Sensor and Control Development for Existing and Future Power Systems

SECA Program Review Meeting

June 18-19, 2002

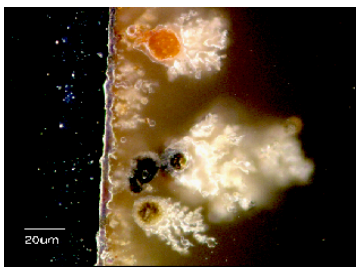
Susan Maley, Sensors and Controls Project Manager
National Energy Technology Laboratory

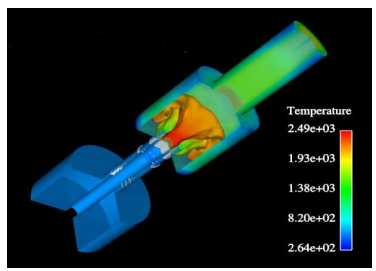
Power Systems Advanced Research

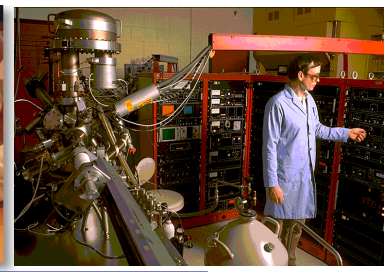
Bridge the gap between fundamental and applied technologies

Reflective of industry needs and responsible for driving new technologies

Ingenuity, Innovation and Implementation







Cross-cutting Technologies and Programs

Modeling & Simulation

SBIR, UCR & HBCU Programs

Materials

Instrumentation, Sensors, & Controls

NETL's Interest - Driving Advancements in Instrumentation, Sensors, and Control Technology

- **Lost cost / high benefit technology**
  - Comparatively small capital investment
  - Lower operating and maintenance costs
  - Enhance efficiency and reduce emissions
  - Increase reliability
- **Opportunity for existing facilities**
  - Dated systems
  - Deregulation
  - Regulatory emissions monitoring and control
  - Installation and operation of SCR systems
- **A must for new facilities**
  - High performance and reliability expectations
  - Protect capital investment
  - Minimize operational and maintenance cost

Instrumentation, Sensor, and Control Systems Program

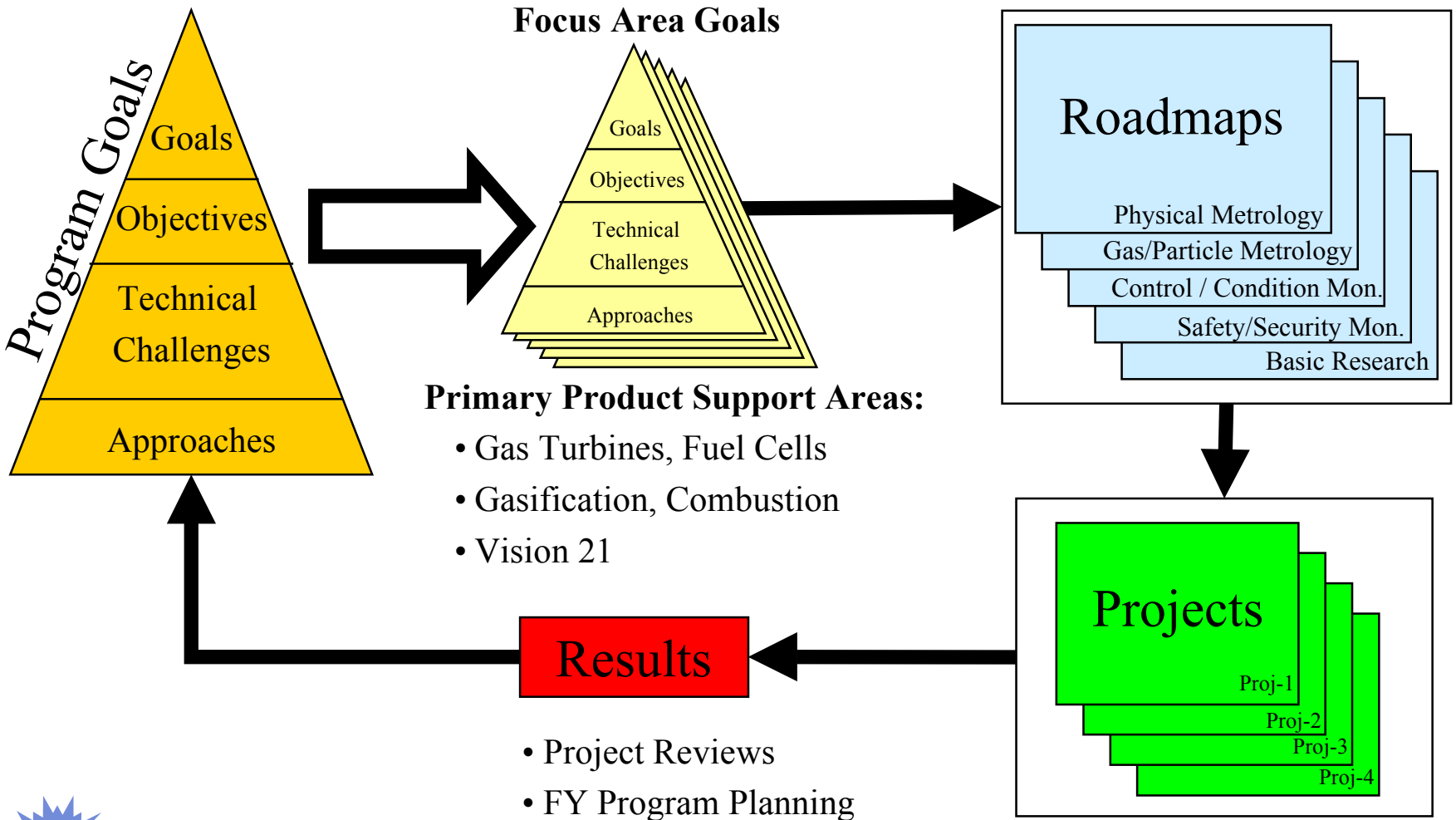
- **Strategies**
  - Develop technology suited for harsh conditions
  - Screen and accept development risk
  - Maintain stakeholder involvement including developers and users
  - Take a whole system approach
  - Capitalize on technology deployment skills
  - Direct recent advancements in sensor technology towards fossil fuel applications

Instrumentation, Sensor, and Control Systems Program

- Program Structure
  - Basic plan with specific road maps
  - Defined metrics for AR projects
  - Funding for a defined timeline
  - Time-phased, results driven program to keep pace with Vision 21 program and industry
  - Internal and external R&D in both fundamental research and engineering development
  - Collaboration with other developers and users
  - Technology transfer through line organizations and industry

ISCS Program Framework

Program Goals are traceable to projects



Vision 21 - *Ultra-Clean Energy Plant of the Future*

- Flexible feedstock
- Electricity and co-products
- Maximum efficiency
- Near-zero emissions

Flexible feedstock

Systems Analysis & Systems Integration

Electricity & co-products

INPUT

Fossil-based Feedstocks
- Coal
- Gas & Oil

Opportunity Feedstocks
- Biomass
- Mun. Waste
- Petcoke

Gasification

Combustion & High Temperature Heat Exchange

Fuel Cells

Turbines

Syngas Conversion to Fuels & Chemicals

Gas Separation

Gas Purification

Environmental Control Technology

OUTPUT

Electricity

Transportation Fuels

Syngas

Chemicals

Hydrogen

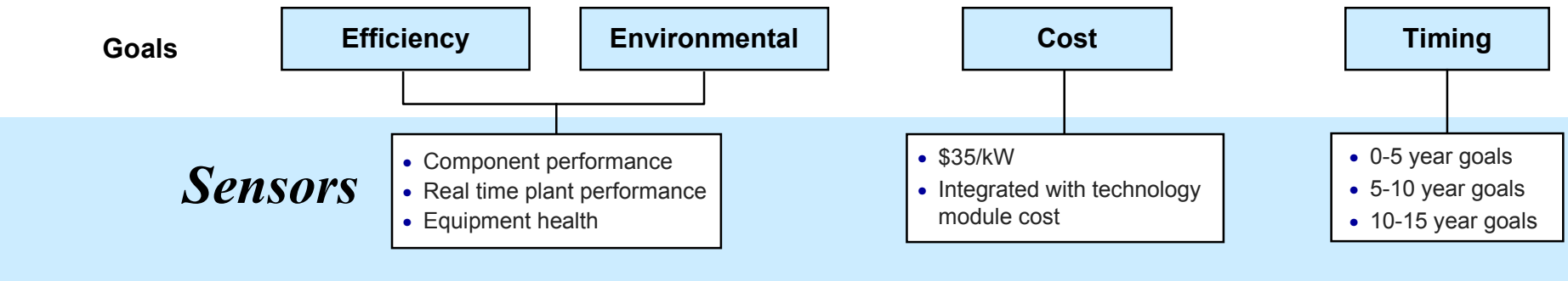
Steam

Materials

Sensors & Controls

Computational Modeling & Virtual Simulation

Vision 21 Technology Roadmap



Barriers

	Program & Support	General Technical
	• Fragmented markets • Treated as add on items	• Limited & constrained accessibility • Harsh operating conditions • Materials limitations

Approaches

0-5 Years	• Identify sensor needs and requirements • Extend sensor development program • Assess state-of-the-art sensors and identify gaps	• Focus on in-situ, real time, fast response, field hardened sensors • Develop sensors based on new concepts and technologies
5-10 Years	• Revise priority needs • Demonstrate new sensors technology in operating plants	• Continue supporting development of sensors • Test and incorporate new sensors into advanced control systems
10-15 Years	• Demonstrate new sensors technology in Vision 21 • Support Vision 21 plant design and operation activities • Assess the payback	• Continue supporting development and sensor demonstration projects

Vision 21 Technology Roadmap

Goals

Efficiency	Environmental	Cost	Timing

Controls

- Real time management of the power plant assets
- Closed loop process optimization

- $35/kW
- Integrated with technology module cost

- 0-5 year goals
- 5-10 year goals
- 10-15 year goals

Barriers

- Development of advanced controls is underfunded
- Long response times for associated hardware (e.g. valves)
- Insufficient knowledge of some processes such as NO_X generation and trace elements

Approaches

0-5 Years	• Define process control needs • Evaluate state-of-the-art control technologies • Direct plant and component development programs toward intelligently controllable systems
5-10 Years	• Direct devlopment of components and plants to leverage advanced control and predictive maintenance • Update program to reflect new plant needs and technology development
10-15 Years	• Demonstrate innovative process control technologies

Sensors and Controls Needs - Workshop Results

Controls ↔ **System Integration**

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

Advanced Materials

- High temperature sensing materials

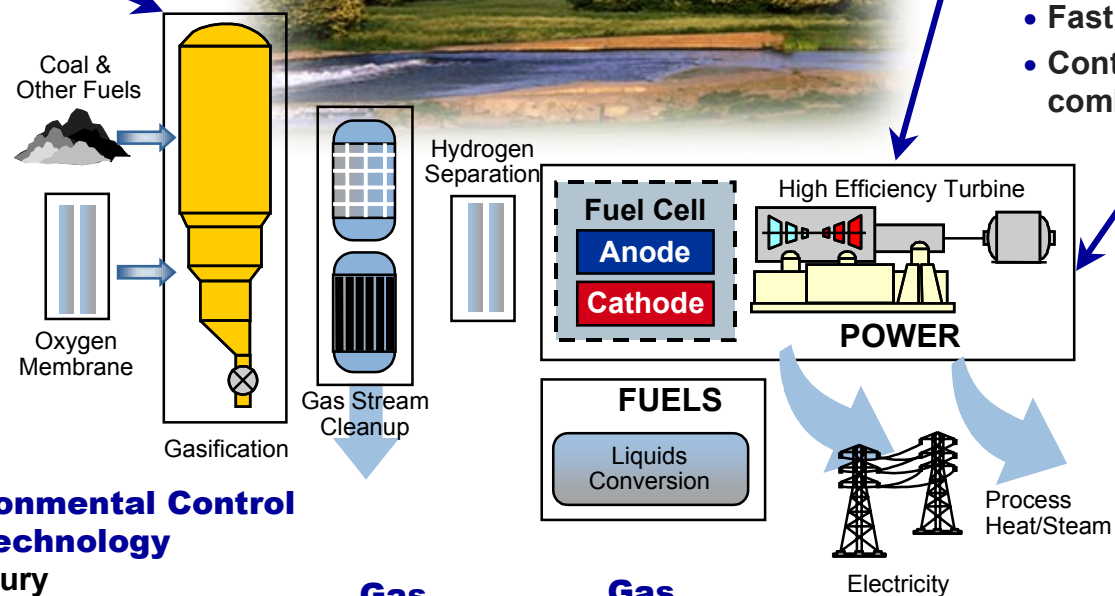
Computational Modeling and Simulation/Virtual Simulation

Turbines

- **Temperature**
- **Particulate**
- **Fuel ratio / burner balancing**
- **Pressure pulsation**
- **Thermal barrier coating**
- **Fast sensors and actuators**
- **Control algorithms for combustion instability**

Gasification and Advanced Combustion

- **Temperature**
- Fuel / air ratio control
- **Robust sensors**
- **Feed flow and analysis**
- Particle sensing
- Mercury
- Standardized signaling
- Alkali monitor
- O_2 control



Fuel Cells

- Sensors for catalyst or anode protection
- Gas Sensors
- **Flow & Pressure**
- **Diagnostic tools for fuel cell manufacturing and operation**
- **Other needs under discovery**

Environmental Control Technology

- **Mercury**
- **NOx**
- Particulate

Gas Purification

Gas Separation

Overlapping Sensor Needs and Barriers

Needs

Physical Measurements

- Temperature, Pressure, Flow

Gases

- H_2, CO, O_2, hydrocarbons

Diagnostic Sensors

Barriers

High temperature

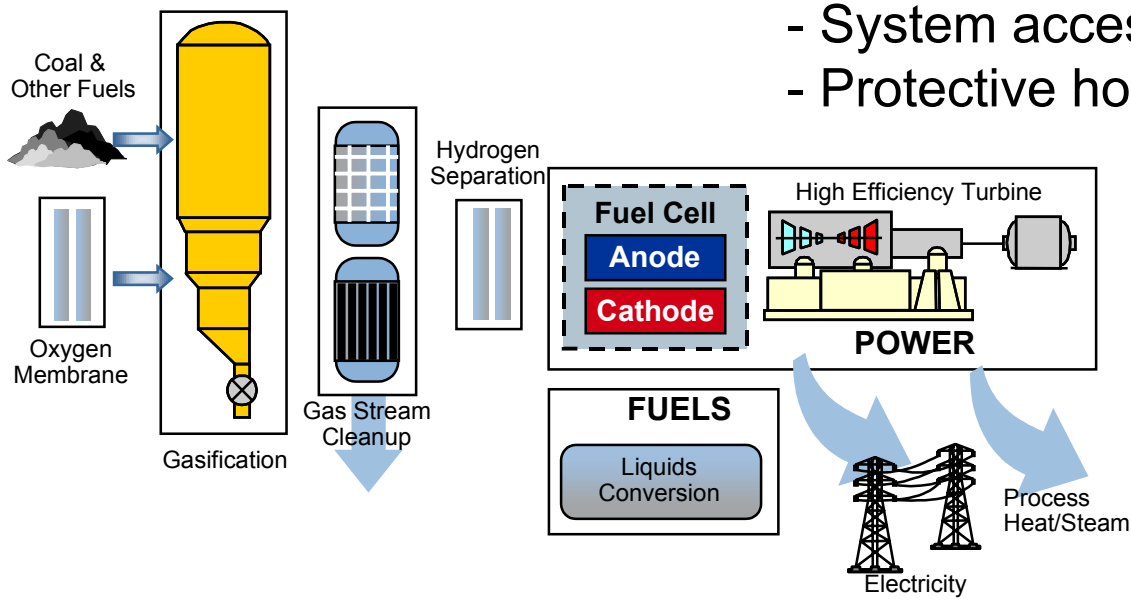
- High rate of failure

Environment

- Cross sensitivity

System Interface

- System access
- Protective housing



Instrumentation, Sensors and Control Active Projects

Controls

- Neural Network-based Intelligent Soot blowing (PPII)
- Distributed Power Sources - Control Requirements

System Integration

- Identify combinations of technology modules (V21)

Computational Modeling and Simulation/Virtual Simulation

- V21 technology module modeling and flow sheet simulation (V21)

Advanced Materials

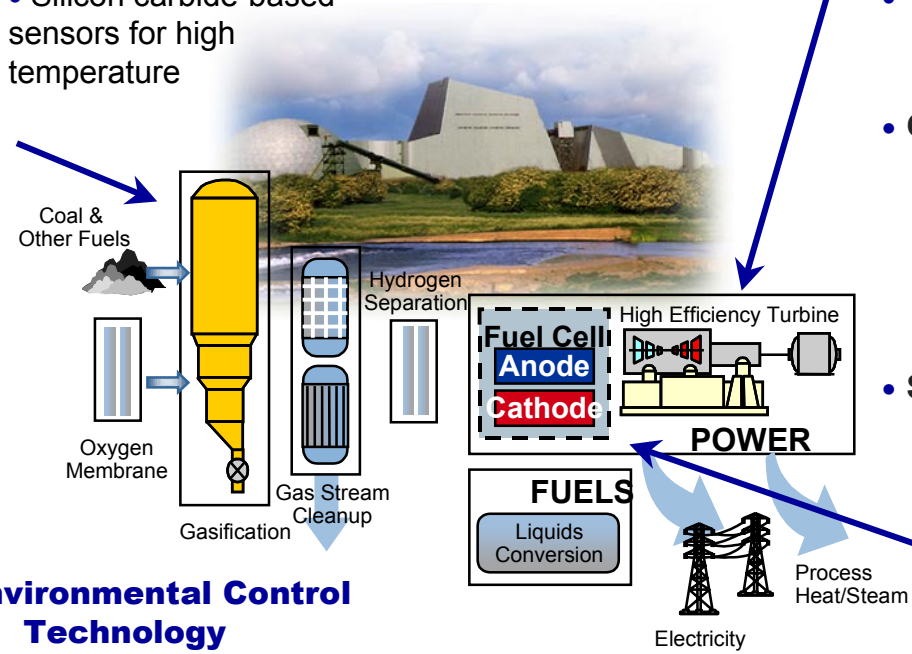
- Silicon carbide-based sensors for high temperature

Turbines

- **Temperature and Pressure**
  - Embedded thermographic phosphors for temperature and pressure indication
- **Fuel ratio / burner balancing**
- **Thermal barrier coating**
  - Infrared sensor for coating diagnostics
- **Condition Monitoring**
  - Flashback sensor
  - Eddy current sensors and parameter analysis
  - RAM monitoring and control algorithms
- **Smart Power Turbine**
  - NETL, GE, Sandia sensor and control development and integration

Gasification and Advanced Combustion

- Temperature sensors for slagging gasifiers
- Solids Velocity Probe for circulating fluidized beds
- On-line carbon content monitor
- Coal content/Ore grade sensor
- On-line rapid corrosion indicator
- Refractory laser-based contouring technique (PPII)



Environmental Control Technology

- Elemental mercury spectrometer
- Micro gas sensors for NO_X, SO_X, NH_3, H_2S using metal oxides

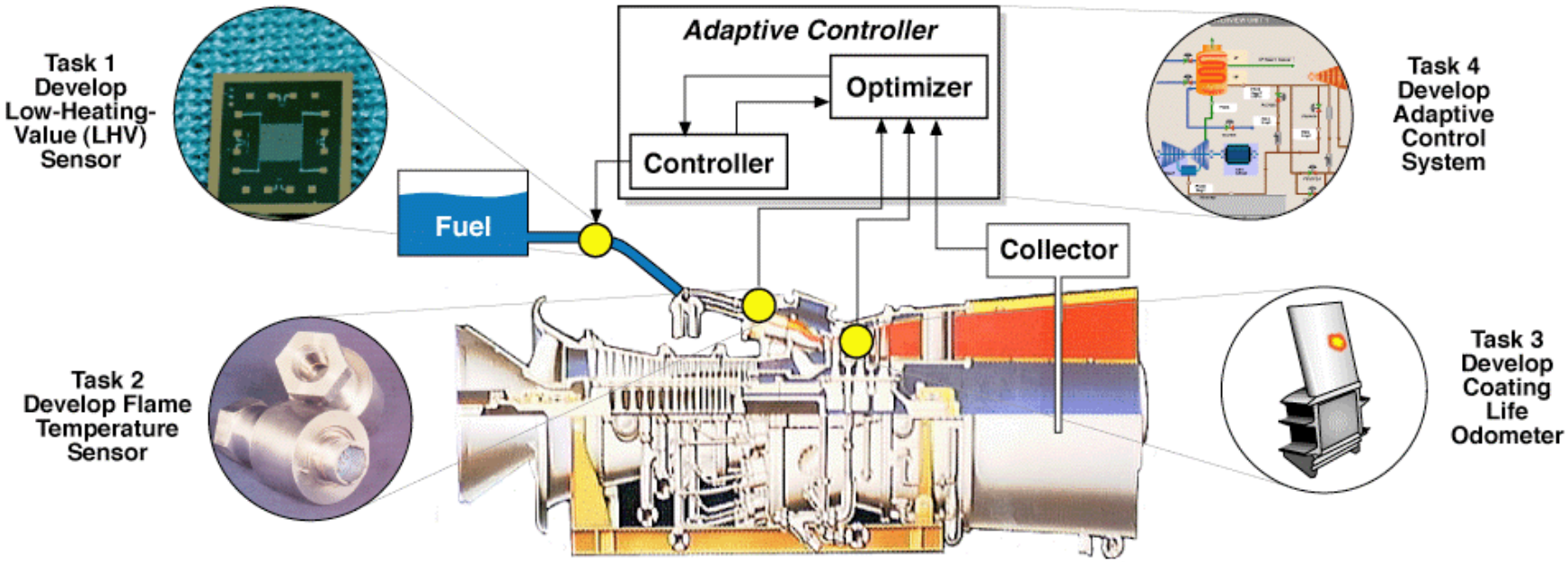
Gas Separation

- Non-destructive technique to determine candle filter integrity

Fuel Cells

- Micro-valve design for flow control
- Identification of diagnostic tools for fuel cell plate manufacturing

Smart Power Turbine Project



Project Objectives:

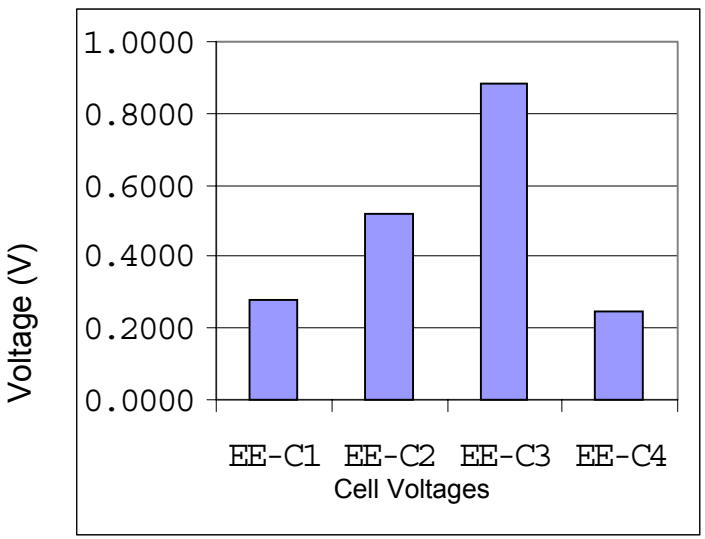
- Fuel LHV measurement - Sandia micro-calorimeter
- Flame temperature sensor - GE CRD High bandgap semiconductor photodiode
- Coating life odometer - Taggants which detect incipient coating loss
- Adaptive supervisory control / optimizer

GE, NETL, Sandia

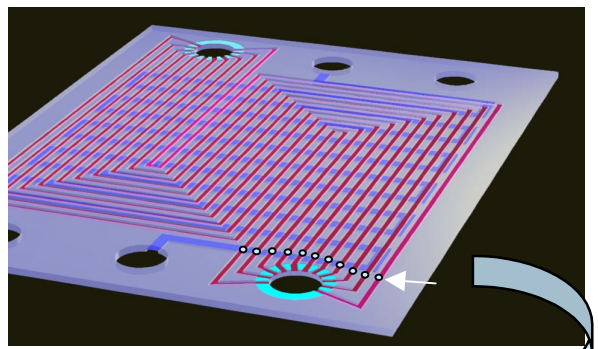
Fuel Cell Flow and Energy Management

- **Challenge:** *Fuel cell output varies cell-to-cell: stack suffers.*
- **GESD research:** *Local flow control using "MEMS" micro-valves.*
- **Benefits:** *Greater cell life, stack performance, and flaw tolerance.*

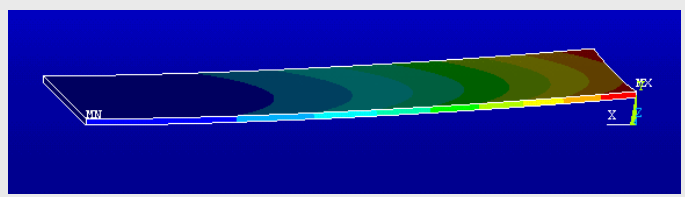
Example of stack non-uniformity in NETL fuel cell test.



Fuel cell flow passages (red) with MEMS valves



UoP ME Dept. Novel Micro-valve Design - Electro-Mechanical FEA Model predicts the required 60 micron deflection

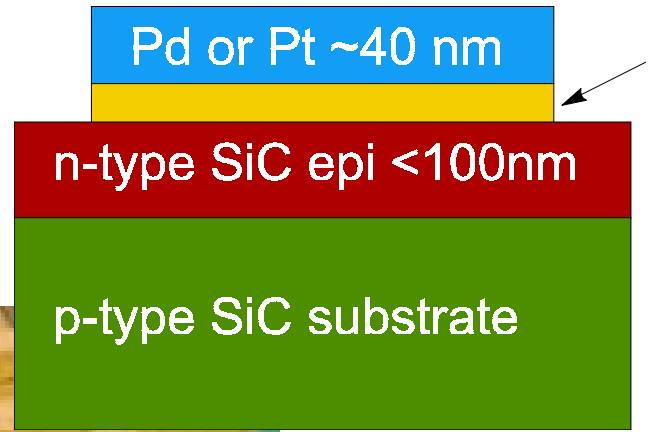


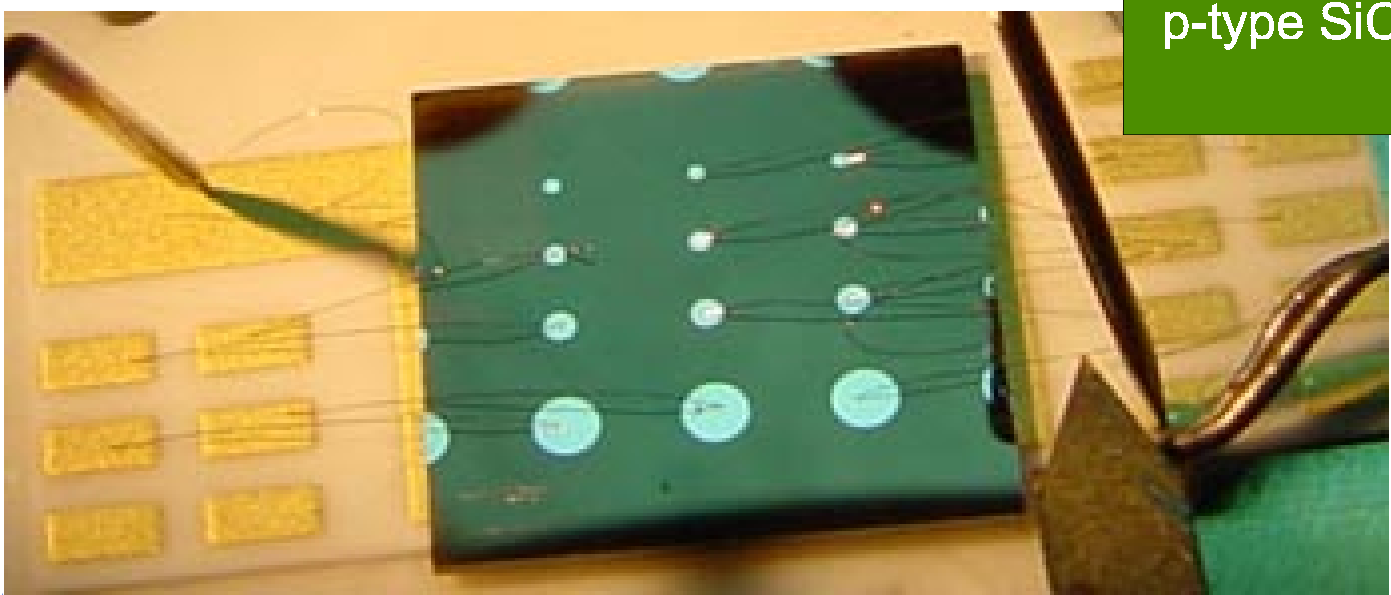
Jimmy Thornton & Randy Gemmen
University of Pittsburgh

Silicon Carbide Based Gas Sensors

Semiconductor silicon carbide (SiC) for high temperature chemically reactive environments:

- Device operation to temperatures > 900 °C
- Chemical stability
- High thermal conductivity

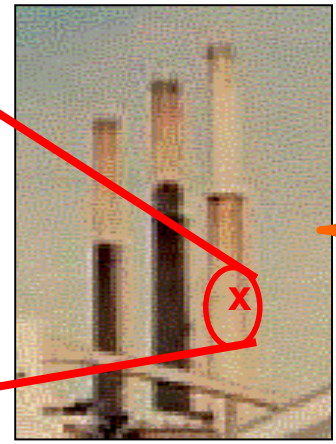




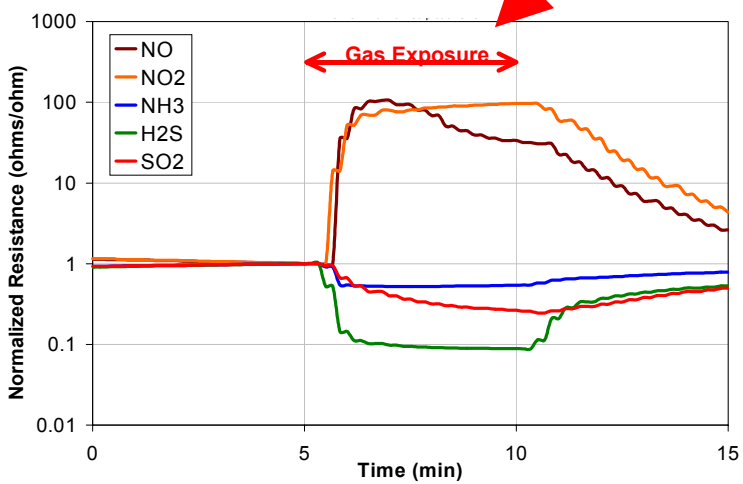
Michigan State University & West Virginia University

Semi-conducting Metal Oxide-based Sensor

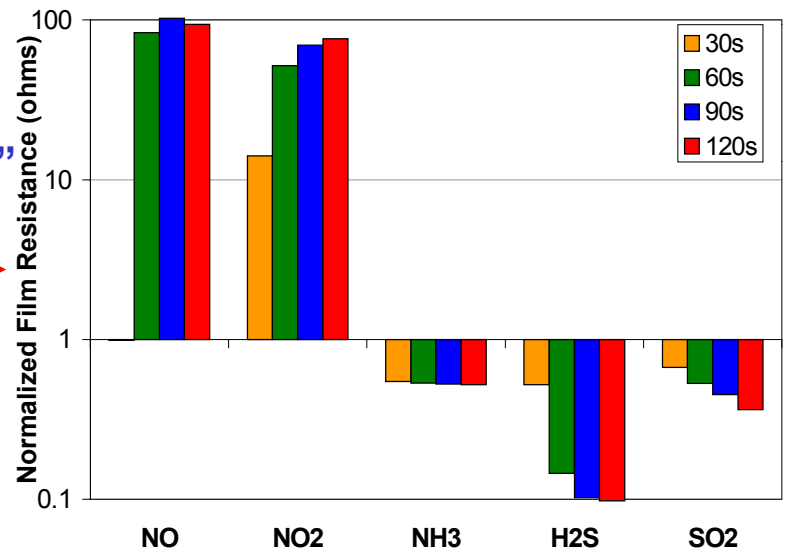
- Real-time, in-situ, continuous monitor
- Robust in flue gas environment
- High sensitivity (<ppm)
- Selective detection
- Low cost



Nitric Oxide
Nitrogen Dioxide
Ammonia
Hydrogen Sulfide
Sulfur Dioxide
Carbon Monoxide
Carbon Dioxide



"Fingerprint" Processing



Sensor Research and Development Corporation

Current Status for Sensor Development

- Numerous innovations with silicon-based devices for ambient / low temperature applications.
- Automotive industry and partners most experienced in developing and applying micro-sensors.
- In general, prototypes available for applications with temperatures 500 ^{o}C and lower.

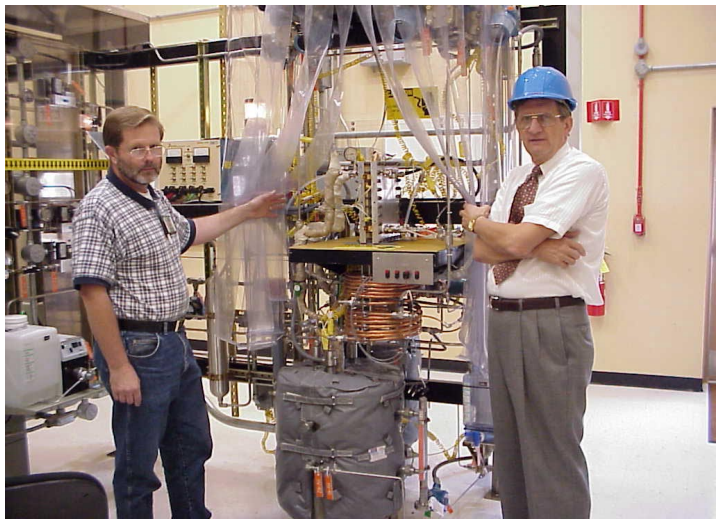
- R&D in gas sensing for elevated and high temperature applications is ongoing.
- Issue of selectivity appears to be primary focus.
- Low interest in high temperature micro-sensor development for physical measurements (e.g. TPF)

Outlook for Sensors - 5 year

- **Prototypes and 500 °C operation with reasonable sensitivity**
- **Select sensors and sensor systems commercially available**

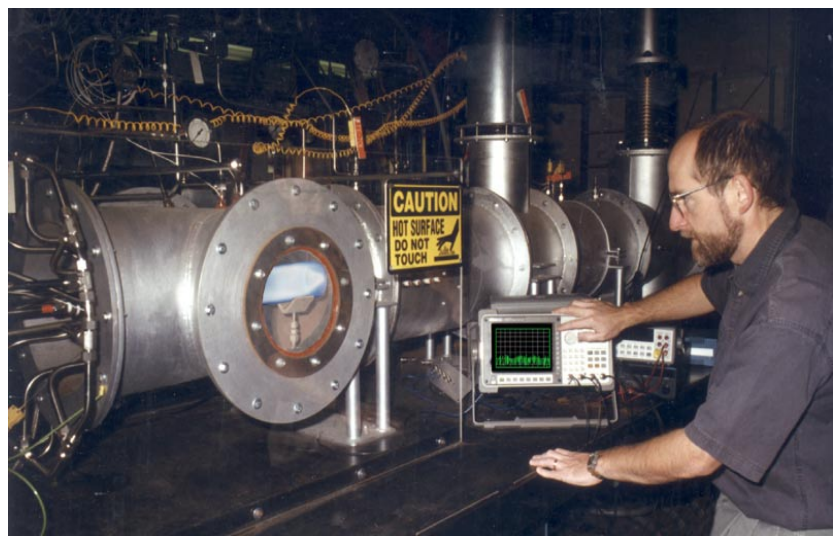
- **Issues to examine**
  - Novel / new materials for high temperature applications
  - Reliability and longevity relatively unproven
  - Packaging and protection systems for sensors have received little attention
  - Accuracy range needs established for application and incorporation into control systems

Outlook for Sensors - 10 year



- Competitive commercial market for certain types of gas sensors operation around 500 °C.
- Market includes automotive, power, chemical, others.
- Breakthrough to 800-1000 °C with sustained operation.

- Commercial/industrial applications of both at-line and in-situ applications
- Novel approaches to integrated sensing and control
- Promotion of a whole system
- Vision 21 type demonstrations



Conclusion

- **Opportunities for improvement and development**
  - Instrumentation improvement
  - Sensor development and
  - New control methodologies
  - Whole system approach
- **Technology to overcome barriers**
  - Materials, electronics durability,
  - Interferences, sampling
- **Research and development programs are**
  - Focused, industry driven, and time-phased
  - Internal and external research efforts

ISCS Program Related Activities

- **Collaboration and Communication**
  - ISA, EPRI, PIWG, SECA
  - National Laboratories, Government Agencies
  - Users and vendors
- **NETL Sponsored Workshop**
  - Program review & roadmapping
- **Issue Program Plan**
- **Innovation and Implementation**
  - Seek out new or novel adaptations through focused, industry driven, and time-phased program and project portfolio
  - Strive towards implementation
  - FY03 and FY04 Solicitations

Additional Program Information

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