SOUTHERN RESEARCH

INSTITUTE

Oxy-Fired Flue-Gas Recycle Pilot-Plant Demonstration

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Project Participants

- National Energy Technology Laboratory (NETL)
  - Management of the project
- Southern Research Institute
  - Design of recycle loop, equipment modifications, and control systems
  - Oxygen Skid, Tank, Piping, Manifold, and Delivery System
  - Overall technical coordination, pilot-scale testing, reporting
- MAXON Corporation
  - Burner design, manufacture, and testing, and technical support
- DOOSAN Babcock Energy Limited
  - Support CRF retrofit, technical support, and provide recommendations
- Southern Company
  - Supporting the testing effort in the Southern Company/Southern Research pilot-scale facility
- *Linde* Gas
  - Supplied an oxygen receiving skid, and technical support
- Reaction Engineering International (REI)
  - CFD model modification for the pilot facility

Overall Project Objective

- The objective of this project was to investigate oxygen-fired flue-gas recycle technology for existing coal-fired utility boilers by retrofitting the existing Southern Company/Southern Research 1 MW pilot-scale test facility, utilizing an advanced oxy-fired coal burner, measuring the operation and output responses to adjustable operating parameters, and using CFD modeling to compare flame temperatures between air and oxygen firing.

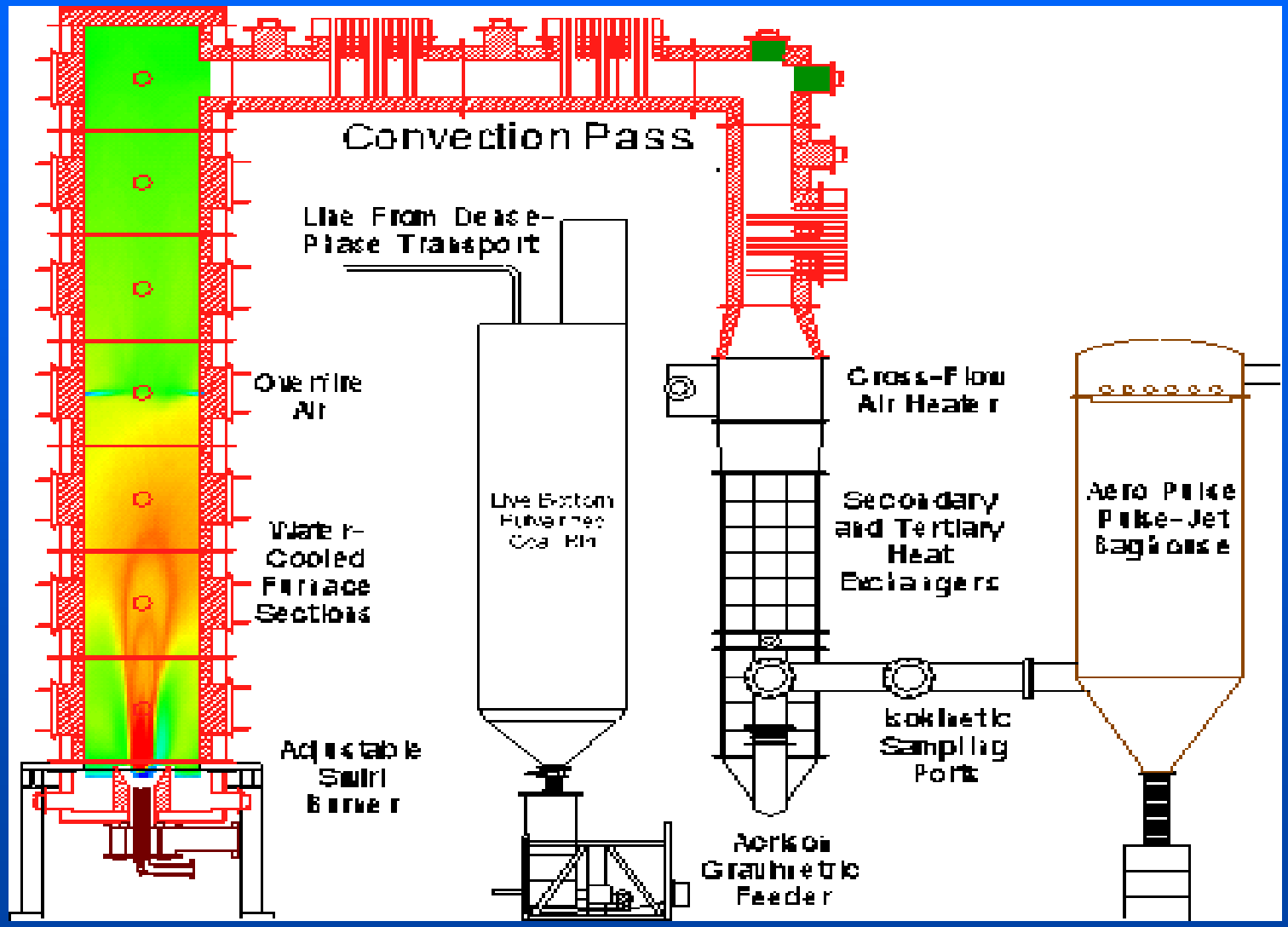
Fundamental Science Driving this Oxy-Fired Technology

- ~75% of Coal-Fired Flue Gas is N_2
- Oxy-Fired Flue Gas is ~1/4 the Volume
- Flue-gas recycle is required for existing plants
  - To avoid excessive flame temperatures
  - Maintain flow and heat-transfer requirements in the furnace and convective sections
- Advanced Oxygen Burners
  - Allow the flame shape and heat release to be controlled
  - Provide a stable attached flame

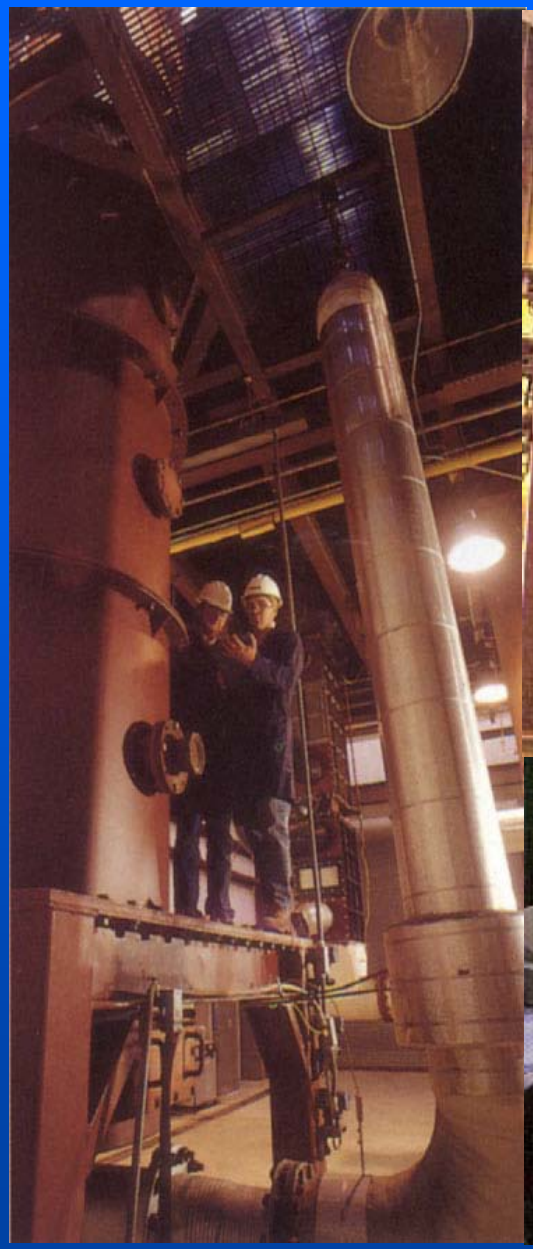
How the Innovative Oxy-Burner Design Works

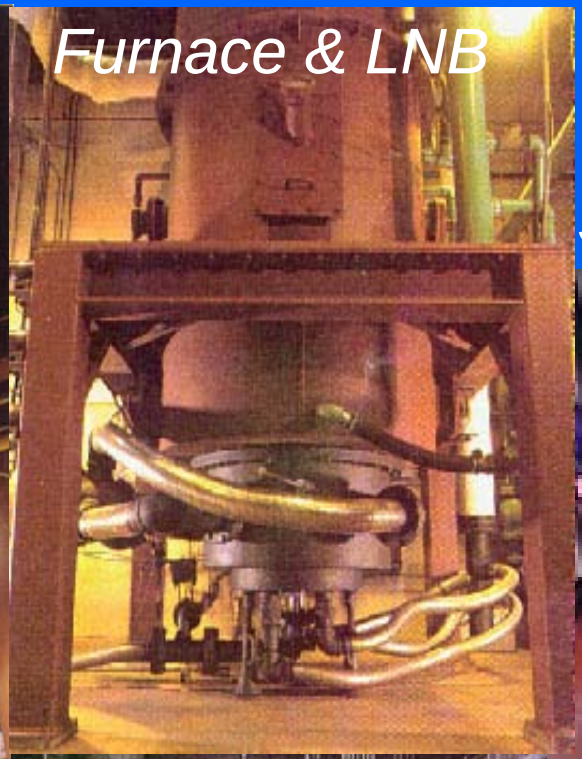
MAXON

Combustion Research Facility



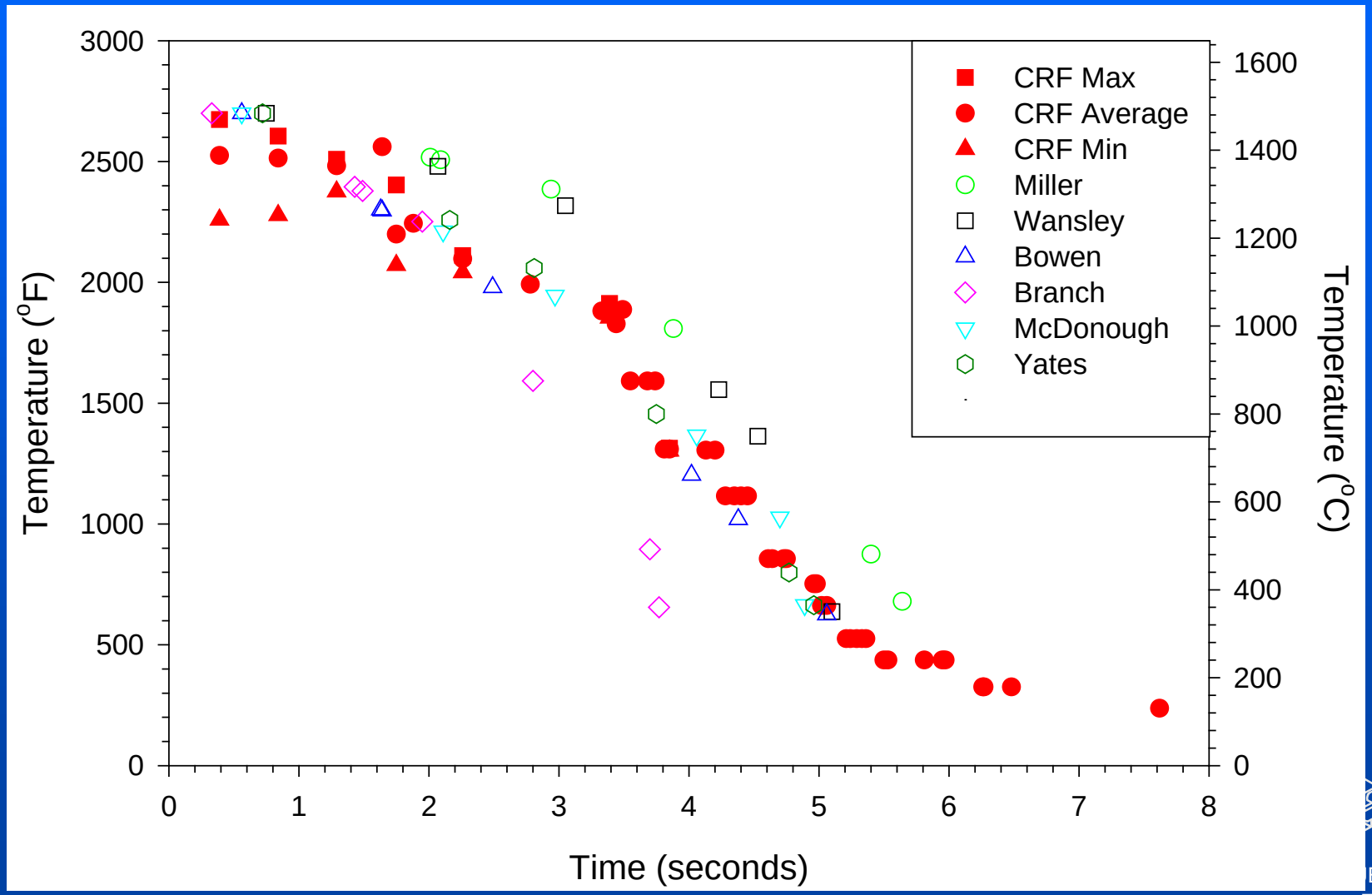
Combustion Research Facility



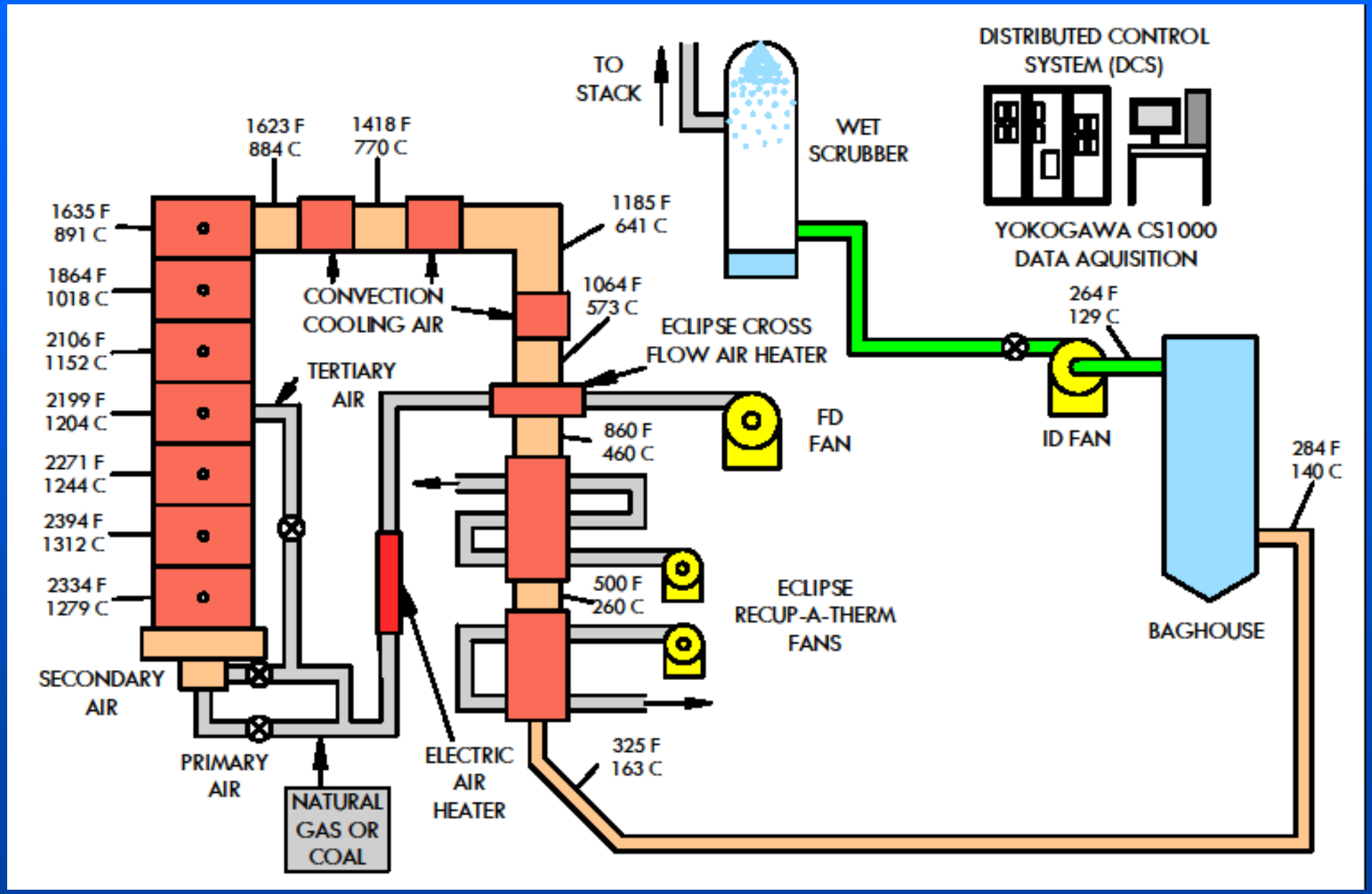


Center Furnace Section Showing Overfire Air Ports

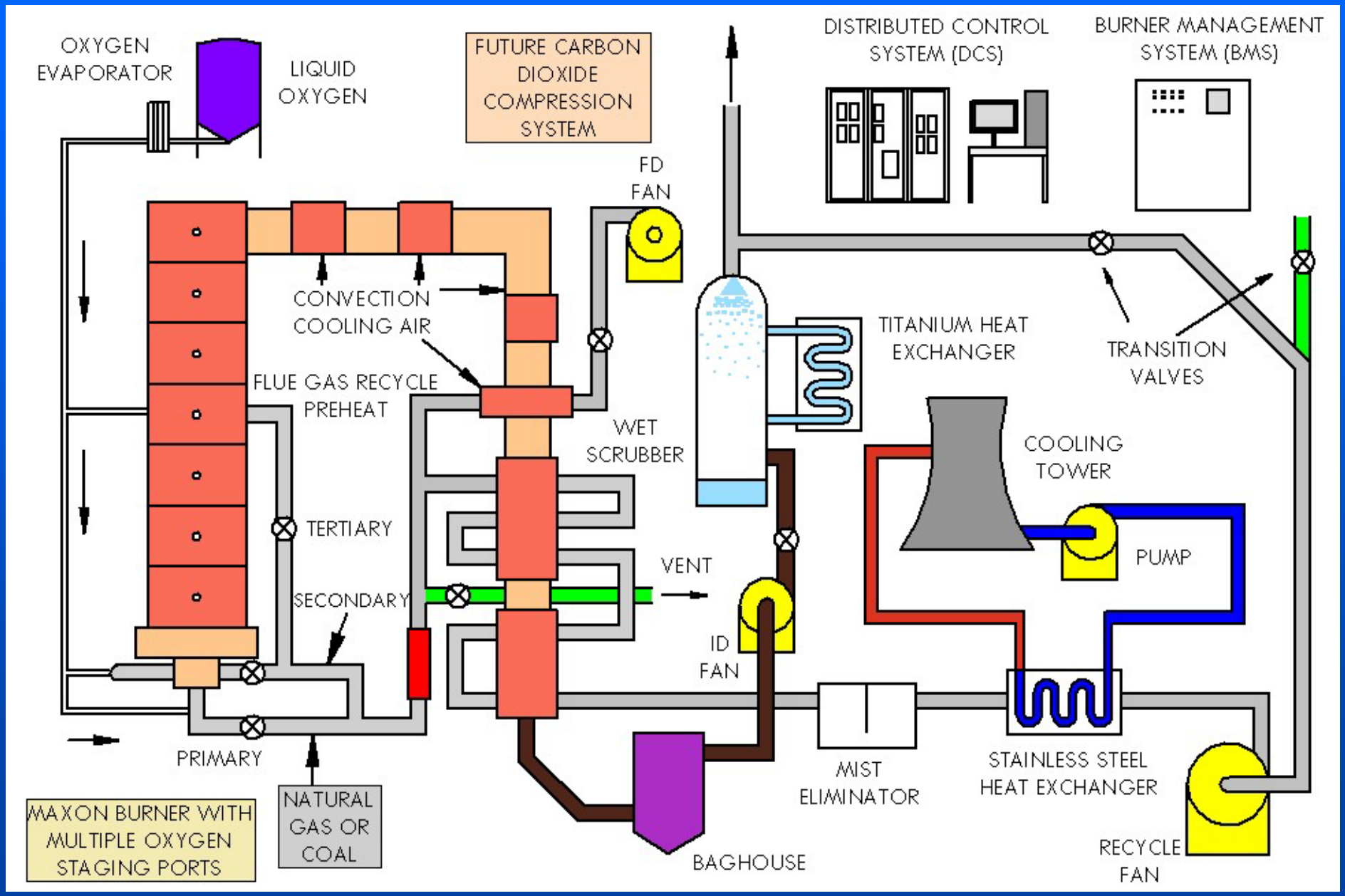
Temperature/Time Profile of the Combustion Research Facility



Original CRF Configuration



Retrofit CRF Configuration



Main Components of the Retrofit

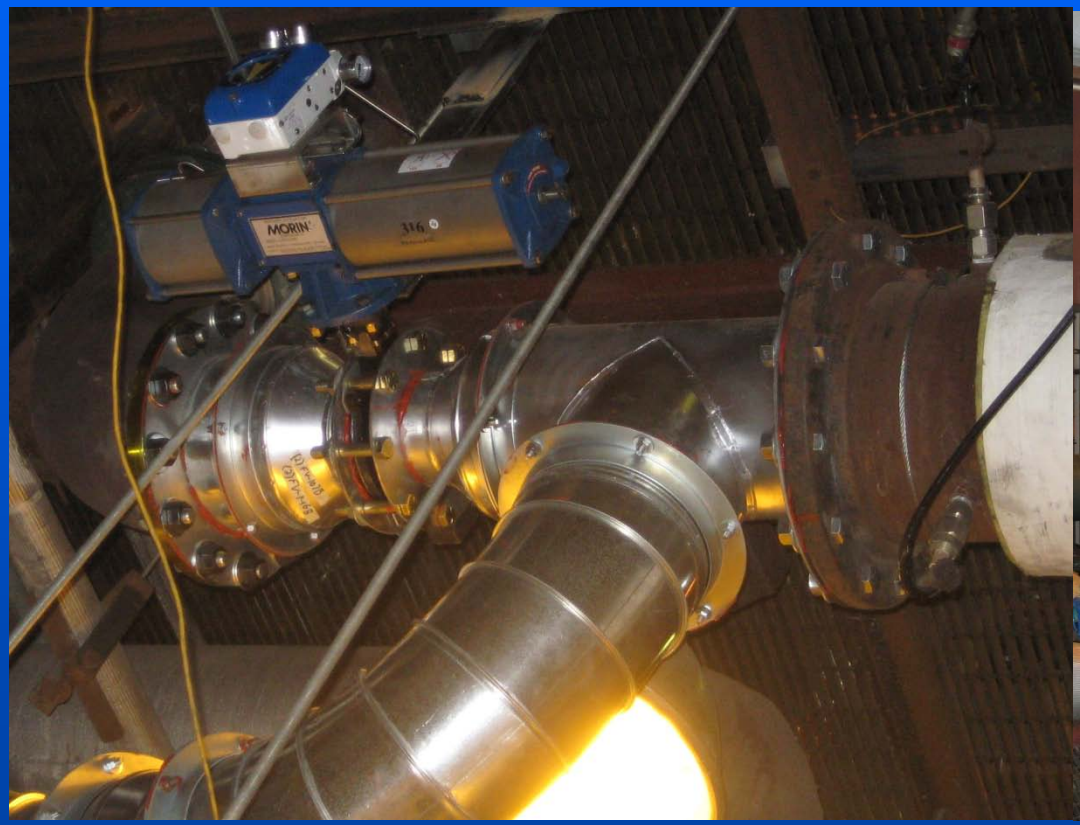
- MAXON Oxy-Fired Burner
- Oxygen Skid and Piping System
- DCS (Distributed Control System) Hardware Updated to Yokogawa CENTUM VP
- New data acquisition and control system and program to modulate the flow of oxygen and recycled flue gas.
- Burner Management System (BMS)
- Recycle System
  - Recycle Fan
  - Ductwork, Valves, Thermocouples, Flow Meters
  - Titanium Scrubber-Liquid Cooler (maintain Temp, near 80 ^{o}F)
  - Recycle Gas Cooler and Mist Eliminator
  - Additional Cooling Tower to recycle water from new coolers
- Permanent Oxygen Tank, Tank Pad, and Spill Pad
- Safety Systems
  - BMS Alarms and Interlocks
  - Additional CO_2 and CO Monitors, Alarms, and Interlocks

Oxygen Tank and Evaporator

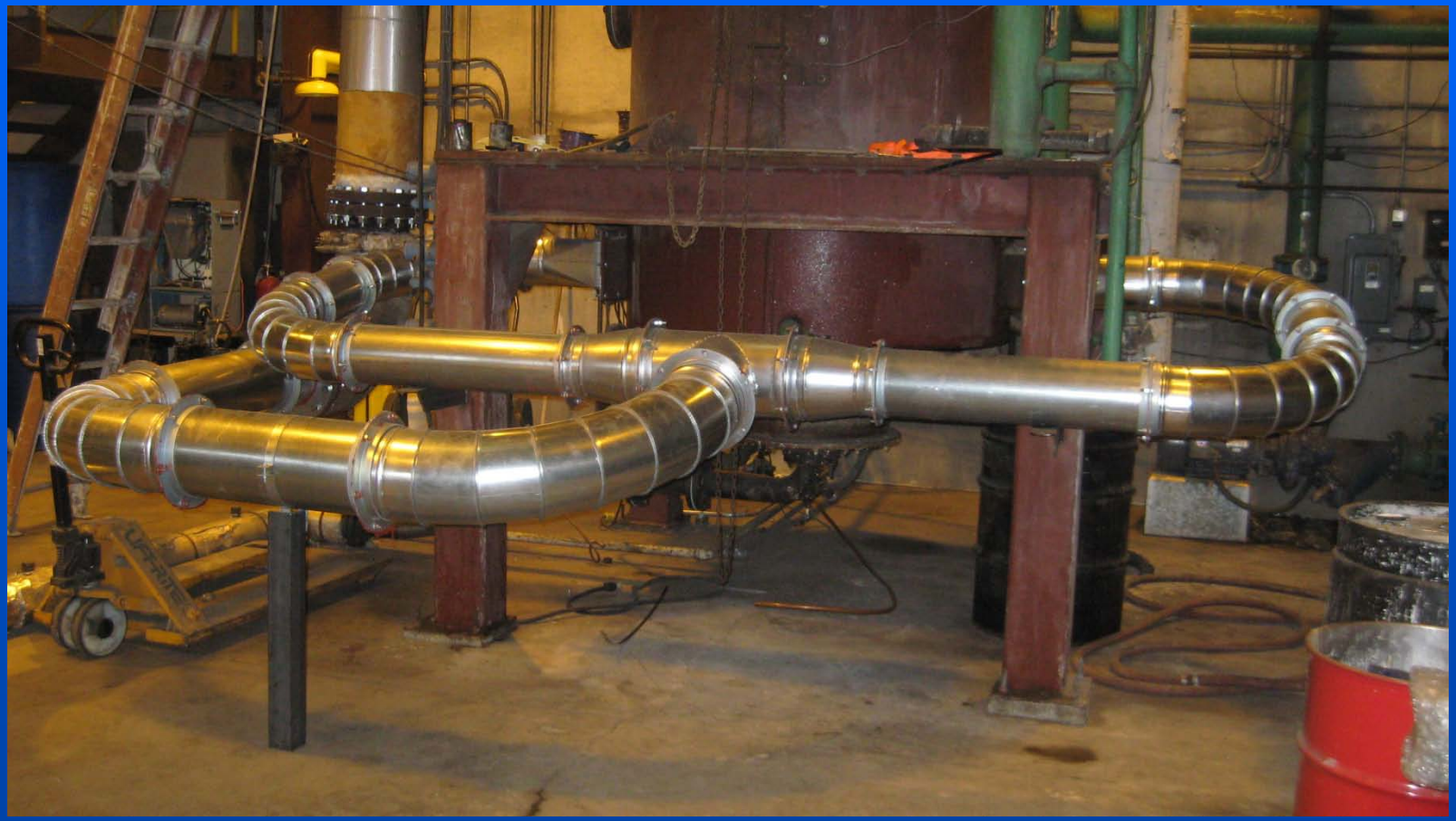
Stack Recycle Takeoff and Fan

Recycle Reheat Ducting

Pneumatic Valves Switch from Air to Recycle in Secondary Line



Recycle Evenly Injected on Either Side of the Burner Quarl



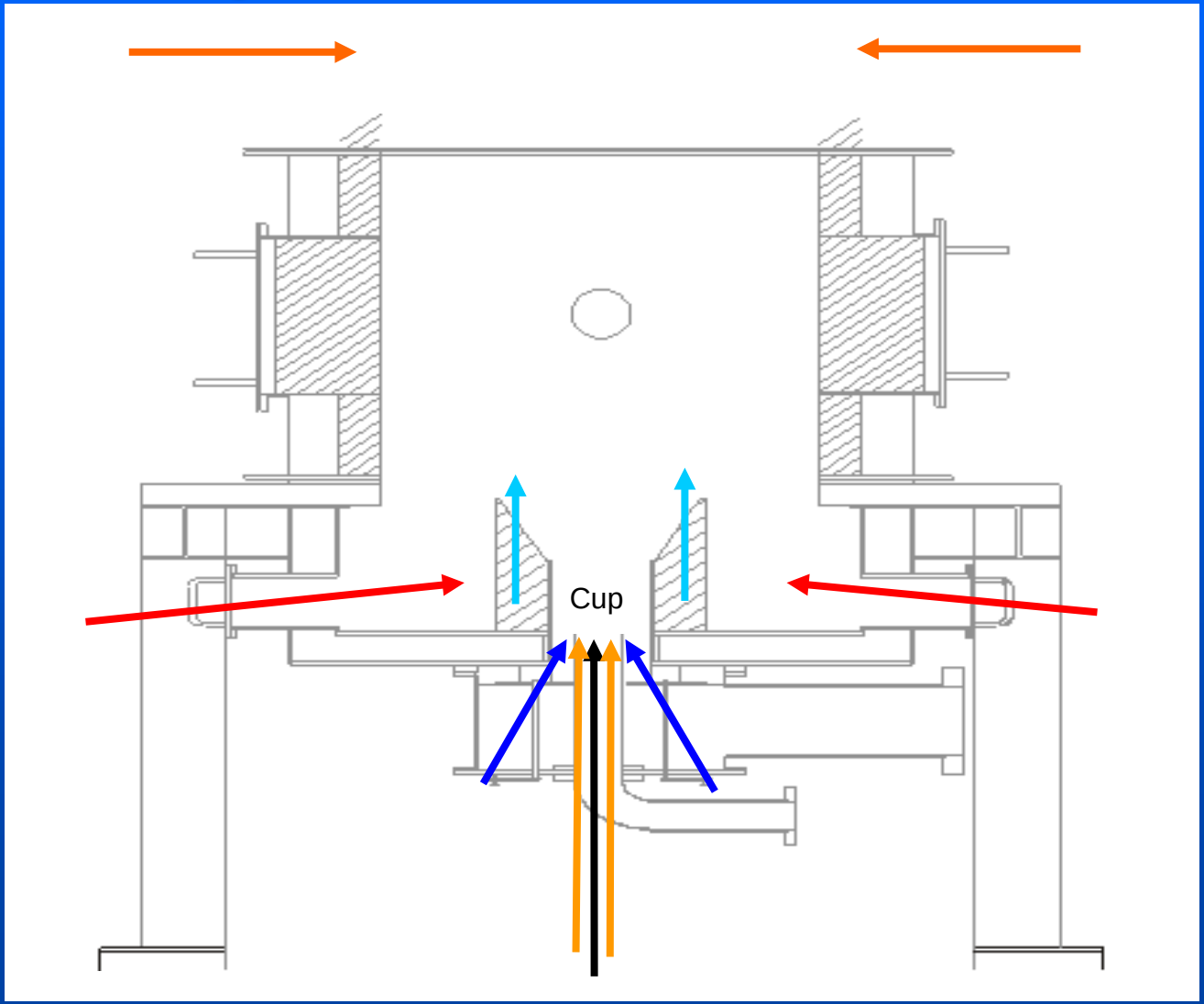
Transport Gas Switched to Recycle Flue Gas During Oxy-Firing

Scrubber and Recycled Flue-Gas Coolers, Mist Eliminator, and Cooling Tower

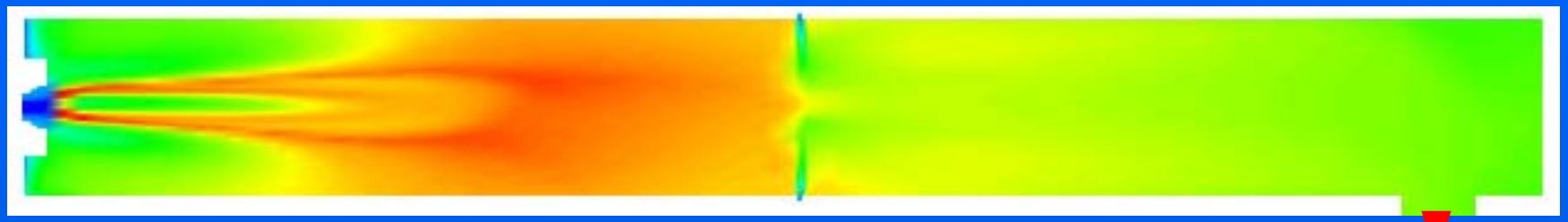
Coal Types Tested

- 3 High-Volatile Eastern Bituminous Coals
  - Choctaw America – Low S, Low Chlorine HvA
  - Blacksville – Higher S, Medium Chlorine HvA
  - Galatia – Medium S, High Chlorine HvB
- PRB sub-bituminous coal – NARC
- Western Bituminous Coal
  - West Elk – Reactive, low-sulfur HvA coal

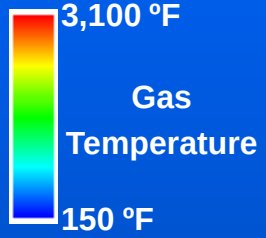
Oxygen, Recycled Flue Gas, and Coal Injection Points



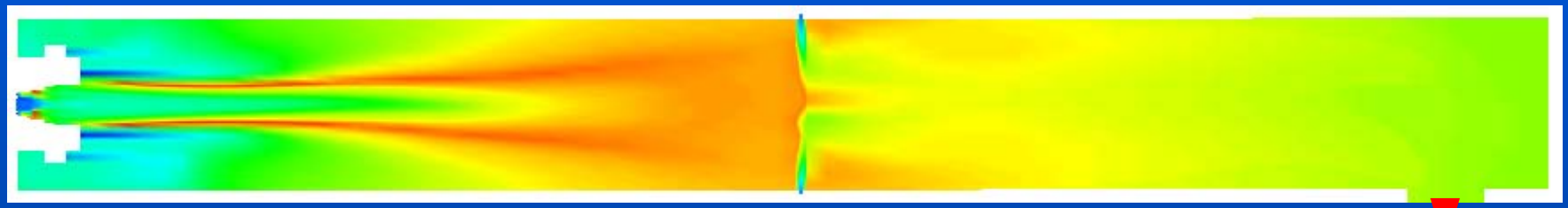
CFD Model Comparison of Air-Blown and Oxy-Fired with Recycle Flame Temperatures



Air Blown



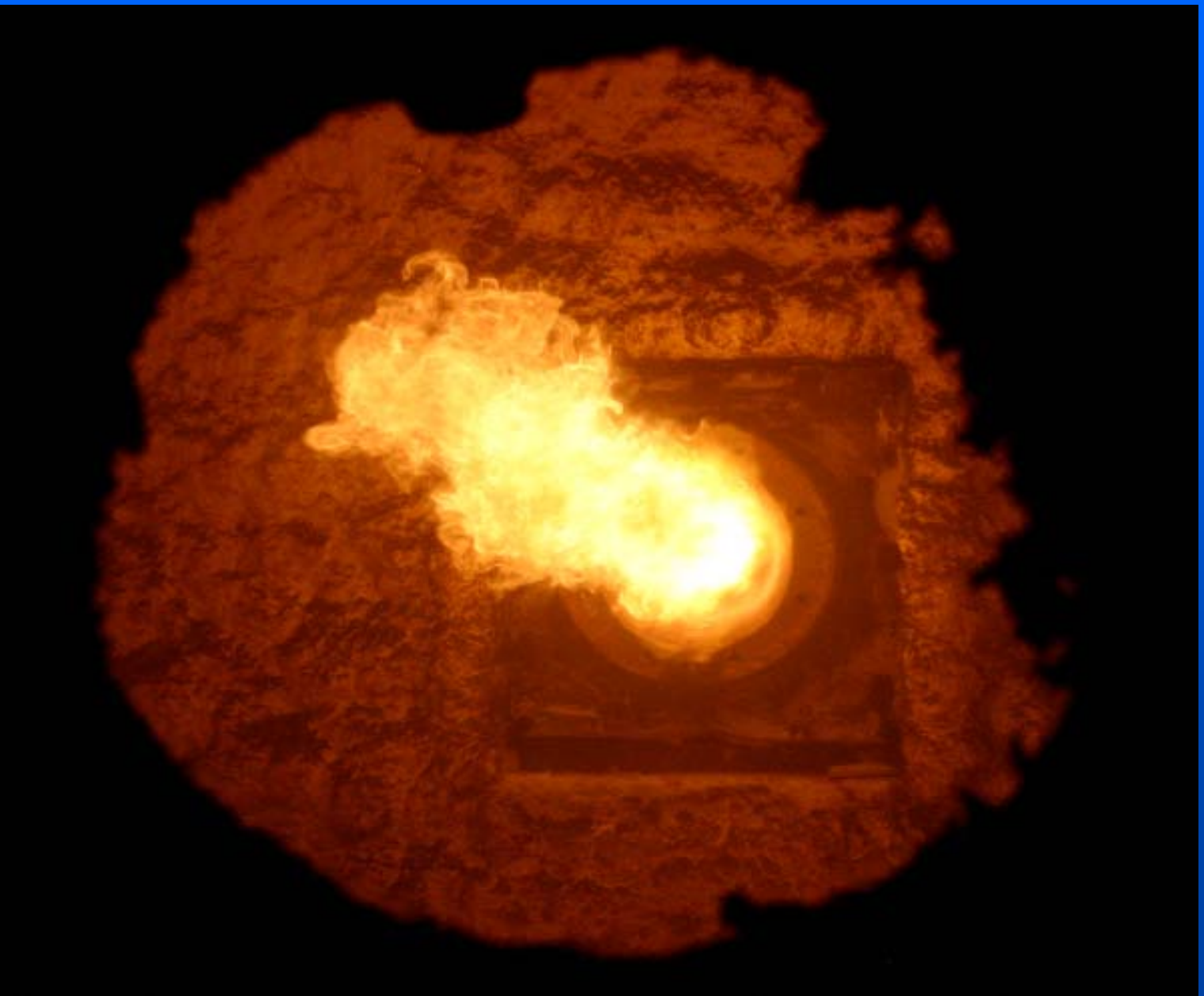
To convective section



Oxy-Fired with Recycle

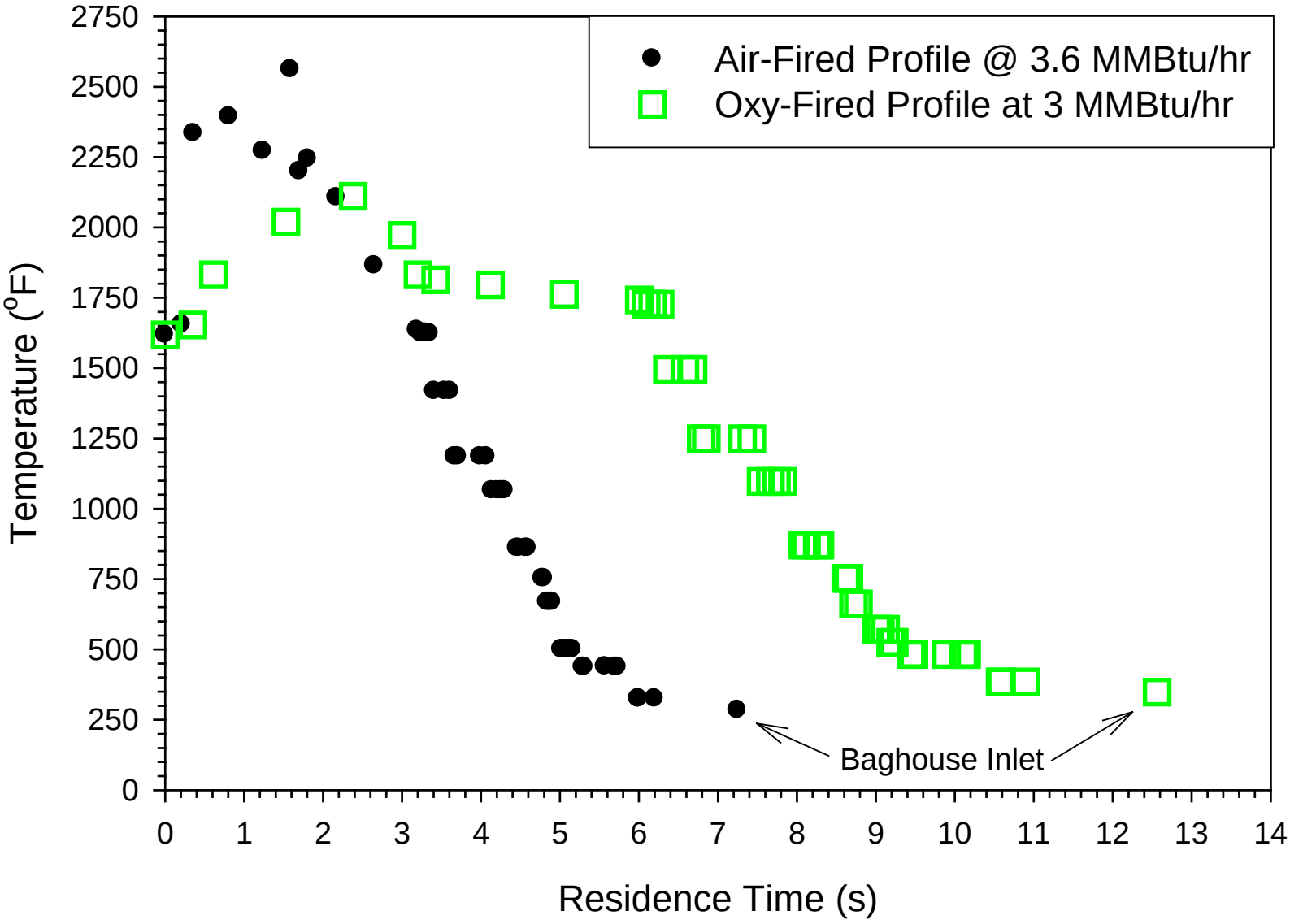
To convective section

MAXON Burner with Oxy-Coal Flame

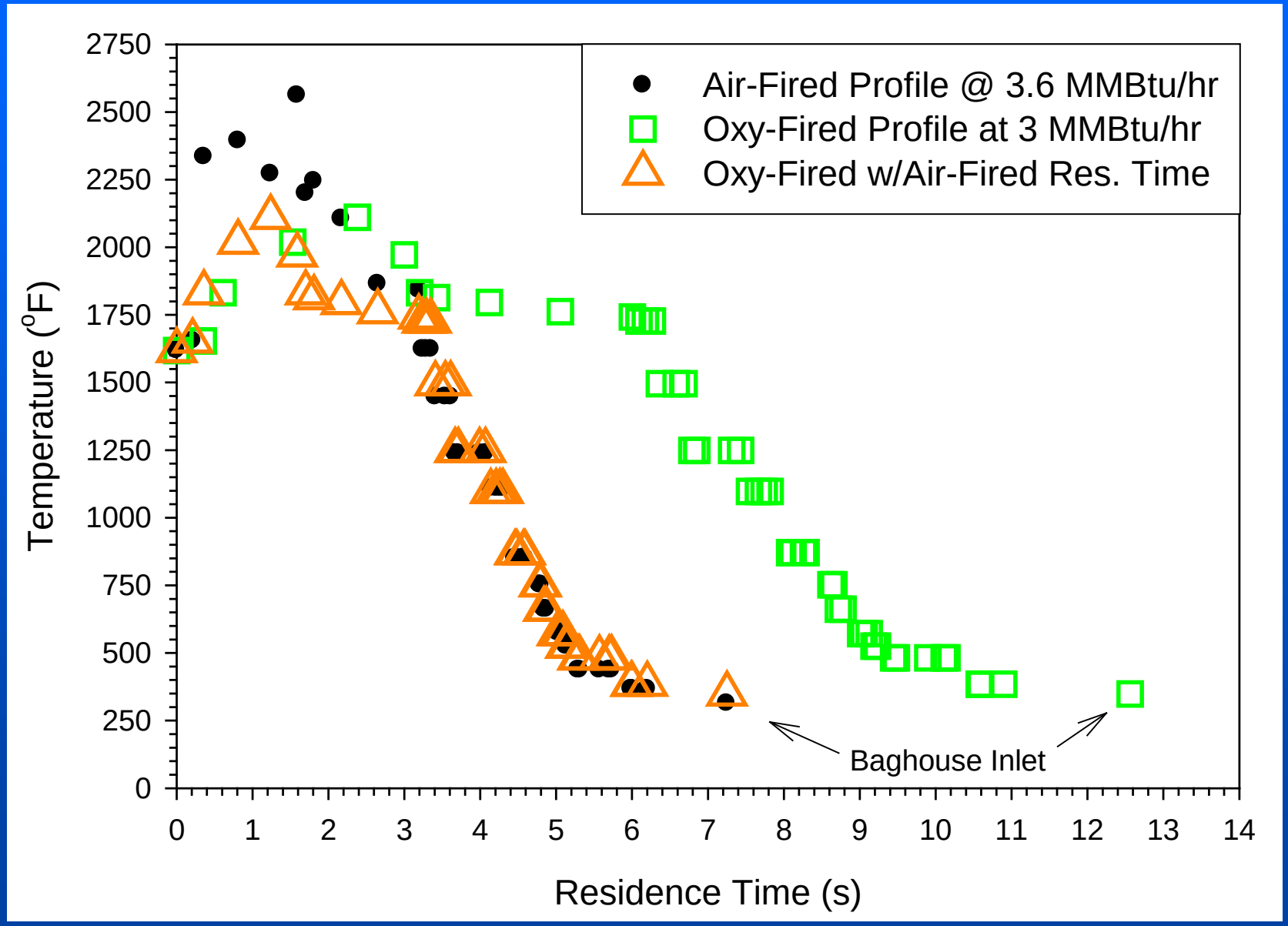


EUEC Meeting
Feb. 2011

Overall Temperature/Time Profile



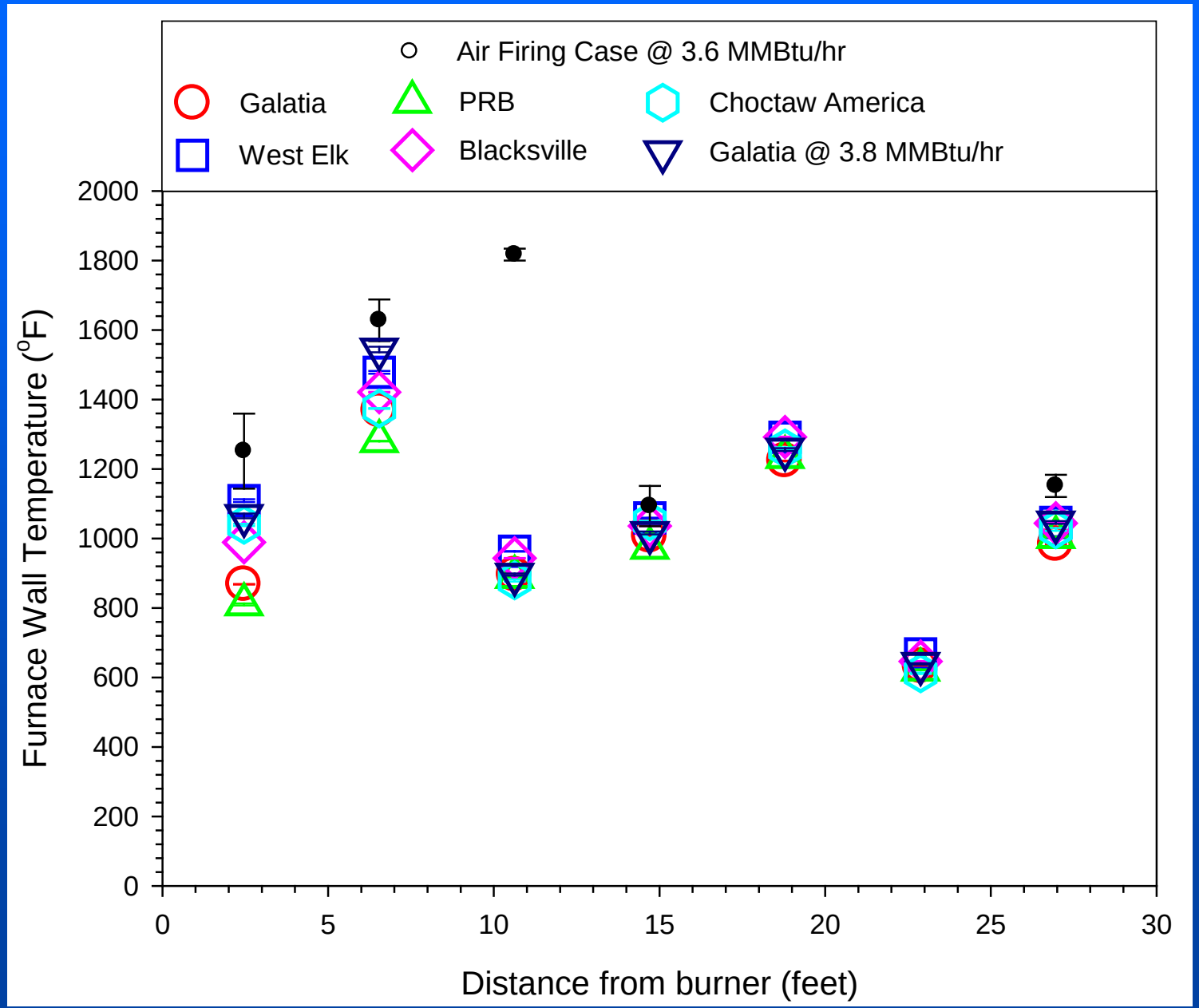
Same Residence Time Air & Oxy



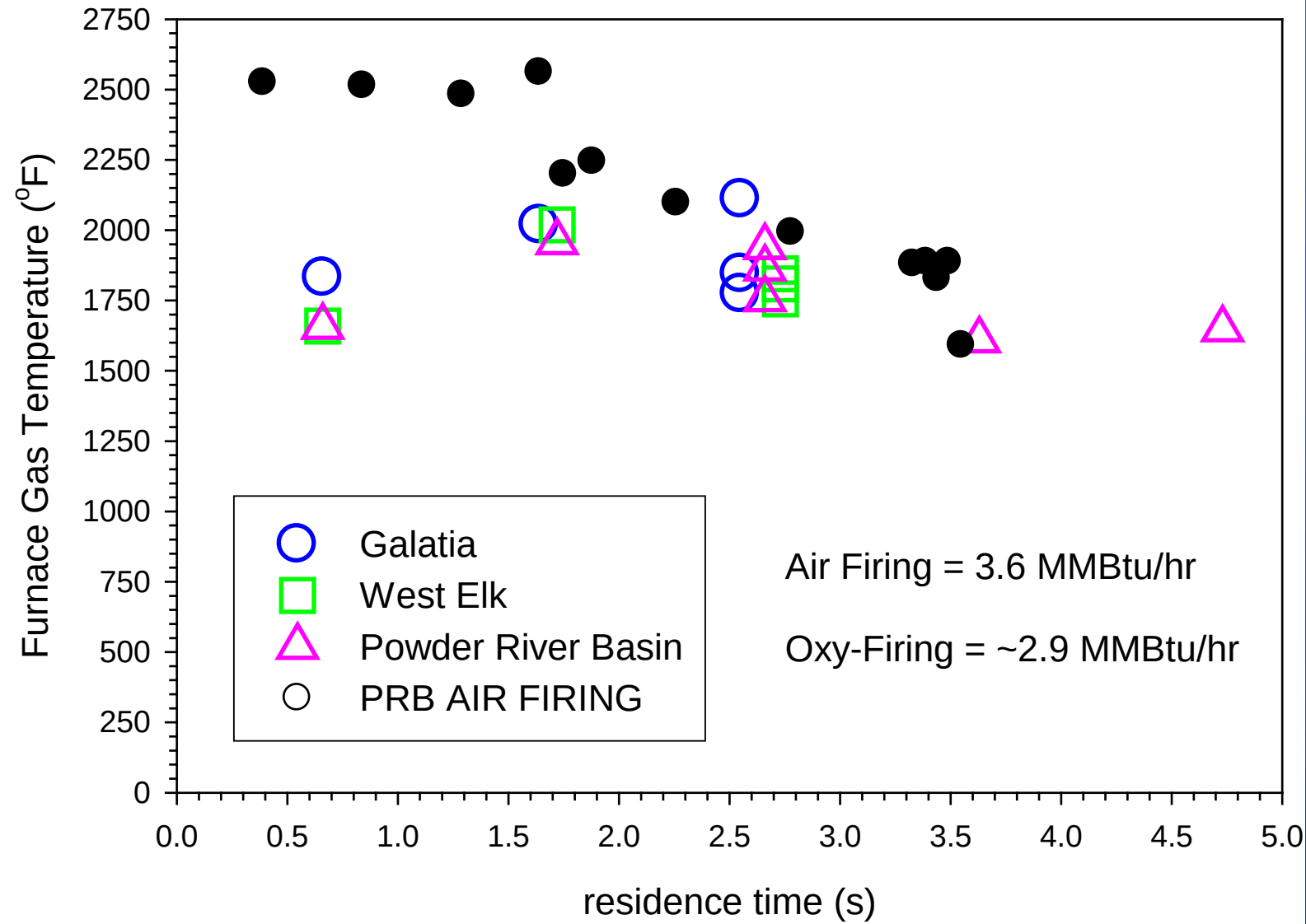
4 Parameter Differences Affecting The Temperature Profile

- Load:
  - Air Firing = 3.6 MMBtu/hr
  - Oxy-Firing was generally at 3.0 MMBtu/hr but ranged from 2.9 to 3.8 MMBtu/hr
- Burner Design
  - MAXON Burner Yields a slightly cooler flame
- Difference in Flows between Air-Firing and Oxy-Firing
  - Nitrogen Addition with Air = 573 scfm
  - Recycled Flue Gas Flow: gen 410, min 330, max 565 scfm
- Convective and Radiative Heat Transfer Differences
  - Thermal Diff. of CO_2 at 980 ^oF = $71.2e^{-6}$ m^2/s
  - Thermal Diff. of N_2 at 980 ^oF = $116e^{-6}$ m^2/s

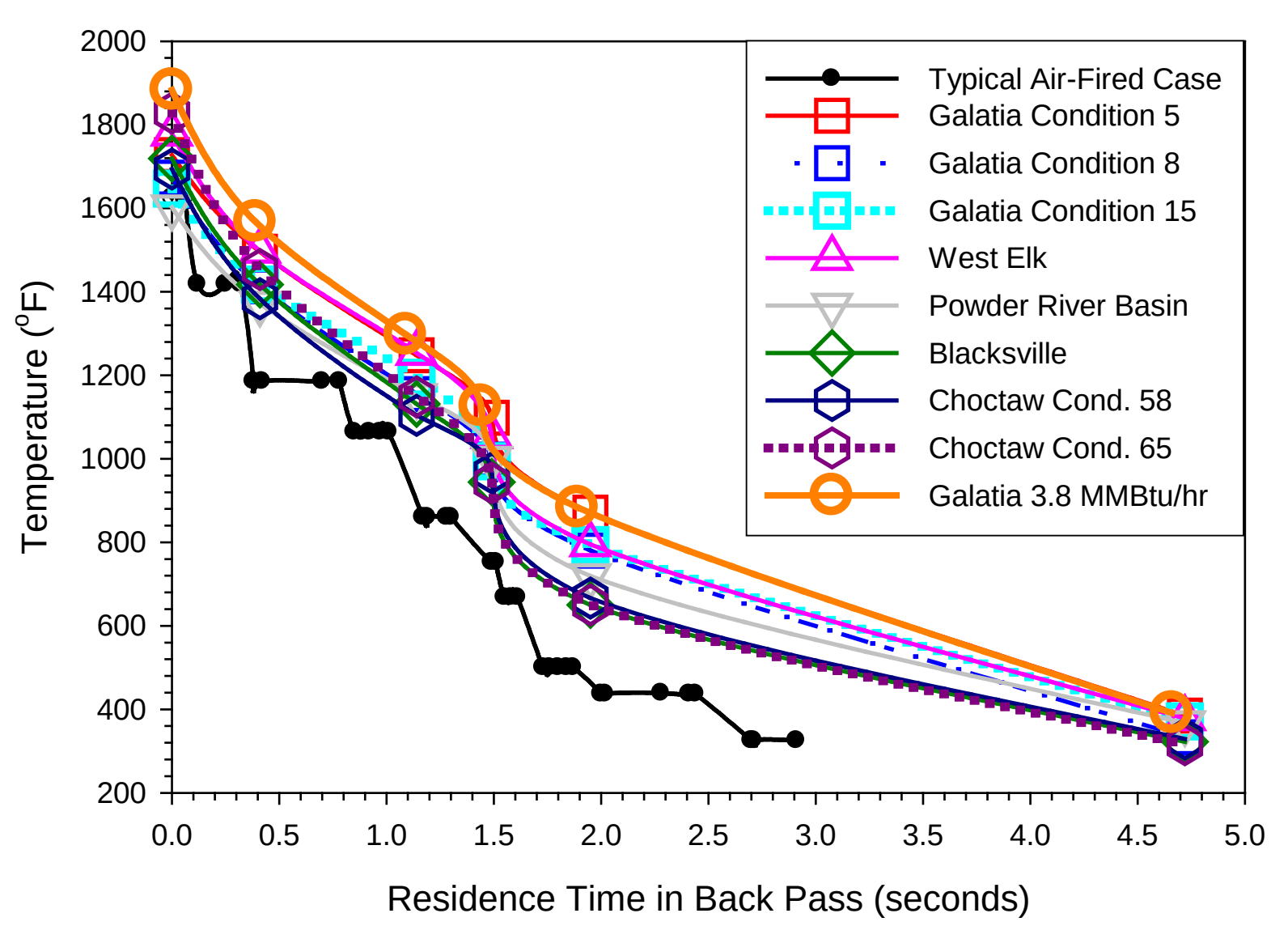
Consistent Wall Temperatures



Furnace Temperature/Time Profile



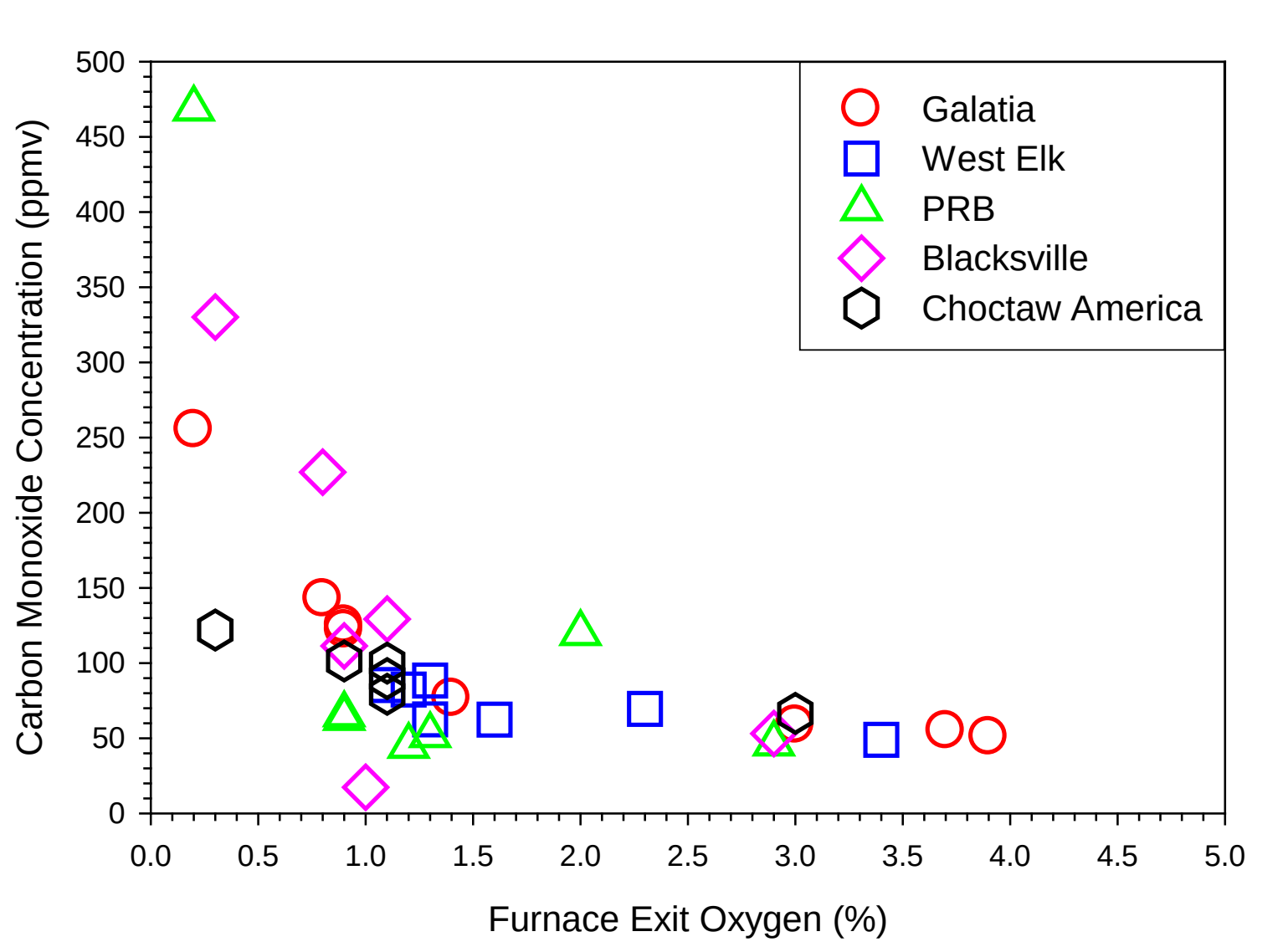
Back Pass Temperature/Time Profile



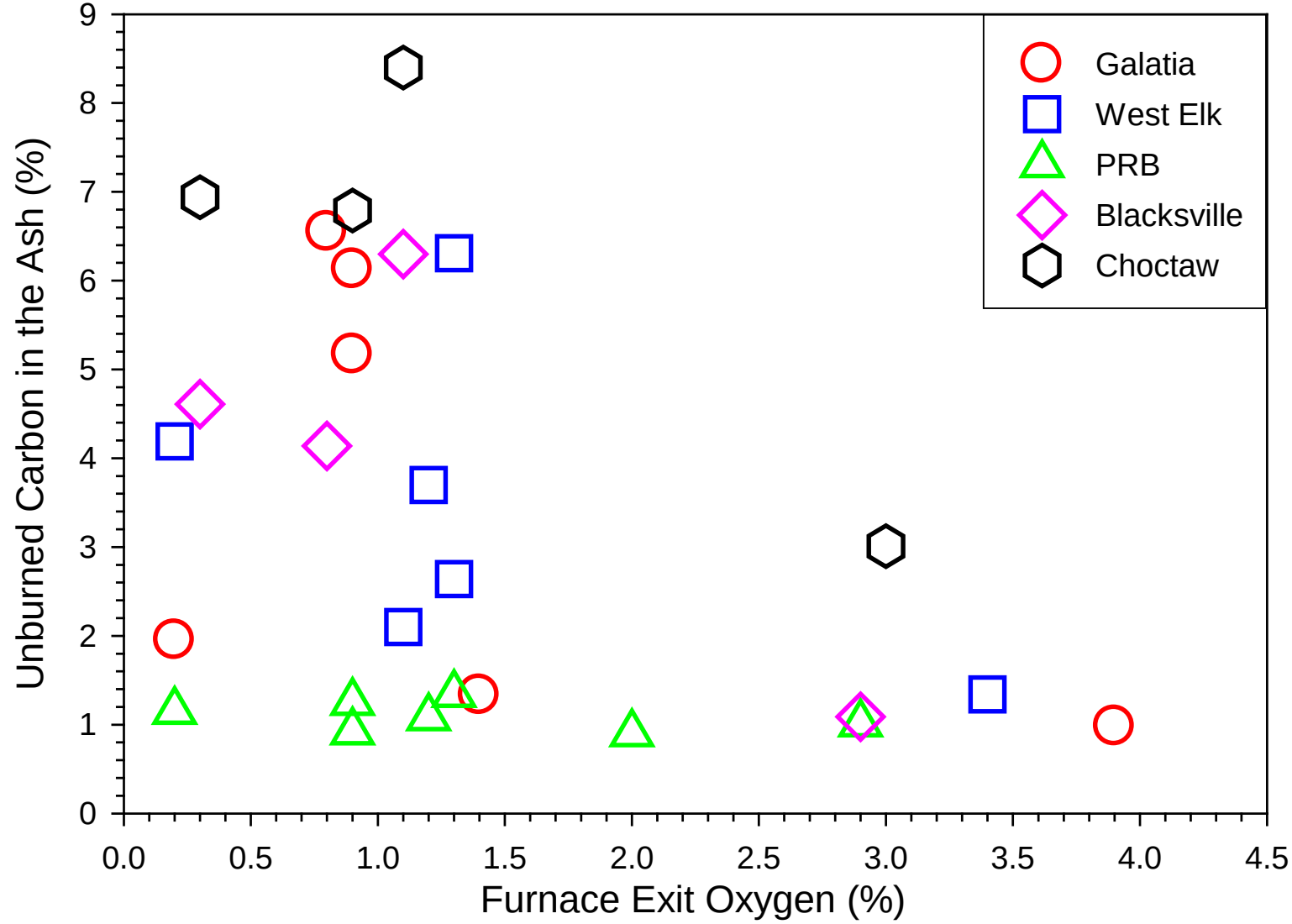
Recycle and Oxygen Staging

- Baseline Combustion Mode
  - All injected oxygen enters through the burner
  - Always some oxygen injected into the cup and through the quarl
  - Pilot always on with ~ 14 scfm of oxygen to maintain stability
  - Other than the primary recycle, all recycle injected at quarl base
- Secondary Recycle Staging
  - Always some oxygen in the recycle gas – 1% or greater
  - Injected oxygen: between 8.7% and 10.6% of total injected oxygen
  - Staged oxygen was taken from oxygen injected through quarl
  - Otherwise conditions were at the optimum baseline conditions
- Tertiary Recycle Staging – Similar to Air-Fired Furnace Staging
  - 15% of the Total Recycle was taken from the secondary ports
  - Injected oxygen: between 13% and 15% of total injected oxygen
  - Staged oxygen was taken from oxygen injected through quarl
  - Otherwise conditions were at the optimum baseline conditions

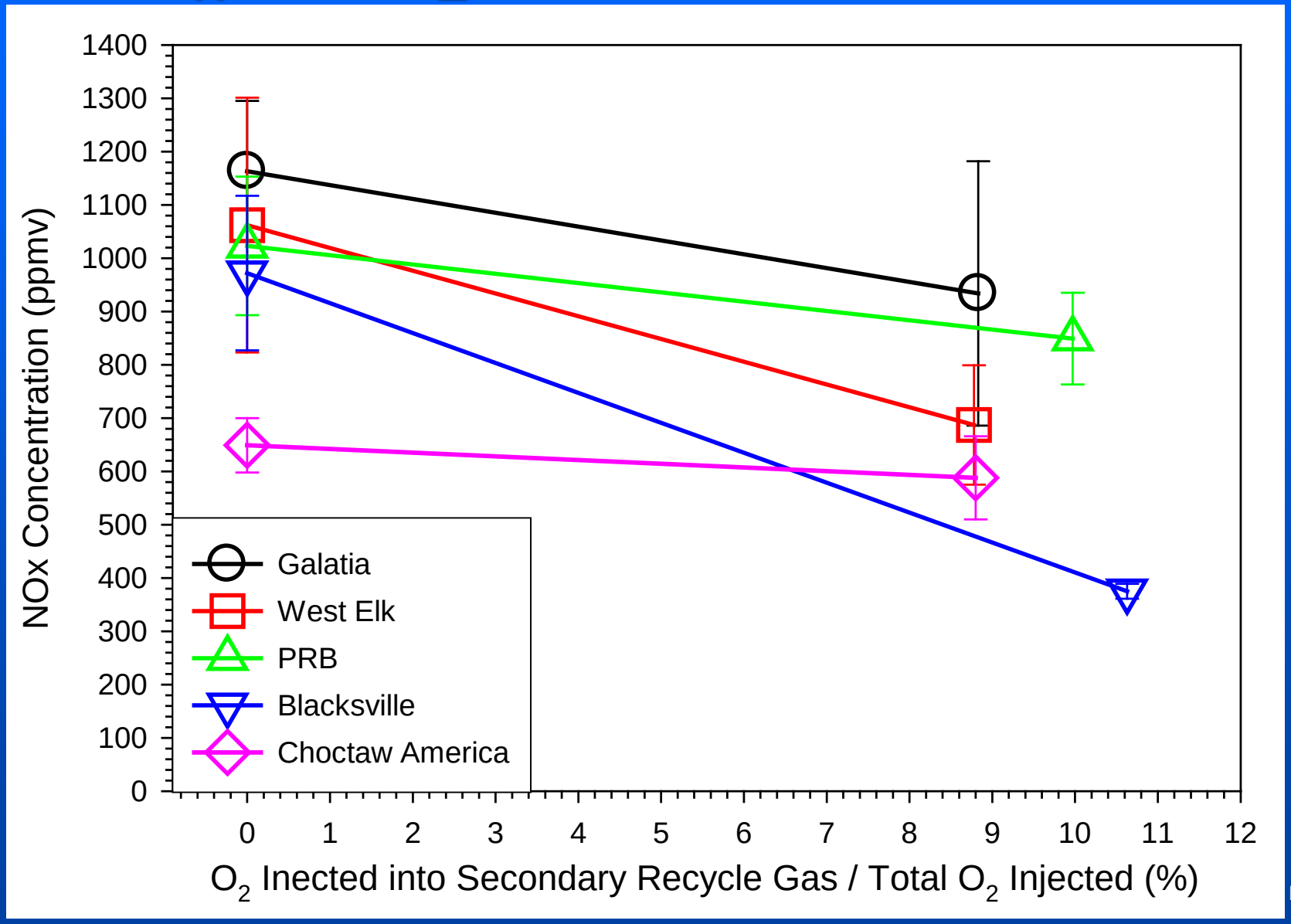
CO versus Furnace Exit Oxygen



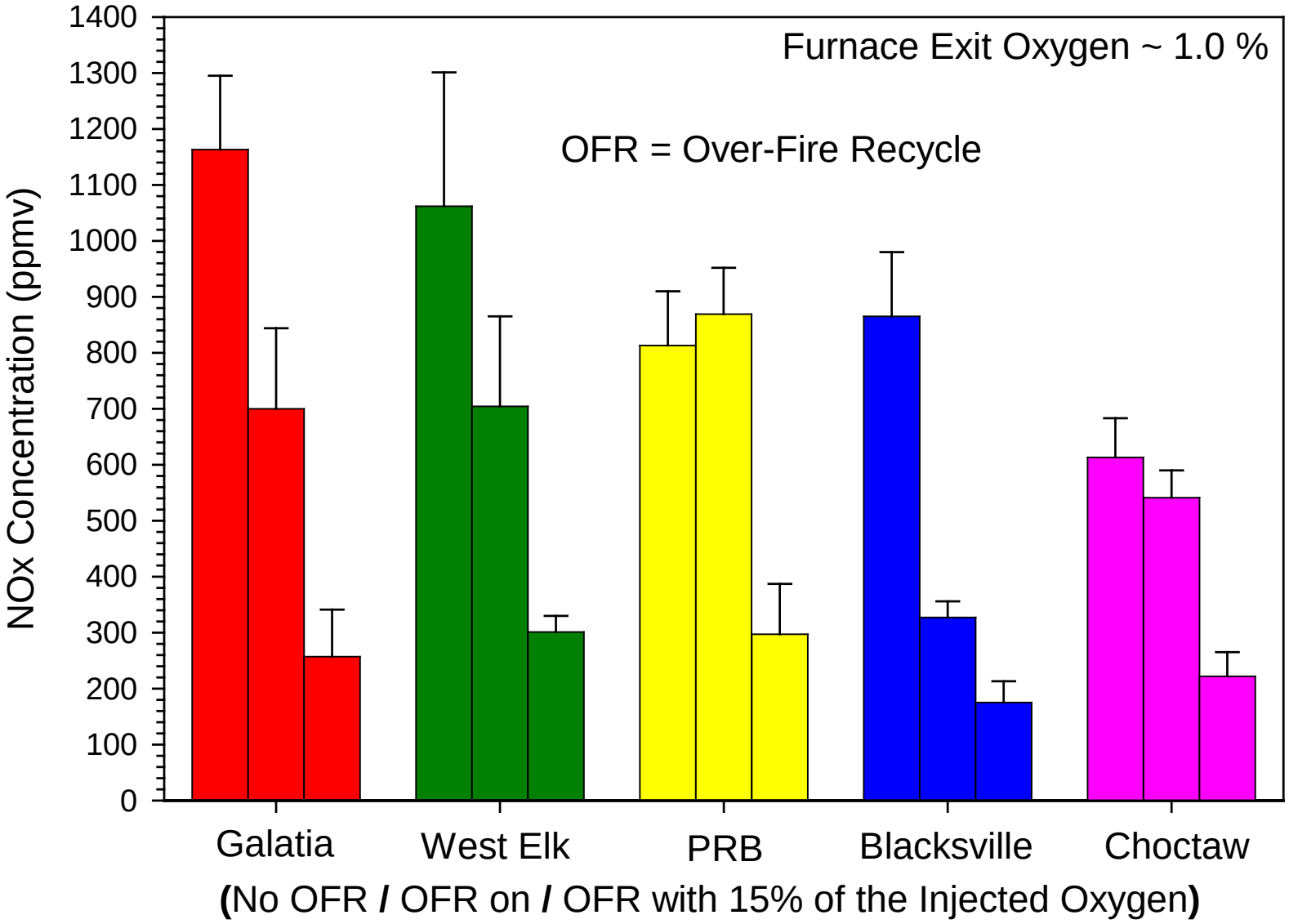
UBC versus Furnace Exit Oxygen



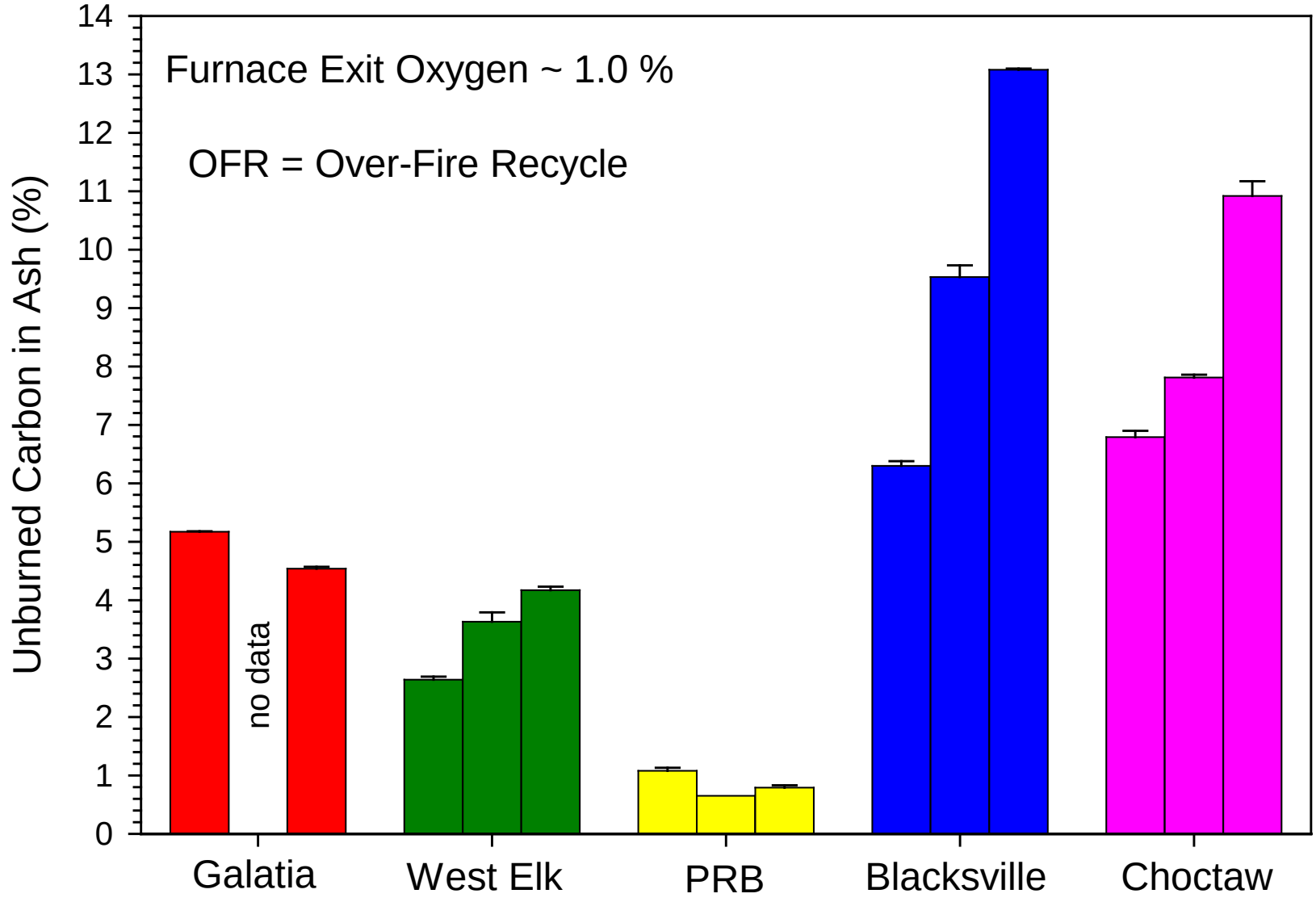
NO_x vs O_2 in Secondary Recycle



NOx w/wo OFR and O_2 in OFR

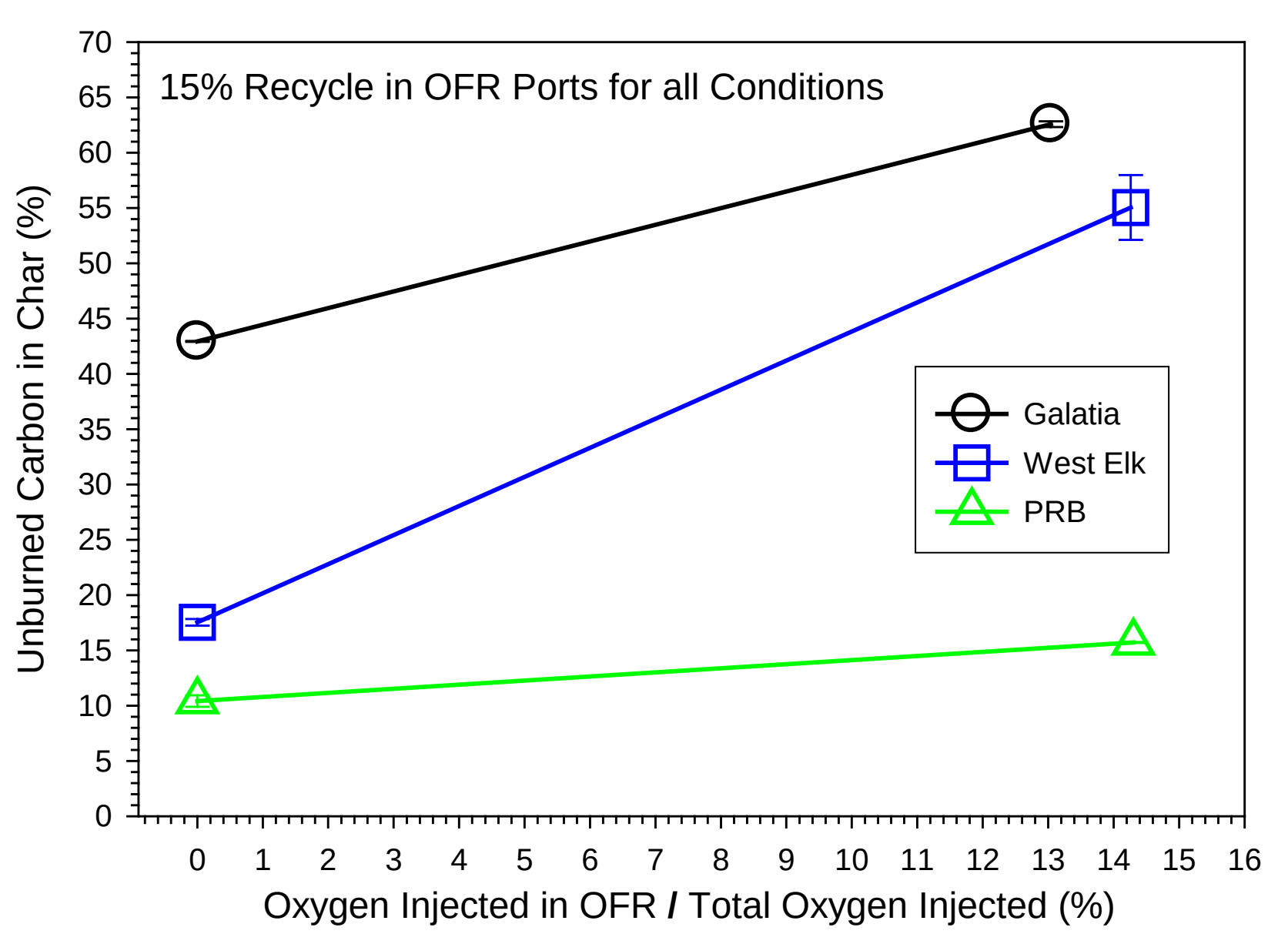


UBC w/wo OFR and O_2 in OFR



(No OFR **/** OFR on **/** OFR with 15% of the Injected Oxygen**)**

UBC of Char Collected Under OFR



CONCLUSIONS

- The Southern Research/Southern Company 1 MW_{th} Pilot-Scale Coal-Fired Test Facility has been successfully retrofit to fire in either the traditional air-fired mode or with 100% oxygen and recycled flue gas, with a fully integrated feedback and control system, including oxygen and recycled flue gas modulation during startup, transfer, and shutdown, safety and operational interlocks, and data acquisition.
- MAXON Staged Oxygen Burner for Oxy-Coal Applications produced a stable flame over a significant range of firing turn-down, staging, and while firing five different U.S. coal types.
- The MAXON burner design or similar will produce lower flame temperatures than for air firing, which will enable (A) Safe Operation, (B) Reduction of recycle flow without concern about furnace flame temperatures, and (C) May likely be affective at reducing slagging and fouling in the boiler and super heater at Full-Scale Power Plants.
- Temperature Profile most significantly affected by lower flow rates.
- Otherwise, heat transfer and temperatures not significantly changed.
- Furnace staging, similar to air firing, yielded most NOx reduction.
- Carbon burnout was comparable with air firing.