

U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Fossil Energy

# Accelerating Sensor Technology Development through FE-Sponsored Programs

**Sotirios (Sam) Thomas**  
Director, Advanced Energy and Hydrogen Systems  
Office of Fossil Energy

**NETL Virtual Annual Review Meeting**  
**Sensor Technologies for Fossil Energy**  
**Session**

**May 20, 2021**

# OUTLINE

## Introduction

## Overviews

Advanced Energy and Hydrogen Systems

Crosscutting Research - Sensors, Controls and Novel Concepts Program

Sensor Activities within Transformative Power Generation

## Summary

## Key Points of Contact



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# ADVANCED ENERGY AND HYDROGEN SYSTEMS

## MISSION AND VISION

Sotirios (Sam) Thomas, Director

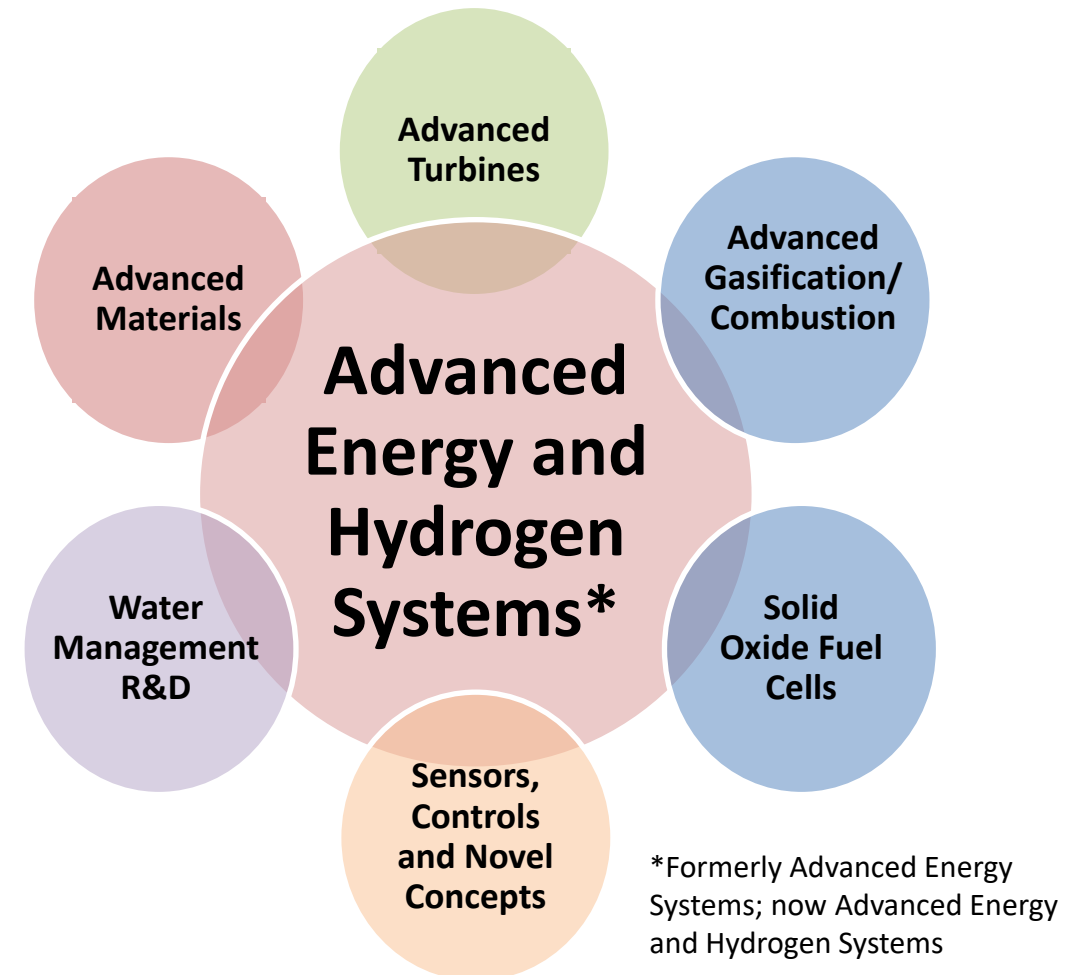
## INTRODUCTION

Advanced Energy and Hydrogen Systems (AEHS) integrates carbon neutral or net-negative greenhouse gas (GHG) emissions technologies with carbon capture and storage (CCS) capabilities and improved fuel conversion efficiency.

Focus is on improving efficiency, increasing plant availability, reducing water consumption, and achieving ultra-low emissions of traditional pollutants. Much of AEHS research is targeted at improving overall system efficiency, reducing capital and operating costs, and enabling affordable carbon capture.

While the primary focus is on fossil-based power systems, improvements to these technologies are also applicable to other fossil energy systems.

## Six Subprogram Activities



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# KEY ADMINISTRATION GUIDANCE

- Executive Order 14008 – “Tackling the Climate Crisis at Home and Abroad”

<https://www.federalregister.gov/documents/2021/02/01/2021-02177/tackling-the-climate-crisis-at-home-and-abroad>

- White House Coal Power Plant Task Force

<https://www.whitehouse.gov/briefing-room/statements-releases/2021/02/26/readout-of-the-white-houses-first-interagency-working-group-on-coal-and-power-plant-communities-and-economic-revitalization/>

- Executive Order 13985 – “Advancing Racial Equity and Support for Underserved Communities Through the Federal Government”

<https://www.federalregister.gov/documents/2021/01/25/2021-01753/advancing-racial-equity-and-support-for-underserved-communities-through-the-federal-government>





# FOSSIL ENERGY 101: ADVANCED ENERGY AND HYDROGEN SYSTEMS

## Division Overview



### Six Subprogram Activities

- Advanced Turbines
- Advanced Combustion/Gasification Systems
- Solid Oxide Fuel Cells
- Sensors and Controls and Novel Concepts
- Water Management for Improved Efficiency
- Advanced Energy Materials

### Functional R&D Responsibilities

- Blue hydrogen power production fuel
- Secure, stable, and reliable zero carbon hydrogen power plants
- Adaptive load-following net-zero or negative emissions power plants
- Reduced water consumption/Improve quality
- Overcoming carbon ore quality regionality and associated technology challenges
- Grid integration into utility-scale power plant concepts
- Plant modularity



# ADVANCED COAL & CARBON TECHNOLOGY R&D THRUSTS

## Carbon Capture

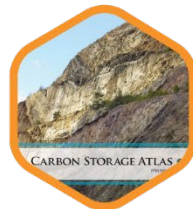
- Negative Emissions Technologies
- Direct Air Capture
- Natural Gas Sources
- Industrial Sources

## Carbon Utilization

- Working Fluid
- Algae Systems
- Conversion to Fuels & Chemicals
- Mineralization into Inorganic Materials

## Carbon Storage

- Monitoring, Verification, Accounting & Assessment of Long-Term Storage
- Storage Infrastructure Demonstration
- Regional Carbon Sequestration Partnerships
- CarbonSAFE



## Advanced Energy Systems

- Hydrogen Fuel
- Advanced Coal Processing
- Gasification
- Solid Oxide Fuel Cells & Gas Turbines
- Transformative Power Generation

## Crosscutting Research

- Sensors & Controls
- High-Performance Materials
- Rare Earth Elements & Critical Minerals
- Energy Storage
- Water Management
- Simulation-Based Engineering
- University Training & Research

## STEP (Supercritical CO<sub>2</sub>)

- STEP Pilot Plant
- Turbomachinery & Recuperators
- Advanced Concepts in Direct-Fired Cycles
- Systems Integration & Operation

Carbon Utilization Photo Courtesy of MicroBio



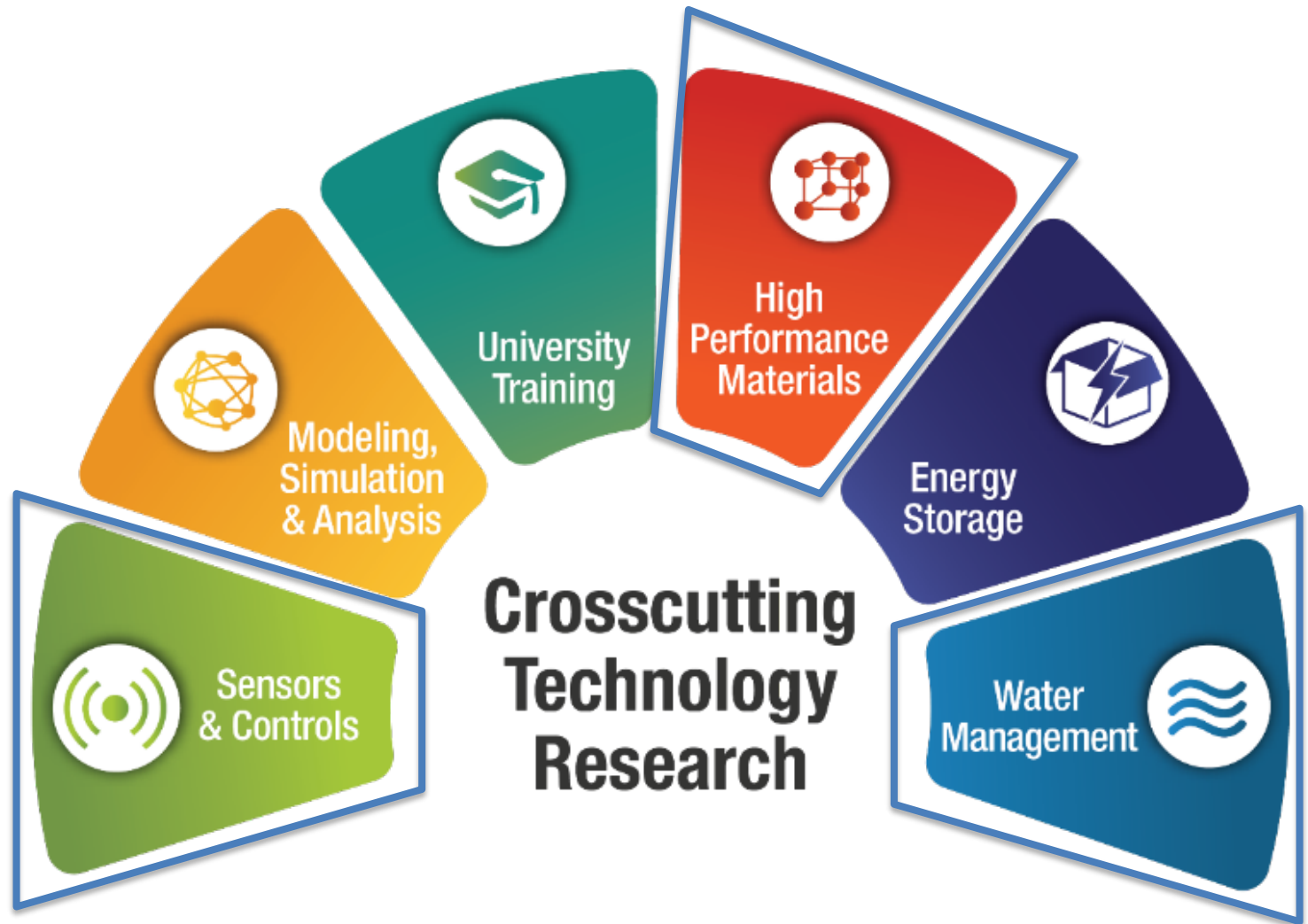
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# CROSSCUTTING TECHNOLOGIES IN AEHS

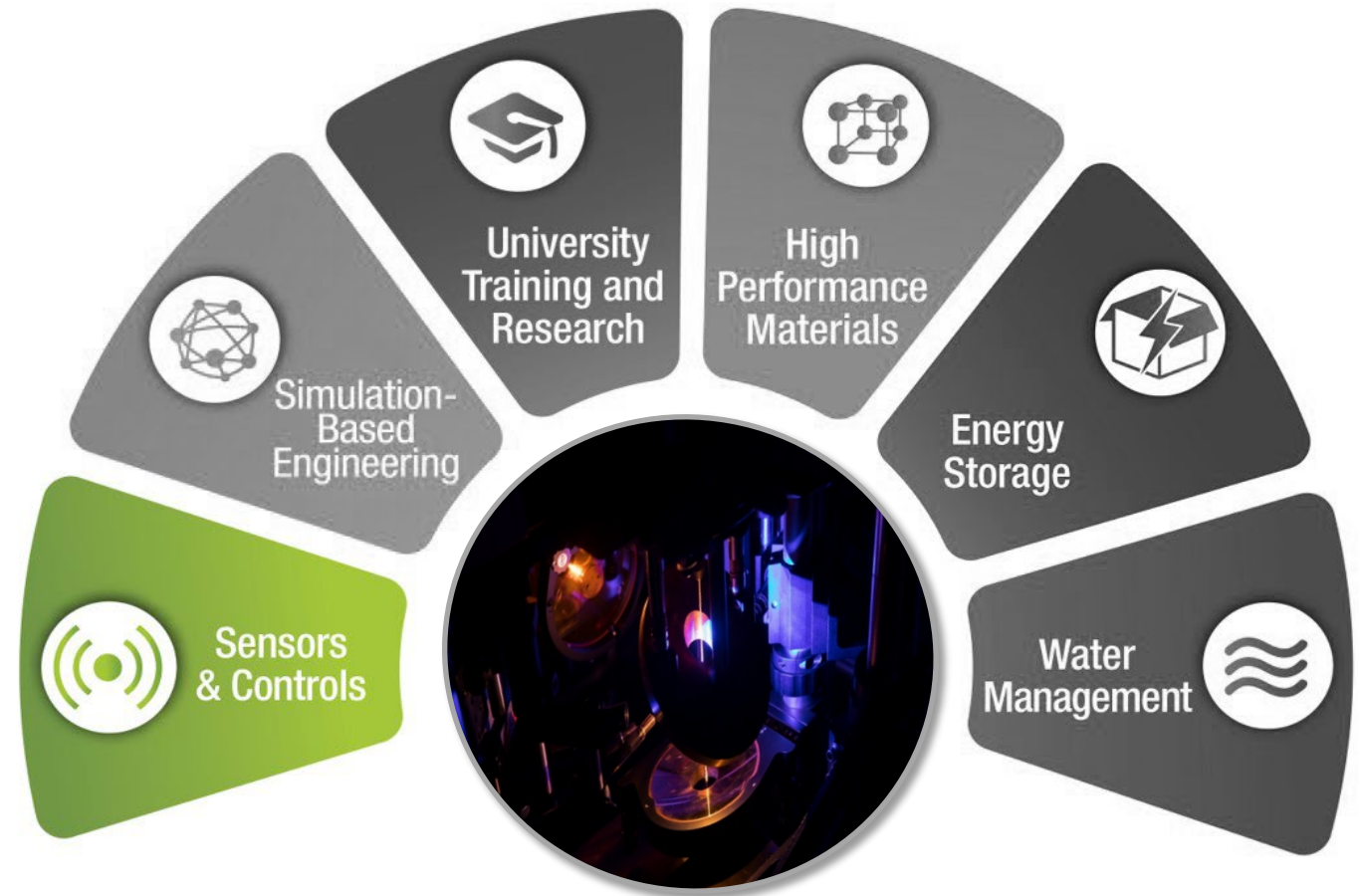
## Crosscutting Technologies

- Applicable to a broad range of fossil and non-fossil applications.
- Improve operational efficiency, flexibility, and reliability
- Enabling a broad range of assets to be more environmentally sound.



# SENSORS, CONTROLS and NOVEL CONCEPTS

**Mission:** Test and mature novel sensor and control systems operable in fossil-fueled power plants for real-time measurement capability, improved overall plant efficiencies, more effective ramp rates, and increased flexibility.





# SENSORS, CONTROLS and NOVEL CONCEPTS

## ENABLE, OPTIMIZE and PROTECT Evolving Generation Technologies

### Enable...

- Real-time measurement in extremely harsh environments using novel technologies
- Operations-based predictive maintenance to maximize life and availability
- Increased flexibility (cycling, ramping) to respond to rapidly changing load demand and bolster grid stability

### Optimize...

- Plant efficiency and heat rate with advanced control and diagnostic methods
- Sensor capability, placement, size and manufacturability
- Maintenance planning to reduce unplanned outages

### Protect...

- Plant equipment and availability by ensuring sensor data, control system, and supply chain security with cutting-edge cyber technology

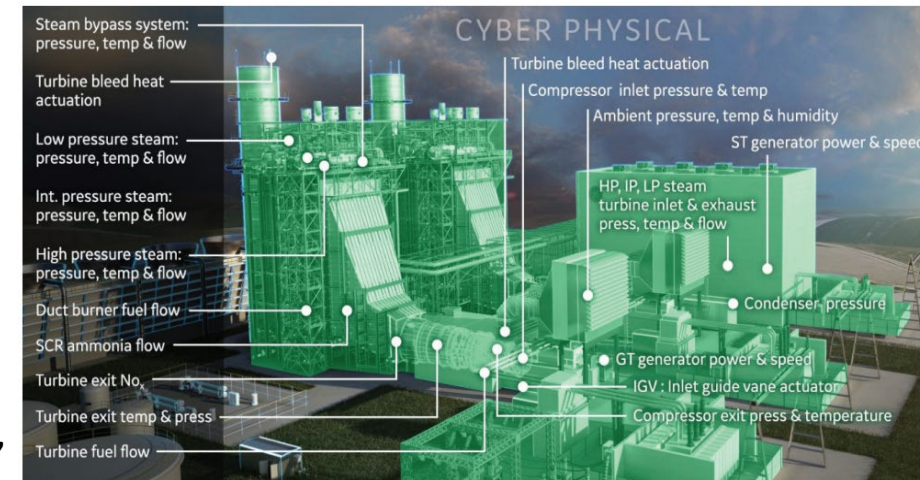
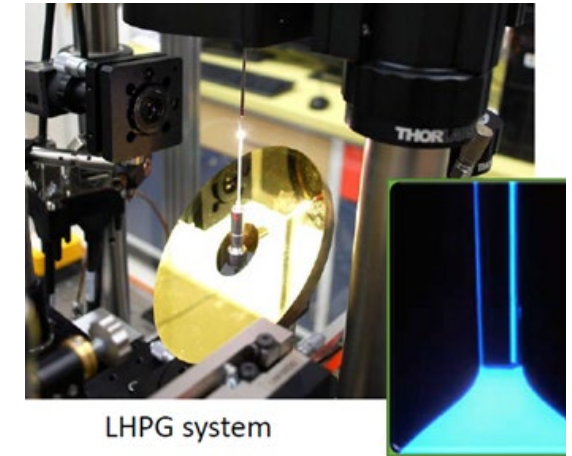


Image Courtesy of GE

# SENSORS, CONTROLS and NOVEL CONCEPTS

## Technologies

### ADVANCED SENSORS

- High-temperatures & harsh environments
- Real-time measurements and diagnostics
- Optical fiber, wireless, embedded
- Materials development, packaging & prototyping
- Testing in relevant environments

### DISTRIBUTED INTELLIGENT CONTROLS

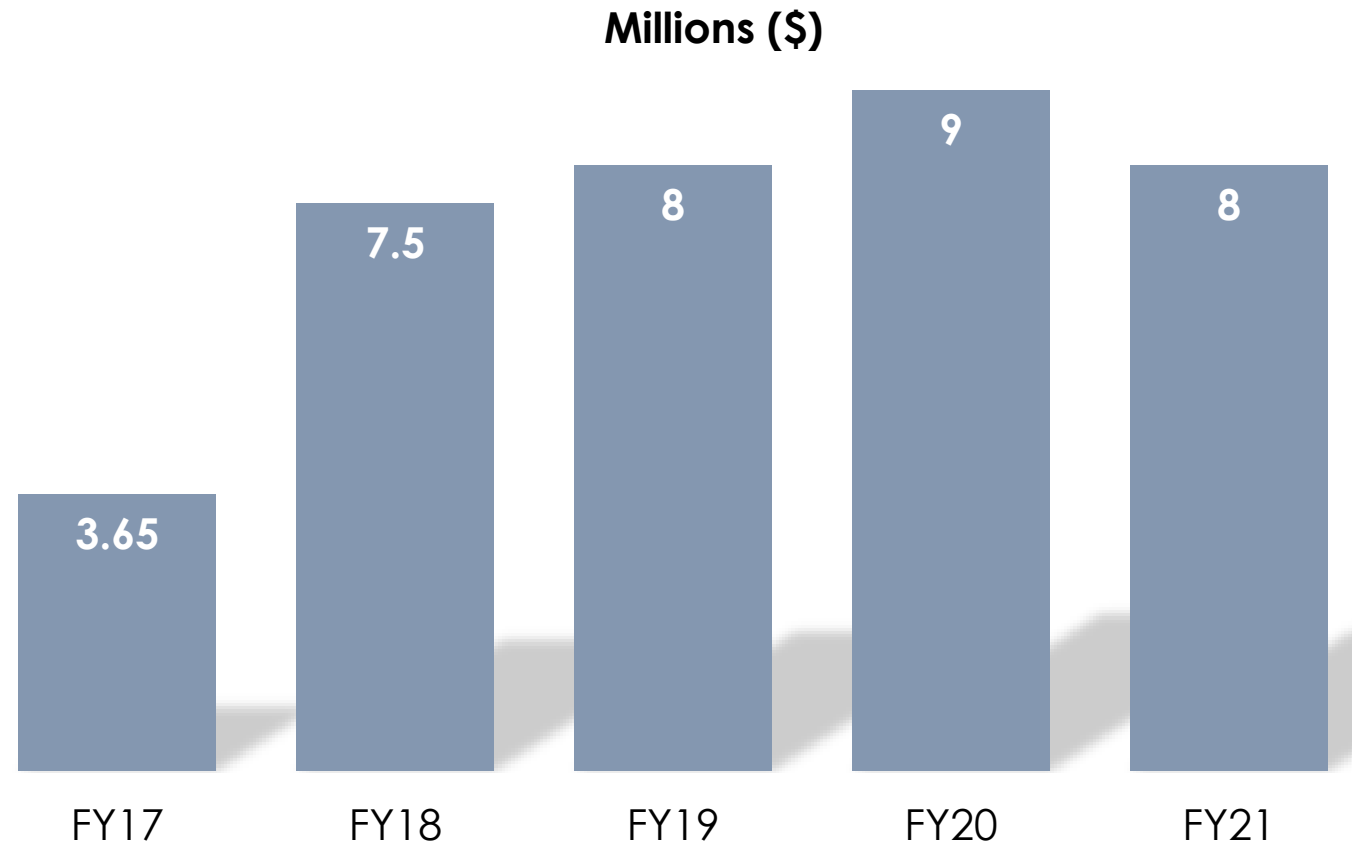
- Control strategies for advanced energy systems & hybrids
- PID and MPC controls
- Cyber-physical systems
- Condition-based maintenance
- On-line System Identification
- Critical component failure prediction

### NOVEL CONCEPTS

- Emerging Technologies
- Cybersecurity (blockchain implementation, visible light communications, etc.)
- Direct Power Extraction



# Sensors, Controls, and Novel Concepts Technology Line – Budget History



# Sensors, Controls, and Novel Concepts Technology Line – Project Summary

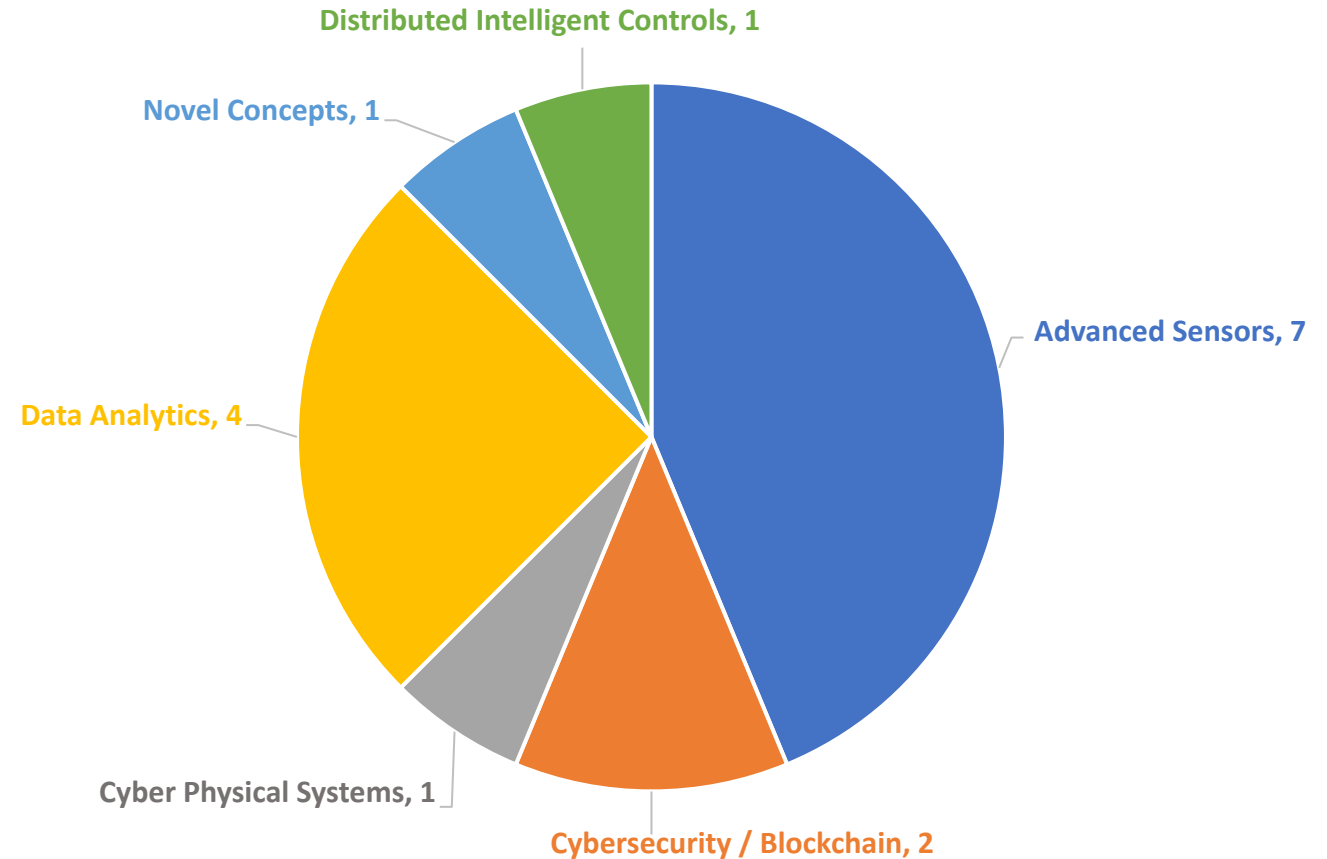
**16** TOTAL PROJECTS

**10** COOPERATIVE AGREEMENTS  
(REQUIRING COST SHARE)

**3** FEDERAL WORK PROPOSALS (FWPs)

**3** SMALL BUSINESS INNOVATIVE  
RESEARCH (SBIRS)

**\$30.77M** TOTAL DOE SHARE  
(ACTIVE)



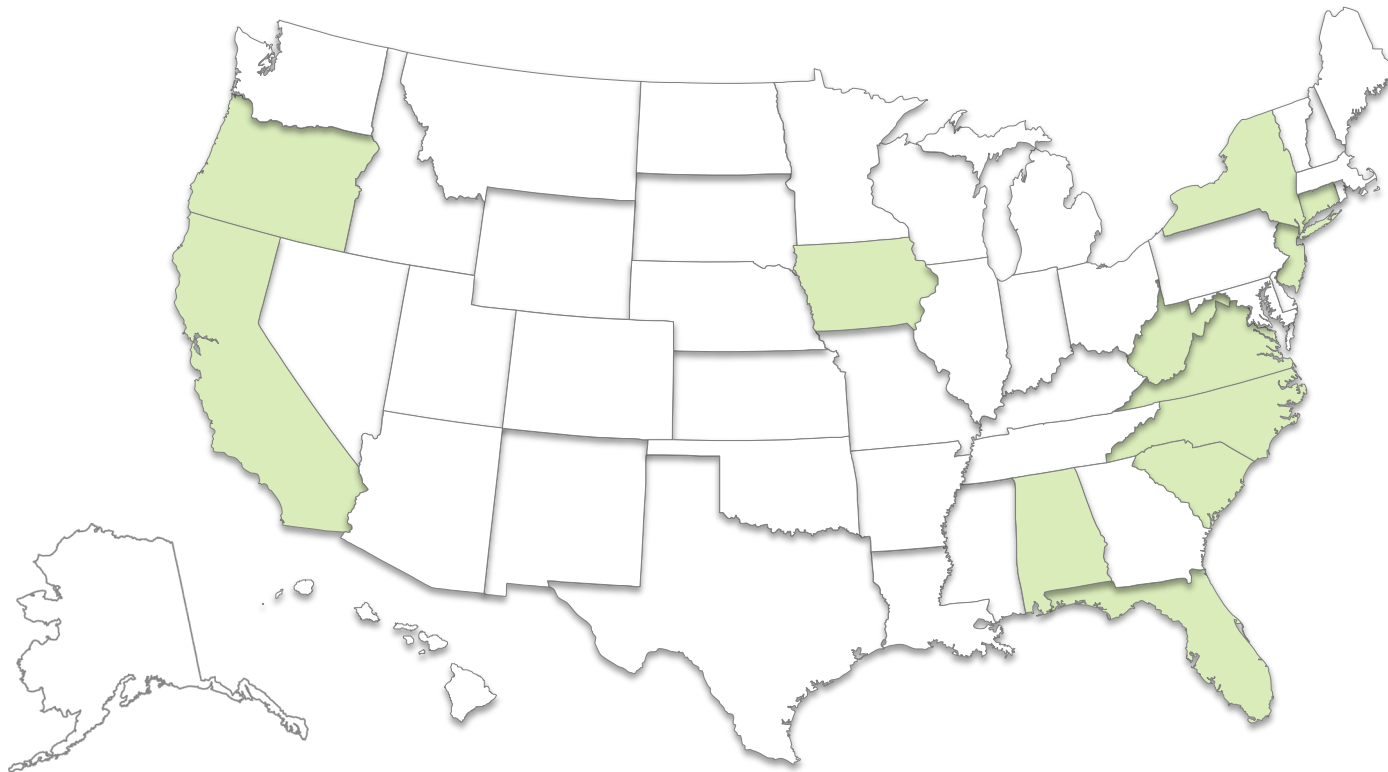
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# Sensors, Controls, and Novel Concepts Technology Line – Portfolio Participating States

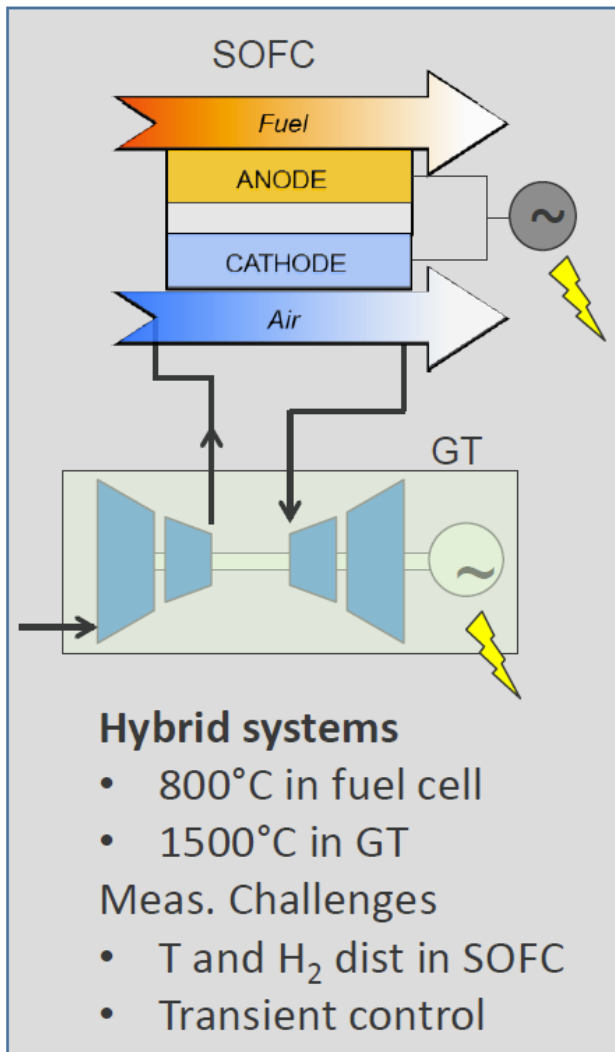
## Projects Funded Under Sensors, Controls, and Novel Concepts Technology Line



**16 projects  
in 12 states**



# ADVANCED SENSORS



## REMS

- Radically engineered modular systems for gasification
  - 1100 - 1500°C
- Meas. Challenges
- Multipoint temp
  - Species
  - NDE of adv. manuf. components
  - Multiphase flow



## Coal-fired Boilers

- Steam 1110°F (600°C), 4000 psig
- Fire side 2500°F (1370°C) +
- Ash / slag / SO<sub>x</sub>

### Meas. Challenges

- Tube temperatures / flow (cycling)
- Corrosion/erosion/exfoliation
- Steam chemistry
- Coal particle size
- Temperature / species dist. Inside boiler

## Subterranean chemistry monitoring

- High pressure brine
- Meas. Challenges
- Salts in water
  - Wellhead measurement
  - Downhole measurement

## Chemical Looping

- > 1000°C
  - Pressurized
  - Erosive
- Meas. Challenges
- Solids circulation
  - Oxidation state
  - Multipoint temp

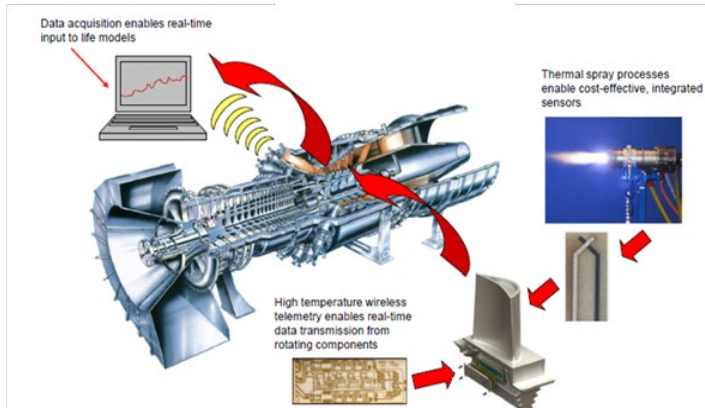


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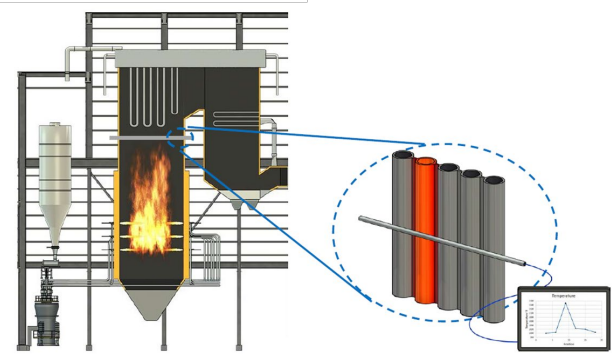
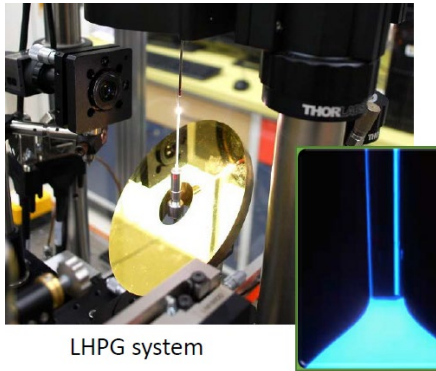
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# ADVANCED SENSORS

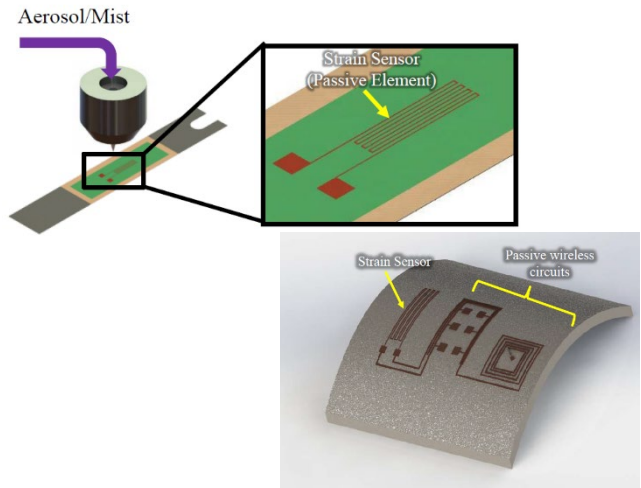
## OPERATIONS-BASED ASSESSMENT



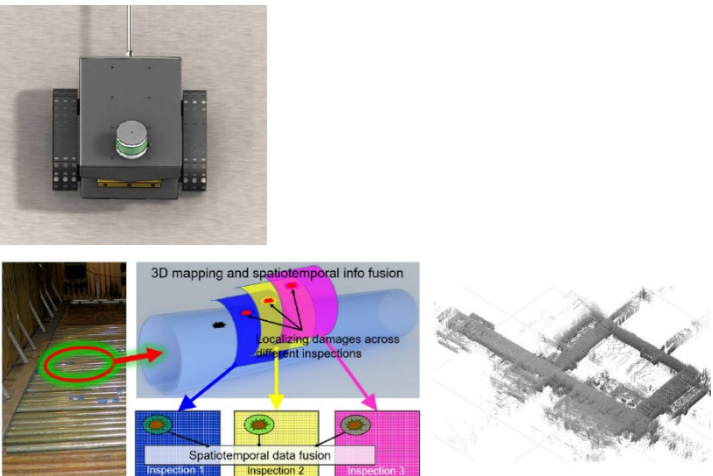
## OPTICAL FIBER SENSING



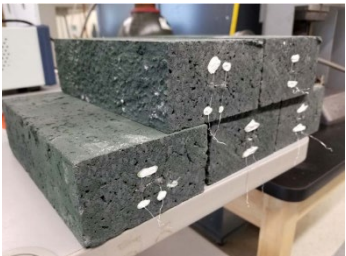
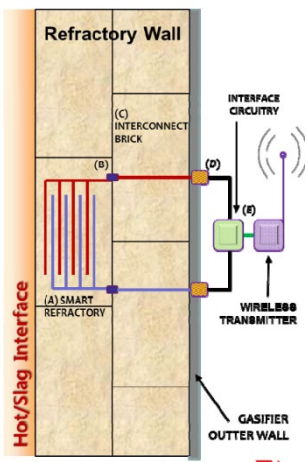
## ADVANCED MANUFACTURING



## DIAGNOSTICS & INSPECTION



## EMBEDDED SENSORS

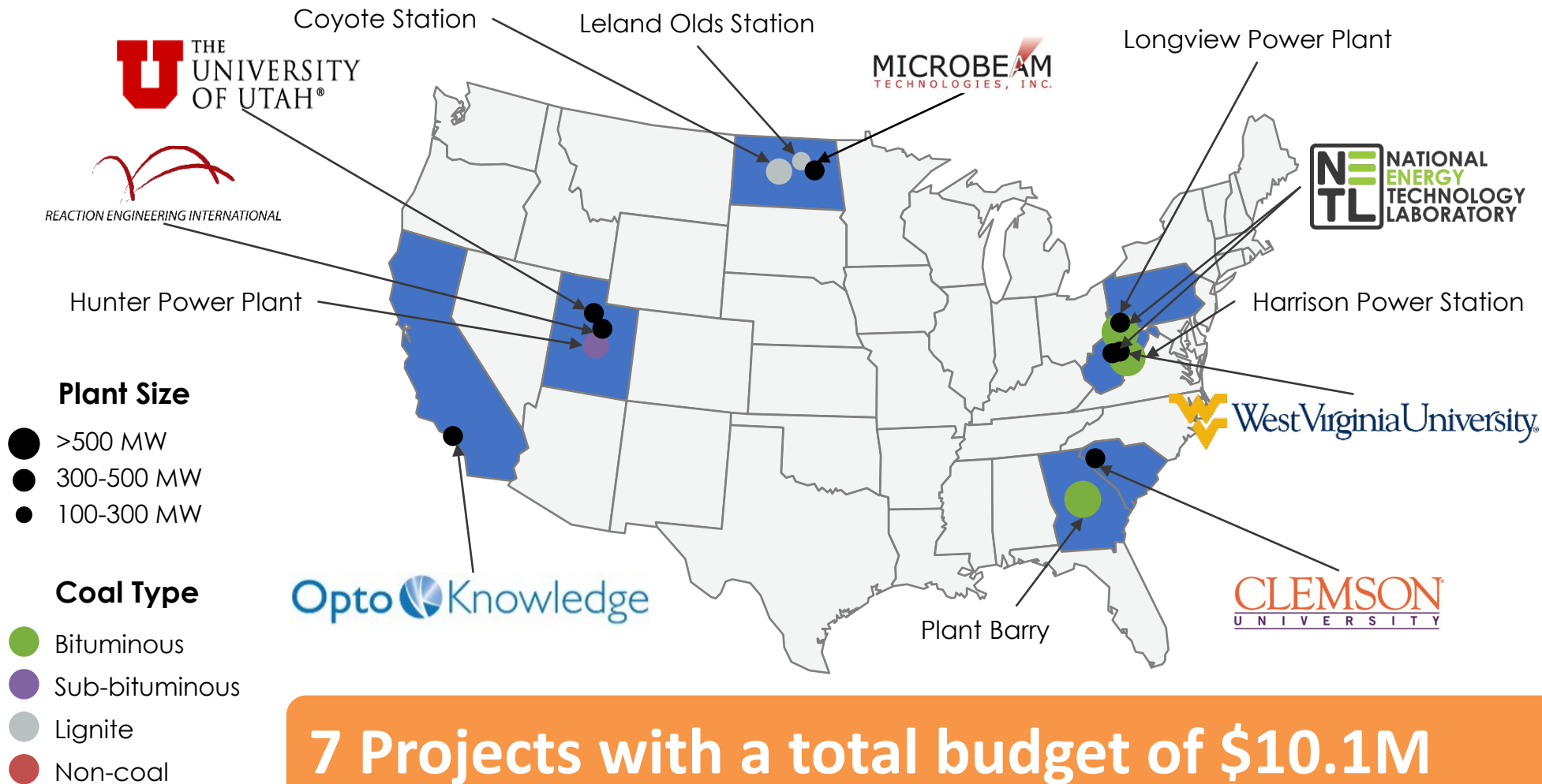


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# Transformative Power Generation Sensors Projects & Plant Test Sites



## Technologies in Development

- Advanced Sensors (incl. temperature, corrosion, wireless, real-time, combustible gases, ash deposition)
- Online Coal Analyzer
- Dynamic Plant Control Systems for Improved Transient Operation
- Condition-based Monitoring Systems

**7 Projects with a total budget of \$10.1M**



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# Technology Development Pathway

An Active Portfolio from Concept to Market Readiness

## COMMERCIALIZATION

Technology available  
for wide-scale market use

TRL 9

## DEMONSTRATION

System demonstrated  
in operational environment

TRL 8

## SYSTEM TESTING

System performance  
confirmed at pilot-scale

TRL 6-7

## DEVELOPMENT

Technology component  
validated/integrated

TRL 4-5

## DISCOVERY

Concept identified/proven at  
laboratory-scale

TRL 1-3

TECHNOLOGY MATURATION

- ↑ Scale
- ↑ Technology Confidence
- ↑ Investment
- ↑ Private Sector Cost Share

Fundamental Studies



Tools

## KNOWLEDGE-BASED DECISION MAKING

- **Systems Engineering and Integration**
  - Engineering analysis
  - Pre-FEED/FEED studies
  - NEPA
- **Decision Science and Analysis**
  - Screening studies
  - Techno-economic analysis
  - Technology Readiness Assessments



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Transformative Power Generation

Crosscutting Research  
Sensors & Controls

Fundamental Studies

↑ Scale  
↑ Technology Confidence  
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↑ Private Sector Cost Share



Tools

## KNOWLEDGE-BASED DECISION MAKING

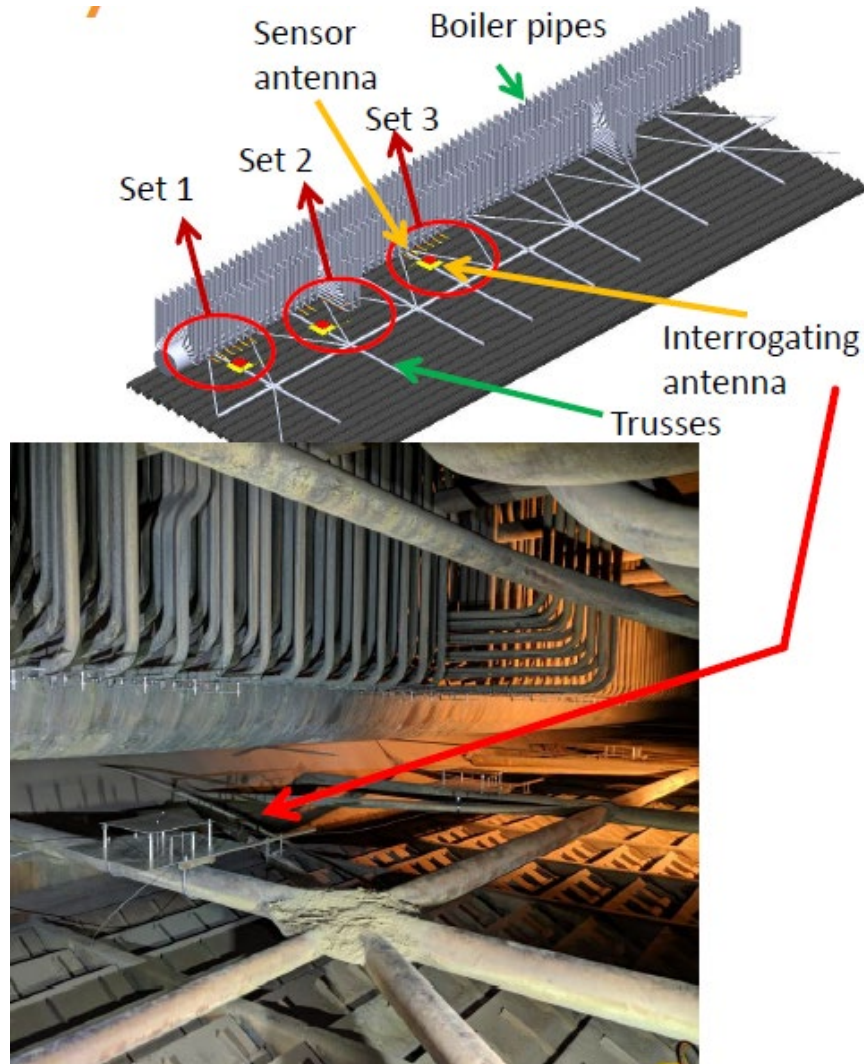
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# TPG and Crosscutting Deploy Sensor Technology



## SUCCESSFUL DEPLOYMENT OF UNIVERSITY OF MAINE WIRELESS SENSOR AT LONGVIEW POWER PLANT (2020)

- Tested a robust, hardened prototype of a novel, wireless surface acoustic wave (SAW) sensing technology
- Real-time temperature measurements were conducted for boiler tube monitoring (36 sensor units + antenna units)
- Testing confirmed correlation between steam temperature and measured temperature
- **This demonstration, funded by TPG, represents a successful technology transition and maturation of predecessor R&D efforts supported by Sensors & Controls program.**



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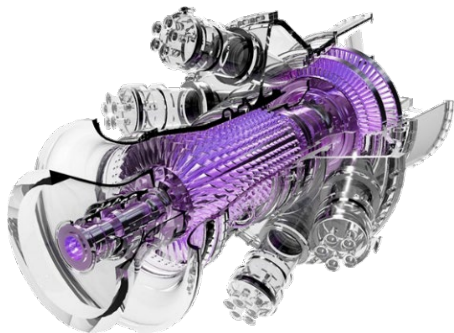
M. da Cunha, "Technology Maturation of Wireless Harsh Environment Sensors for Improved Condition-Based Monitoring for Coal-Fired Power Generation," DOE/NETL 2020 Virtual Project Review Meeting, September 30, 2020.  
[https://netl.doe.gov/sites/default/files/netl-file/20TPGVPR\\_Cunha.pdf](https://netl.doe.gov/sites/default/files/netl-file/20TPGVPR_Cunha.pdf)

[energy.gov/fe](https://energy.gov/fe)

# SENSORS, CONTROLS and NOVEL CONCEPTS

## Future Development Efforts:

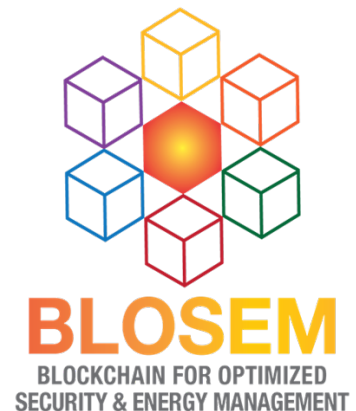
- Advanced sensors for new technologies (H<sub>2</sub>, SOFC, etc.) addressing unique performance, environmental, material compatibility and manufacturing issues
- Control and optimization strategies for new hybrid systems (SOFC with H<sub>2</sub> turbine, generation with energy storage, etc.)
- Operations-based predictive maintenance of emerging advanced generation and hybrid technologies to improve availability and economics
- Development and testing of plant cybersecurity mechanisms as the threat landscape evolves



GE's Hydrogen Turbine Project



200 kWe POC – Courtesy LG Fuel Cell Systems





# In Conclusion

## These (Your) Efforts Are Helping to Meet DOE Strategic Goals

- Advance Technology Readiness Levels
- Explore Emerging Concepts
- *Driving Innovation & Delivering Solutions*

## Encourage Interactions with Others Throughout the Meeting

- Helps Grow a Robust Program
- Allows Us to Amplify Your Work and Successes
- Builds New Collaborative Relationships



# KEY POINTS OF CONTACT

## Sensors, Controls and Novel Concepts



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## Transformative Power Generation



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