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OXY-FUEL BURNER AND INTEGRATED POLLUTANT REMOVAL RESEARCH AND DEVELOPMENT TEST FACILITY

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JUPITER OXYGEN ENERGY TECHNOLOGY

- Development and Application of Oxy-fuel Technology
- Patents and Licensing
- Consulting Service

Fossil Fuel: coal, natural gas, oil, and biomass

Project Funding

Project revision	Start date	Government cost share	Recipient cost share	Total estimate
0	10/1/2006	$ 2,051,670	$ 517,455	$ 2,569,125
1	4/1/2008	$ 972,674	$ 243,162	$ 1,215,836
2	4/1/2009	$ 669,784	$ 173,492	$ 843,276
2010-11	4/1/2010	$ 2,825,387	$ 705,560	$ 3,530,947
Project total	Completion date 9/30/2012	$ 6,519,515	$ 1,639,669	$ 8,159,184
		79.9%	20.1%	100%

Project Participants

- Jupiter Oxygen Corporation
- NETL
- Industry and academic partners

SNC Lavalin America, Inc
Reaction Engineering International

Purdue University
Coaltech
Professor Stamps, Evansville University
EPRI

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Project Objectives

- Design, construct, and operate a 5 MWe equivalent test boiler facility
- Design, construction, and operate a 20 KWe equivalent IPR® facility
- Operate the test facility at steady state optimum oxy-coal combustion and perform parametric studies.
- Demonstrate oxy-coal combustion NOX levels no higher than 0.15 LB/MMBTU
- Demonstrate that $C0_2$ from the boiler/ IPR® meets the specifications for deep saline aquifer sequestration and/or enhanced oil recovery
- Evaluate the retrofit impact of oxy-coal combustion and the IPR® process on power plant design issues
- Generate the necessary technical data required to demonstrate the technologies are viable for technical and economic scale-up and conform to DOE's Carbon Sequestration Program goals

Project Objectives

- Design and construct an air-coal combustion burner for the 5 MWe equivalent test boiler. Operate air-coal burner to develop an air-coal combustion base line for the test boiler.
- Develop and implement a high flame temperature closed loop control strategy for the 5 MWe equivalent test boiler.

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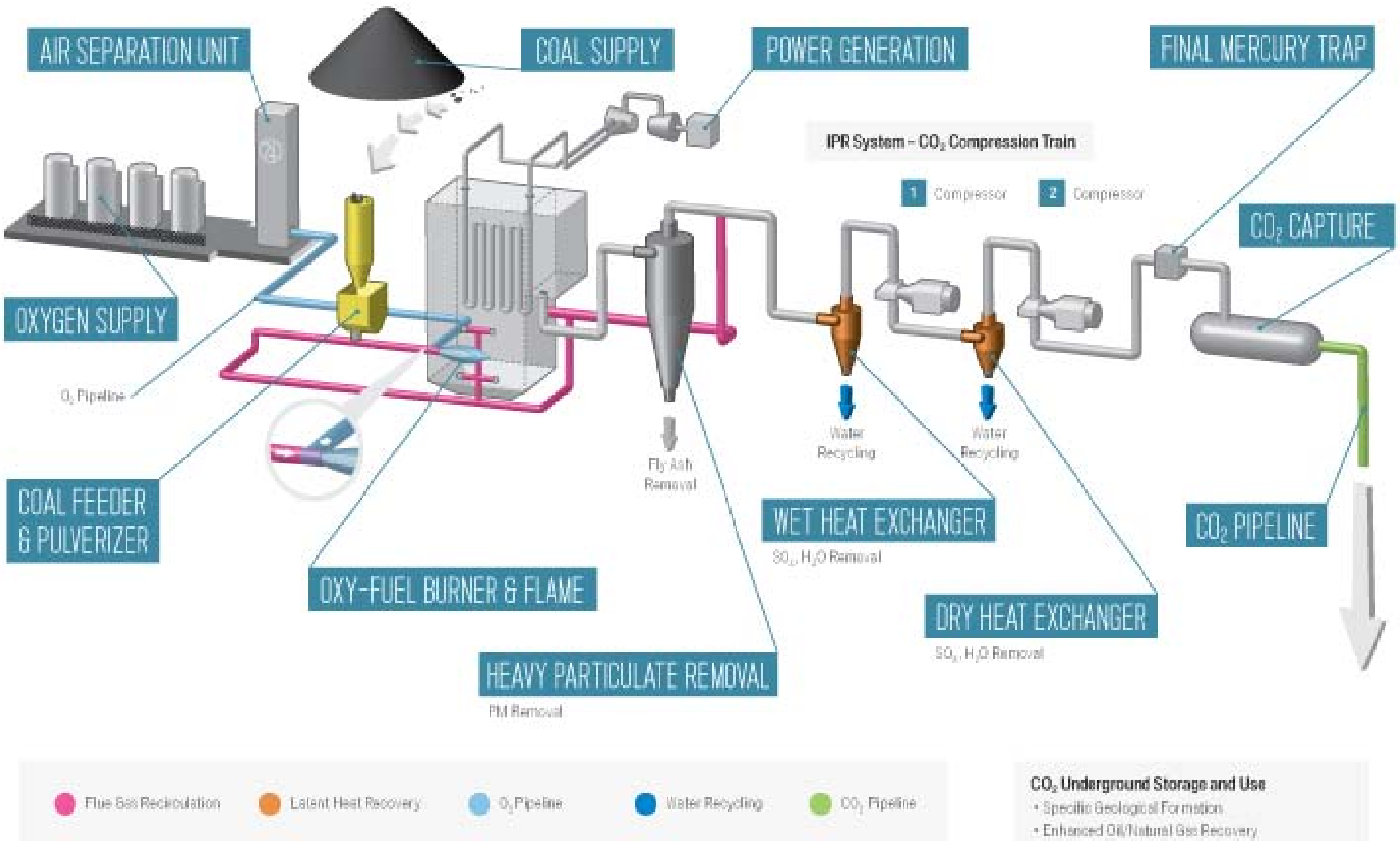

Technology Background

JOC High Flame Temperature Oxy-Combustion

- Development of oxy-combustion technology for Jupiter Aluminum facility in Hammond, IN
  - Oxy-combustion process in use since 1997 in the aluminum furnace
- Jupiter Oxygen as a CRADA partner with the NETL (2003)
  - Successful retrofit of 0.5MWe equivalent boiler with JOC high flame temperature oxy-combustion
  - Produced saturated steam while maintaining boiler interior temperature profile the same as with air firing
  - Boiler efficiency gains resulted
- Jupiter Oxygen/NETL project funded by DOE (2006)

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Technology Background
JOC High Flame Temperature Oxy-combustion

- Key characteristics
  - Eliminate air from the combustion system
  - Fuel and oxygen mixed at the burner undiluted with flue gas recycle except to motivate coal (unlike low temperature oxy-combustion which dilutes oxygen with flue gas recycle prior to combustion)
  - Results in a high flame temperature to enhance heat transfer in the radiant zone
  - Flue gas produced is primarily carbon dioxide and water
  - Flue gas recycle introduced around the flame/combustion zone to adjust the total flue gas volume flow and transfer heat duty to the convective zone as required
  - Additional FGR does not lower flame temperature

Technology Background
JOC High Flame Temperature

- Benefits
  - Significantly reduce NO_x emissions at combustion
  - Enhanced radiant heat transfer increases boiler efficiency which results in boiler fuel savings
  - Less fuel results in lower carbon generation, reduced capture costs, and lower oxygen demand
  - Reduced volume of flue gas and concentrated carbon dioxide in flue gas also reduces the cost of carbon capture
- Challenges
  - Burner stability and performance
  - Balancing heat duty in radiant and convective zones for retrofit projects or conventional new build projects
  - Minimizing air in-leakage to boiler

Technology Background
NETL Integrated Pollutant Removal (IPR®) System

- Key Characteristics
  - A series of compression stages where cooling upstream of each stage is leveraged for heat recovery and CO_2 purification
  - Heat recovery step employs both direct-contact and indirect heat exchange
  - Condensed water is removed from the flue gas and recycled for power plant use
  - Water-soluble materials are removed from the flue gas
- Advantages
  - Integration of IPR® with the power plant thermal cycle minimizes parasitic load for the work required to remove pollutants and capture/process CO_2
  - Condensed water captured from the combustion flue gas is sufficient offset 100% of the boiler feed water makeup and up to 7% of the cooling water makeup for the plant
  - IPR® uses "off the shelf" technology
- Challenges
  - Optimizing material selection costs while minimizing corrosion concerns
  - Treatment of captured water for release and/or use in the plant water supply

Project Accomplishments

- Retrofitted and operated a 5 MWe equivalent test boiler facility
  - No major boiler modifications required
  - No increased fouling and slagging indicated (study continues)
  - No damage to boiler materials indicated (study continues)
  - Operated the test facility with air-natural gas and oxy-natural gas combustion
  - Performed parametric studies with natural gas combustion
  - Designed, constructed, and operated a pulverized coal feed system with a scaled up oxy-coal burner from the CRADA work
  - An oxy/coal burner has been developed thru several stages in cooperation with Maxon Corporation and with CFD modeling by REI.
  - A 2nd generation oxy/coal burner incorporating four tangential oxygen nozzles to promote mixing has been tested at various loads.
  - Evaluation of results and comparison of data to CFD models has lead to the development further enhancements to the burner design.
  - The JOC burner generation 2.1 is currently in initial testing at Hammond.

Project Accomplishments

- Designed, constructed, and operated a 20 KWe equivalent IPR® facility
  - Test IPR® system has yielded gas composition and liquid composition process results
  - Demonstrated CO_2 capture at 95% to 100%
  - Pollutant removal from captured CO_2
    - 95% NOx , SOx, particulate
    - 60% to 90% mercury
  - Water treatment tests (on flue gas condensate) point to $FeCl_3$ as an effective flocculent especially when paired with polymeric flocculent
  - In-situ corrosion sensors have been installed to characterize material possibilities in-service
- Flame analysis instrumentation upgraded to include
    - In-furnace camera viewing the entire flame
    - Mono-chromators and spectrometers detecting gray-body and radiant-gas signatures for independent temperature determination
    - Total-radiometers coupled with cameras to track total radiation while taking port-occlusion-caused attenuation into account.

Project Accomplishments

- Air-coal baseline burner
  - An air/coal burner has been specifically design and fabricated for the Jupiter Test Facility boiler along with auxiliary equipment.
  - The air/coal burner system has been successfully operated on the test boiler and several test runs were completed at various loads.
  - Test results are currently being evaluated by the JOC team
- System economic study
  - Full-scale parametric model of a power plant retrofitted with high temperature oxy-combustion and an IPR® system has been developed.
  - Provided retrofit design basis to NETL systems group.
  - NETL systems group is has developed a cost estimate for high flame temperature oxy-combustion retrofit to a commercial power plant.

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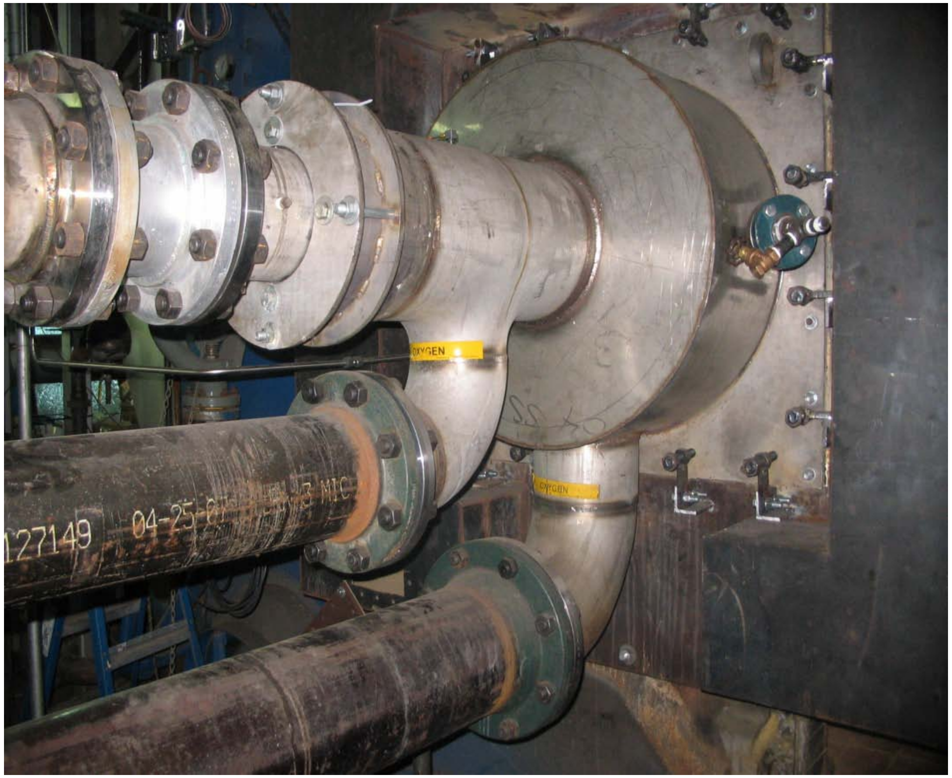
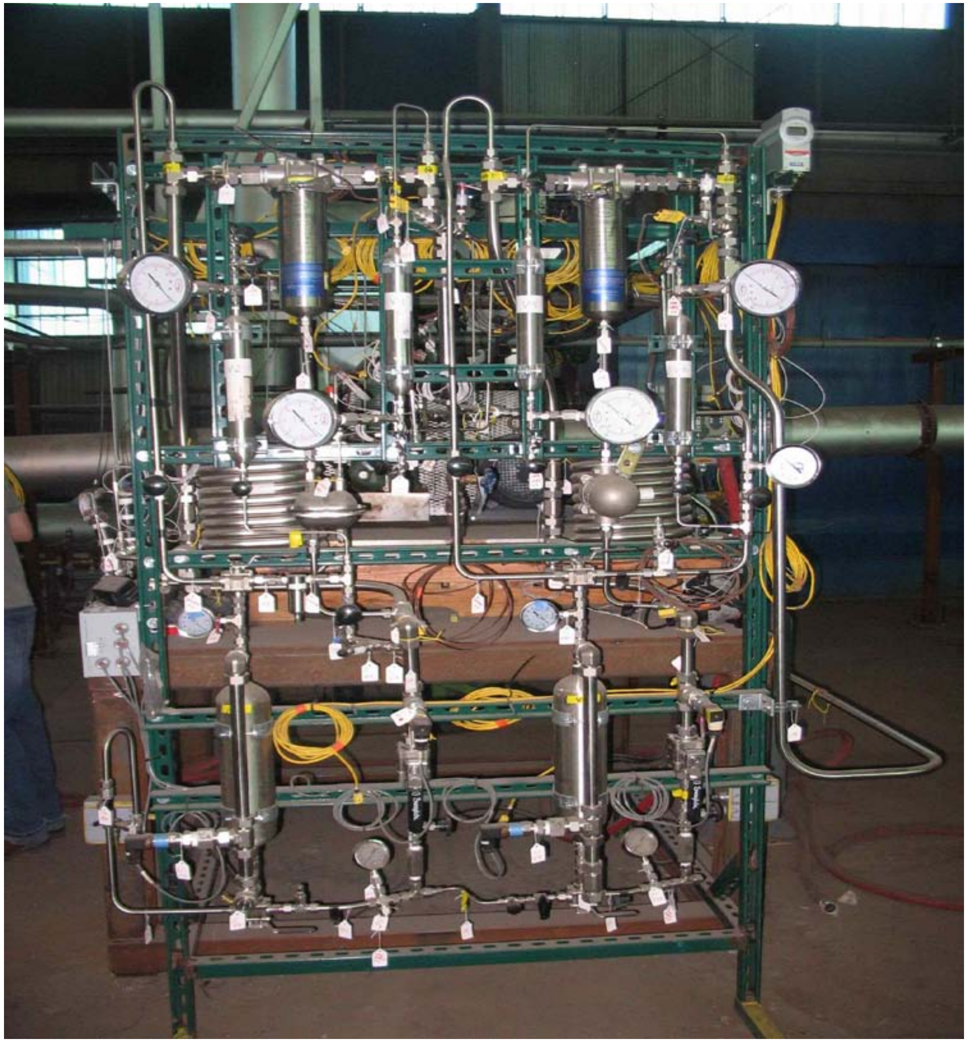
5 MWe Equivalent Test Boiler

50 MMBTU/hr OXY-COAL BURNER



20 KWe
equivalent
IPR System



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Coal Pulverizer and Flue Gas Recycle Loop

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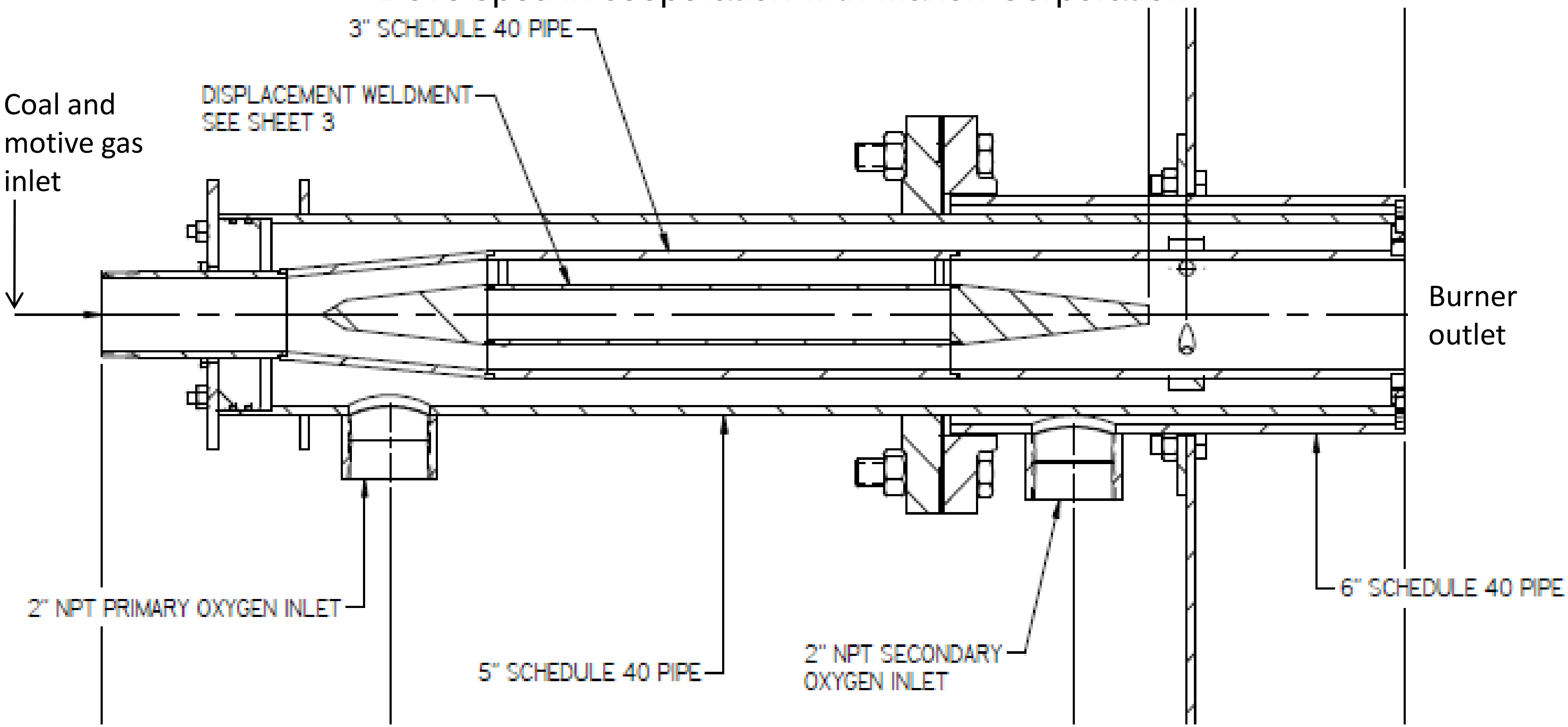
2nd Generation High Temperature OXY-coal Burner (bench scale model)

Developed in cooperation with Maxon Corporation



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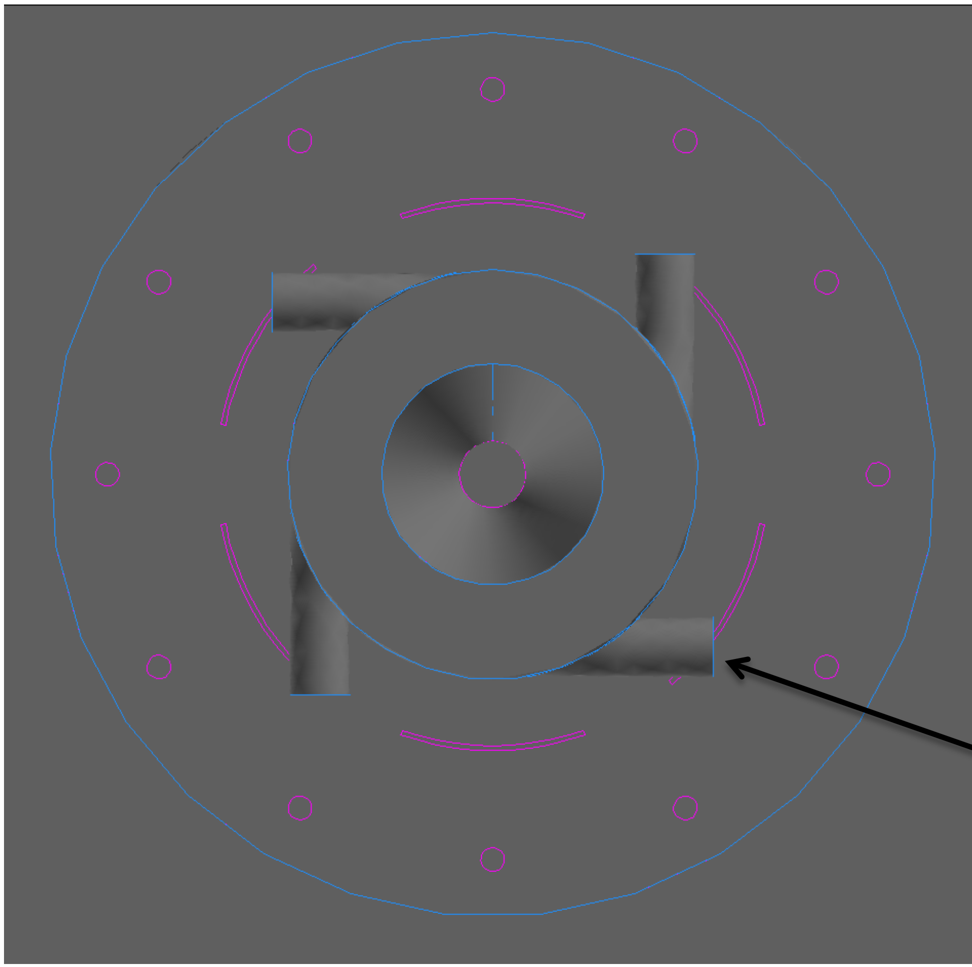


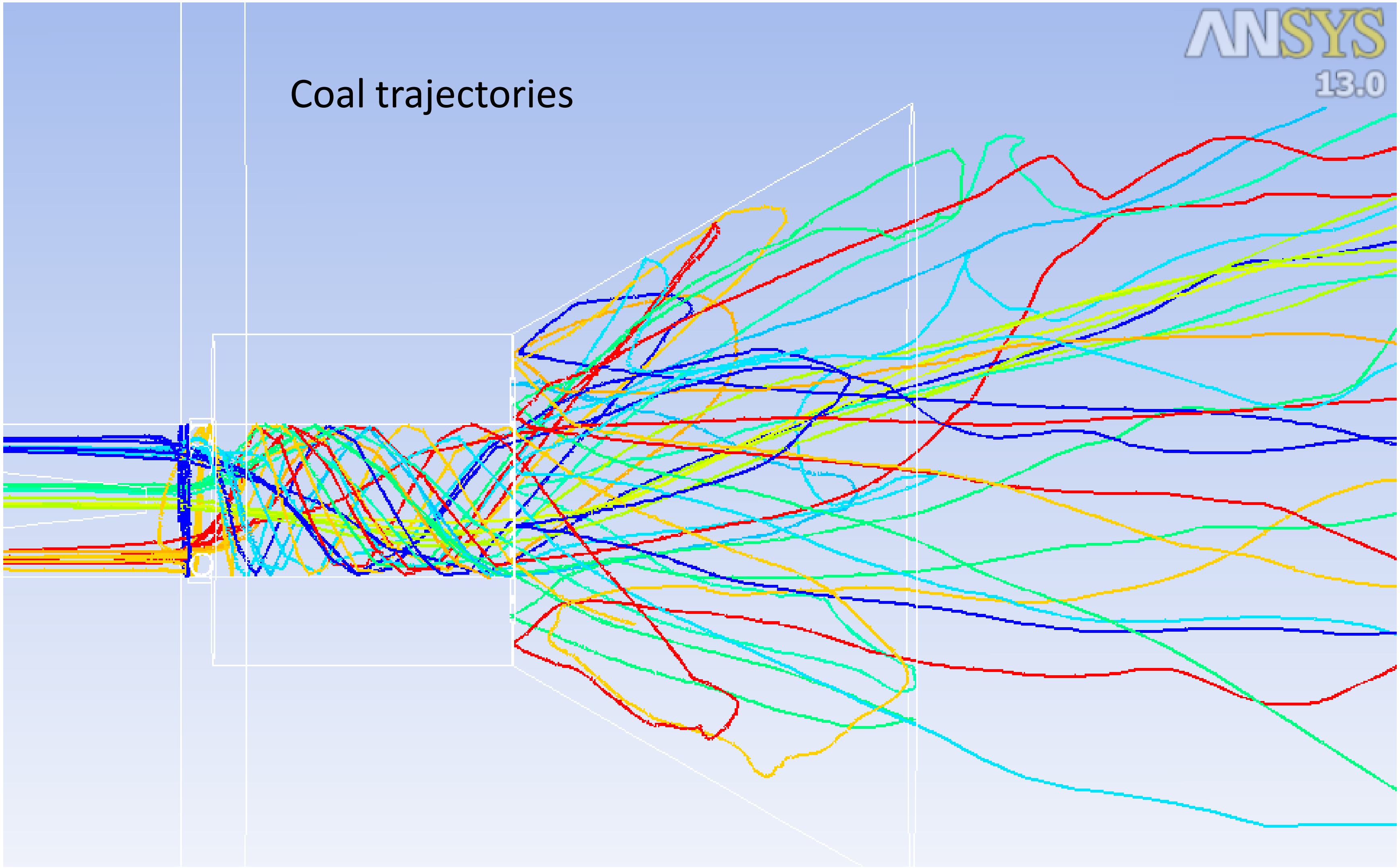
2nd Generation OXY-coal Burner (bench scale model – end view)

Developed in cooperation with Maxon Corporation

CFD modeling by NETL

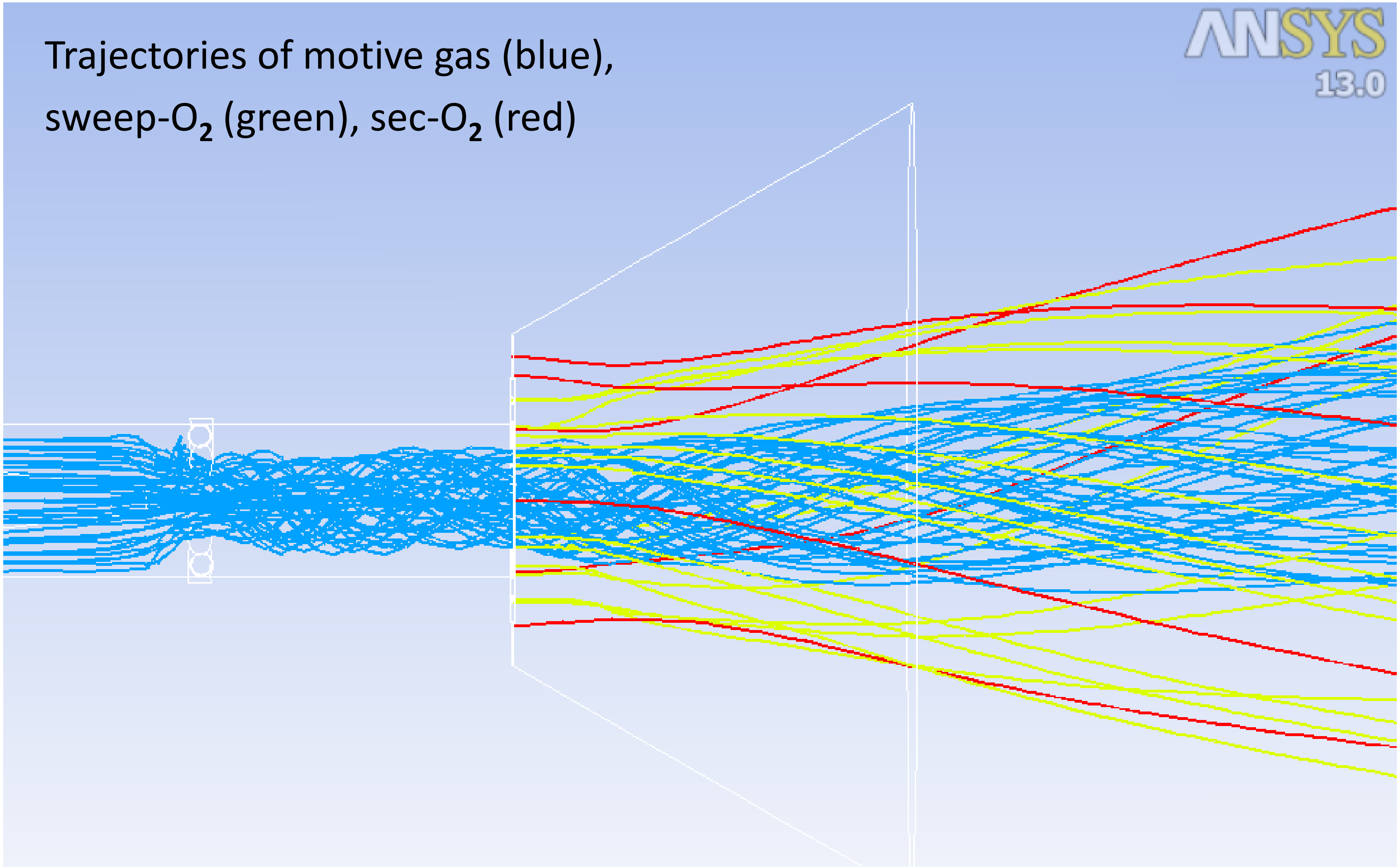
Primary oxygen
Tangential ports (4)

2^{nd} Generation OXY-coal Burner
(3.4MMBTU/hr bench scale model)



2nd Generation OXY-coal Burner

(3.4MMBTU/hr bench scale model)



2nd Generation OXY-coal Burner Design vs. Results

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	Design case	Actual operating point
Firing Rate (MMBtu/h)	50	41
Total Coal Flow, (lb/h)	4142	3,395
Motive Gas (FGR) Flow (lb/h)	7195	10725
Total Primary Oxygen (lb/h)	5903	4675
Secondary Oxygen (lb/h)	3159	2660
Total Oxygen: (lb/h)	9061	7335
Oxygen content at the nozzle	40.0%	27.5%
Exhaust excess O_2 (vol %, wet)	3.00%	3.56%
Ash LOI		0.24%

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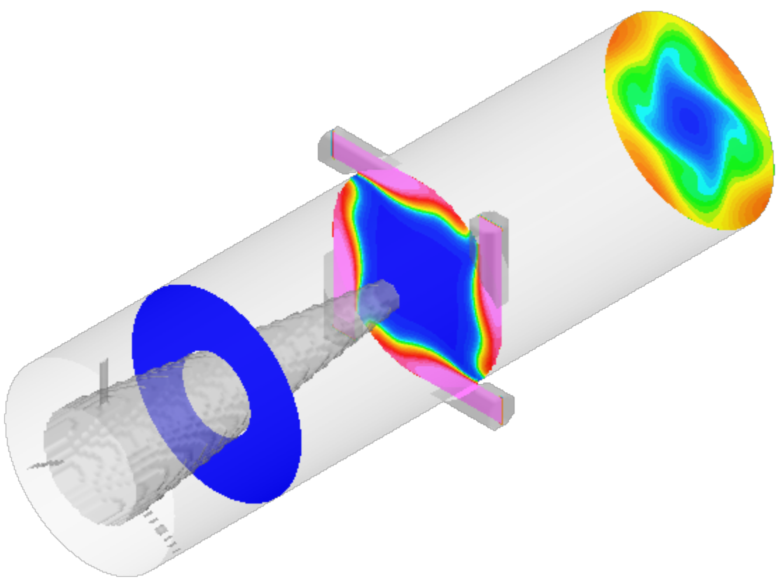
2^{nd} Generation OXY-coal Burner Design vs. Results

O_2 Concentration Profiles

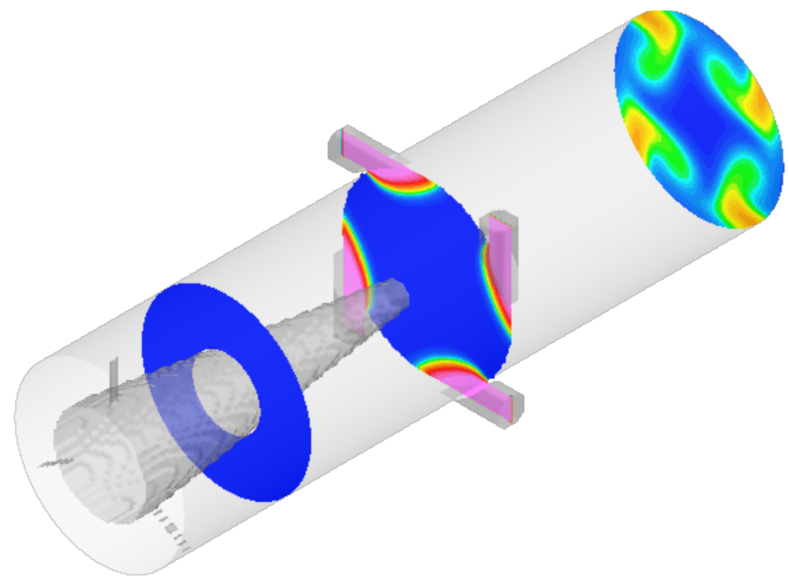
Design Coefficient of Variation = 39%

Nozzle exit oxygen content= 40%



Operating Coefficient of Variation = 52%

Nozzle exit oxygen content = 27.5%



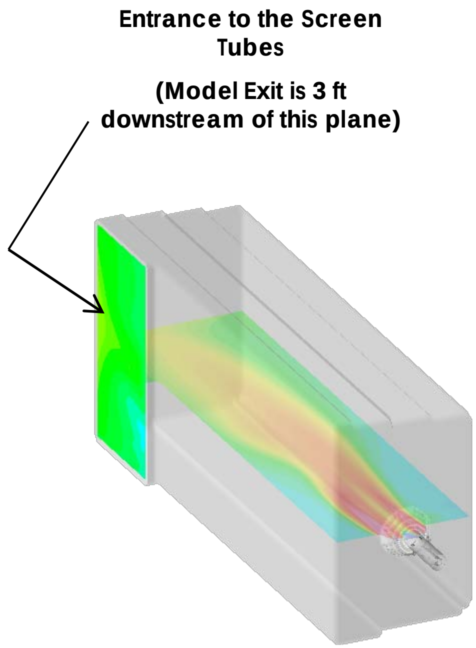
Modeling by Reaction Engineering International

Burner and boiler modeling cases by REI

Case3	Based on package boiler tests conducted on 9/7/11 Generation 2.0 Burner 27.5% Oxygen at the nozzle
Case4	41 MMBtu/h Generation 2.1 Burner 3.0% O_2 in motive gas (100% FGR as motive) 40% oxygen at the nozzle
Case5	41 MMBtu/h Generation 2.1 Burner 10.0% O_2 in motive gas 40% oxygen at the nozzle
Case6	41 MMBtu/h Generation 2.1 Burner 20.0% O_2 in motive gas 40% oxygen at the nozzle

Burner and boiler modeling results at the screen wall by REI

	Case3	Case4	Case5	Case6
Burner design	2.0	2.1	2.1	2.1
Screen wall temperature (ºF)	2165	2231	2211	2240
Unburned Carbon in Fly Ash	11.3%	1.1%	1.7%	1.9%
Particle Burnout	98.4%	99.7%	99.6%	99.5%
Predicted Radiant Furnace Heat Loss (MM Btu/h)	23.49	27.47	27.31	27.00
Percent Heat Input Lost in Radiant Section	58.4%	68.6%	68.1%	67.4%
Peak flame temperature (F)	4500	4800	4800	4700



Project work going forward

- Generation 2.1 oxy-coal burner testing
  - Burner testing and comparison against CFD modeling
  - Conduct test matrix of control variables
  - Perform extended steady state run at optimal operating conditions
- Slagging and fouling study
  - Slagging and fouling study to be completed during up coming oxy/coal testing
- Develop air-coal combustion base line
  - Evaluate data from recently completed testing and performance of air/coal burner with respect to oxy-coal performance

Project work going forward

- IPR® evaluation
  - Improved gas analysis at all stages
  - Energy recovery optimization modeling
  - In-situ and correlative lab tests for corrosion in IPR-produced environments
- Generate additional technical data
  - High flame temperature oxy-coal/ IPR® retrofits
  - Captured CO_2 meeting EOR/sequestration specifications
  - Commercial scale-up study with economics
  - Meeting DOE Existing Plants Program Goals

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Summary

Combined Jupiter Oxygen high flame temperature oxy-combustion technology and NETL IPR® pollution control and carbon capture system for coal fired power plants

- Technologies provide a means to retrofit existing power plants and build new ones.
- Boiler system fuel savings can be expected from high flame temperature oxy-combustion technology.
- 95-100% carbon capture is feasible.
- Technologies allow fully carbon capture ready power plants to exist today which can be completely compliant with clean air regulatory requirements.
- Water recovery will exceed boiler feed water makeup requirements and partial cooling water makeup requirements.
- Heat integration from cryogenic oxygen plant and IPR® compressors can lower fuel costs.

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Summary

- While high flame temperature oxy-combustion burner and IPR® scale-up and optimization will continue during the current project year, these technologies are ready for commencement of a demonstration pilot project.
- The 5 MWe equivalent boiler retrofit completed for this JOC-NETL project has demonstrated
  - High flame temperature oxy-combustion can make steam in a conventional, older boiler without changing boiler interior materials
  - The IPR system uses commercialized equipment, and scale-up also will use commercialized equipment.
- Total parasitic power requirements for both oxygen production and carbon capture currently are in the range of 20%.
- Preliminary economic projections indicate that new and retrofitted coal fired power plants can achieve 95-100% carbon capture with COE increase of not more than 35% provided a net CO_2 revenue of approximately $20 per ton.

Thank you