Office of Research and Development
IPT Sensors & Controls
Sensors & Controls Testing

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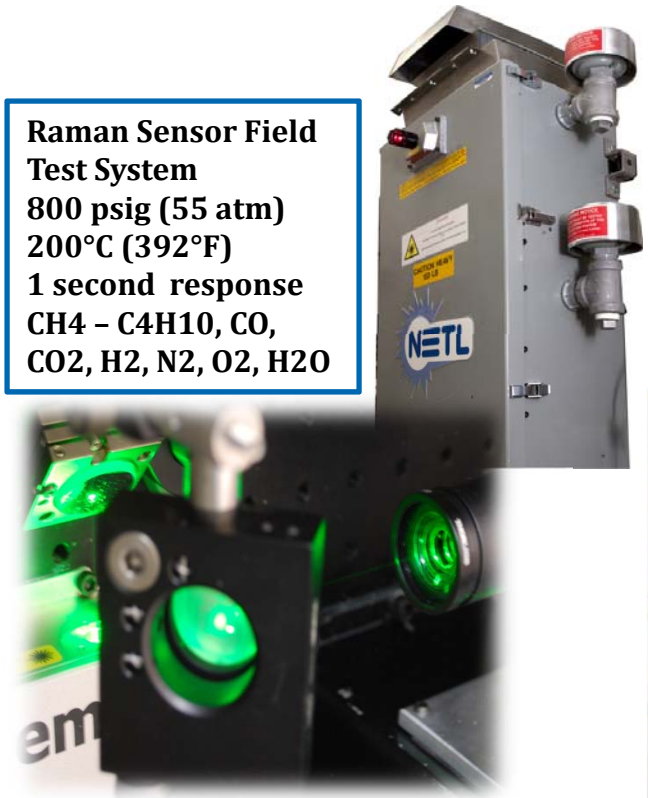
U.S. DEPARTMENT OF ENERGY | National Energy Technology Laboratory

Introduction

- Overview of ORD IPT Sensors & Controls
- Sensors testing in the High Pressure Combustion Facility
- Advanced Controls Testing in HYPER

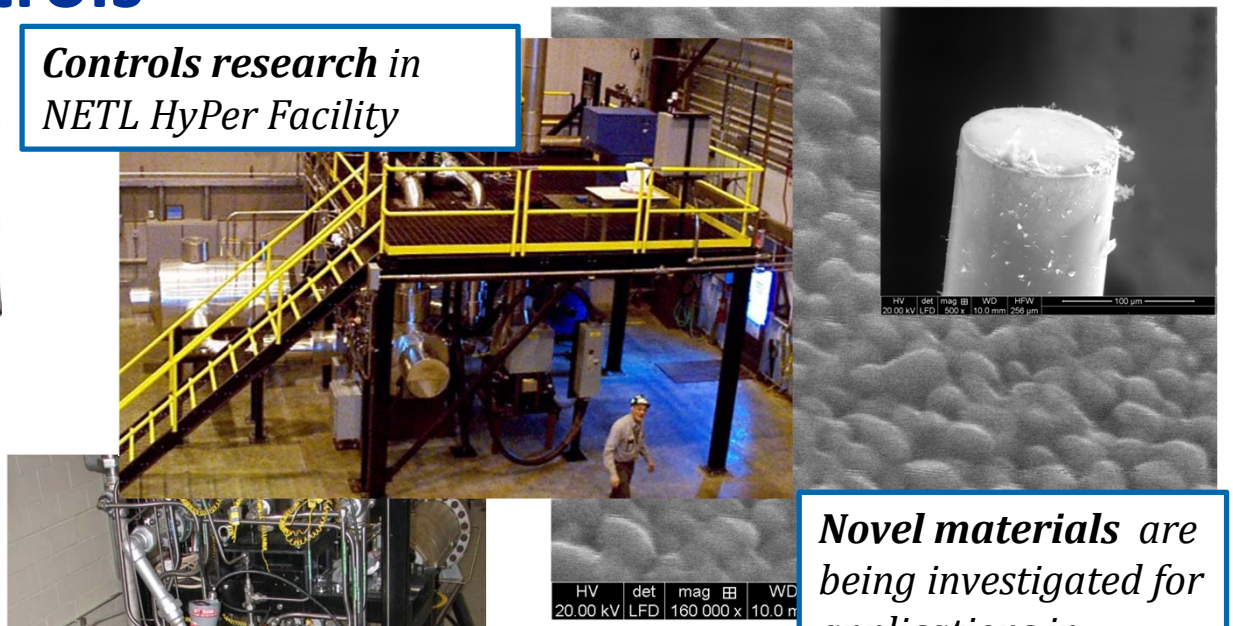
Sensors and Controls

Raman Sensor Field Test System
800 psig (55 atm)
200°C (392°F)
1 second response
CH4 – C4H10, CO, CO2, H2, N2, O2, H2O

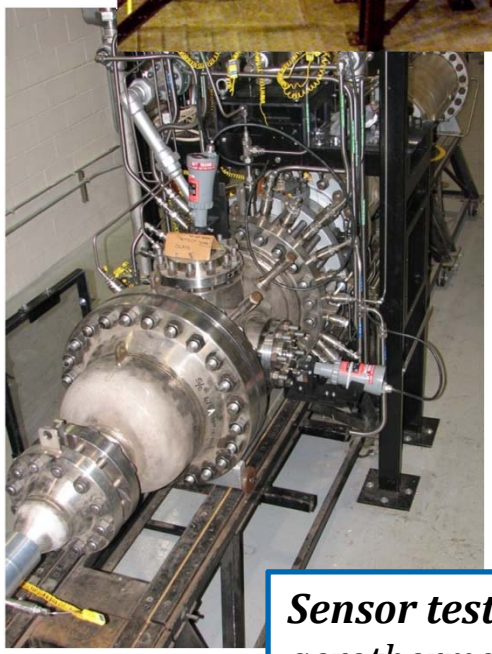


Raman Gas Composition Sensor *uses Raman scattering in an optical waveguide for real-time analysis of fuel gas composition*

Controls research *in NETL HyPer Facility*



Novel materials *are being investigated for applications in reducing and oxidizing gas streams at temperatures approaching 1000°C.*



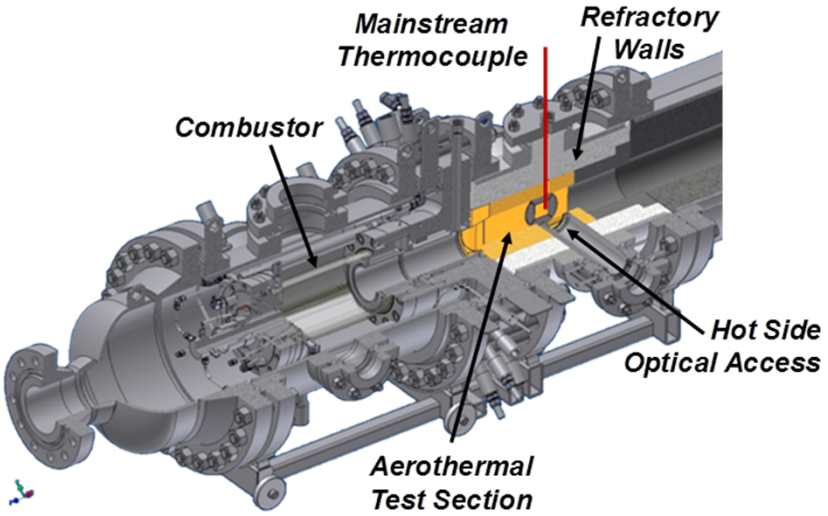
Sensor testing *on NETL aerothermal test rig*

Developing novel sensors and controls for power generation systems to enable greater efficiency, fuel flexibility, and cleaner use of fossil energy resources.

Sensors Testing in the High Pressure Combustion Facility

Testing of high temperature sensors in the B6 High Pressure Combustion Facility

- Provides a cost efficient path to advance the Technology Readiness Level
- DOE FE funded through Crosscutting Technologies
- Non-FE funded via WFO or Cooperative Agreement



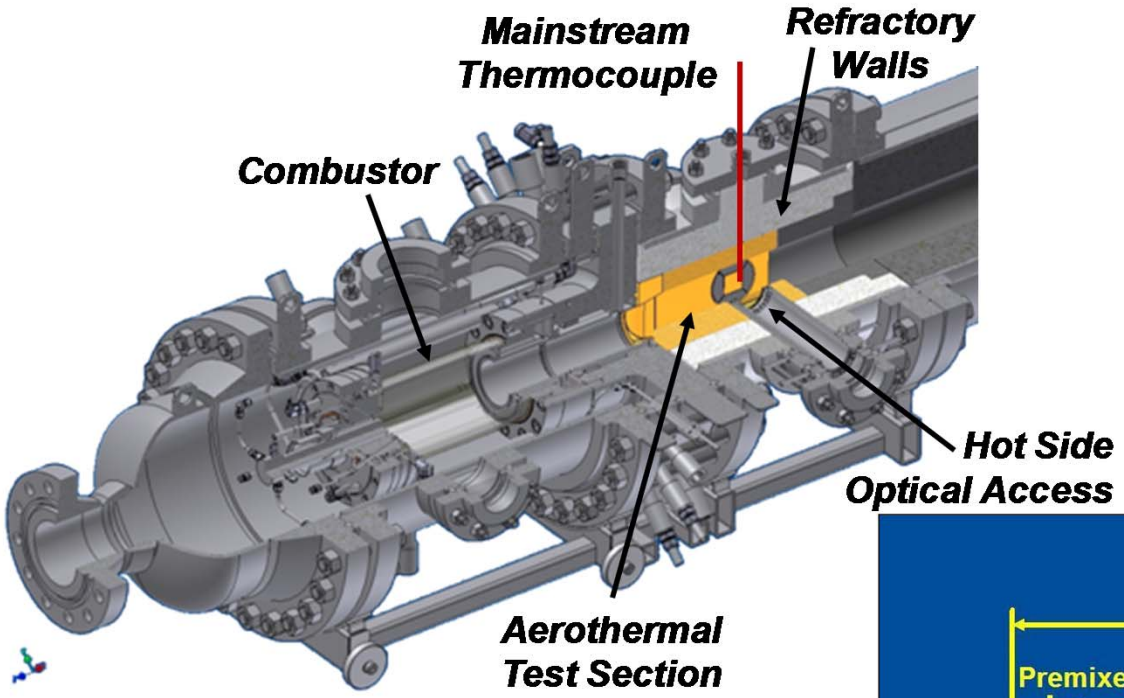
Rig capabilities

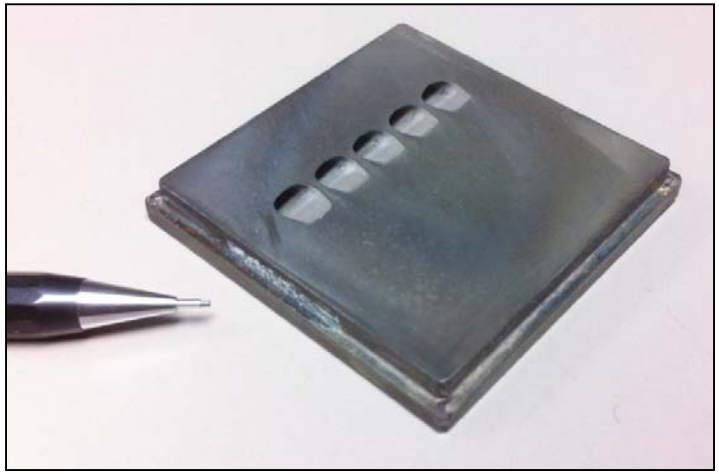
1 kg/s (~2 lbs/s) air flow @ 10 atm

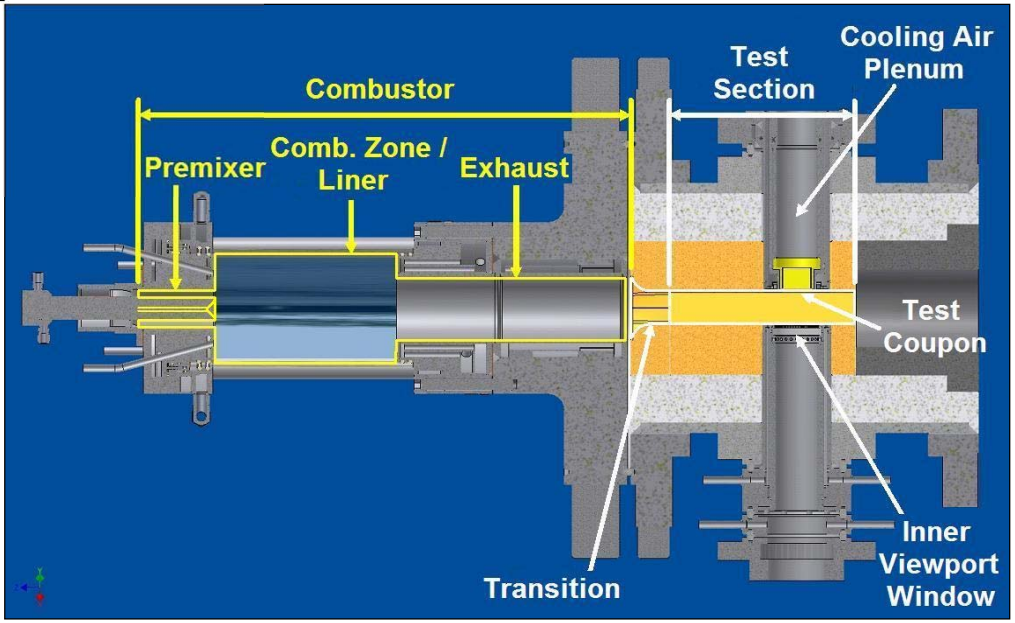
Natural gas fuel

Hot gas path temperatures of 1000-1300°C (1830 – 2370°F)

A Modified Combustion Facility To Perform Experiments In Gas Turbine – Like Environment





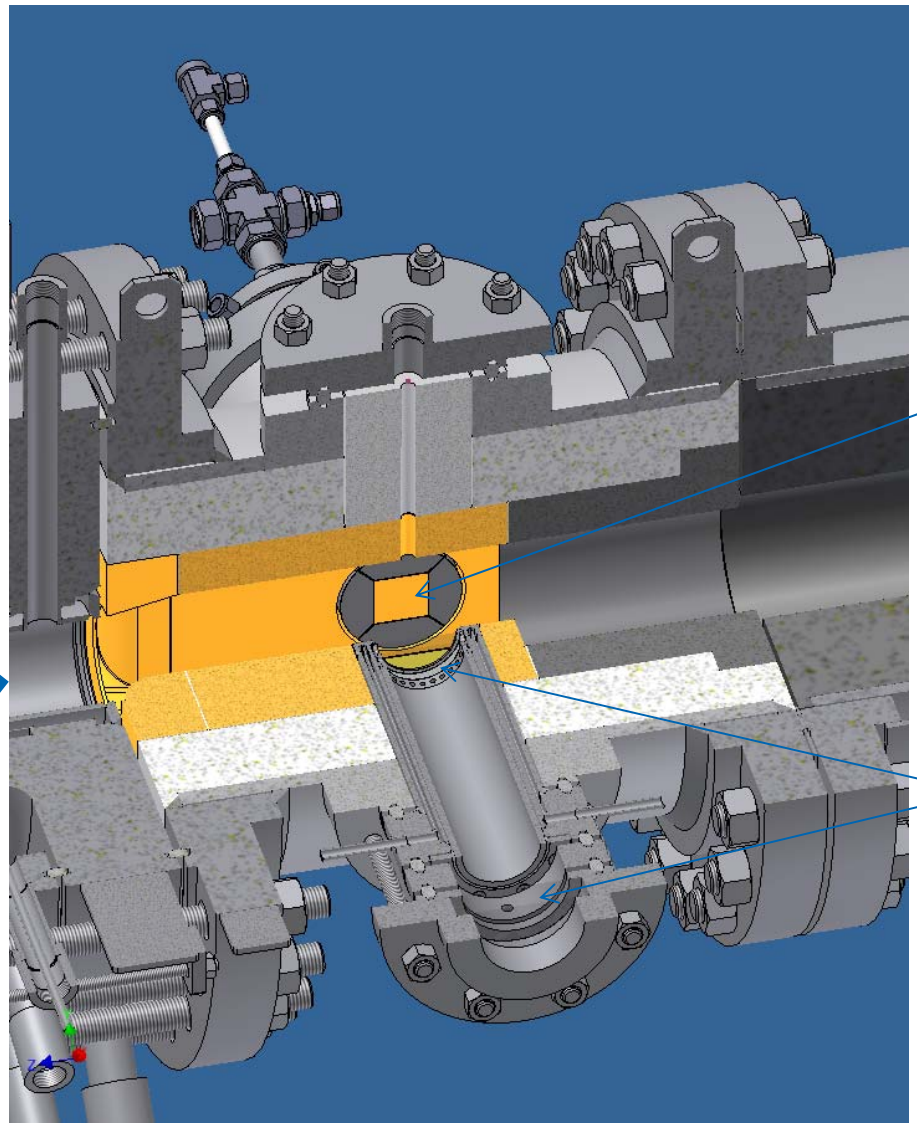


Lean, premixed, swirl stabilized, natural gas combustor

Industrial gas turbine scale combustor

Section View

Flow from swirl-stabilized premixed NG combustor

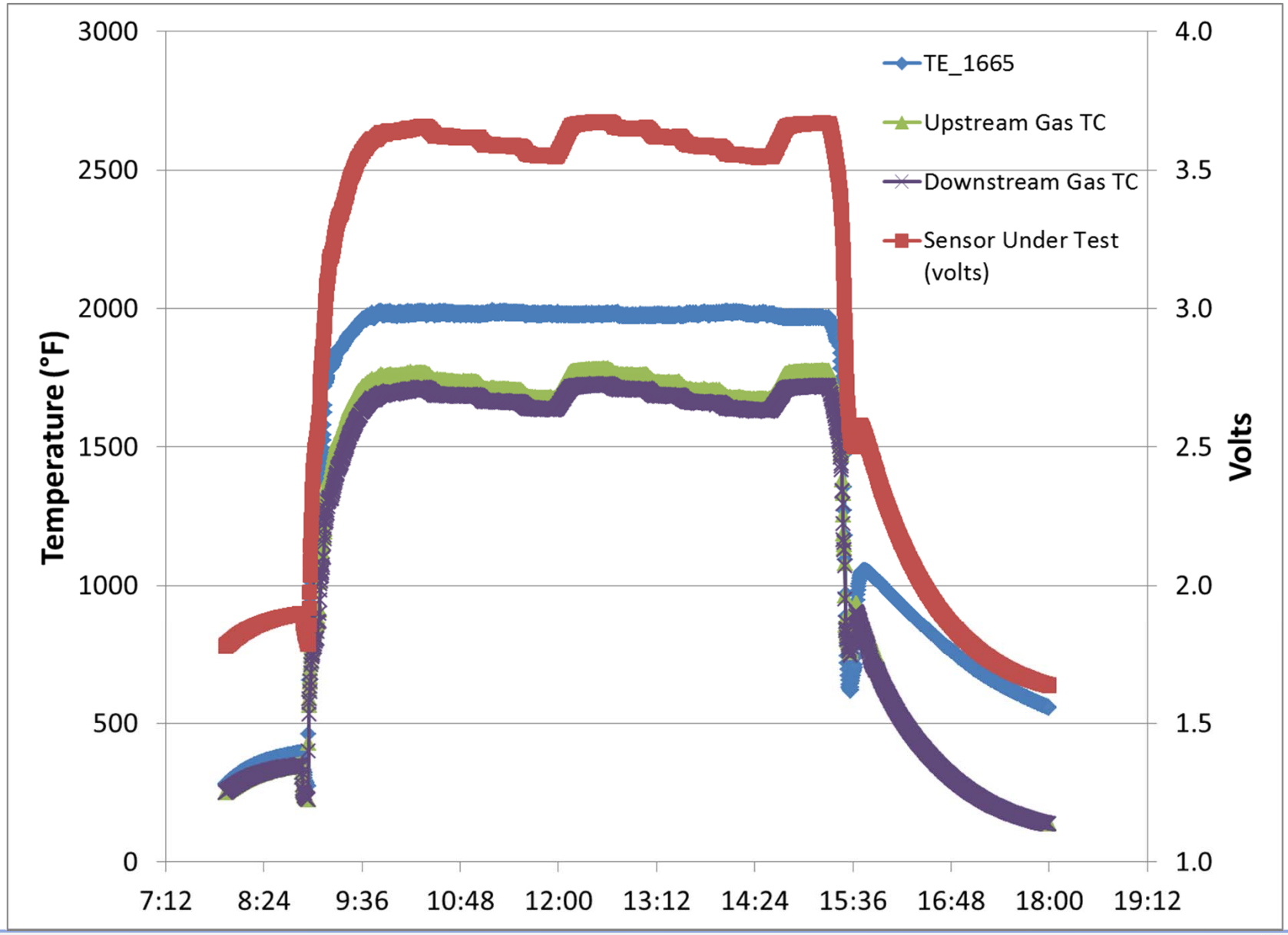


Test specimen platform (2” x 2”)

Viewport (fused silica windows)

Temperatures: 1000-1300C (typical 1175C)
Pressure: 1 – 10 bar (typical 2 – 5 bar)
Velocities: 30 – 80 m/s (typical 70 m/s)

Typical Operations



Previous Sensors Testing

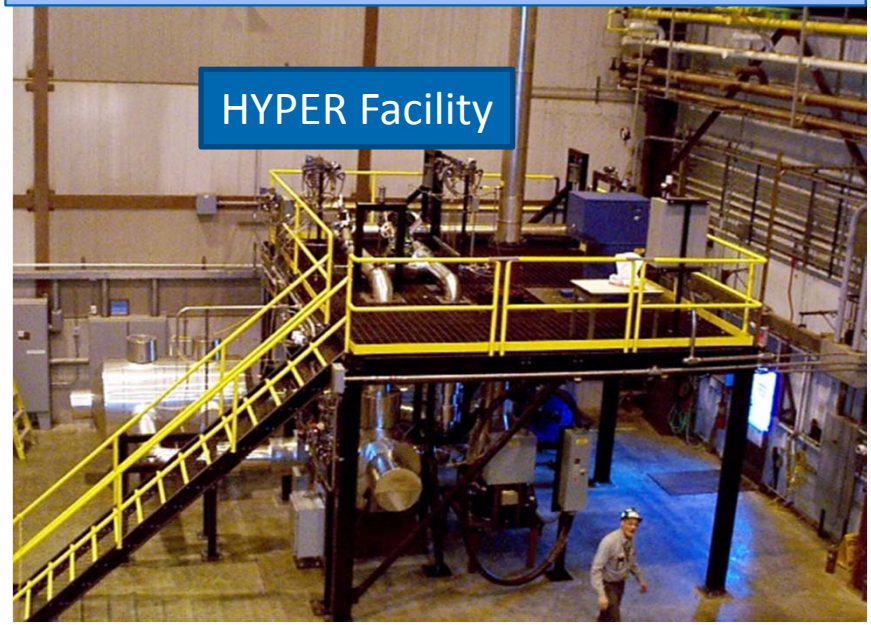
- **Virginia Tech**
  - Sapphire optical fiber temperature sensor
  - Distributed optical fiber temperature sensor
- **Los Gatos Research**
  - Multicomponent gas analyzer (CO_2, H_2O, CH_4, O_2)
  - Off-Axis Integrated Cavity Output Spectroscopy (OA-ICOS)
- **Environetix & University of Maine**
  - Surface acoustic wave (SAW) wireless temperature sensor
- **Sporian Microsystems**
  - SiBCN temperature sensors, packaging
- **And ORD sensors as well (CCADS, RGA)**

Advanced Controls (and Sensors) Testing in HYPER

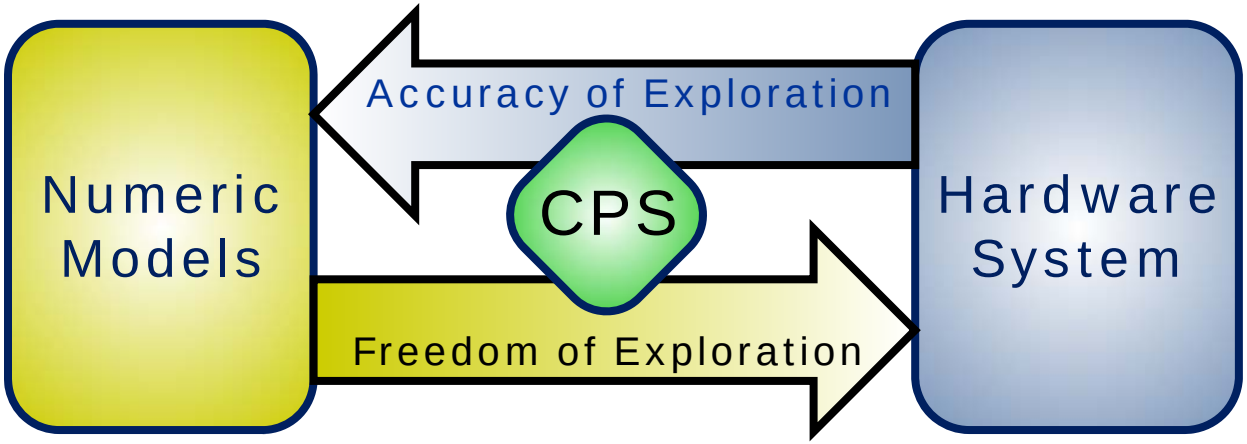
Development and testing of advanced control methods for hybrid power plant systems at the NETL HYPER facility.

- **Public Domain Facility**
- **Model and Process Validation**
- **DOE Program Support**
- **Coal Syngas Systems**
- **Integration Issues**
- **Quantifying Transient Effects**
- **Component Impact**
- **Controls Development**
- **Operating Envelope**
- **Performance Criteria**

- Cyber-physical simulation (hardware in the loop) 1D distributed fuel cell model data; exhibits real nonlinear power system dynamics.
- The control system provides advanced control testing with safety interlocks.
- Collaborative research with Ames Laboratory on highly unconventional controls for power plant applications



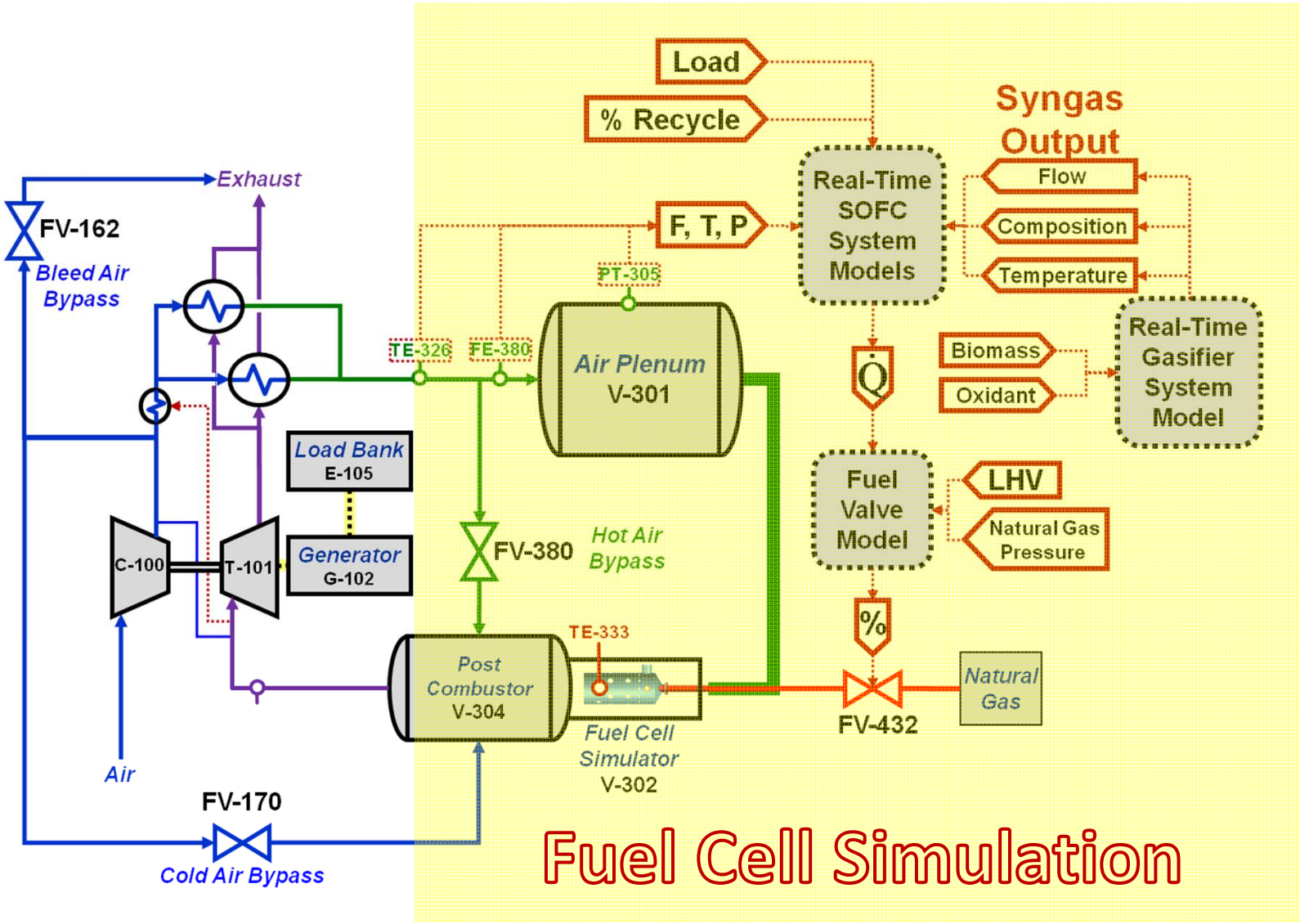
Cyber-Physical Simulation Approach

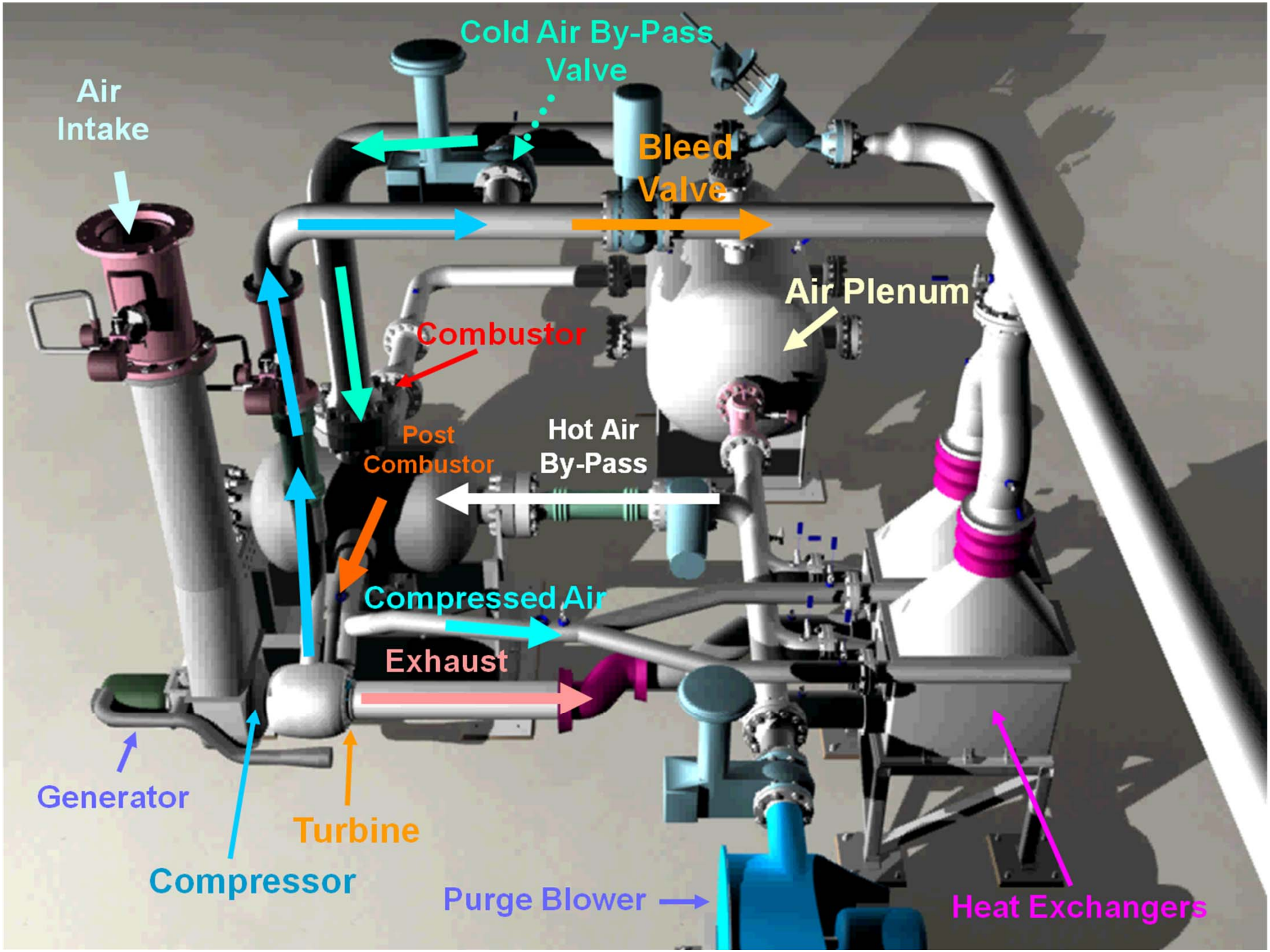


- **Combines real and virtual simulations**
- **Cost effective means to test dynamic behavior with while maintain accuracy**
- **Used by auto industry for controls testing**
- **Real-time (5ms to 30ms) models required**

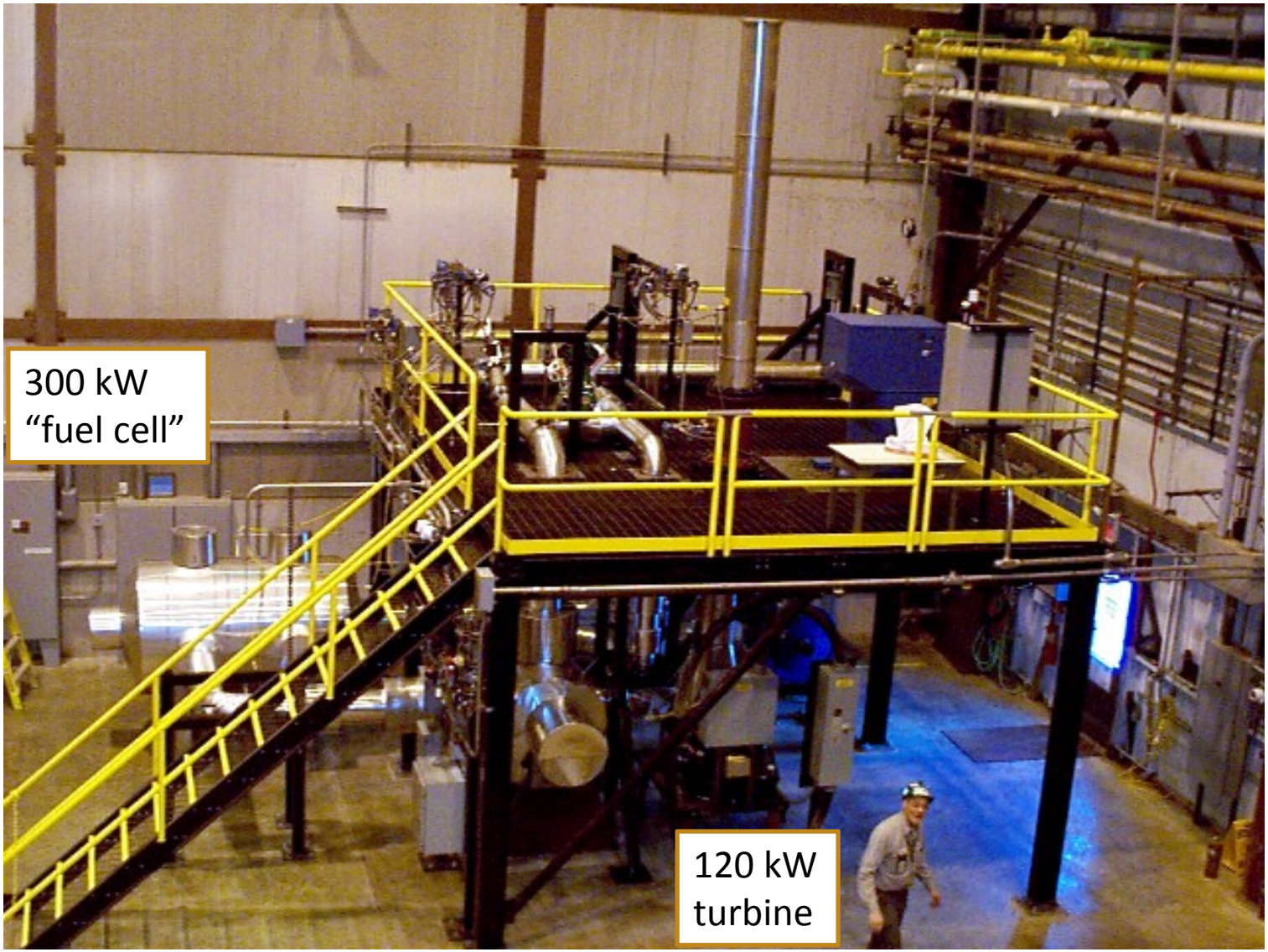
Hardware Simulation of FC/GT Hybrids

Overview of the Hybrid Simulation Facility

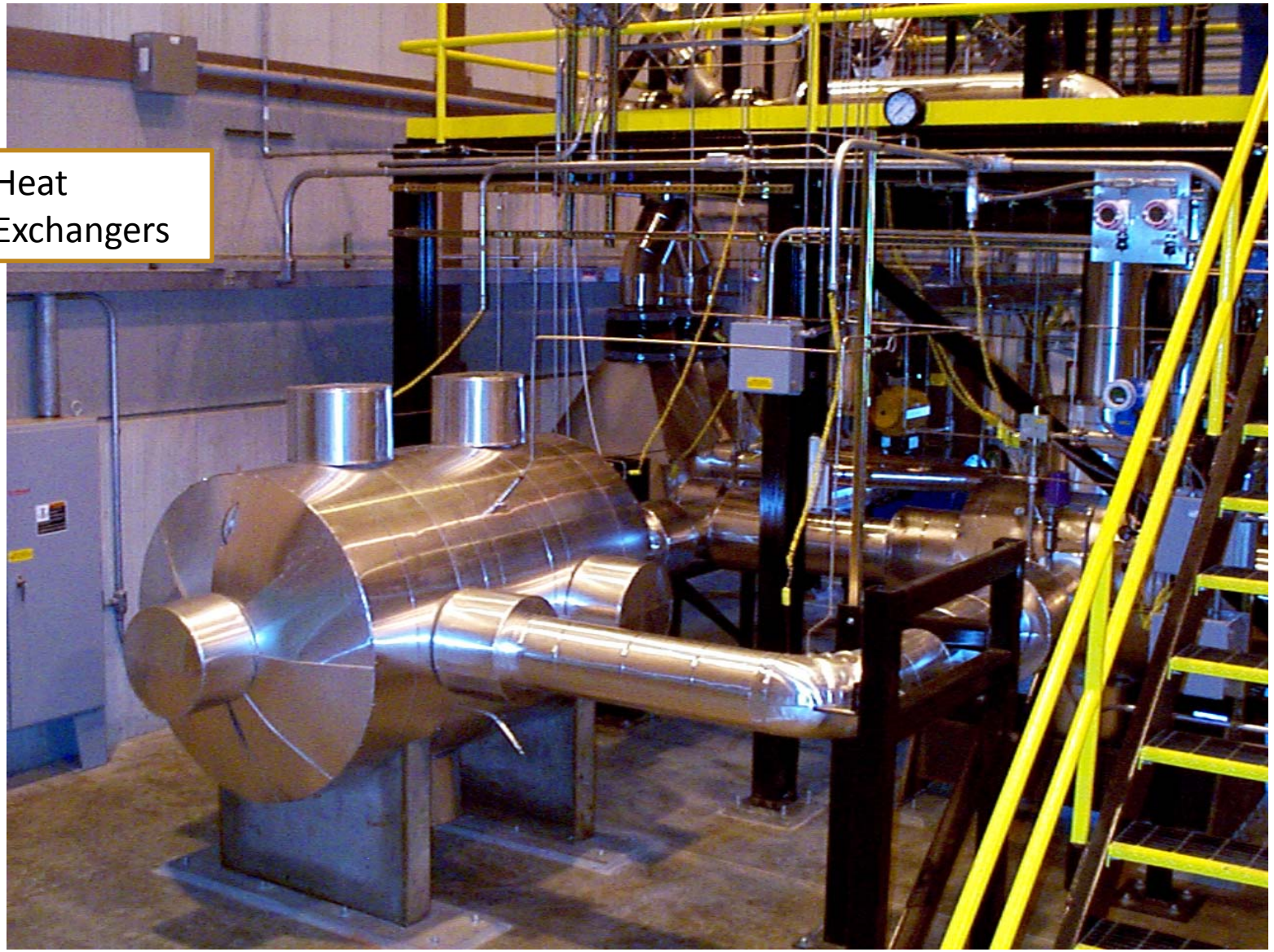



Cold Air By-Pass Valve
Air Intake
Bleed Valve
Air Plenum
Combustor
Post Combustor
Hot Air By-Pass
Compressed Air
Exhaust
Generator
Turbine
Compressor
Purge Blower
Heat Exchangers

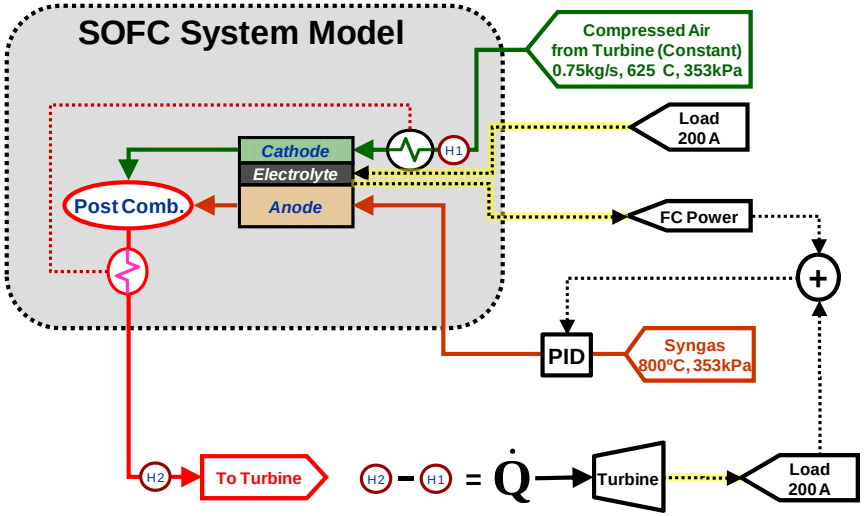
Hybrid Performance Project (Hyper) Facility



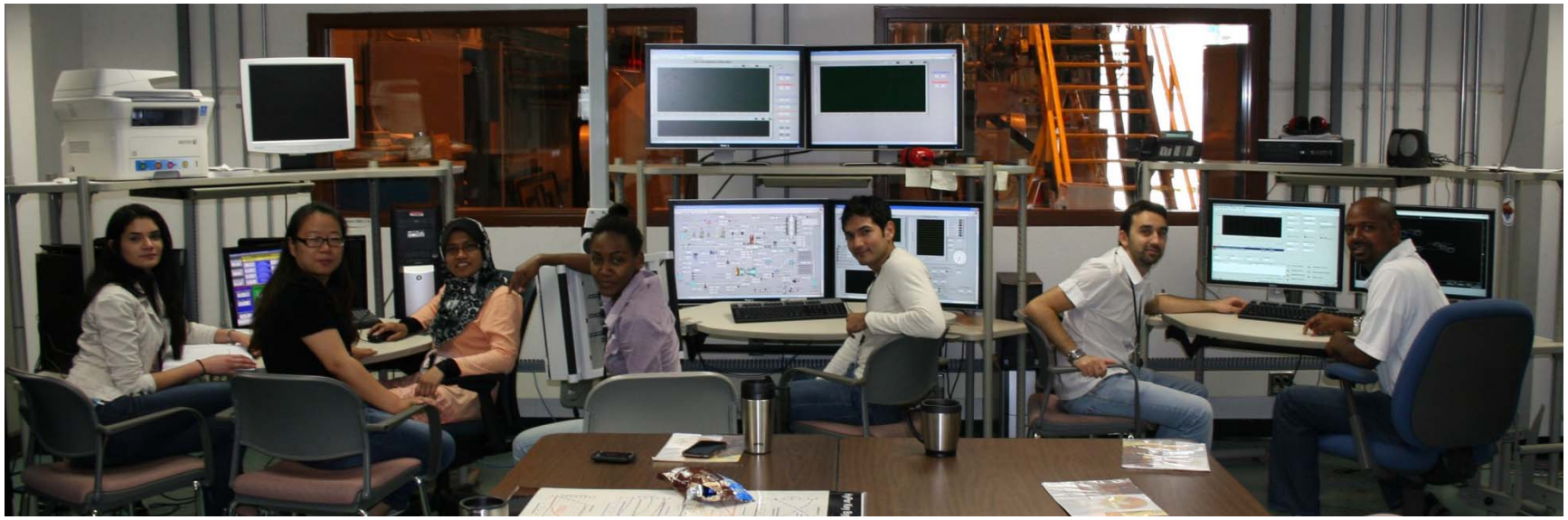
Hybrid Performance Project (Hyper) Facility



Mitigating Fuel Cell Degradation with Controls



Our team develops novel controls that dramatically improve the lifetime of advanced power systems

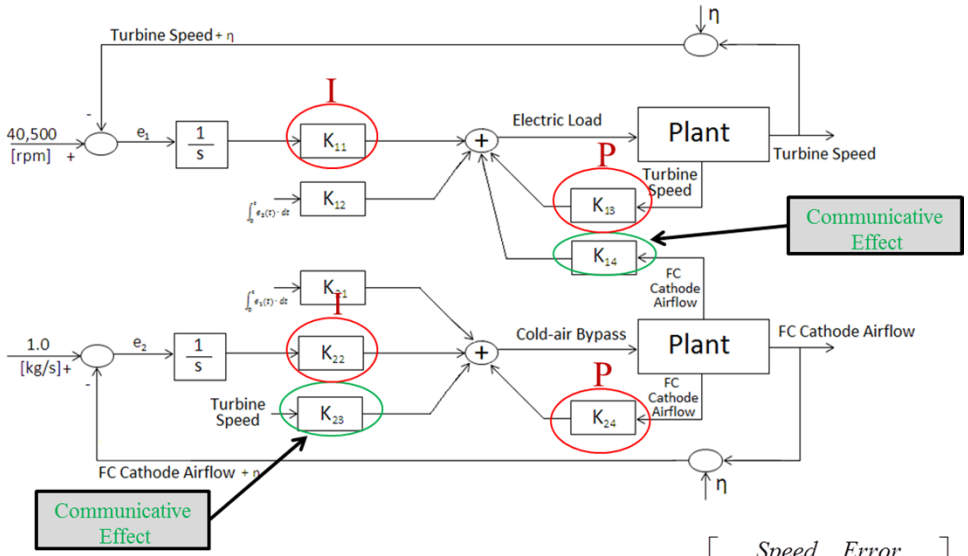


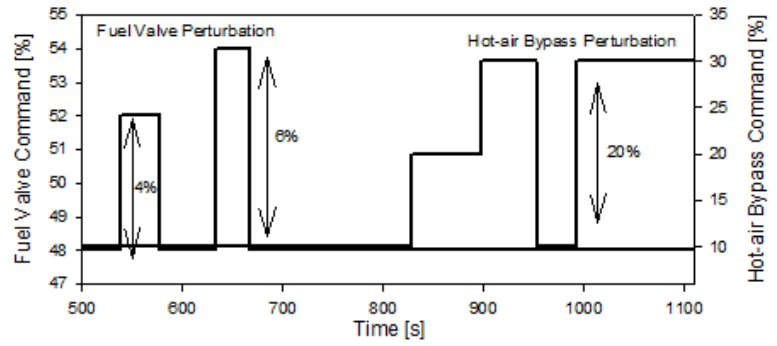
Tucker, D.; Abreu-Sepulveda, M.; Harun, N. F. "SOFC Lifetime Assessment in Gas Turbine Hybrid Power Systems," J. Fuel Cell Sci. Technol, v. 11, 051008 (2014)

Multivariable Controls Development

Working toward the development of dynamic controls to achieve the highest degree of disturbance rejection

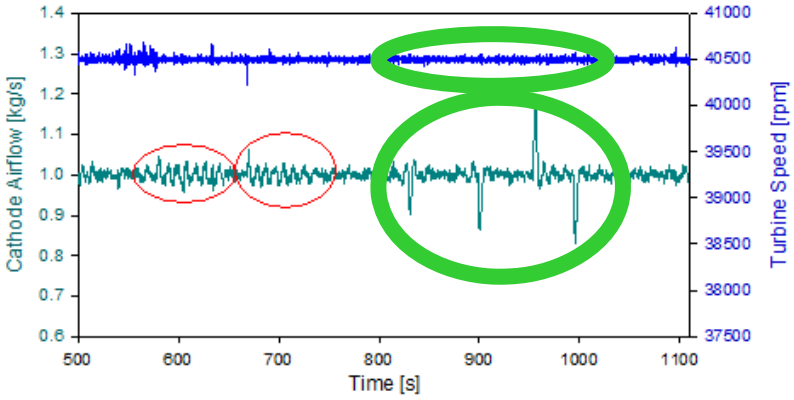
MIMO Control Implementation

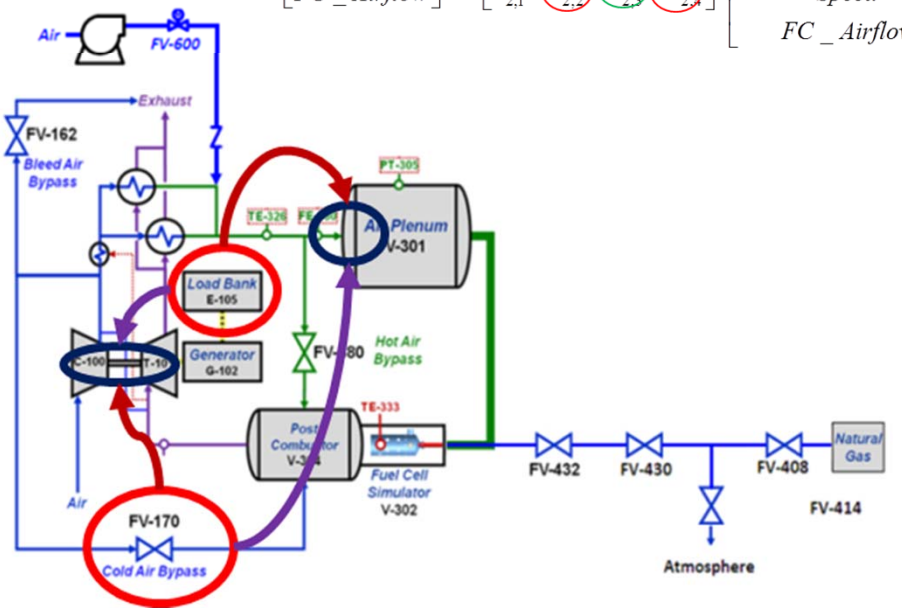


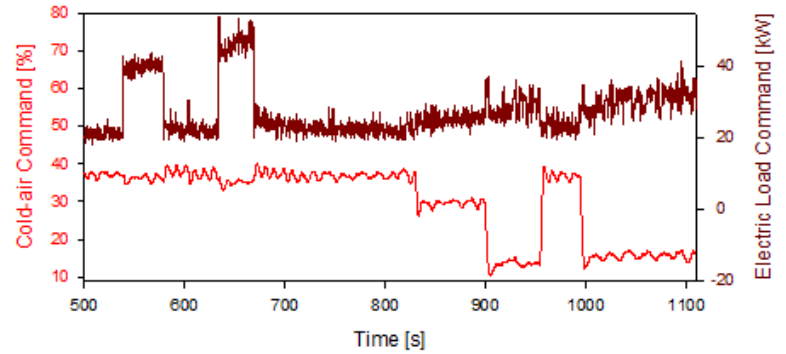


➢ ***Hyper Control Law:***

$$\begin{bmatrix} Speed \\ FC\_Airflow \end{bmatrix} = -\begin{bmatrix} k_{1,1} & k_{1,2} & k_{1,3} & k_{1,4} \\ k_{2,1} & k_{2,2} & k_{2,3} & k_{2,4} \end{bmatrix} \cdot \begin{bmatrix} Speed\_Error \\ FC\_Airflow\_Error \\ Speed \\ FC\_Airflow \end{bmatrix}$$



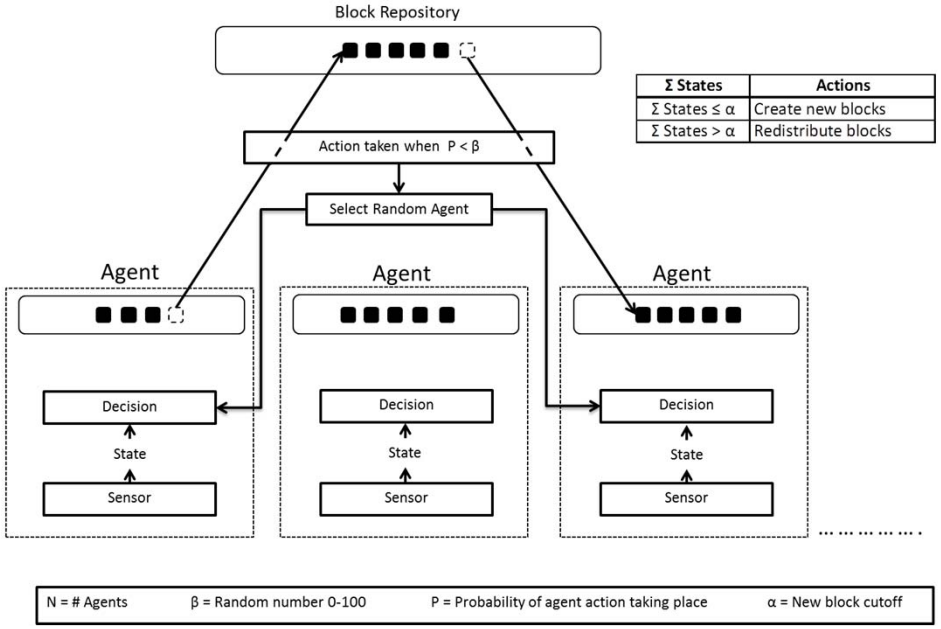




Stigmergy Testing
(Collaboration with Ames National Lab)

- **Stigmergy controller in the MicroNET**
  - Used for multivariable agent-based control of Hyper
  - Behavior is confined by state function blocks in the Hyper control system

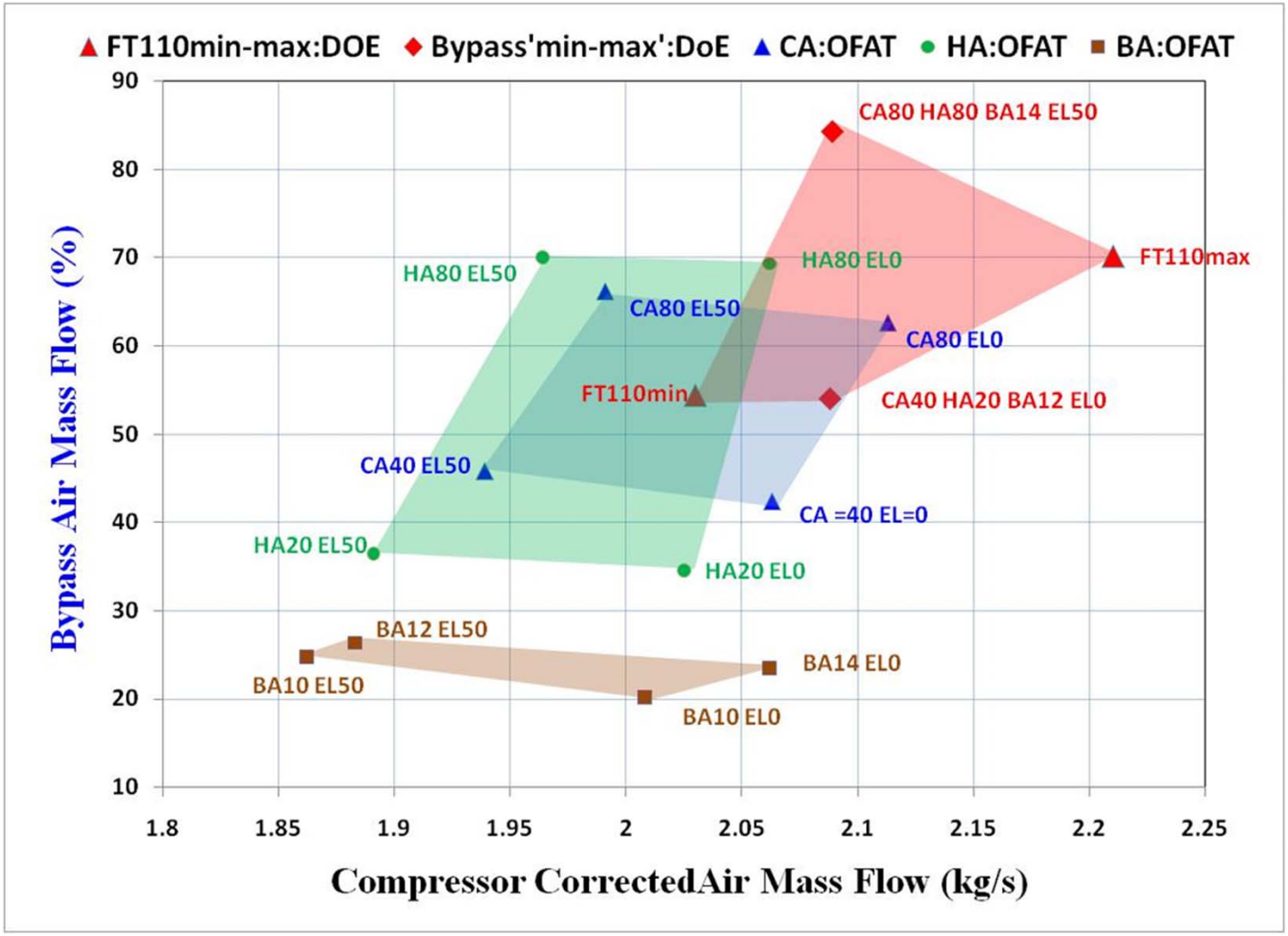
Stigmergic Control Architecture



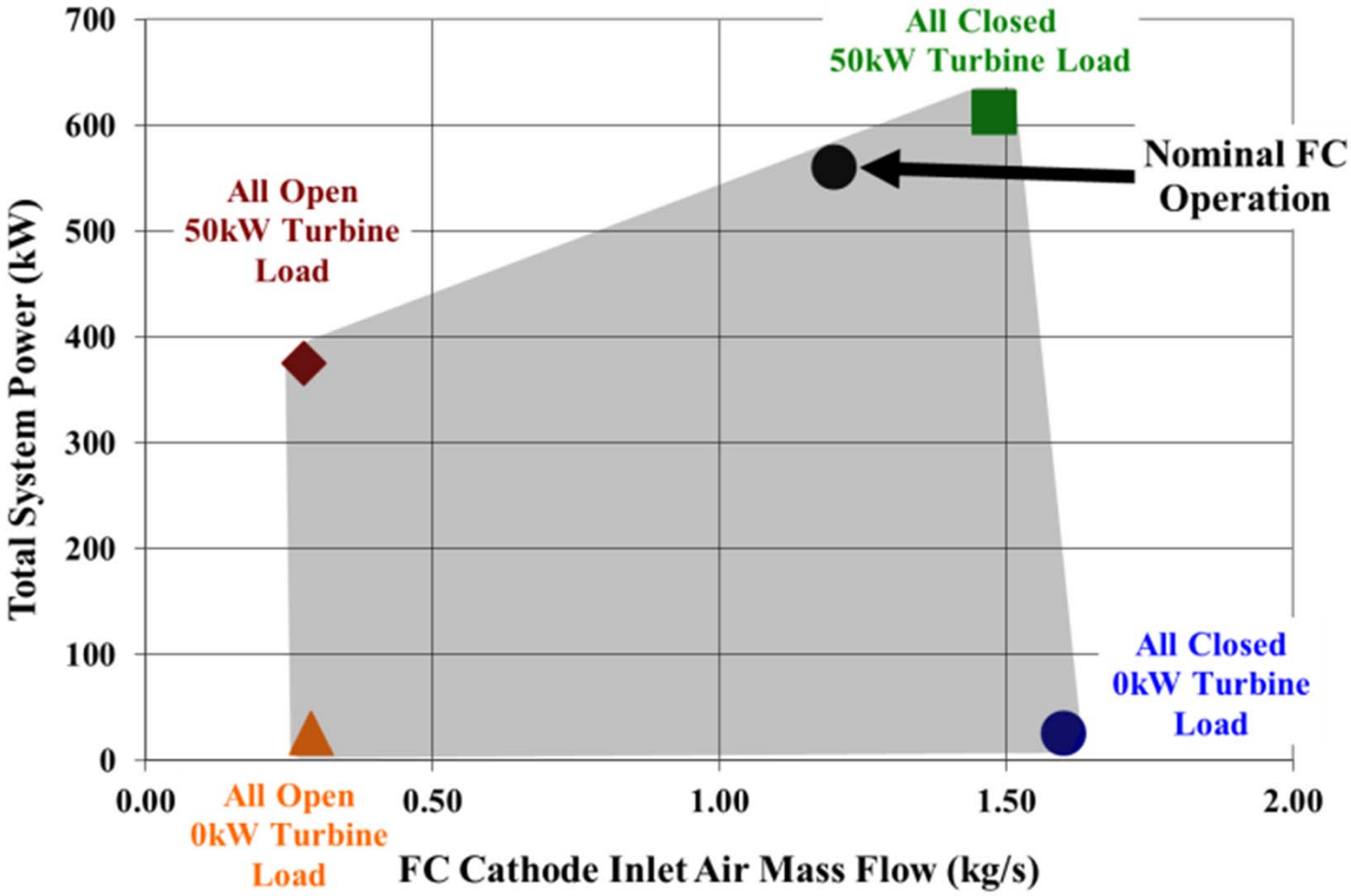
Operating Envelope

Optimizing the flexibility and applications of novel power cycles

Operating Envelope with Multiple Valves



Operating Envelope with Multiple Valves



ASME 2015 Power and Energy, San Diego, CA, (to appear 6/28/2015)

Sensors testing, too!

Students and Visitors from Worldwide

Hyper Collaborations

Domestic Collaborations

West Virginia University
Georgia Institute of Technology
University of California, Irvine
Oregon State University
Iowa State University
Florida International University
Ames National Laboratory
Woodward Industrial Controls

International Collaborations

The University of Genova
McMaster University
Chongqing University
University of Manchester
Technical University of Denmark
The German Aerospace Research Center (DLR)

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Questions?

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HyPer: David Tucker (David.Tucker@netl.doe.gov)

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