Southern Research Institute

Oxy-Firing and Chemical Looping

Seminar

Thomas K. Gale, Power Systems Research Group

Problems Being Addressed

- Fears of Global Warming are Creating Political Pressure to Act.
- CO_2 is an atmospheric insulator
- Coal-Fired Power Plants emit lots of CO_2
- CO_2 Emissions Regulations are likely to be implemented in the near future.
- Coal is our most abundant domestic energy source.

General Solution to Save Coal

- Capture CO_2 from Coal-Fired Power Plants
- Scrub out the impurities
- Compress and Condense to Liquid CO_2
- Sequester liquid CO_2 in deep geologically stable formations.

Methods to Capture CO_2 from Flue Gas

- Add CO_2 Scrubbers to existing, unmodified power plants – Huge Chemical Plant
  - Solvent Scrubbing and Dry Sorbent Scrubbing
- Fire with oxygen instead of air, and then scrub the remaining impurities during the CO_2 compression process – Huge ASU
- Chemical Looping: an advanced, longer-term technology.

SOUTHERN RESEARCH

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Oxy-Fired CO_2 Recycle for Application to Direct CO_2 Capture from Coal-Fired Power Plants

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Project Participants

- National Energy Technology Laboratory (NETL)
  - Management of the project
- Southern Research Institute
  - Overall technical coordination, pilot-scale testing, reporting.
- DTE Energy
  - Engineering support / preparation for demonstration in future.
- MAXON Corporation
  - Burner design, manufacture, and testing, and technical support
- BOC Gases (*Linde* Gas)
  - Oxygen tank and skid, simulations, safety, and eng. support.
- Reaction Engineering International (REI)
  - CFD model modification for the pilot facility.
- CORR Systems
  - Design of recycle loop, modifications, and control systems.
- 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

Overall Project Objectives

- The objective of this project is to investigate, develop, optimize, and model oxygen-fired CO_2 recycle technology for 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 comparing these responses with CFD modeling results.

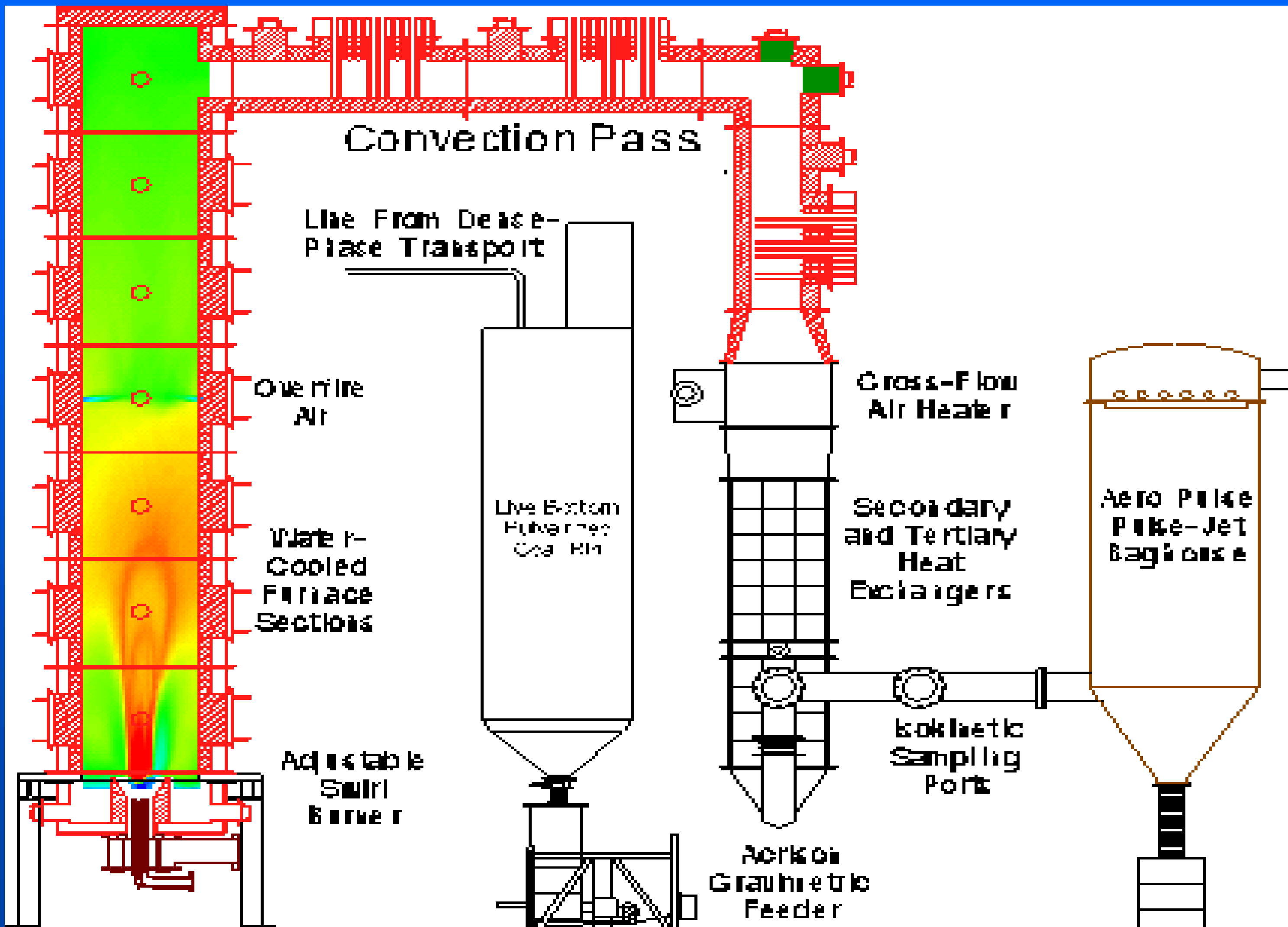
Fundamental Science Driving This Oxy-Fired Technology

- ~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.

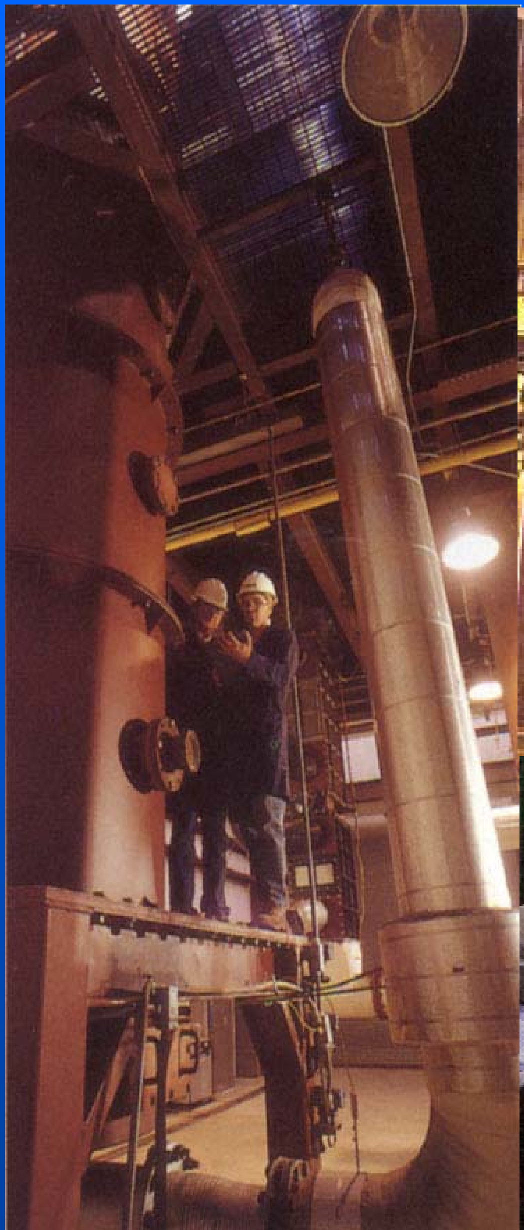
Oxy-Fire and Chemical Looping SEMINAR at Ole Miss

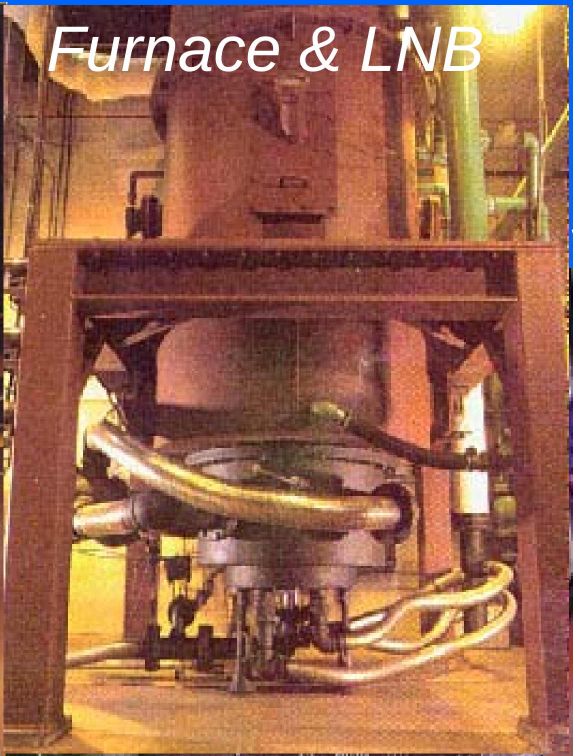
How the Innovative Oxy-Burner Design Works

Combustion Research Facility



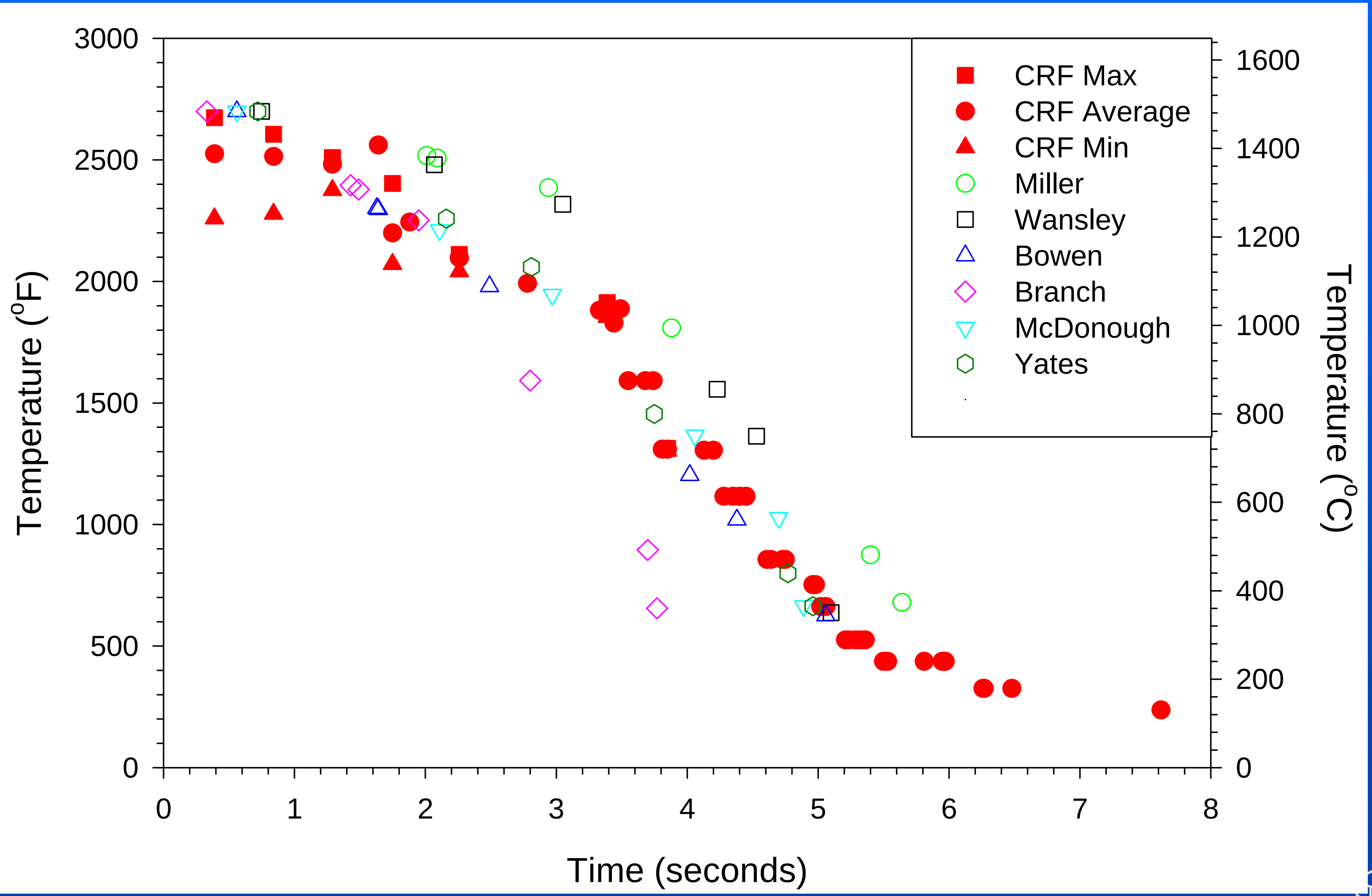
Combustion Research Facility



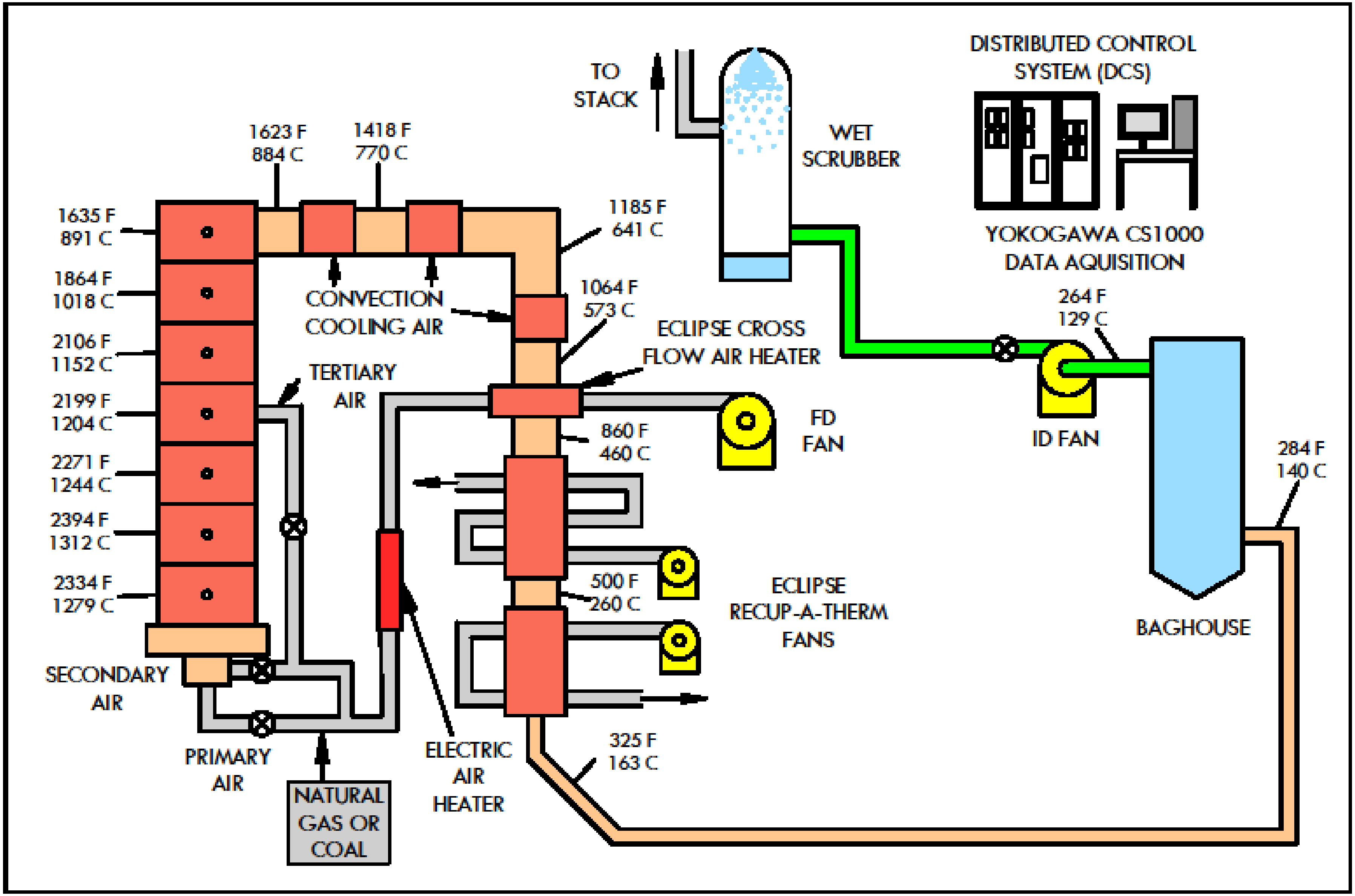


Center Furnace Section Showing Overfire Air Ports

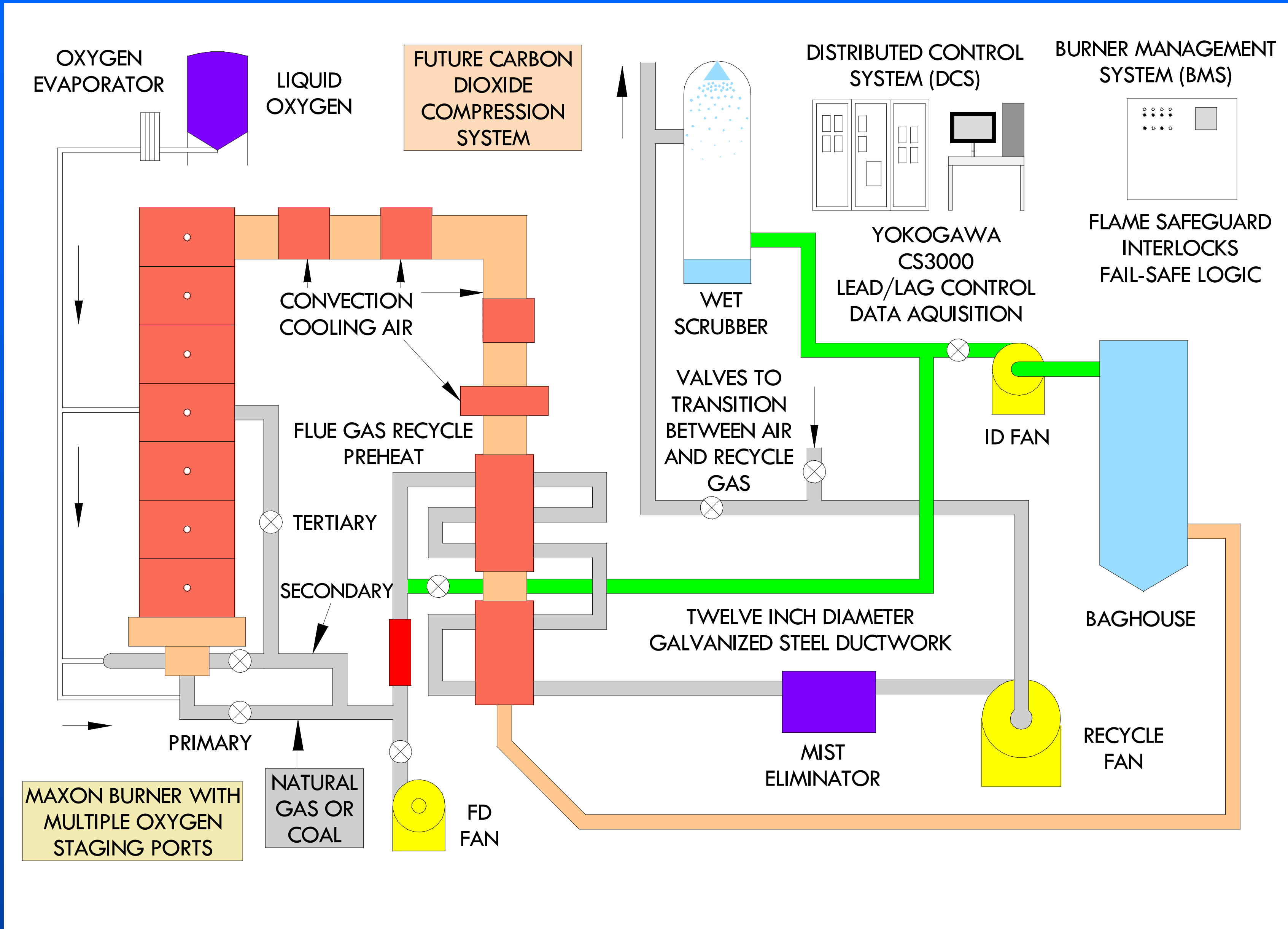
Temperature/Time Profile of the Combustion Research Facility



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 CS3000
- New data acquisition and control system and program to modulate the flow of oxygen and recycled flue gas.
- Burner Management System
- Recycle System
  - Recycle Fan
  - Ductwork, Valves, Thermocouples, Flow Meters
- Permanent Oxygen Tank, Tank Pad, and Spill Pad
- Safety Systems
  - Procedures relative to oxygen use
  - CO_2 and CO monitors and alarms/interlocks

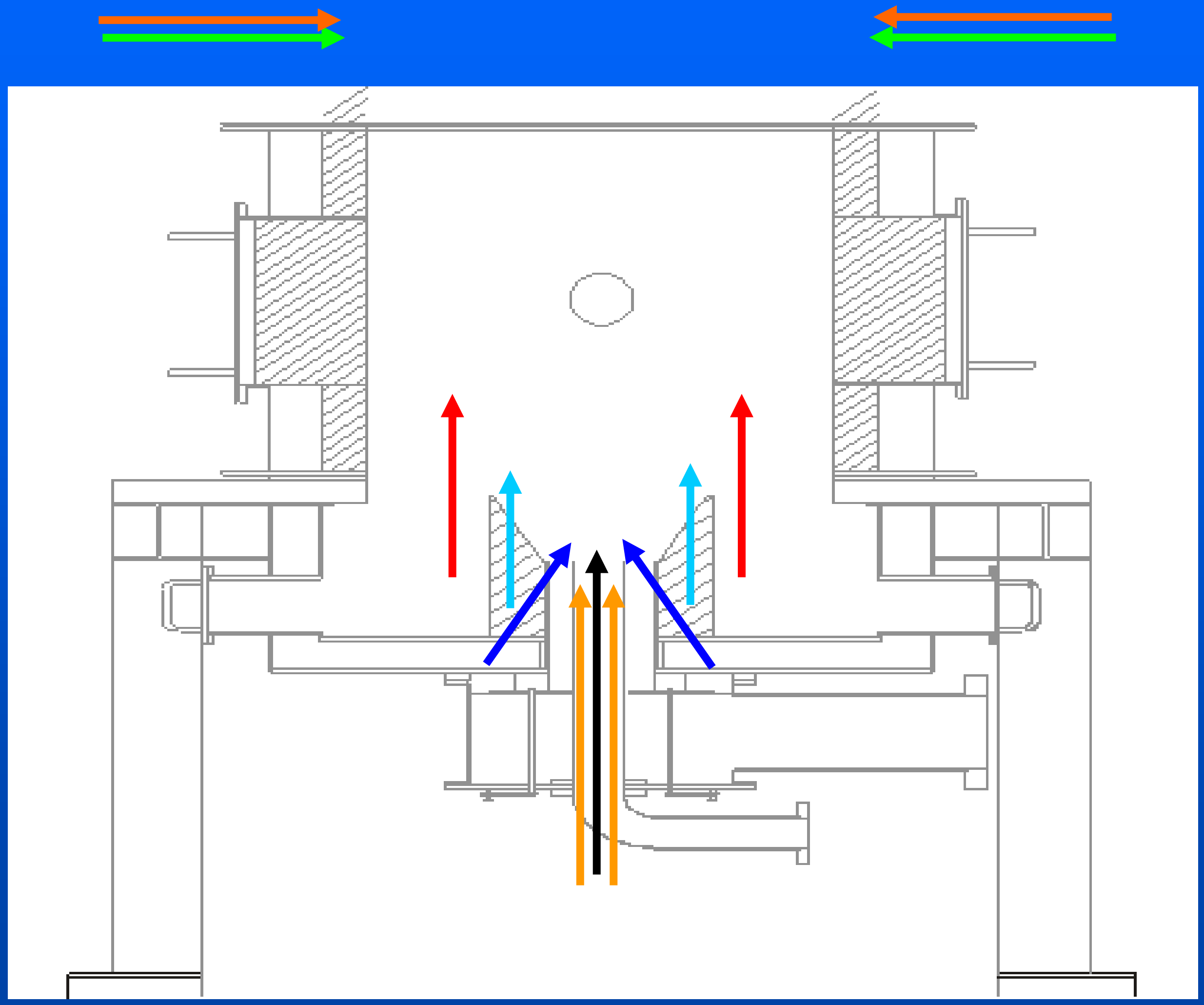
Technical & Economic Advantages

- Oxy-burners maintain a stable attached flame and can light off without natural-gas assist.
- The ¼ volume oxy-fired flue gas is much less expensive to purify and compress for carbon sequestration.
- Recycling dry flue gas through PRB coal pulverizers eliminates concern of pulverizer fires.
- Burners and recycle rate can be tuned to achieve low cost operation and maximum heat transfer for a given boiler type and plant configuration.
- New Plants: Advanced Thermodynamic Cycles can recover some of the energy penalty.

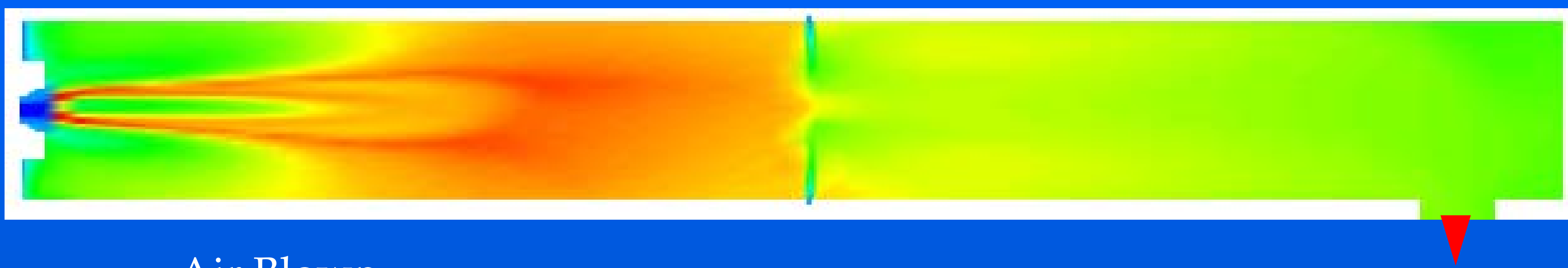
Technical & Economic Challenges

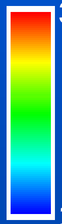
- Cost of retrofit is significant for existing plants.
- Energy penalty to produce oxygen is about 25%.
- Additional energy penalties come from purification of CO_2 and compression and sequestration.
- Concern about corrosion of low-temperature ductwork and equipment.

Oxy-Burner CFD Modeling by REI

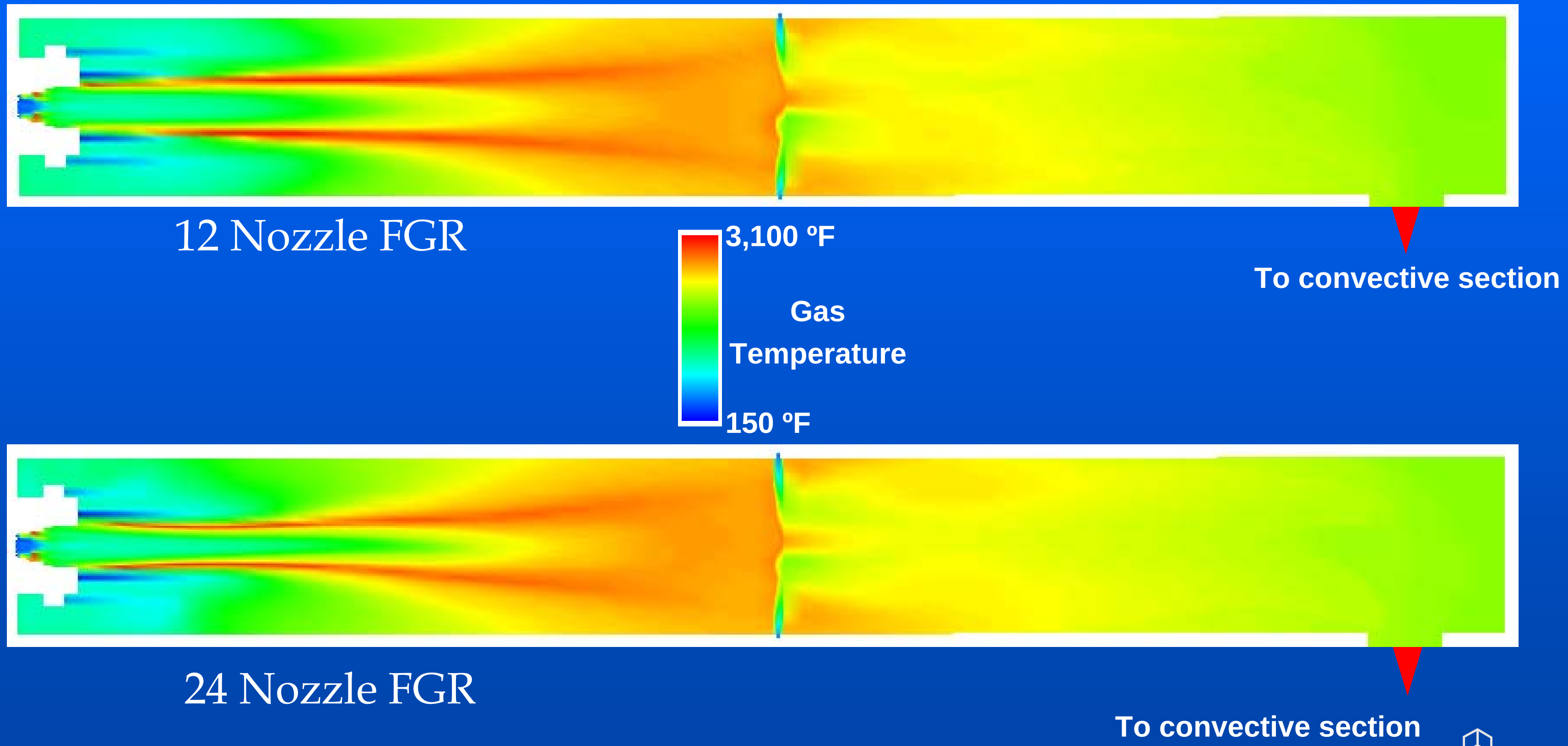


Standard Air-Blown Case

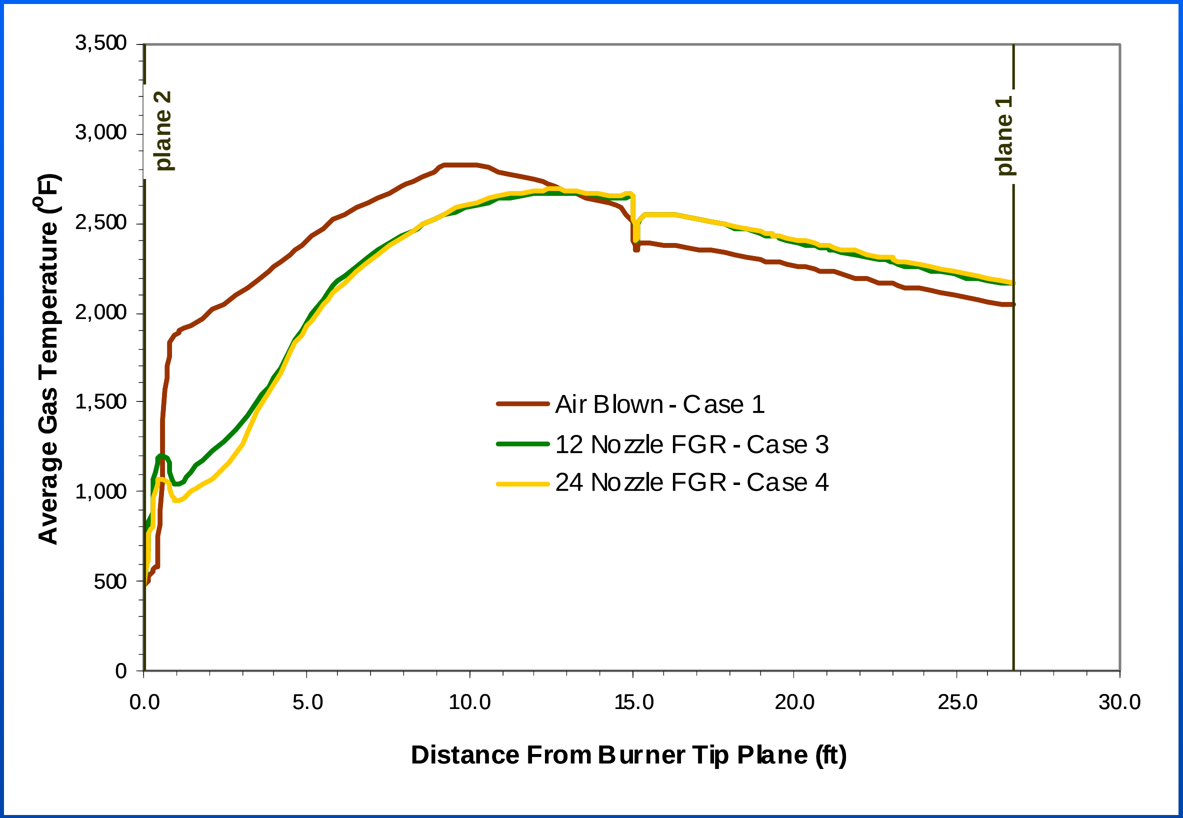




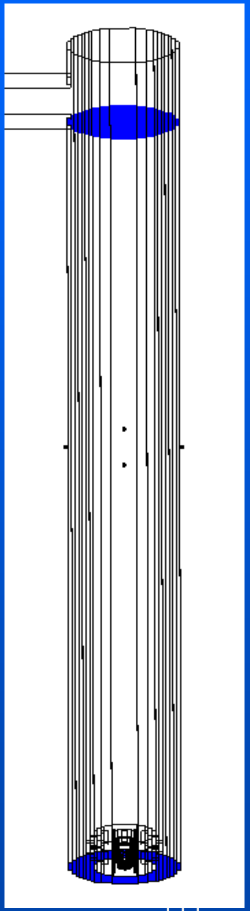
Oxy-Fired w/Flue-Gas Recycle Predictions



Oxy-Fired w/Flue-Gas Recycle Predictions

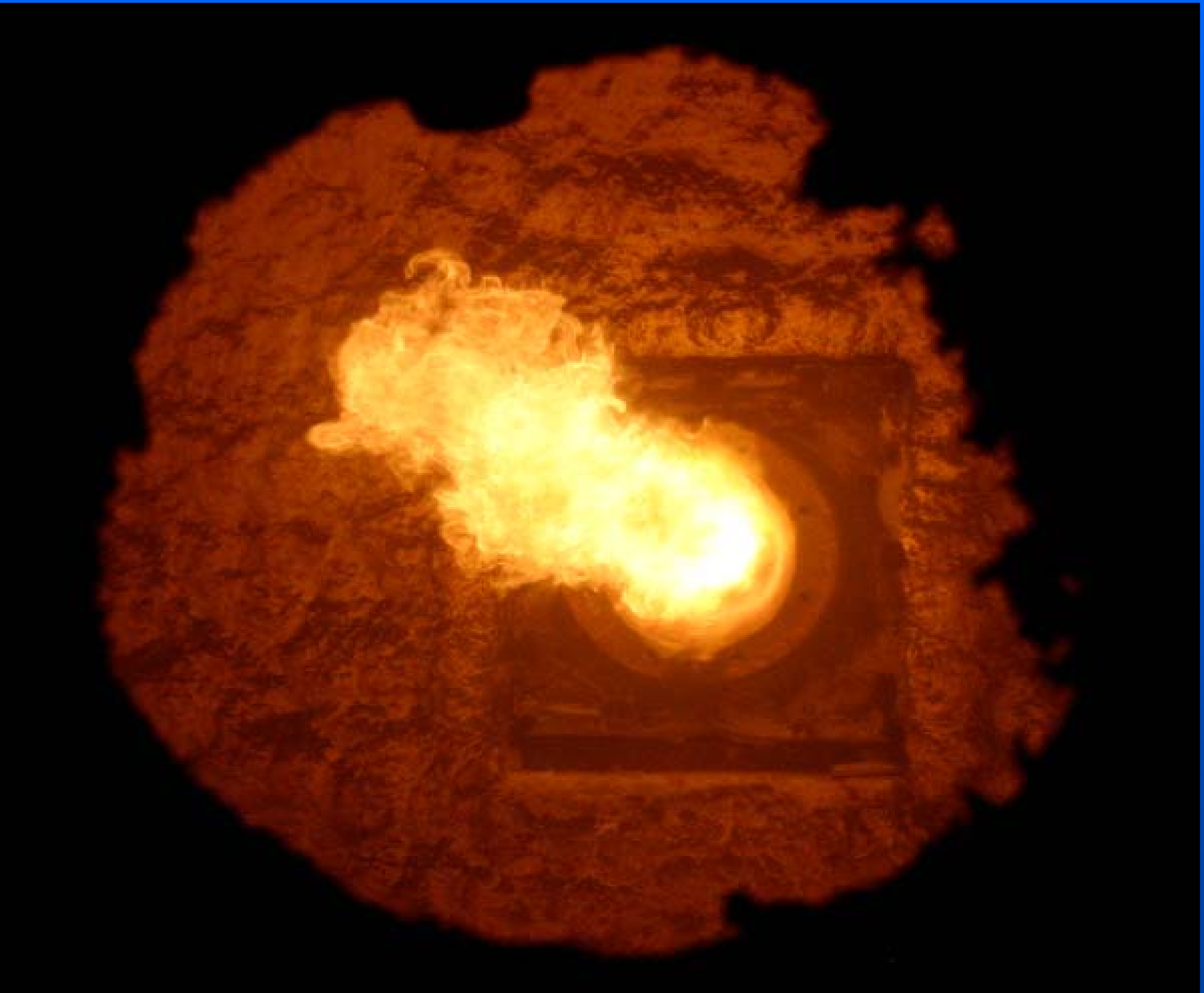


Plane 1



Plane 2

MAXON Burner Test Results



MAXON Burner Test Results

- Illinois Bituminous
- 2400 ºF test chamber
- 3% excess O_2
- Staged oxygen prototypes
- Air conveyed = 0.3-0.4 #NOx/MM BTU
- CO_2 conveyed = 0.16-0.18 #NOx/MM BTU

Oxy-Fire and Chemical Looping
SEMINAR at Ole Miss

MAXON Burner Test Results

- Indonesian Coal
- 2400 ^{o}F test chamber
- 3% excess oxygen
- Staged oxygen prototypes
- Air conveyed = 0.18-0.2 #NOx/MM BTU
- CO_2 conveyed = 0.08-0.1 #NOx/MM BTU

Plans for Testing

- Variables
  - Coal Type
  - Firing Configuration
    - Staging
    - Percentage of Recycle
    - Oxygen Purity
- Responses
  - Flue-Gas Composition and purity
  - Inleakage
  - Heat transfer and temperatures
  - Consistency and stability of operation
  - Apparent corrosion or acid-gas build up.

Coal Type

- 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

Firing Configuration

- Purity of the oxygen feed
  - 90 to 99.5%
- Amount of CO_2 recycle (+/- 20%)
- O_2 Concentration in the primary flow
- Amount of O_2 in the burner quarl tip
- Staging (O_2 concentration) through the recycle-gas ports on the sides of the burner
- Amount of Staging through the Overfire-Air Ports

Responses / Measurements

- Furnace gas-temperature profile (gas-suction pyrometry)
- Furnace and convective pass wall and tube temperatures
- Heat flux in the convection pass
- Heat flux in the furnace
- Char burnout (found from unburned carbon in the ash).
- Flue-Gas Concentrations of CO_2, CO, NO_x, SO_2, and O_2
- MKS 2030 FTIR measurements of H_2O, NH_3, H_2S, SO_3, H_2SO_4, HCl, hydrocarbons, and other organics.
- A H_2 GC monitor will be used to directly measure N_2.
- Physical Examination of deposits, metal surfaces, and tubes for relationships between firing conditions and deposition, erosion and corrosion.

APPROACH

- Perform the same series of tests for each coal
- Start with Baseline:
  - Burner Staging according to MAXON's design optimum
  - Recycle level to achieve same total gas heat capacity as equivalent flue-gas on air-fired unit.
  - No oxygen in recycle and No overfire staging or flow.
  - Highest oxygen purity input (only argon as inert, no N_2)
- Independently examine each parameter around the baseline condition
  - Burner staging optimization examined first, then left at optimum
  - Recycle flow changed next.
  - Recycle staging (O_2 in ports on side of burner) varied next, then off.
  - OFA Changed with just recycle, and then staging (wo secondary staging).
- Carbon Burnout will be measured at the optimum condition for gas composition, i.e., low NO_x, high CO_2 concentration, low concentrations of impurities in recycle, and low operation instability.
- Oxygen purity changes will also be examined at the otherwise optimum condition.

Simultaneous Efforts During Testing

- Significant effort has gone into the design of the facility to eliminate inleakage to the system. However, some inleakage is still expected, and additional significant effort will continue during the testing, in an effort to eliminate as much inleakage as possible.
- The MKS 2030 FTIR Monitor will continually measure the composition of the flue gas during all test conditions for irregularities, especially high concentrations of unusual acid gases, such as carboxylic acids.
- At the conclusion of a test period, be it for a week or several days, the duct work and other metal surfaces will be examined for corrosion, erosion, and deposition.

Subsequent Testing Efforts

- MAXON has developed a new oxy-fired burner that we plan to test in the facility that internally mixes the recycled flue gas with the oxygen.
- In 2009 and 2010 will be using the facility to test a technology for treating coal and compressing and purifying CO_2 exhaust at the same time.
- Looking for opportunities to work with our oxy-fired technology team to demonstrate this technology at a full-scale plant.

SOUTHERN RESEARCH
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Chemical Looping
The Future of Coal-Fired Power Generation

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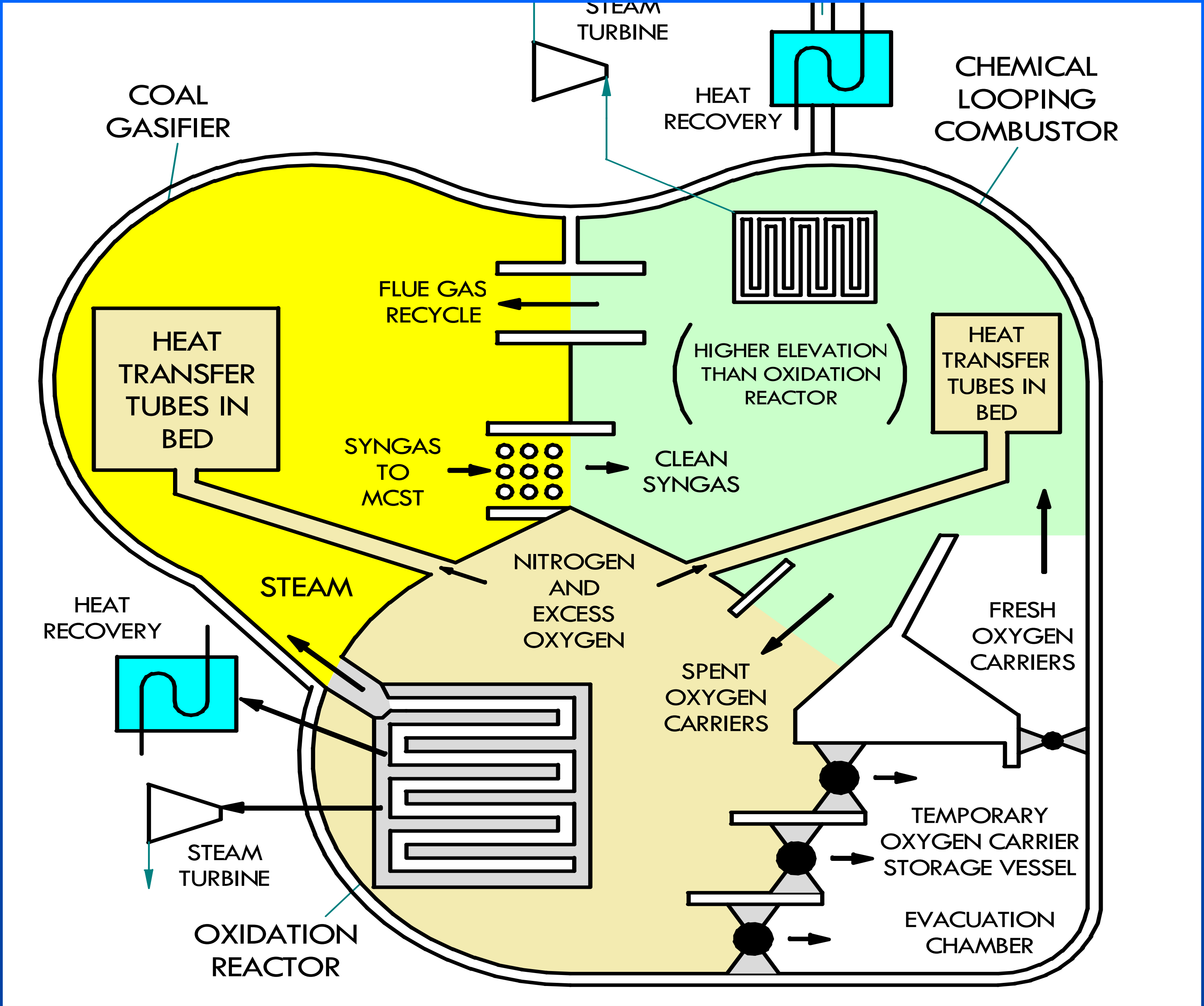
Description of Chemical Looping Technology

- Two Separate Reactor Vessels are used to complete the combustion process, instead of one boiler.
- In the first reaction vessel air is used to combust a mineral, such as iron, nickel, or calcium sulfide – EXOTHERMIC
- The nitrogen from the air exits the stack after the heat has been extracted.
- The oxidized minerals are then transported to the second reaction vessel where they are reduced back to their original unoxidized state, at the same time they oxidize coal syngas.
- The minerals are known as oxygen carriers, because they carry the oxygen that reacts with the coal syngas.
- Because there isn’t any air in the reaction chamber with coal syngas, the exhaust stream concentrated CO_2, without any nitrogen.
- Heat generated from the exothermic air/mineral oxidation can be used both to generate steam for steam turbines and to provide heat to drive the gasification of coal.

Conceptual Chemical Looping System



Oxygen Carrier Types

$NiO/MgAl_2O_4$

$Mn_3O_4/Mg\text{-}ZrO_2$

$Co\text{-}Ni/Al_2O_3$

Co_2TiO_4

NiO/SiO_2

Fe_2O_3/SiO_2

Fe_2O_3/Al_2O_3

Fe_2O_3/TiO_2

CuO/SiO_2

CuO/Al_2O_3

$NiO.4MgO/3Ni.2Mg.Al_2O_4$

NiO/Bentonite

Mn_2O_3/SiO_2

$CaSO_4$

Technical & Economic Advantages of Chemical Looping

- Chemical Looping uses Air for combustion without separation of the nitrogen and oxygen – **No 25% Energy Penalty** – and Still produces a concentrated stream of CO_2 in the exhaust that is much less expensive to sequester a mixed CO_2/N_2 exhaust.
- The oxygen carriers are recycled, and when using CaS as the mineral, the sulfur from the coal is removed in the process as an added benefit.
- The chemical-looping concept can be applied to both combustion and gasification processes, depending on how the system is configured and the operating conditions.

Technical & Economic Challenges of Chemical Looping

- Adds Complexity to the System
- New concept that will take $$ and time to develop into a commercial unit.
- The current $$/(replacement time) for oxygen carriers is too high.
- Acceptance by utilities and operators.
- New regulations and pollution-control technologies will be associated with this.

Overall Future of Coal-Fired Power Generation in the Face of CO_2 Emission Regulation

- Strong Immediate Regulations – Existing Plants: (1) CO_2 scrubbers, (2) Oxyfiring with flue-gas recycle, or (3) Plants close
- New Plants may include: (1) Oxyfired coal-fired furnaces without much if any recycle and advanced thermodynamic cycles to offset the energy penalty, (2) Other advanced power systems, such as oxy-fired IGCC.
- Long Term: Chemical Looping combustion and gasification process look promising.