Advanced Sensors & Controls FWP

Overview

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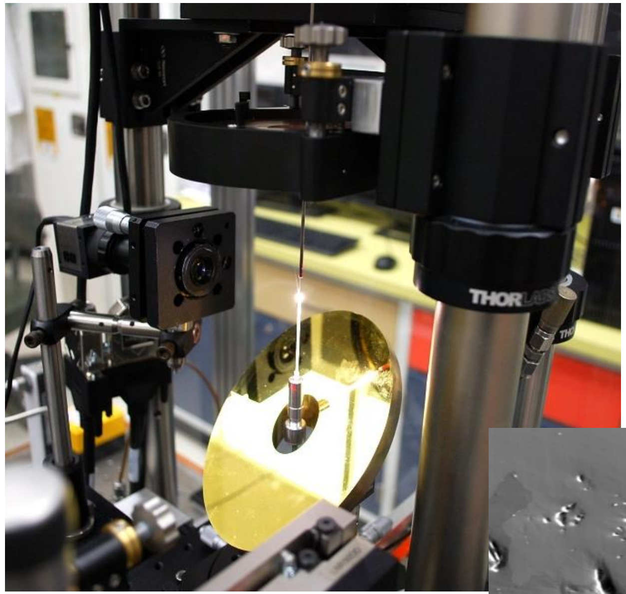
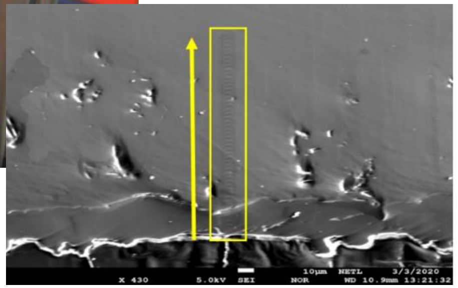
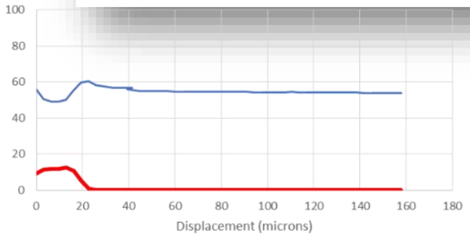
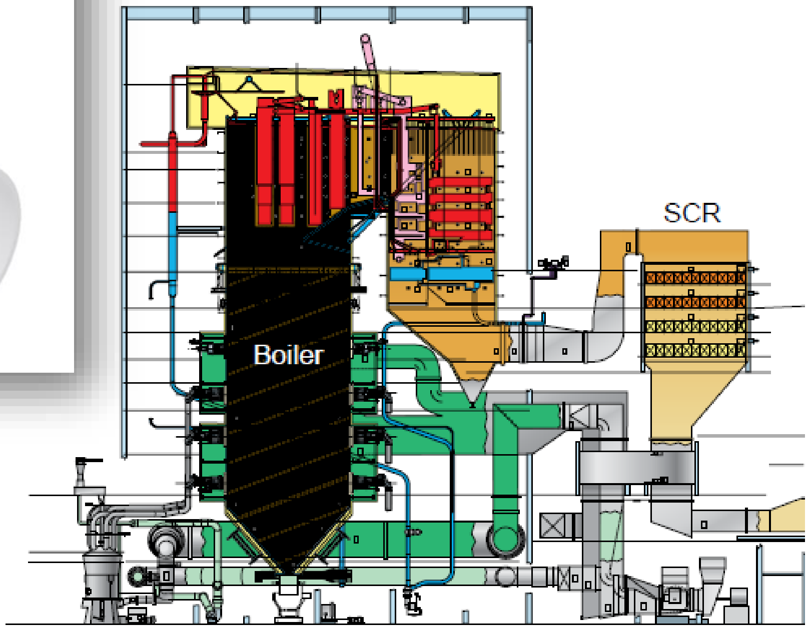
Presenter: Ben Chorpening, TPL









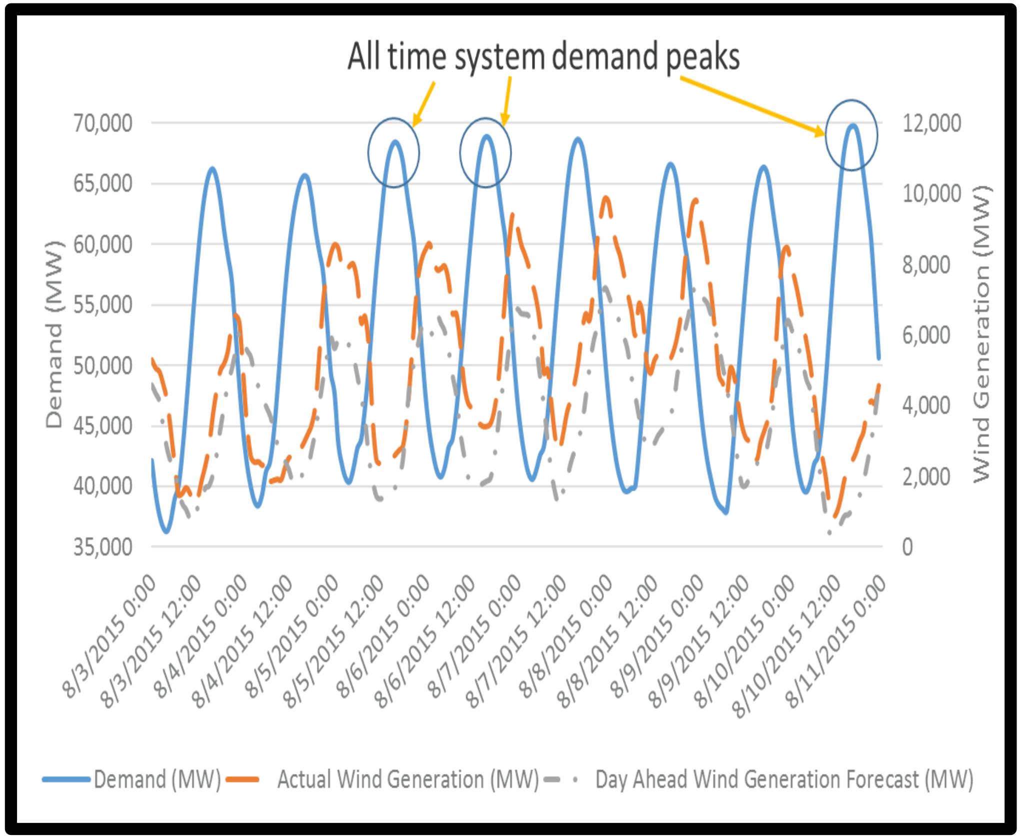
2020 Virtual Integrated Project Review Meeting - Sensors, Controls, & Novel Concepts, August 26-27, 2020

Changing Landscape for Fossil Energy Power

Adapting to Changing Role

Fossil energy power generation is needed now and in the future, but its role is shifting from baseload operation to fulfilling dispatchable power needs in regions of the United States.

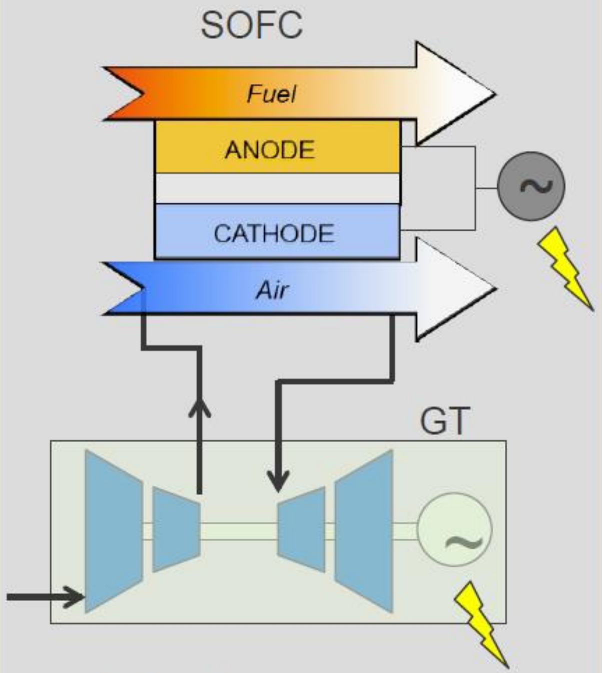
Novel sensors and controls will help to **increase efficiency**, **minimize emissions**, and **reduce operating costs** of existing power generation technologies under this increased load following role; and help enable next generation power systems with high efficiency and greater operational flexibility.



Data from Texas (ERCOT)

Renewable power production often does not match demand

Sensors & Controls Development for Harsh Environments



Hybrid systems

- 800°C in fuel cell
- 1500°C in GT

Meas. Challenges

- T and H_2 dist in SOFC
- Transient control

Gasification

- 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 / SOx

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

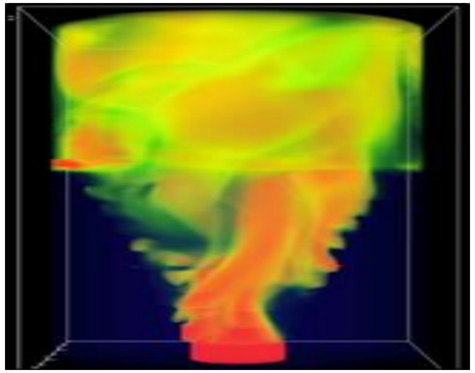
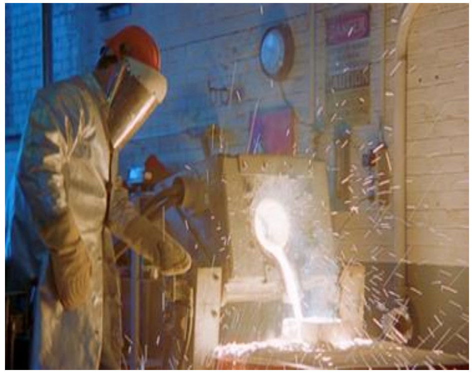
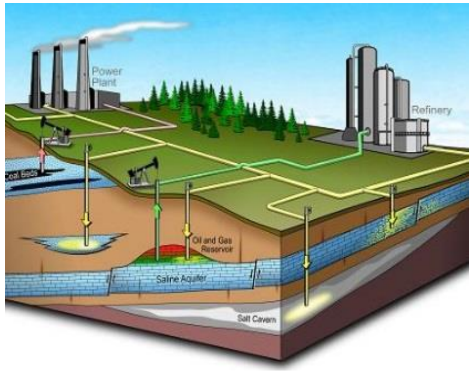
- > 1000°C
- Pressurized
- Erosive

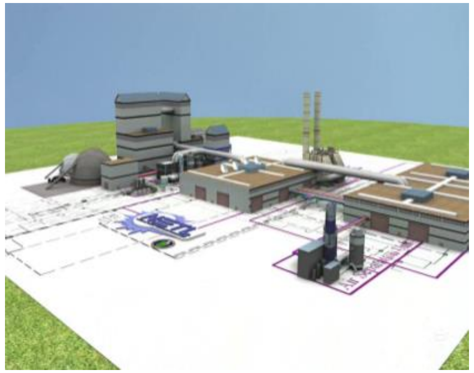
Meas. Challenges

- Solids circulation
- Oxidation state
- Multipoint temp

Research and Innovation Center Core Capabilities

NATIONAL ENERGY TECHNOLOGY LABORATORY

APPLIED MATERIALS SCIENCE & ENGINEERING

Developing and deploying affordable, high-performance materials designed for severe service applications.

DECISION SCIENCE & ANALYSIS

Utilizing multi-scale computational approaches to provide in-depth objective analyses in support of the DOE mission.

CHEMICAL ENGINEERING

Pioneering efficient energy conversion systems that can enable sustainable fossil energy utilization.

SUBSURFACE SCIENCE

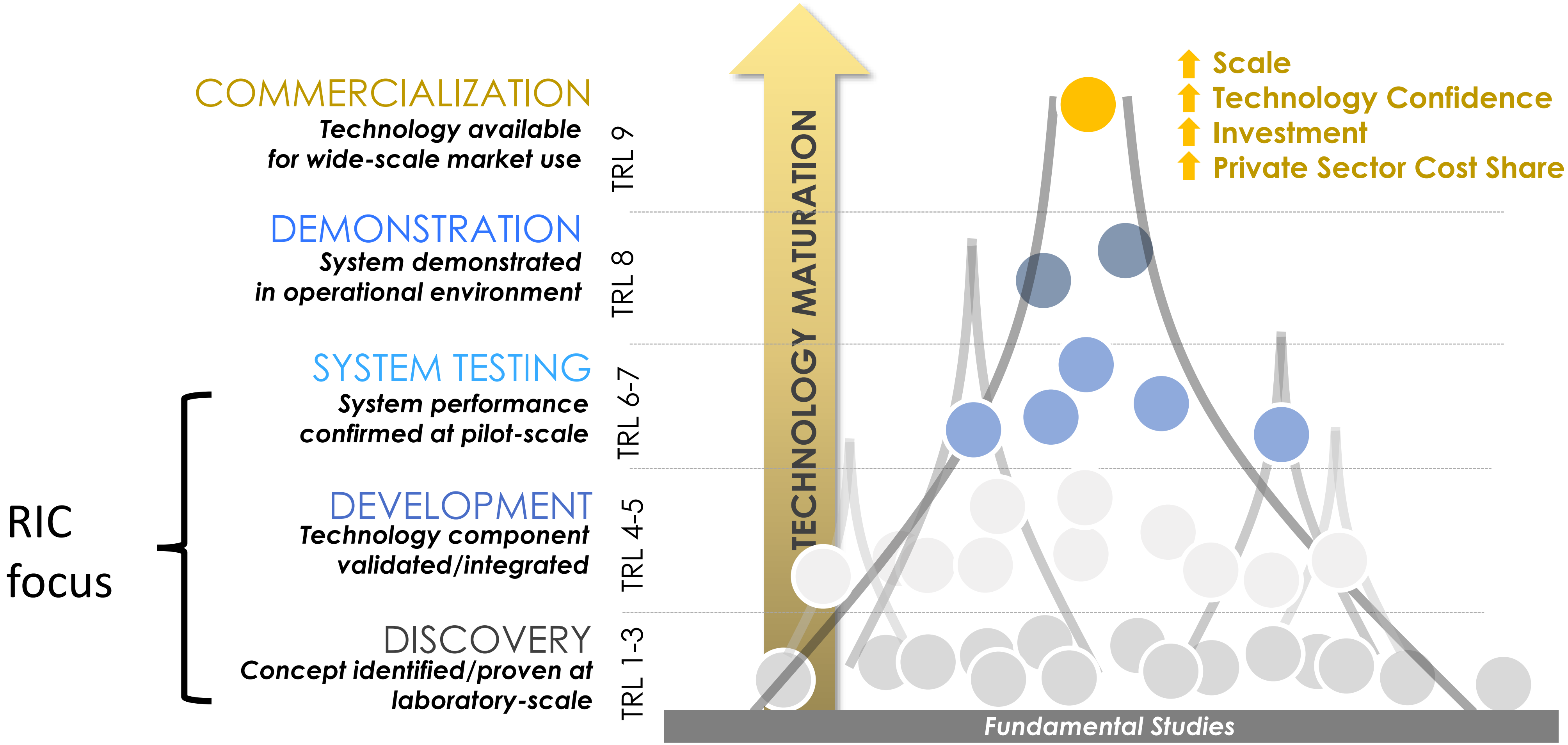
Enabling the sustainable production and use of fossil fuels through engineering of the subsurface.

SYSTEMS ENGINEERING & INTEGRATION

Accelerating technology innovation, development and deployment to enable new clean energy technologies to gain market acceptance.

Technology Development Pathway

An Active Portfolio from Concept to Market Readiness

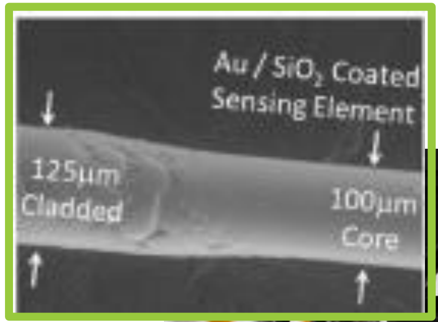


Overview of Adv Sensors & Controls FWP

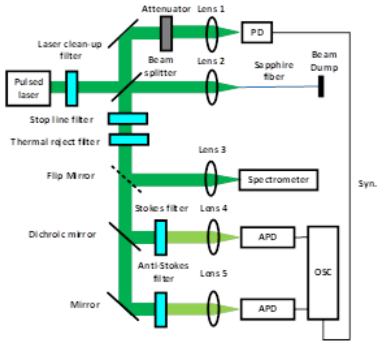
- Sensors and Instrumentation
  - High temperature optical fiber sensors (Tasks 21-25, 32, 33)
  - SAW sensors for gas sensing (Task 26)
  - Raman Gas Analyzer (Task 41)
  - LIBS for Subterranean Chemical Sensing (Task 71)
  - In-Situ Temperature Measurements via Reactive Particles (Task 47)
- Controls
  - Agent-Based Controls for Power Systems (Task 51)
- Techno-Economic Analysis
  - TEA of Sensor and Control Technologies (Task 64)
- Cybersecurity and Novel Concepts
  - VLC – Alternative to WiFi (Task 81)
  - AI-based approach for screen and design of funct. materials for harsh env. (Task 86) new
  - Quantum sensors for fossil energy (Task 87) new

Optical Fiber Sensing for Harsh Fossil Energy Applications

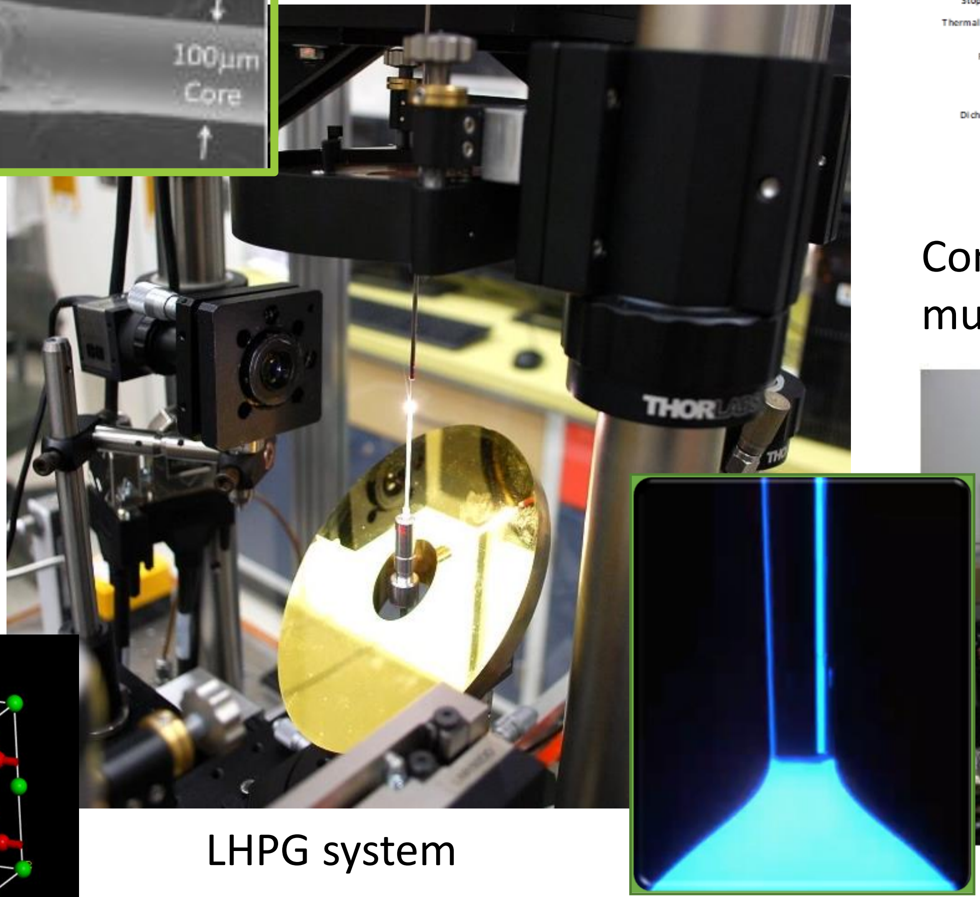
Developing materials and sensing approaches to develop a fiber-based sensing concepts that can provide spatially resolved chemical species and temperature measurements from an optical fiber at above 800°C

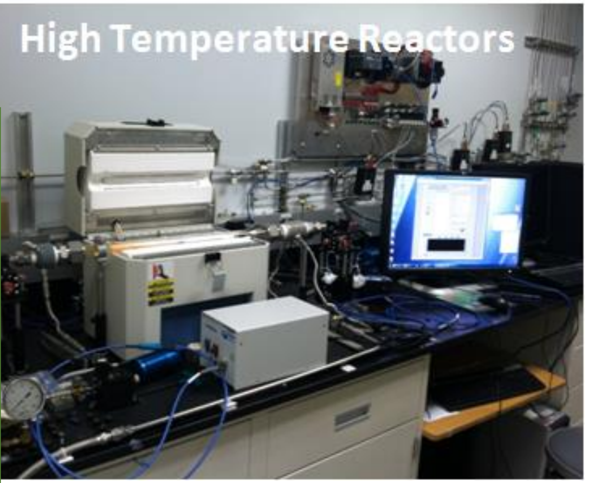


Functional nanomaterials

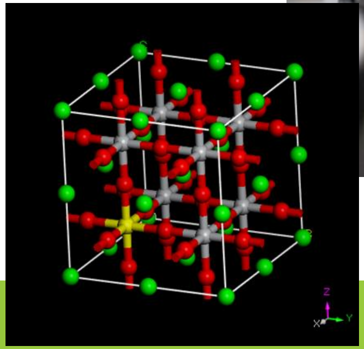


Commercial and novel multipoint interrogation





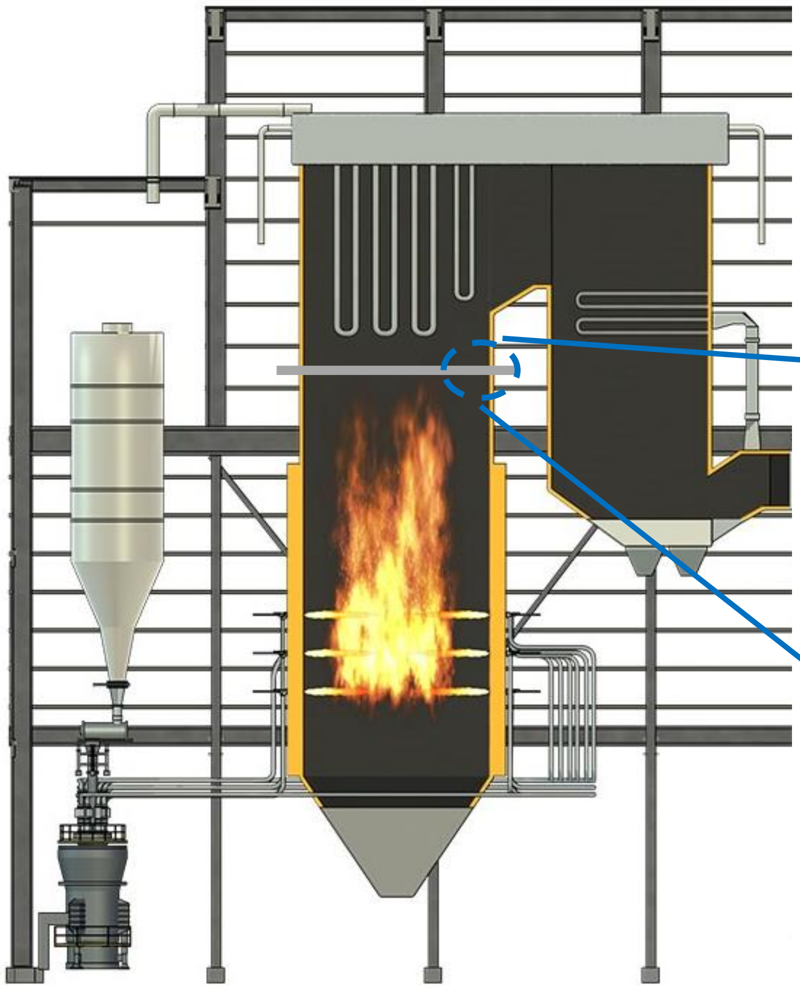
Material modeling



LHPG system

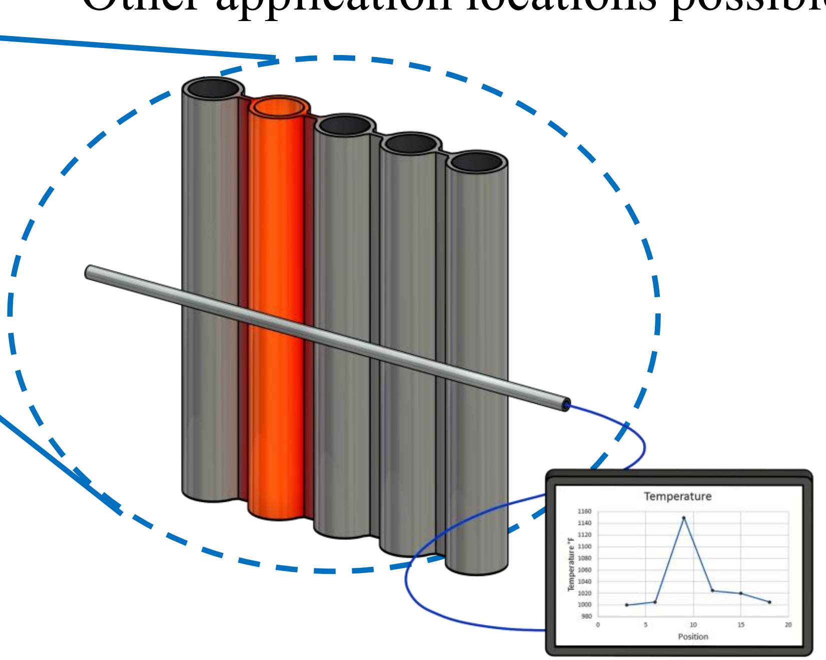
Fossil energy relevant gases

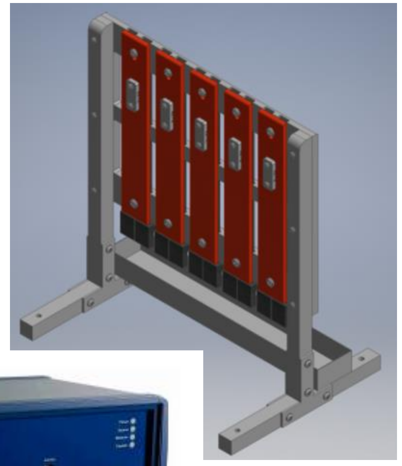
Multipoint Boiler Tube Temperature Monitoring



Measure temperatures from every tube

- Expected spatial resolution 1 inch (200 ft long)
- Identify local hot spots on tube wall
- Spot maldistribution of steam flow at low power
- Gold-coated silica fiber possible: <1200°F (650°C), air
- Other application locations possible

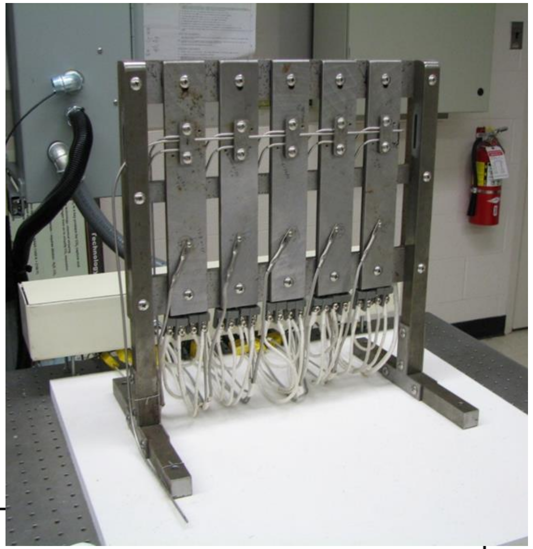


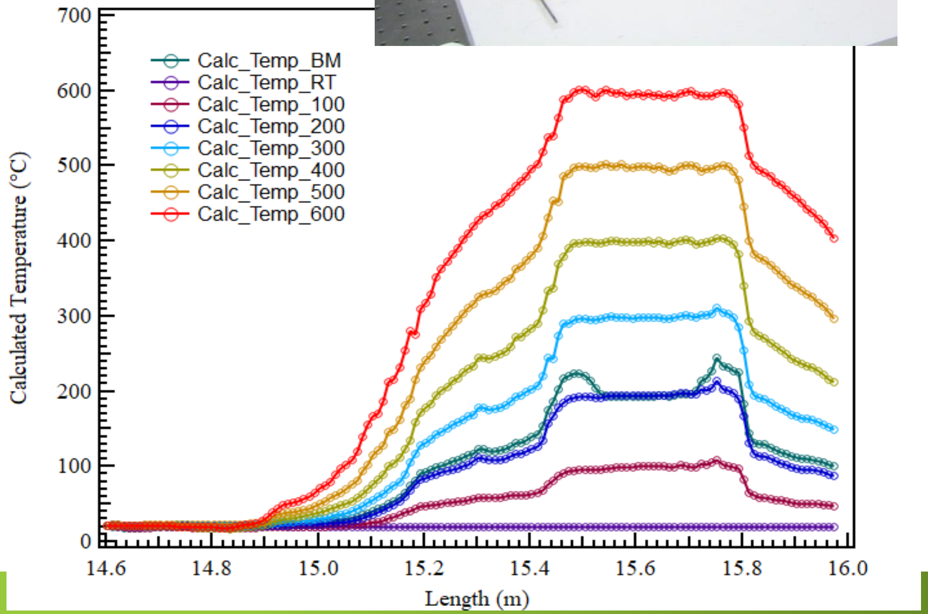


Apply commercial optical fiber readout instrument (silica fiber)

- Preparations were completed for a pilot-scale field test of distributed temperature sensing
  - gold coated SMF fiber 5 meters long
  - pilot scale pulverized coal combustion unit at University of North Dakota Energy and Environmental Research Center (UNDEERC)
- Dry run of installation and testing in NETL laboratory
  - Installation of the gold-coated fiber into a 1/8 inch stainless steel tube for protection
  - Included mechanical connection to a 30 meter section of ordinary silica fiber which will be needed to reach the control room at UNDEERC
  - Tested through several temperature cycles up to 600°C using the plate heater apparatus to check the temperature sensing performance in comparison with thermocouples
  - Custom postprocessing of data necessary to obtain accurate temperature readings at the higher temperatures
  - LabVIEW program developed to automatically post process
- Pilot scale test on hold due to COVID-19

2-inch wide heated bars simulate boiler tubes

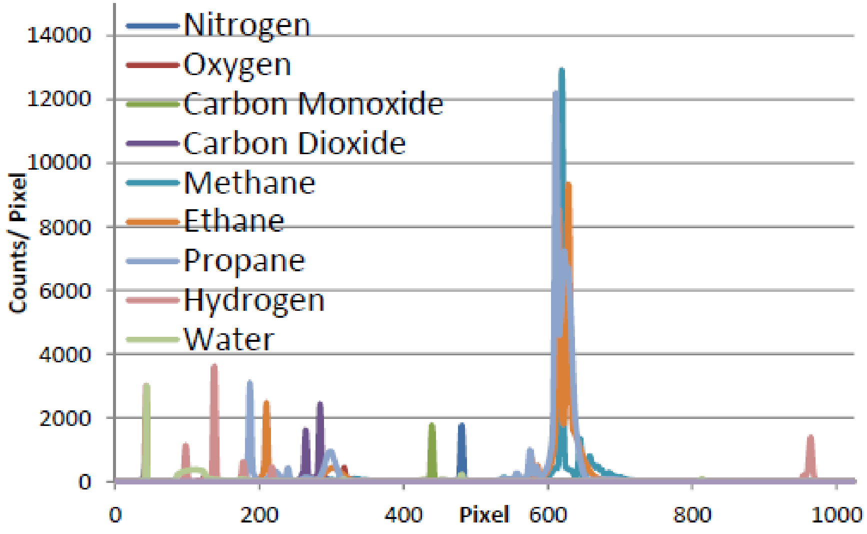




Fast Raman Gas Analyzer

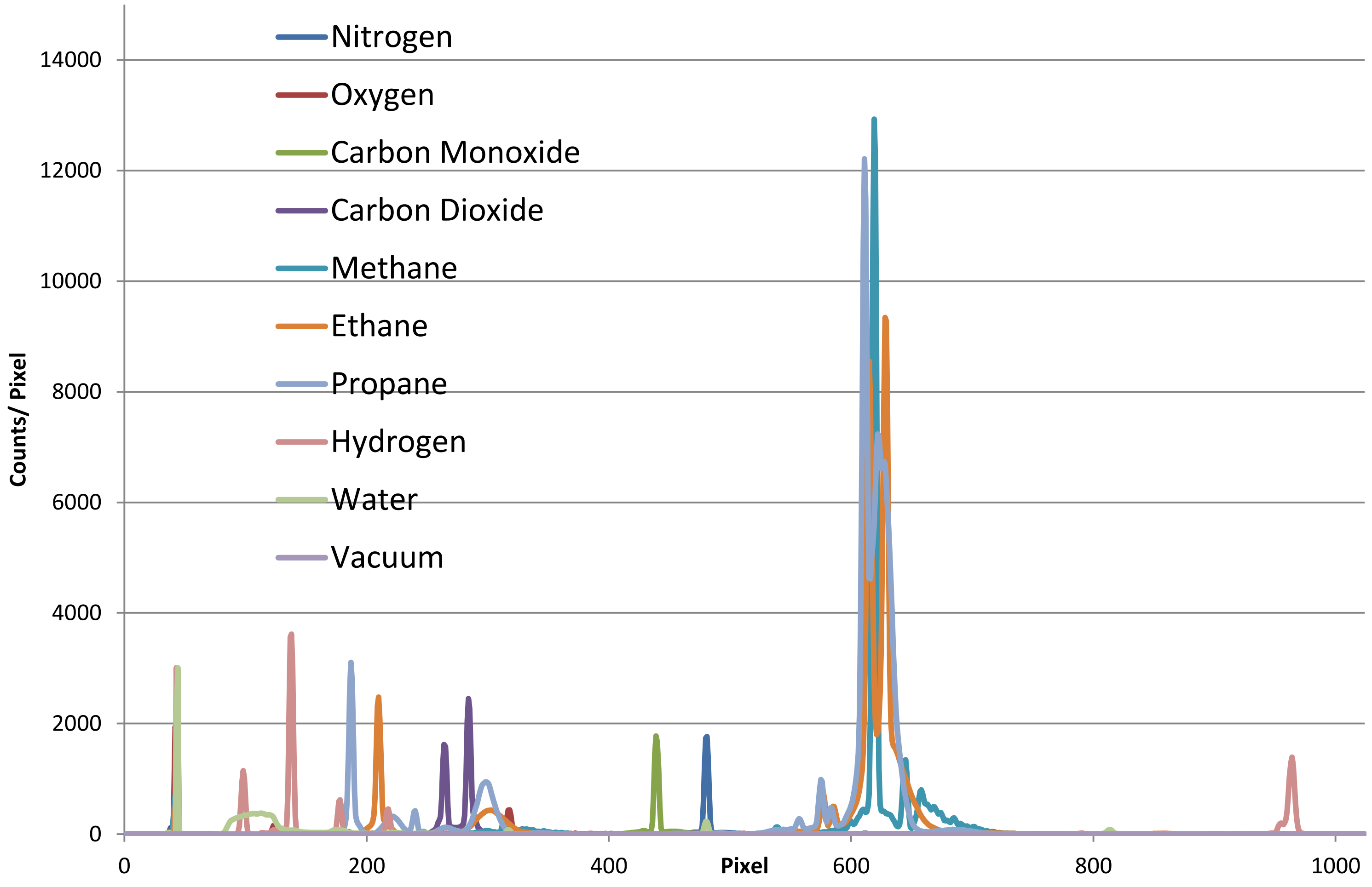
- Applications to **power generation** and **chemical process control**
- Prototype tested in pilot scale laboratory applications
- Fast - 1 second measurement time
- Species concentrations measured to 0.1%
- Optical waveguide technology boosts Raman signal more than 1000X
- No recalibration needed in normal operation
- **Seeking collaborative partners or licensees**

No commercial technology has this combination of speed, accuracy, and multi-gas capability.



US Patent 8,674,306, NETL and U. of Pittsburgh

Raman Spectroscopy of Gases



All major species simultaneously (no noble gases)

Measures difficult gases: H_2, N_2, O_2 (they have no IR transitions)

Easily distinguishes CO from N_2 (difficult for mass spectrometer)

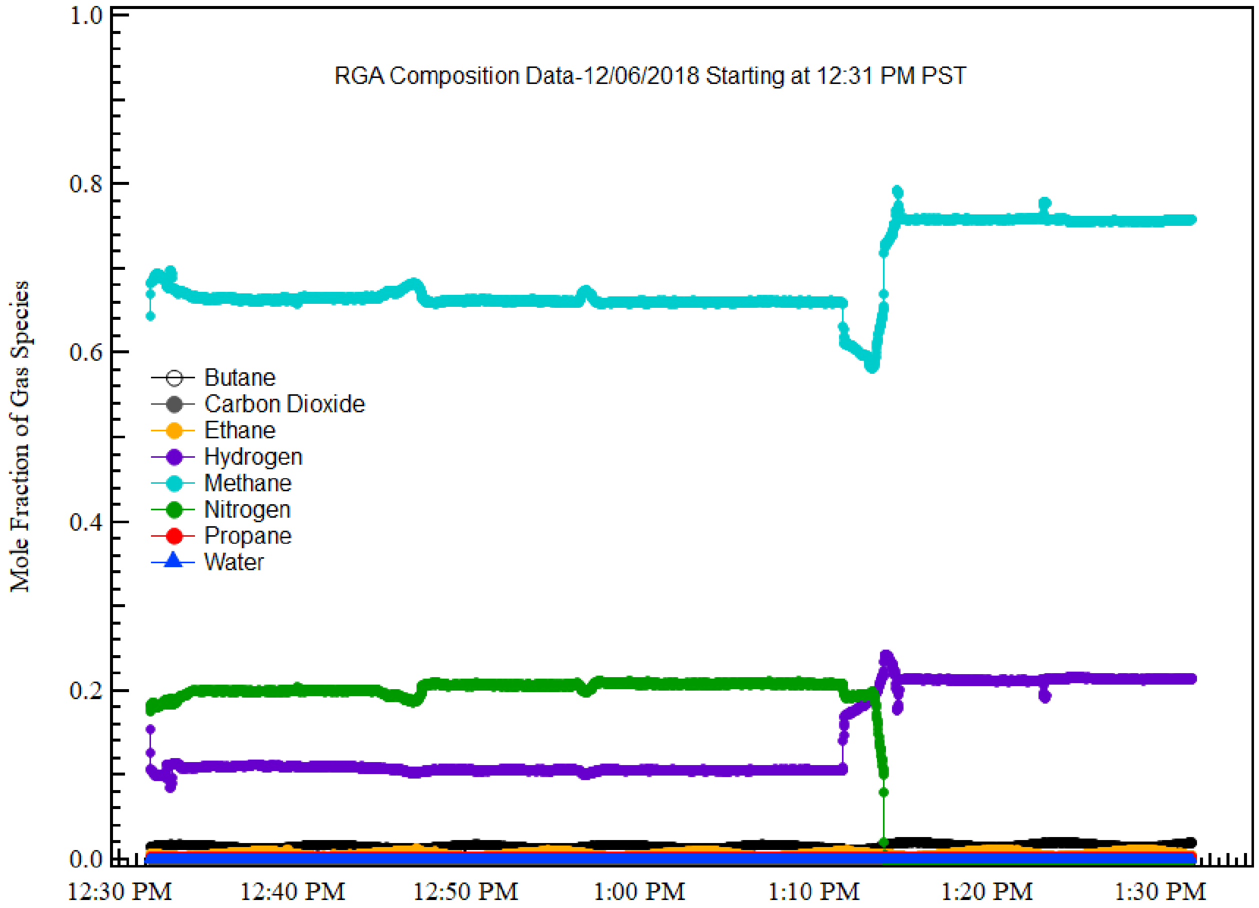
Operates at process pressure

Task 41. Raman Gas Analyzer Field Testing and Development

- Continue technical maturation and field testing of the RGA, an NETL developed, fast, on-line instrument that measures gas composition for smarter combustion, gasification, and industrial process operation
- Also applicable to fuel reforming and hydrogen production

NETL RGA prototype for field testing.

- 1000 psi
- Design for NEC Class 1 Div 2



Data from test at turbine OEM, showing fast response to composition change in NG fuel blend (with hydrogen)

Task 47. In-situ Temperature Measurements via Reactive Particles

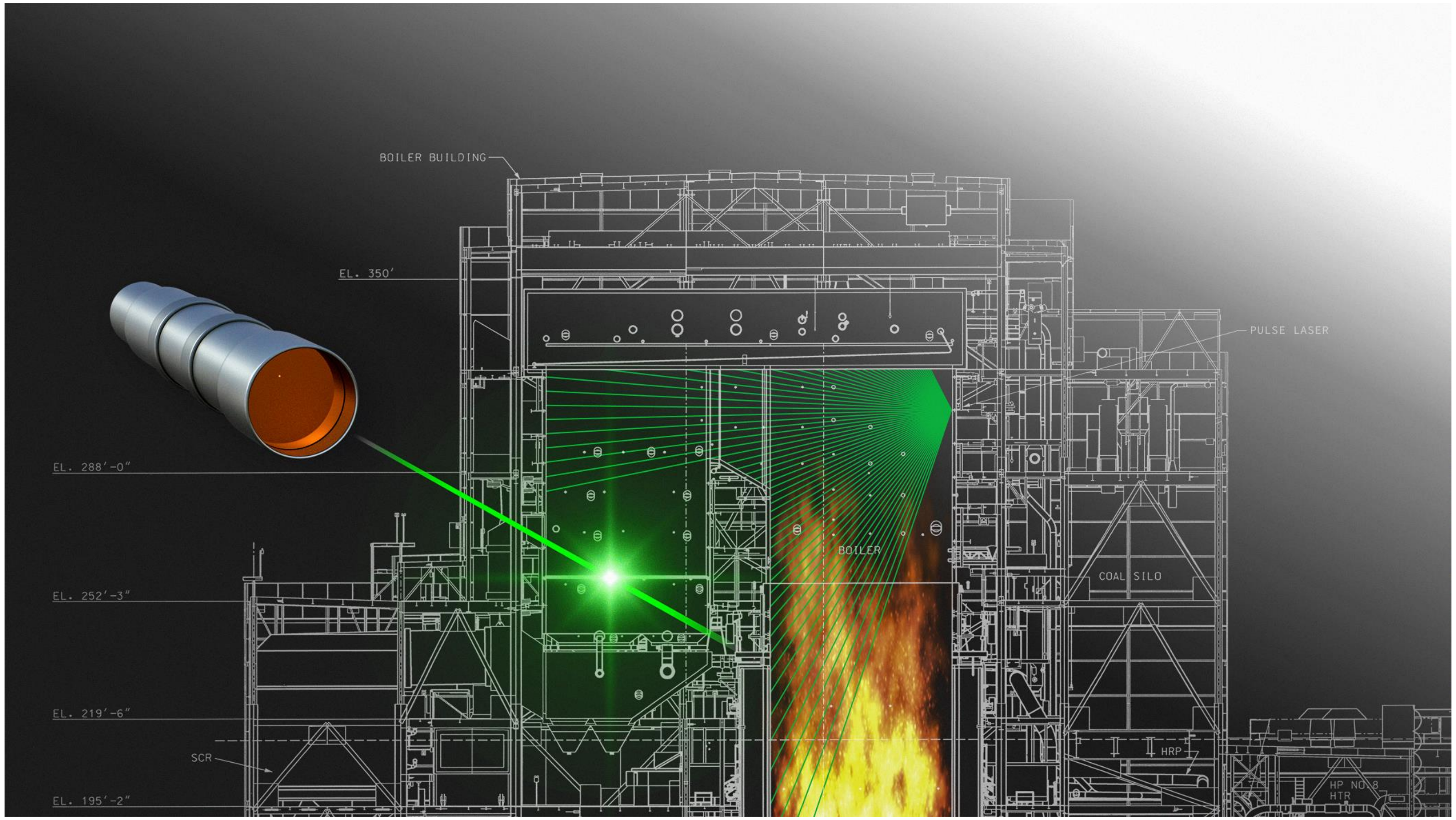
- Developing multilalyer particles for injection into boiler with coal
- Temperature to be mapped from reaction pattern
- A simplified testing apparatus was developed to assess the green light emission from pyrotechnic core formulations
- Synthesized, characterized, and tested 15 different pyrotechnic formulations
  - Compositions contained a mixture of metallic fuel, oxidant, color source, and binder
- Bright green color was obtainable with $BaCl_2$ colorant, high oxidant ($KClO_4$) to fuel ratio (3:1), and any metal fuel tested (Mg, Co, or Sn)
  - Light from the formation of BaCl+ radical in gas phase
  - Boric acid and copper sulfate are other potential sources of green light
- Performing dip-coating studies for the application of the protective layers
  - Used Mg spheres as representative substrate for inner core
  - Needed to control reaction location of particles

$BaCl_2/KClO_4/Sn^0$/Ethyl Cellulose

Ba(NO3)2/$KClO_4/Mg^0$/Ethyl Cellulose/PVC

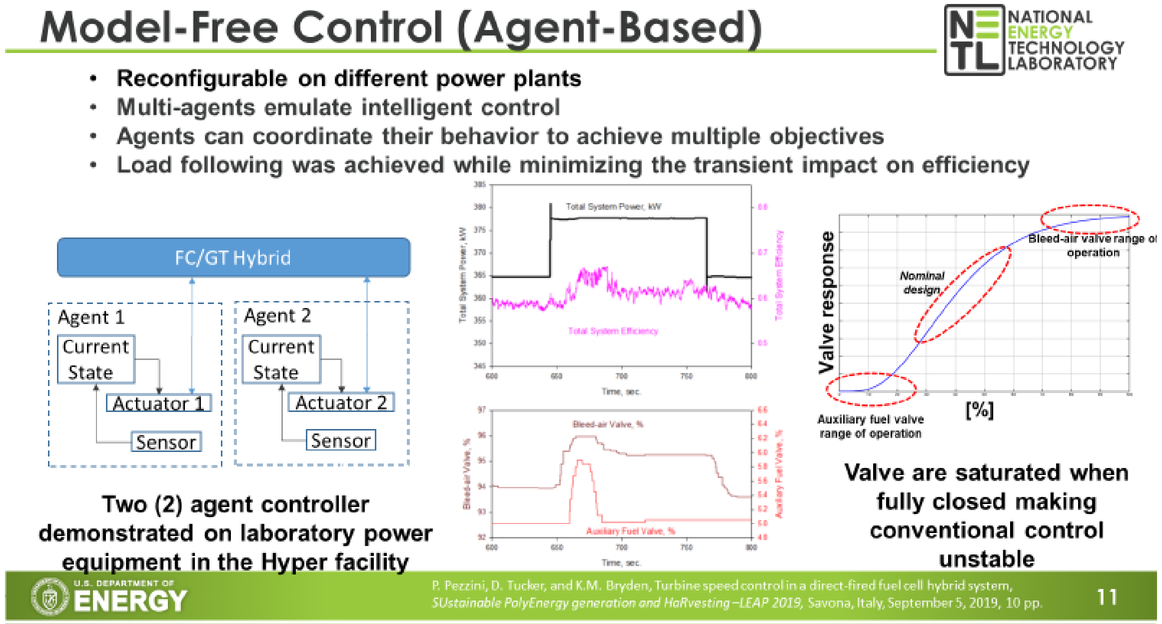
Task 48. Ultrafast Laser Measurements for Power Generation Environments

- Goal: Improve boiler operation at varying loads.
- Objective: Provide a laser-based measurement of species and/or temperature inside a coal-fired boiler or HRSG along a line of sight with spatial resolution better than 1 meter and a single point of access.

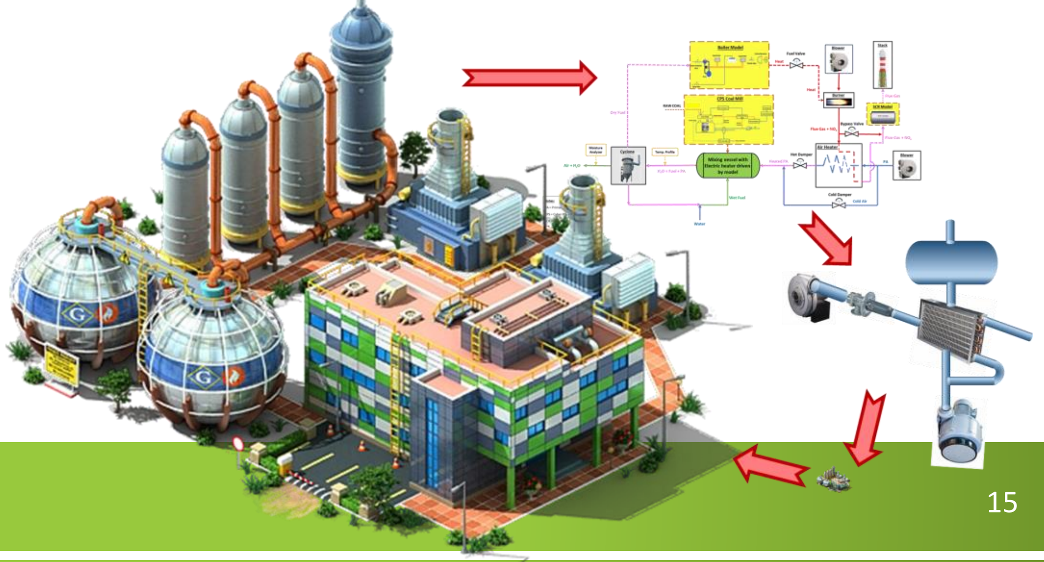


Task 51. Development and Testing of Agent-Based Controls for Power Systems

- Objective: Develop and test the suitability of agent-based controls for power plant applications
  - Benefit is in applications where the link between actuation and result is difficult to model
- Through discussion with PacificCorp, the coal pulverizer subsystem has been identified as having the potential to benefit from improved controls for more flexible operations
- Agent-based controls applied to the hot air and cold air input streams will provide improved control of temperature in the coal pulverizers during off-design operations and load ramping



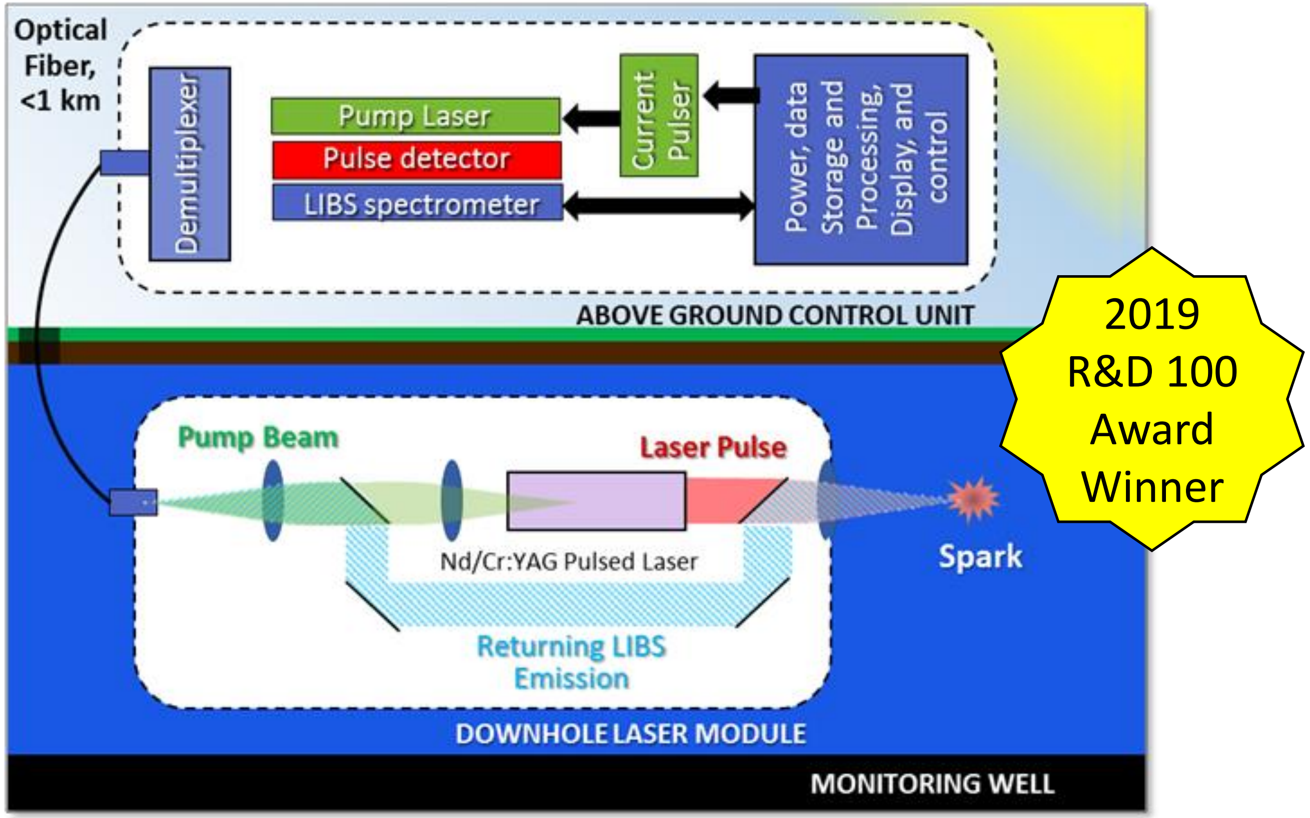
Data from turbine speed control experiment utilizing two co-worker agents and two actuators that are fully closed (i.e., saturated) at nominal conditions, performed in the Hyper facility, using a real turbine.

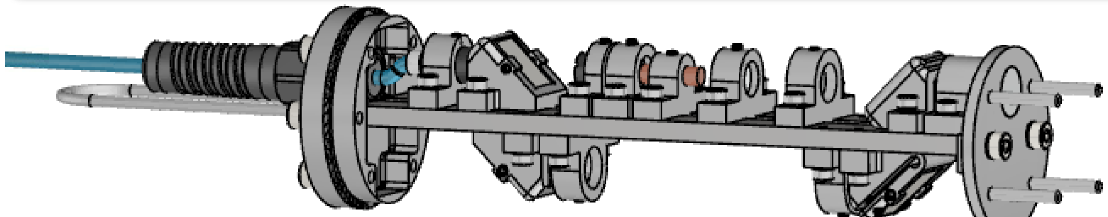


Design of a cyber-physical system emulation of a power plant, focusing on the temperature control of the pulverizer air temperature using two actuators, similar to the Hyper demonstration.

Task 71. Development of LIBS for Subterranean Sensing

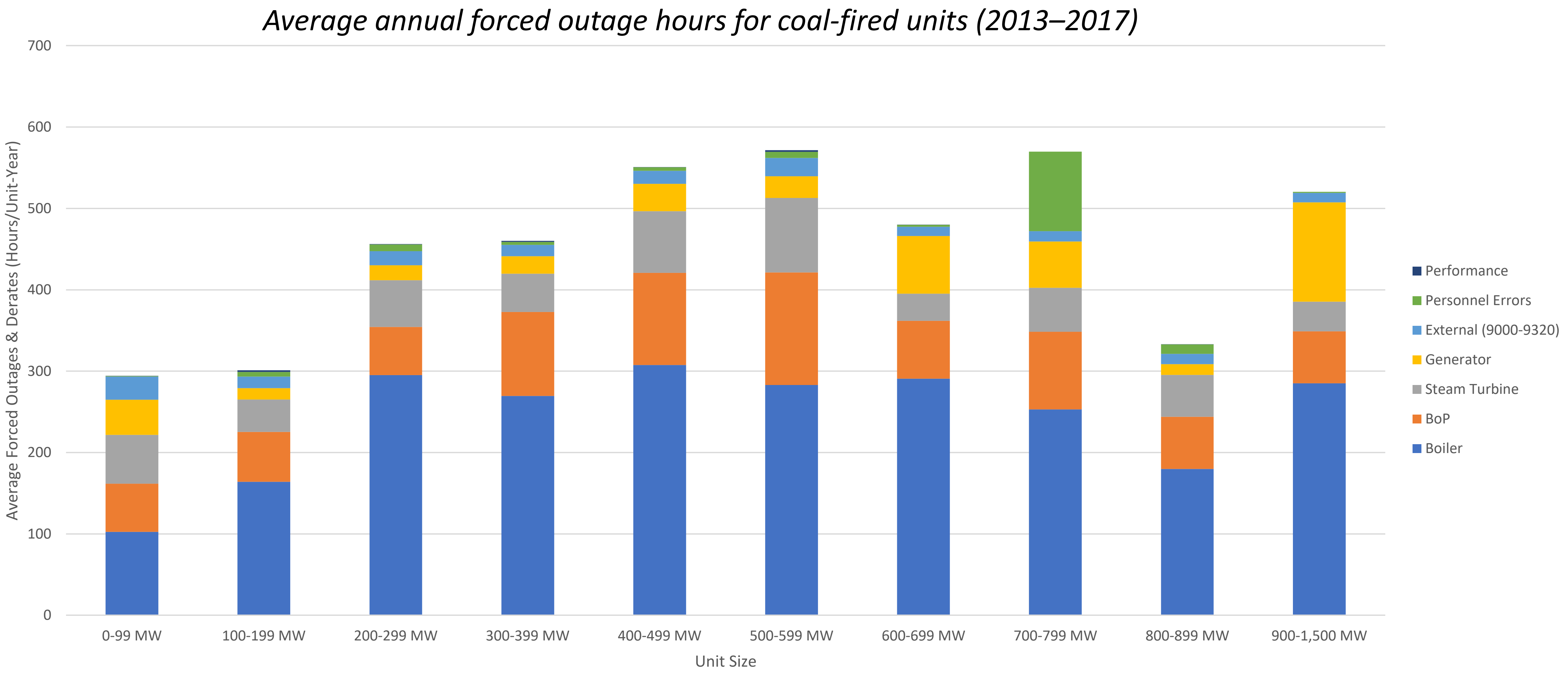
- Objective: Development, optimization and testing of a deployable miniaturized LIBS system for subterranean chemical sensing.
- A miniaturized submersible measurement probe was recently completed.
- Laboratory bench experiments have shown the ability of this new probe to measure several elemental species in solution.
- Field use of this device will require the construction of a laser safety shield/interlock system for outdoor use
- This task will address these remaining issues and begin field testing with the NETL-designed miniaturized submersible measurement probe





Current subsurface probe design

Task 64. TEA Analysis: Forced Outages for Coal-Fired Power Boilers



Source: NERC GADS PC GAR-MT,

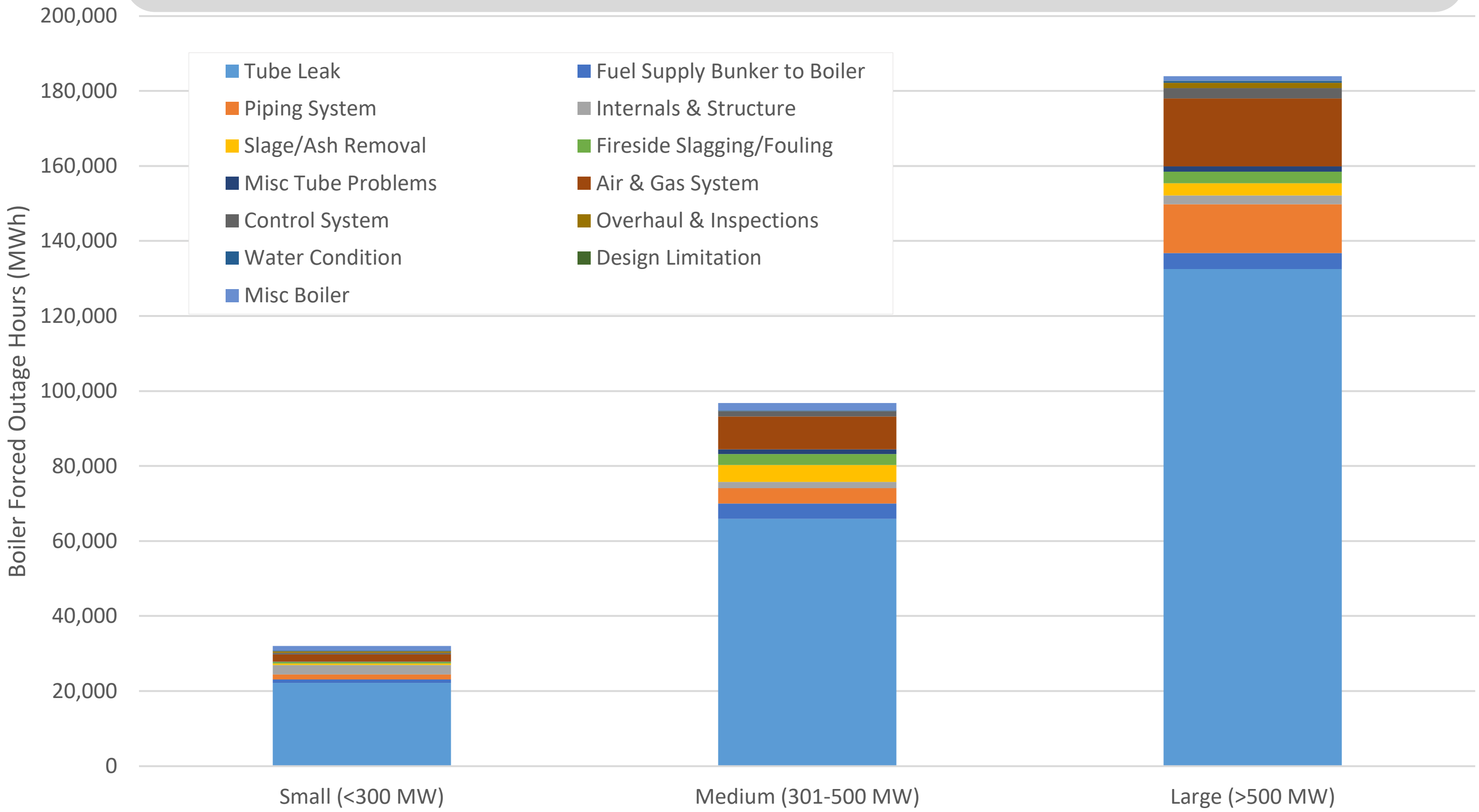
Task 64. TEA Analysis: Boiler Instrumentation Gap Analysis

Focus on outages due to boiler problems – causes, sensing, tech gaps

Boiler outage cause codes from EV / GADS data

- Fuel supply bunker to boiler
- Piping system
- Internals and Structure
- Slag/Ash removal
- Tube leak
- Fireside slagging/ fouling
- Misc tube problems
- Air and Gas system
- Control system
- Overhaul and inspections
- Water condition
- Design limitation
- Misc boiler

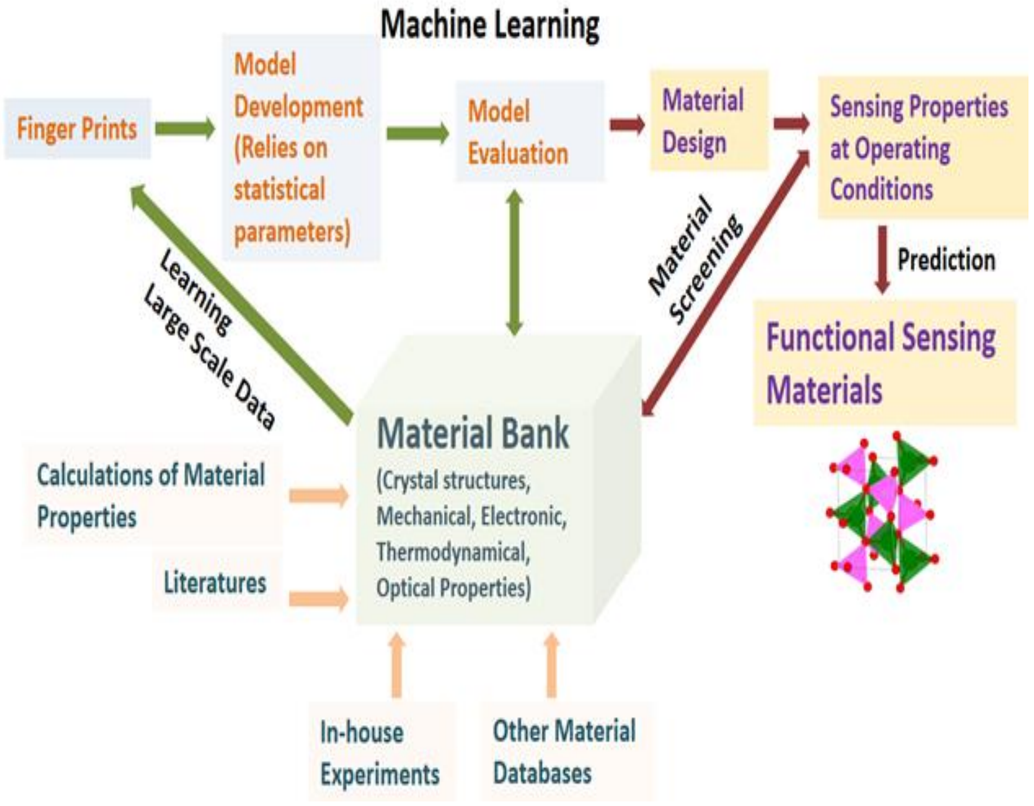
Tube leaks cause forced outages for coal boilers at more than 10x the rate of next highest failure



Task 86. Machine Learning-Based Theoretical Approach for Screening and Design of Functional Materials for the Harsh Environment Applications

- Establishing a machine learning-based model architecture to boost the development of gas sensor materials that function in harsh environments: challenges:
  - Lack of systematic approach to predict sensing properties of material candidates other than at ambient conditions
  - Machine learned prediction of the response signals for sensing materials at various operating conditions; specifically at high temperature

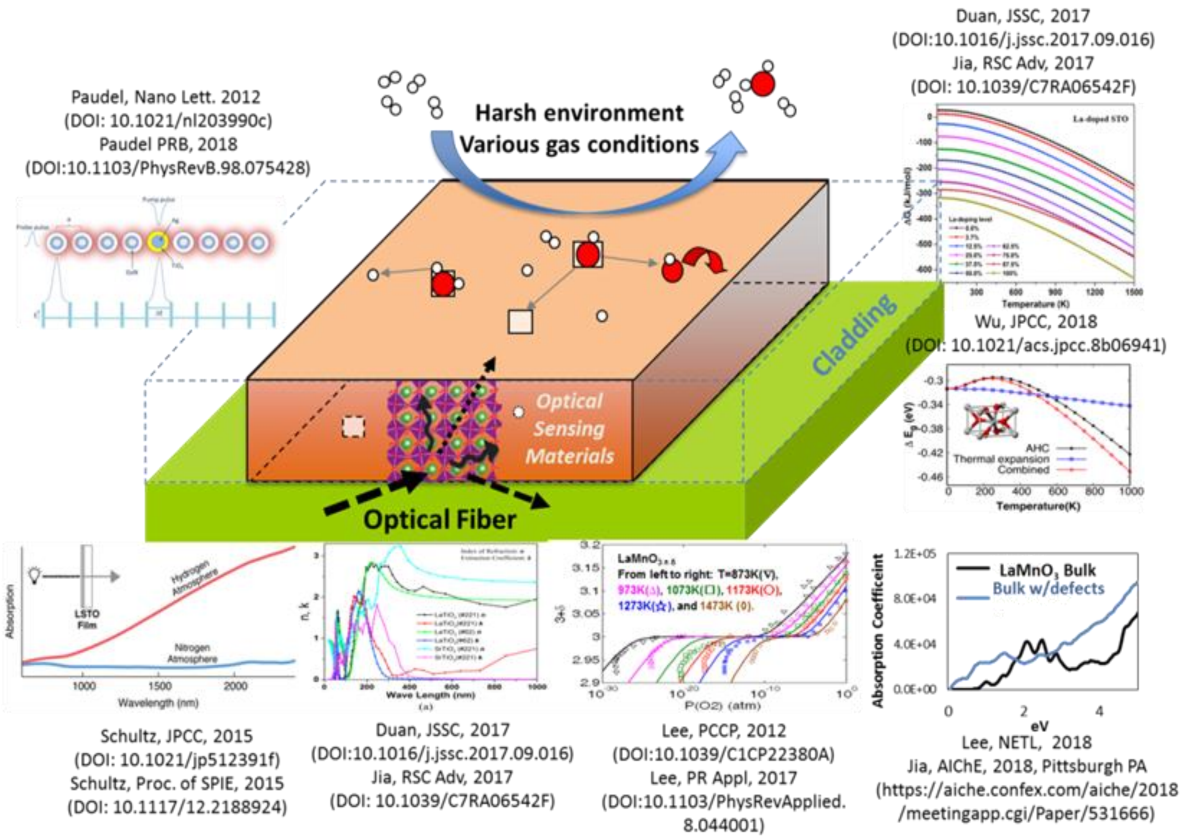
- Initiated to build a database of sensor materials: Material Bank
  - Currently setting up a list of materials applicable as optical gas sensors; mainly focusing on metal oxides and perovskites
  - Data mining the mechanic/electronic/optical properties for the materials in the list will be conducted using "Materials Project" (open access web database)
  - Unavailable physical properties from Materials Project and other resources will be calculated, and will be combined with collected properties
  - Material bank will be finalized to proceed for machine learning prediction



Task 87.0: Quantum Sensing for Fossil Energy Applications

NATIONAL ENERGY TECHNOLOGY LABORATORY

- Objective: Use quantum sensing materials, quantum optics, quantum computing, and quantum sensing methodologies for realizing unprecedented performance in advanced sensing instrumentation for high priority FE applications, with at least an order of magnitude improvement as compared to classical counterparts within acceptable costs.
- Review of QIS relevant to FE complete, submitting for publication



Schematic of mechanism of an optical hydrogen sensor and related finishing/ ongoing projects in NETL FWPs.

Pause for Questions

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