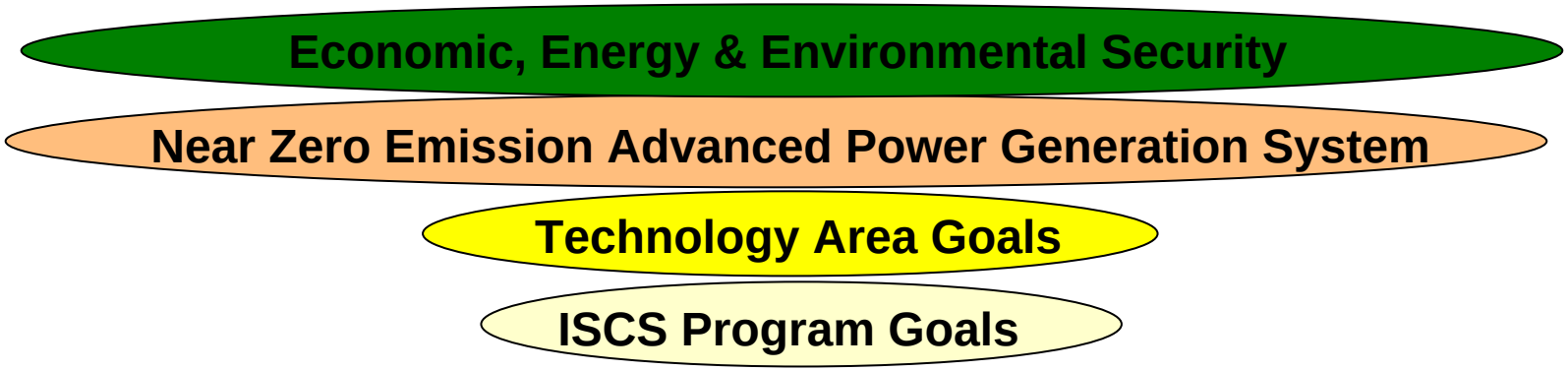
Prioritized Sensing Needs for an IGCC based Near Zero Emission CoGeneration Plant



Advanced Research Program
in
Sensors and Control

Program
Goals
Framework and Delineation
Overview of Interest Areas

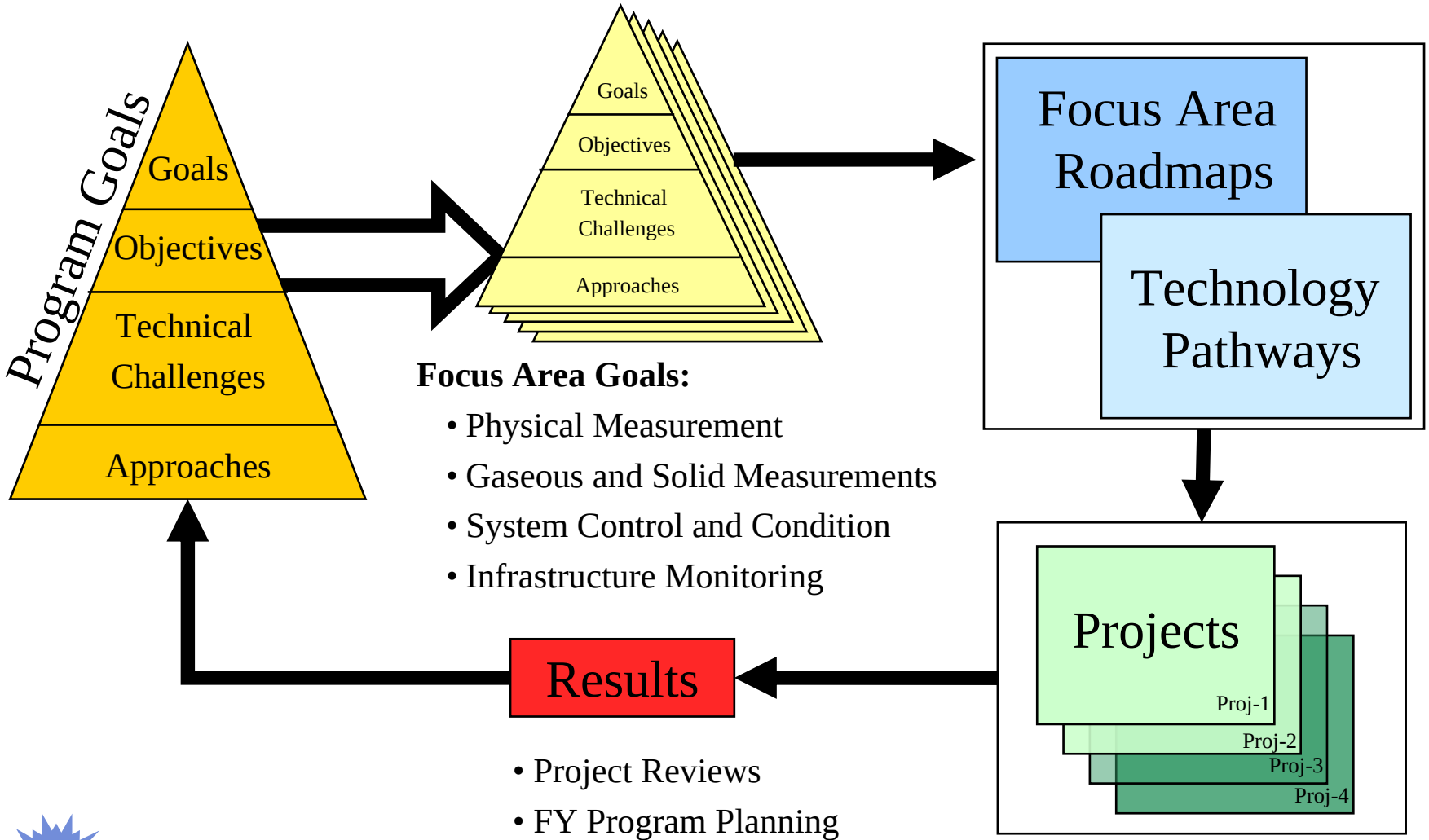
Program Goals



Measurement Area Goals

- **Physical Measurements**	Temperature, pressure & flow for harsh environments
- Gas and Solid Measurements	Low cost gas sensors for high temperature environments Trace level contaminant detection Real time solids characterization
- Control and Condition Monitoring	Creation of artificially intelligent , integrated controls Information creation & exchange for systems management
- Infrastructure Security Monitoring	Measurement and control technology for reliability and security enhancements of related infrastructures

ISCS Program Framework
Goals Traceable to Projects



Sensor and Control Program Delineation

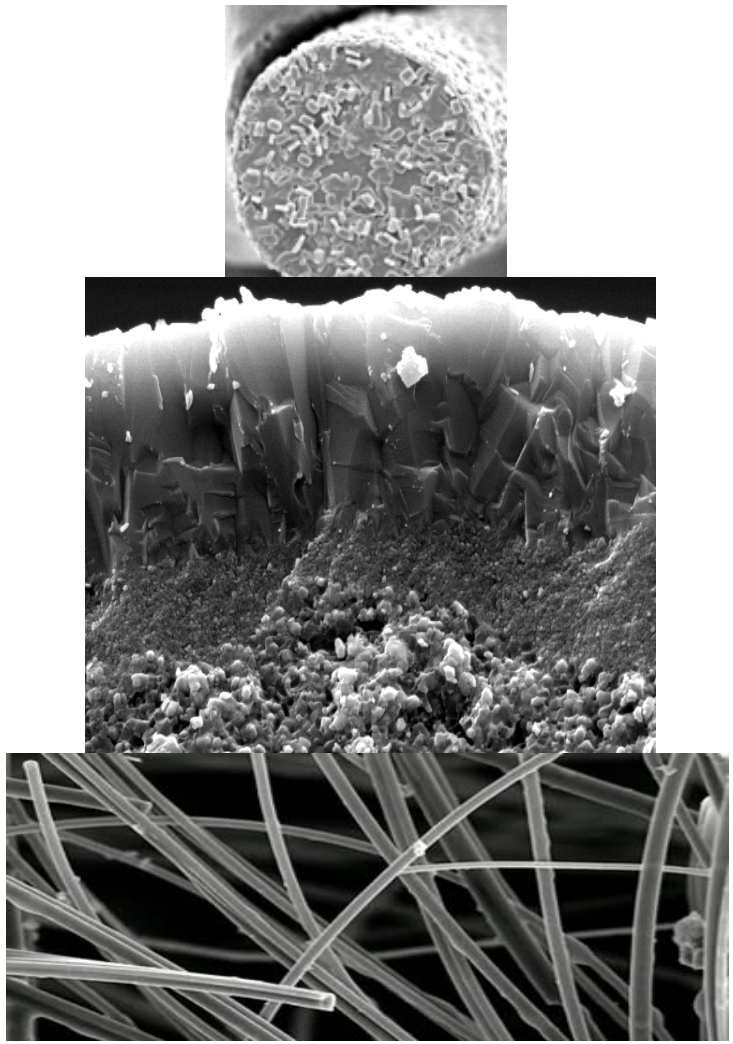
- **Physical Measurements**
  - T,P, Flow, Strain/Stress
- **Solid and Gas Measurements**
  - Coal Quality
  - Syngas
  - >500°C targeted
- **Control and Condition Monitoring**

- **Sensor Materials**
  - Fiber optics and substrates
  - Active sensing layers
- **Sensor Design**
  - Selectivity
  - Survivability
  - Responsiveness
- **Sensor Packaging**

Sensor Networking
Advanced Control
System Integration

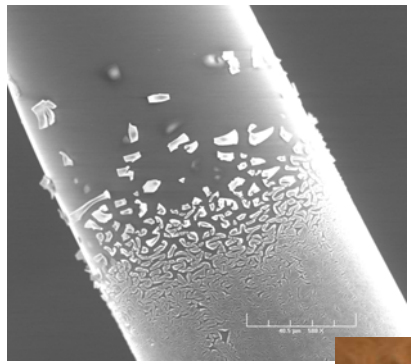
Materials for Sensing in Harsh Environments (Optical and Micro Sensors)

- 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 ^{o}C)



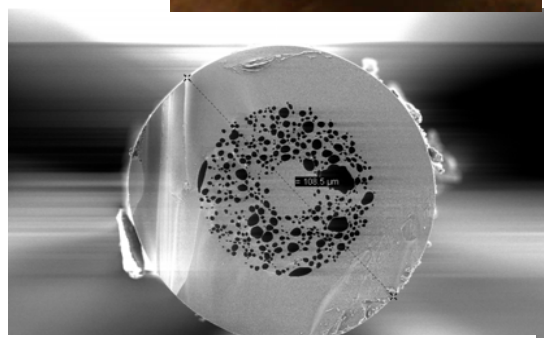
Fiber-based Sensor Material Development

- **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)

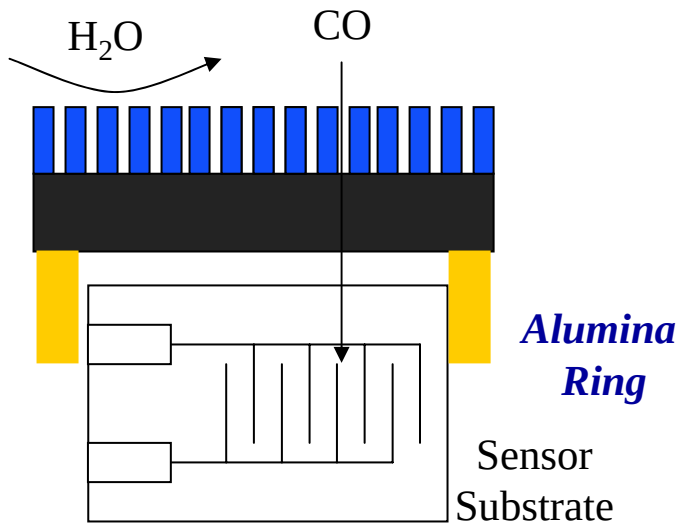
Coated Sapphire Fiber (Prime)

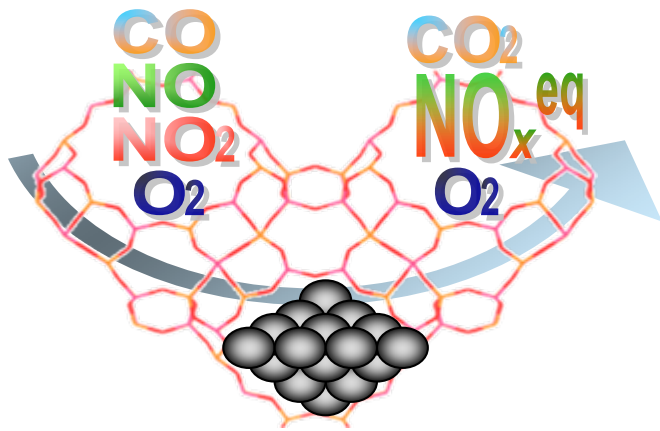


Holey Fiber (VT)

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
- Nano derived material applications by OSU, UMR, ASU, UC, and GE





Micro Sensor Design

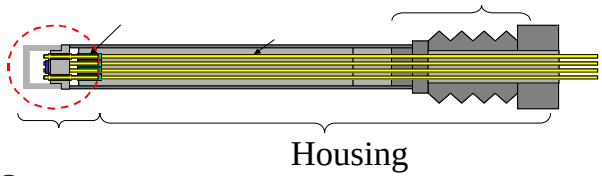
- **Targeting micro gas sensors for high temperature environments (~500°C)**
  - Target gases for fossil energy environments include NOx, SOx, NH_3, CO, CO_2, H_2, H_2S, and Hydrocarbons
  - Silicon carbide, YSZ, etc for substrate materials
  - Metal oxides, precious metals, etc for active sensing materials
  - Sensor arrays, backside heaters, reference elements, etc contribute to robust design
  - Low cost for routine replacement
- **Targeting micro sensors for physical measurements such as temperature and pressure**
- **Program participants include, SRD, OSU, MSU, Sporian MicroSystems, Univ Utah, UF, NETL**

Metal Oxide Gas Sensor Array (SRD)

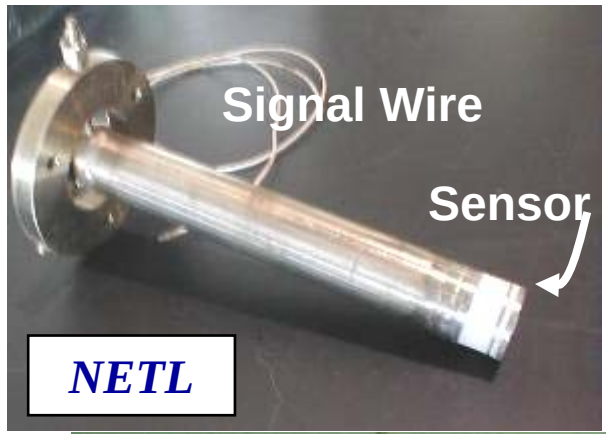
H_2 Pt/SiC Prototype Sensor (MSU)

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**



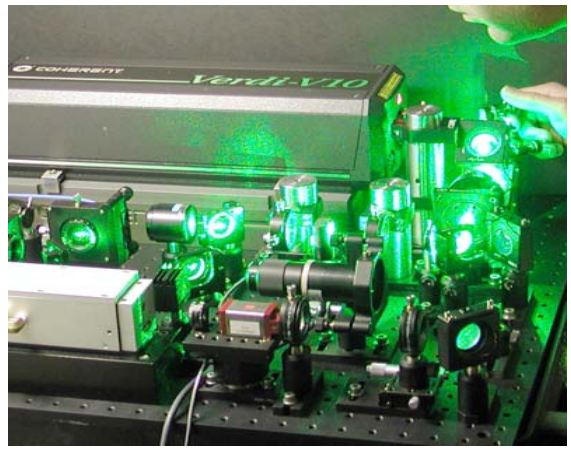
Sporian



Prime OSU

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)



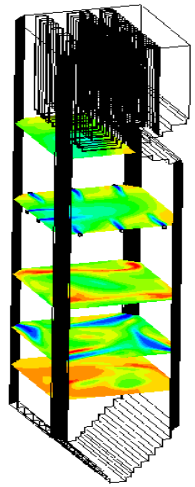
- **Advantages with these techniques**
  - Non-intrusive, rapid, continuous measurements
  - Readily adapted for regulatory monitoring
  - Relative ease in calibration

- **Challenges with these techniques**
  - Optical access
  - Rugged, compact, field ready systems

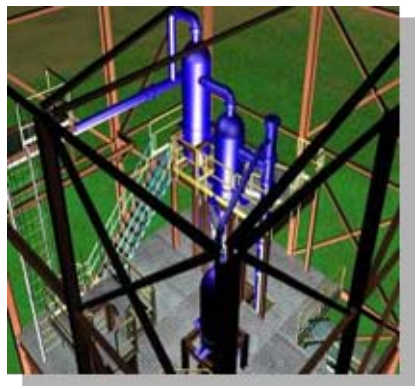
- **Participants include SNL, Nuonics, Purdue, NETL**

Condition Monitoring and Advanced Control

- **Sensor Networks**
  - Pervasive low cost networked sensing for condition monitoring and control
  - 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 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
- **Challenge**
  - What data to collect, where to send it, coordinated output….
- **Participants include GE, Alstom, Cybosoft, Ames NL, U Maryland, UIll-Urbana**



Process Control for Near Zero Emissions Power Plants
viewpoint

- **Stakeholder feedback – Advanced process control can be applied using today's technology. Requires commitment to consider in early design stages.**
- **Capitalize on developments outside of traditional power plants (e.g. chemical industry, other) for control, communications, integration**
- **Shadow system is key for model development, model validation, model predictive control**
  - Opportunity for process simulation, analysis, troubleshooting
  - Enable optimization, artificial intelligence, and other advanced concepts to be evaluated
  - Enhancement of virtual engineering capabilities

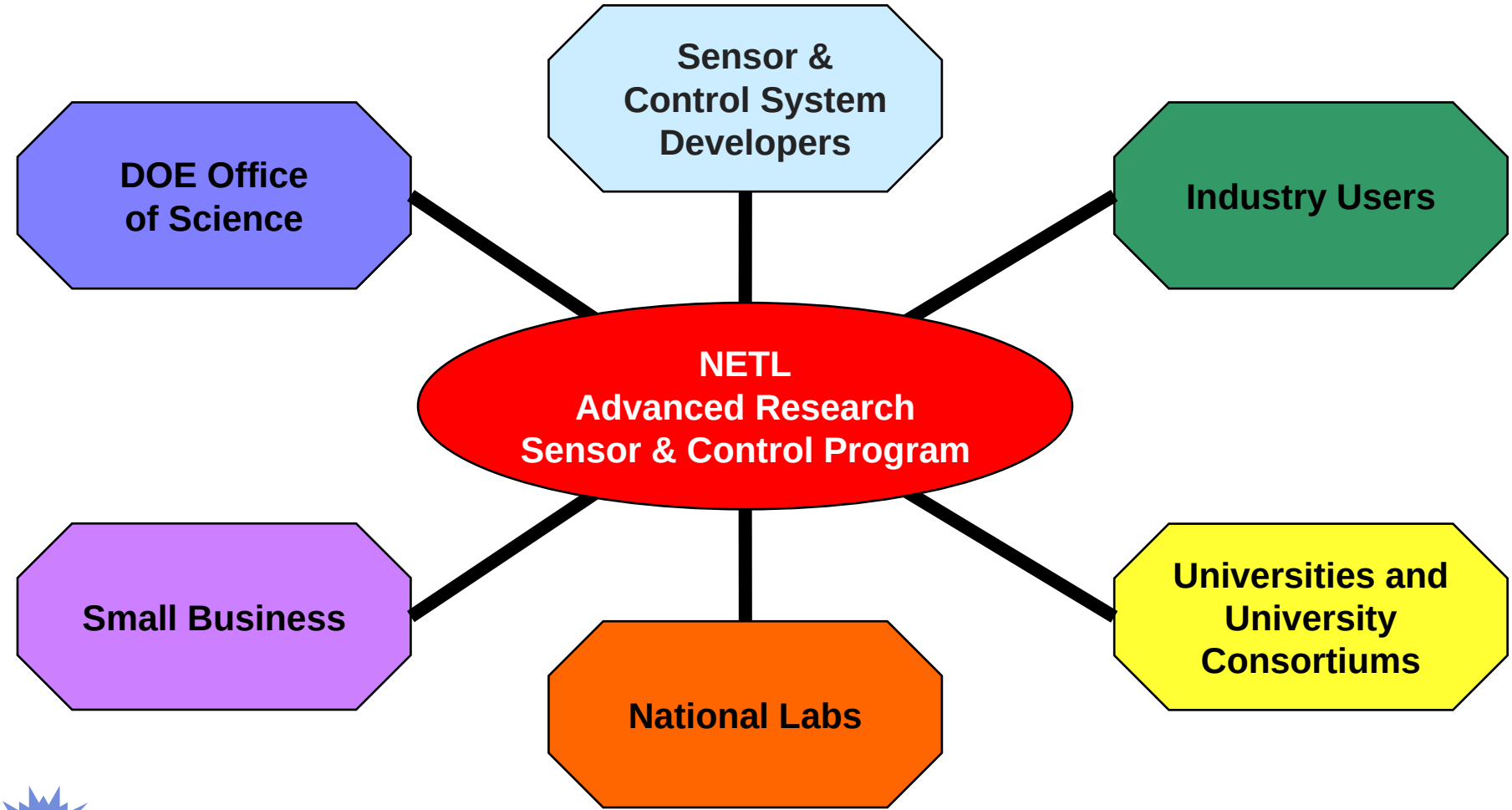
General Summary
Program and Project Accomplishments

- Significant developments in temperature measurement – primarily oriented towards optically based measurements.
- Laser and optical based techniques continue to improve upon light sources, materials and techniques for selective and trace level gas detection. Practical application of new developments need to be addressed for commercial applications
- Micro sensors for high temperature fossil energy applications have demonstrated feasibility and undergone developments to produce prototypes for power plant applications
- Continued pilot and full scale testing is needed to aid in transition from laboratory derived prototypes to robust and industrially viable equipment.
- Realized much success on the fundamental level and are challenged to involve industry and development to transfer technology that shows commercial viability

People make the Program

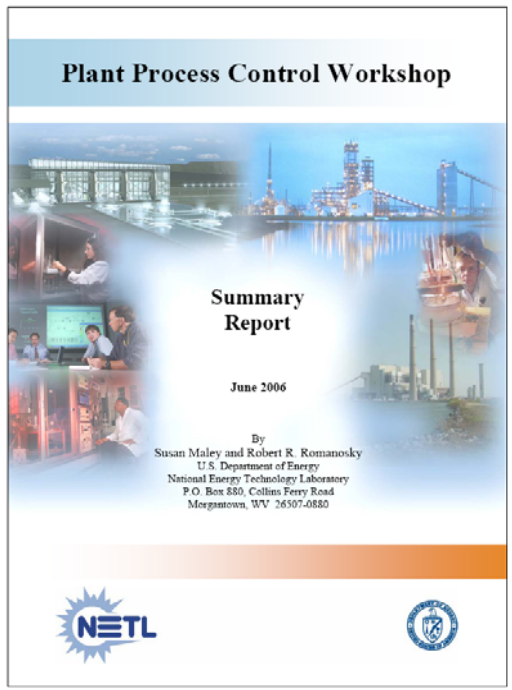
Stakeholders
Program input via Workshops
Program Contacts

Stakeholder Identification and Collaboration



Valued Stakeholder Input

- **Focused stakeholder workshops to develop and review program**
  - Proceedings posted in the web
  - 2001 Workshop on Sensor and Control Needs
  - 2002 Sensor and Control Program: Portfolio Review and Roadmapping Workshop
  - 2006 Plant Process Control Workshop
  - 2007 Stakeholder Workshop on Advanced Process Control for Next Generation Power Plants
- **Participation in Industry lead conferences and working groups**
- **Establish industrial interaction for pilot and full scale testing to enhance technology transfer**



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