Development of Cost Effective Oxy-Combustion for Retrofitting Coal-Fired Boilers - DE-FC26-06NT42747

2010 NETL CO_2 Capture Technology Meeting
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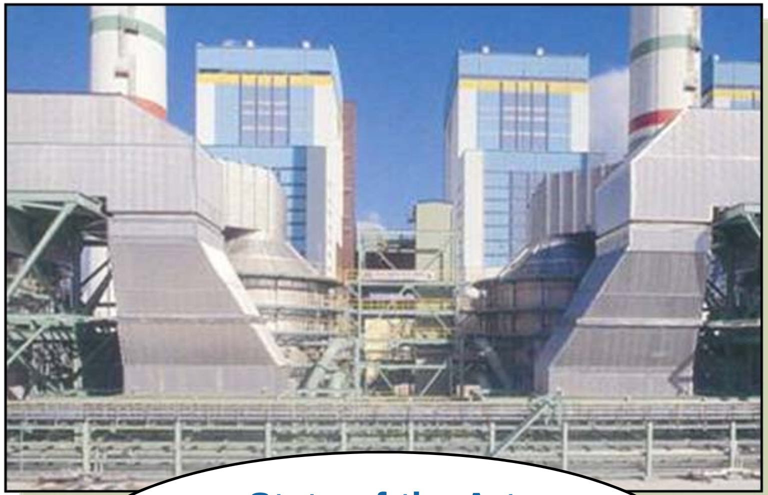
Who We Are: Babcock & Wilcox PGG



State-of-the Art Steam Generating Systems

State-of-the Art Environmental Control Systems

Since 1867, we are the *original* Babcock & Wilcox with extensive experience in engineering, manufacturing, constructing and servicing steam generating and environmental control systems.

George Babcock

Stephen Wilcox

B&W Oxy/Coal Combustion Experience

- 1979 Numerical Modeling per request of a major oil company
- 2000 Member CANMET

Recent Developments with Air Liquide Collaborations

- 2001-2002 - Oxy-combustion with IL#6 coal performed at 5 million Btu/hr SBS facility, sponsored by the State of Illinois
  - **Substituted secondary air with recycled flue gas & oxygen**
  - **Gained experience with oxygen/flue gas mixing and combustion**
- 2003-2004 - Oxy-combustion with PRB, sponsored by DOE
  - **Demonstrated oxy-combustion at 5-million Btu/hr, achieved stable low-NO_x flame with acceptable heat transfer conditions**
- 2005-2006 - Economic analysis
  - **Working with DOE, Parsons, Air Liquide**
  - **Oxy-combustion compared favorably to amine scrubber**
- 2007-2008 – 30 MW_{th} Demonstration at B&W's CEDF
  - **Near-Full scale burner development fed directly from an on-line pulverizer**

Development of Cost Effective Oxy-Combustion for Retrofitting Coal-Fired Boilers

- **Funding Sponsors**
  - DOE $2,762,643
  - B&W/Air Liquide $690,644
  - Total $3,453,287

- **Project Duration**
  - March 2006 to December 2010

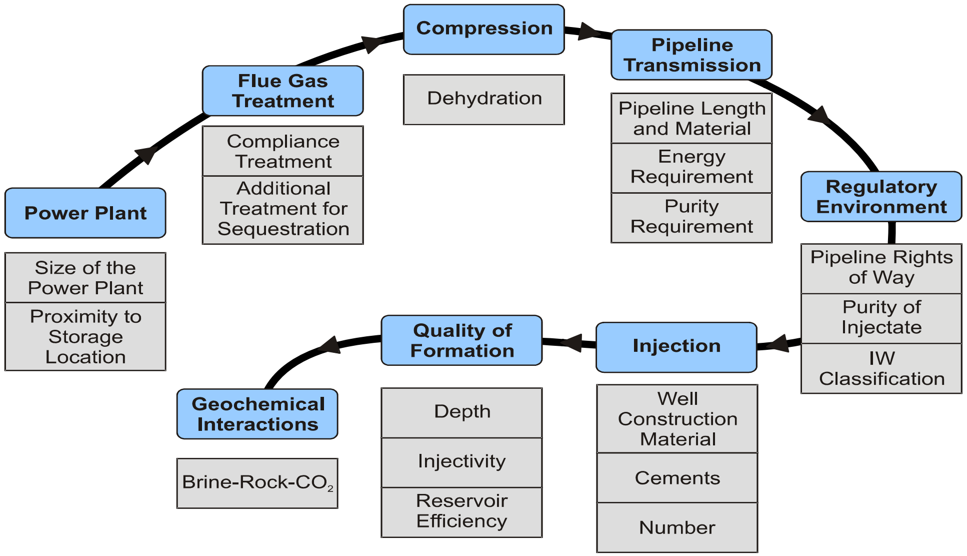
- **Project Team**
  - B&W
  - Air Liquide
  - Battelle Memorial Institute

Project Objectives

To Significantly Expand the Applicability of Oxy-Combustion:

- Evaluate the effect of coal rank that is currently used in existing boilers (i.e., bituminous, sub-bituminous and lignite) in an oxy-combustion design.
- Determine the equipment requirements for the boiler island, flue gas purification, CO_2 compression, transportation, and storage for different coals and combustion systems (cyclone and wall-fired).
- Investigate the potential for multi-pollutant (NO_x, SO_2, and particulate) reduction.
- Validate an existing 3-dimensional computational flow, heat transfer, and combustion model for oxy-combustion scale-up to a commercial size boiler.
- Conduct an engineering and economic assessment of the technology for commercial-scale for cyclone and wall-fired units.

Process Modeling: Reported on 2009 NETL Meeting



Performed:

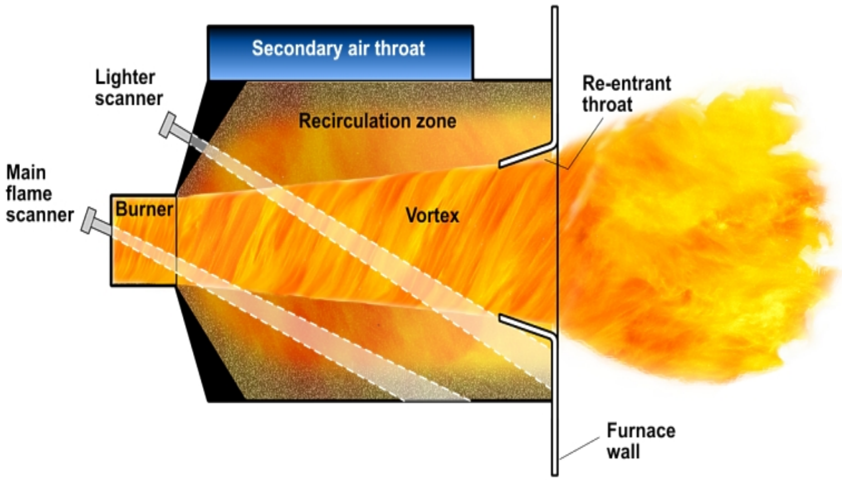
- Boiler Island
- Sequestration
- CO_2 CPU

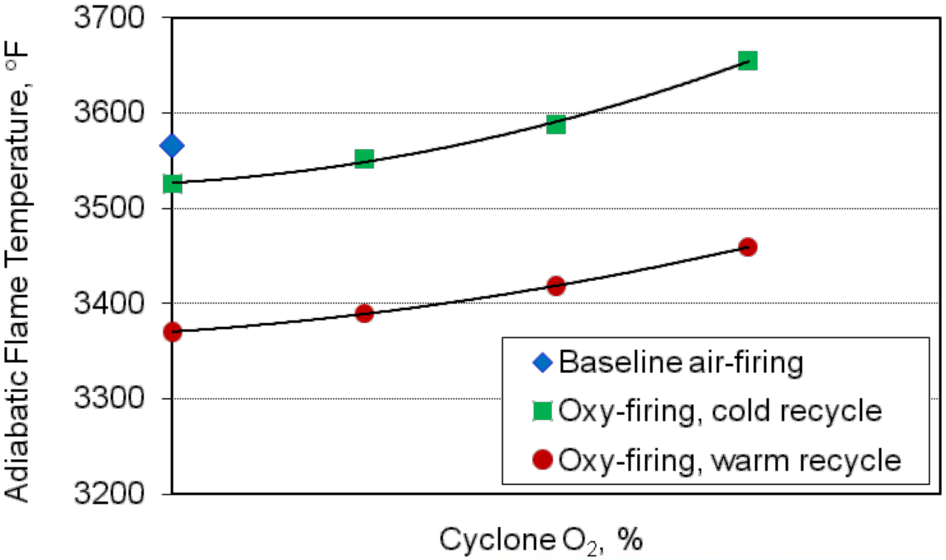
Concluded:

- Since the CO_2 product is required at very high pressure (2200 psig), it is more economical to purify the flue gas and obtain a high purity CO_2 product stream than to compress the entire flue gas to product pressure, even if the downstream pipeline and reservoir can handle contaminants in the flue gas
- CO-Sequestration might be possible but requires <u>Deeper</u>, hence <u>warmer</u>, storage formations. <u>Higher Injection pressure</u> may required to compensate for lower gas density. <u>Additional cost</u> for higher volume of gas is expected.

Pilot-Scale Evaluation

- **Previously, studied wall-firing at 1.8 and 30 MW_t**
- **Demonstrated Oxy-firing in 1.8 MW_t cyclone**
- **Oxy-Combustion for Cyclone Boilers**
  - Combustion in a slagging environment
  - Potential problem with oxy-firing
- **Oxy-cyclone reduces the temperatures**
  - Baseline/air-firing
  - Oxy-cyclone with partially reduced moisture recycle gas
  - Oxy-combustion with no moisture removal - warm recycle
- **The Key to Cyclone Slagging**
  - Oxygen distribution in boiler





Coal Analyses

As-Received Basis	Bituminous Ohio #5	Sub-bituminous Black Thunder		Lignite North Dakota
		Cold RFG	Warm RFG	
Proximate Analysis (%)				
Moisture	6.47	26.56	26.15	35.6
Ash	5.57	4.94	4.64	6.79
Volatile Matter	41.51	32.11	32.20	28.5
Fixed Carbon	46.45	36.39	37.01	29.11
Ultimate Analysis (%)				
Carbon	71.1	50.98	51.80	41.91
Hydrogen	5.02	3.84	3.83	3.04
Nitrogen	1.41	0.76	0.81	0.64
Sulfur	2.56	0.38 ↔	0.24	0.74
Oxygen	7.87	12.53	12.53	11.29
Calorific Value (Btu/lb)	12807	8841	8829	6938

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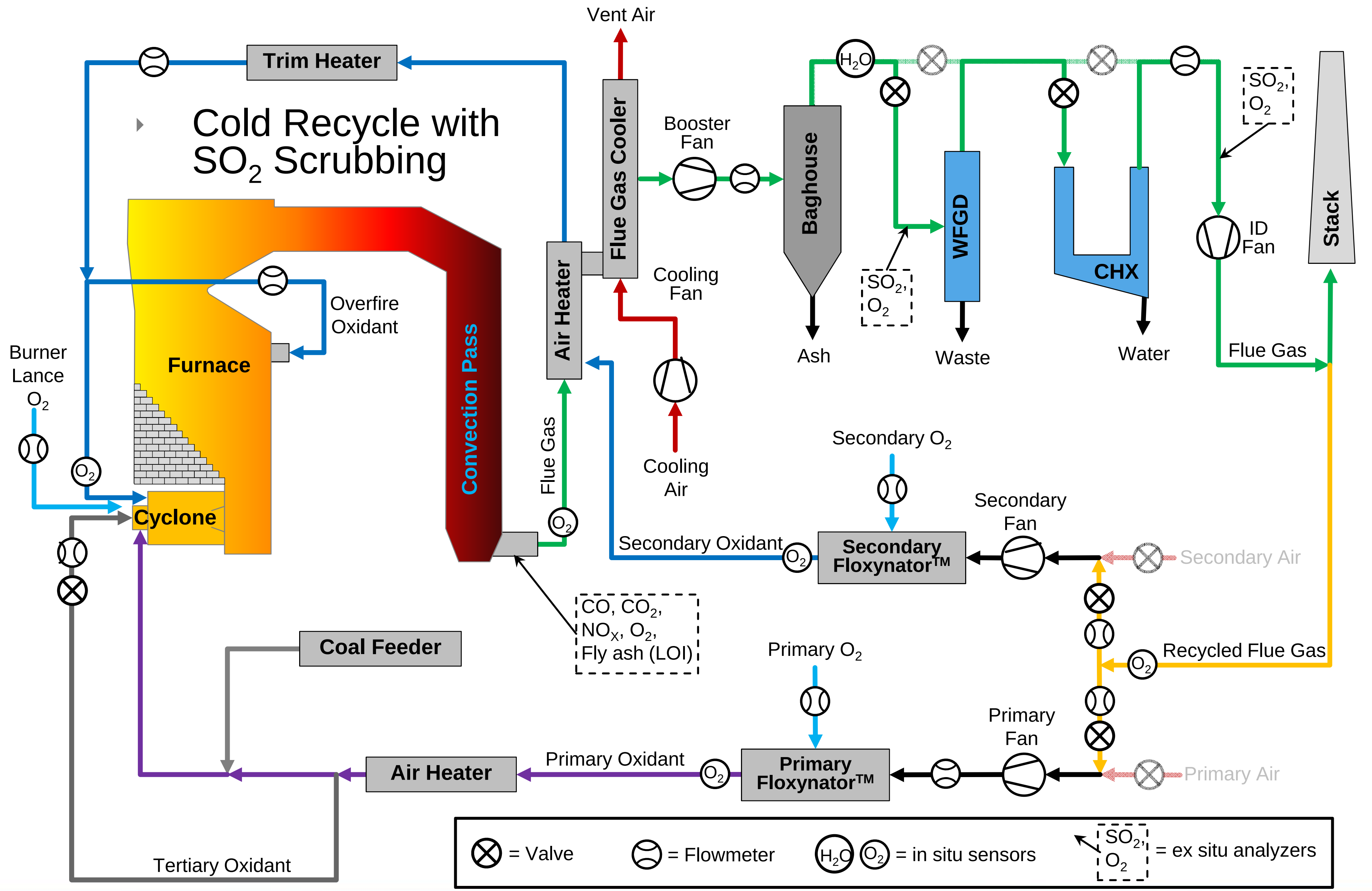
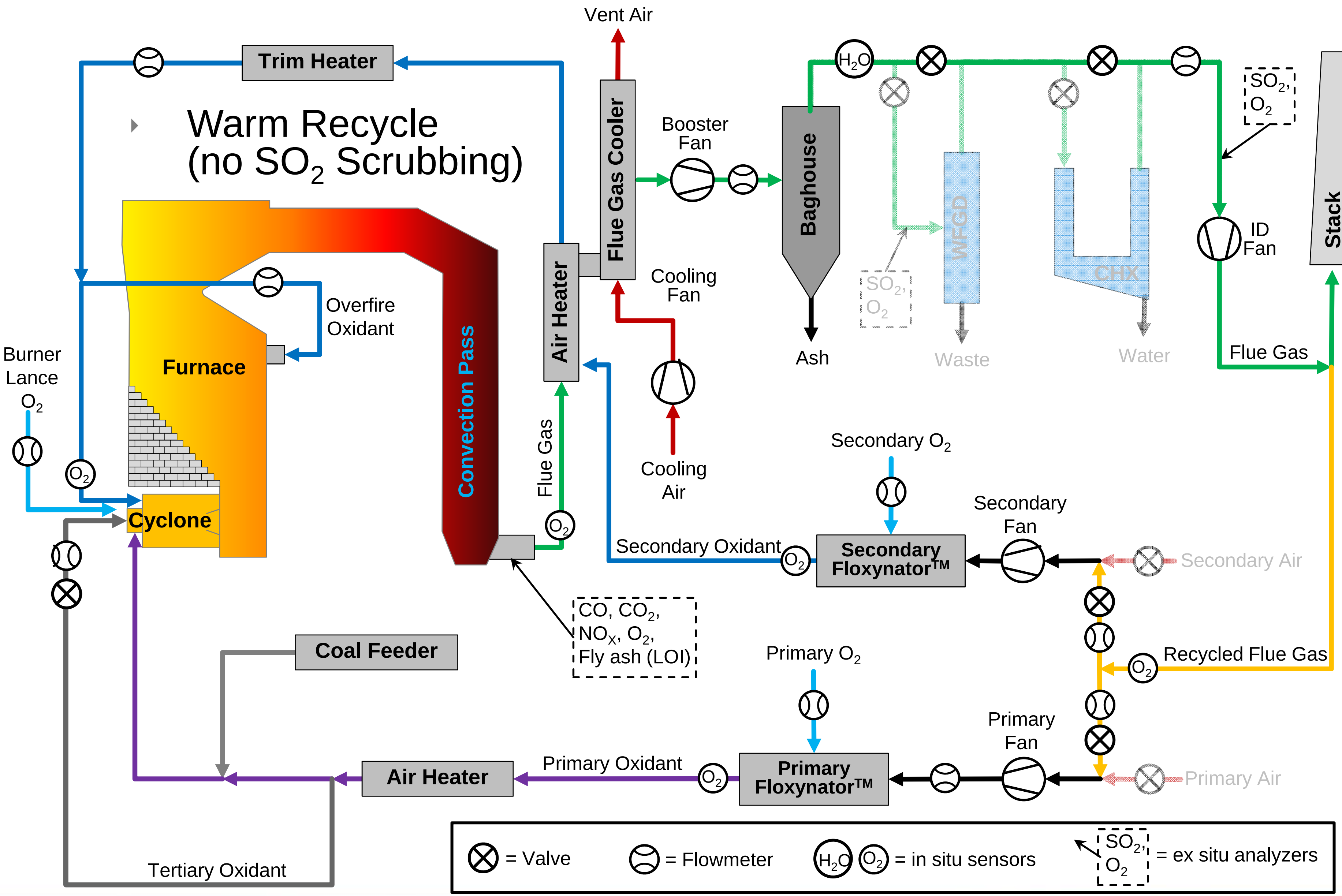
Cold Recycle with SO_2 Scrubbing

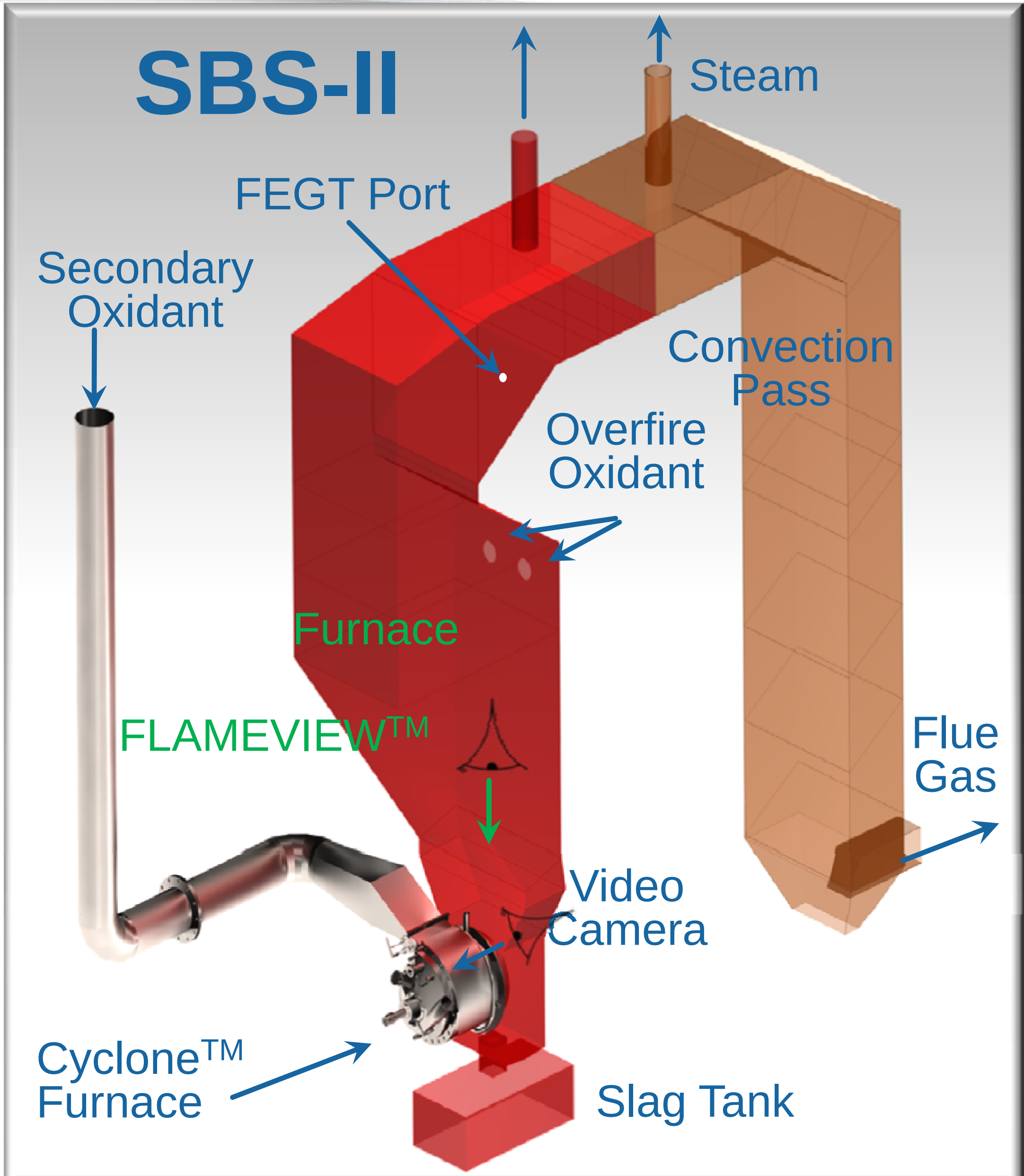


Warm Recycle (no SO_2 Scrubbing)

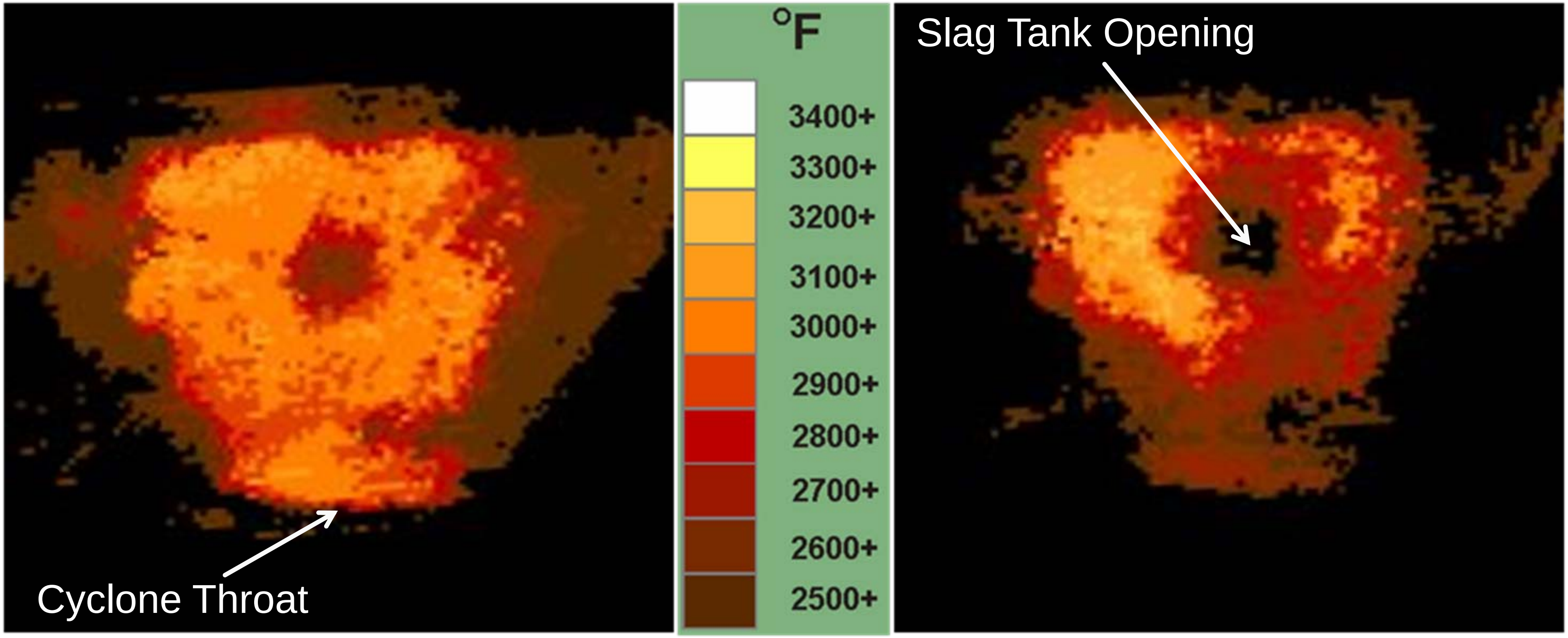


Pilot-Scale Summary

- Oxy-firing was demonstrated in a slagging environment
- Achieved up to 90% CO_2
- Smooth transition from air-firing to oxy-firing
- Heat absorption in oxy-firing similar to air-firing
- NO_X , CO, and LOI were lower with oxy-firing than air-firing conditions
- Higher SO_3 with oxy-firing than air-firing at the convection pass exit but reduced by WFGD/CHx
  - need to develop SO_3 reduction system that is commercially acceptable (avoid CHx)

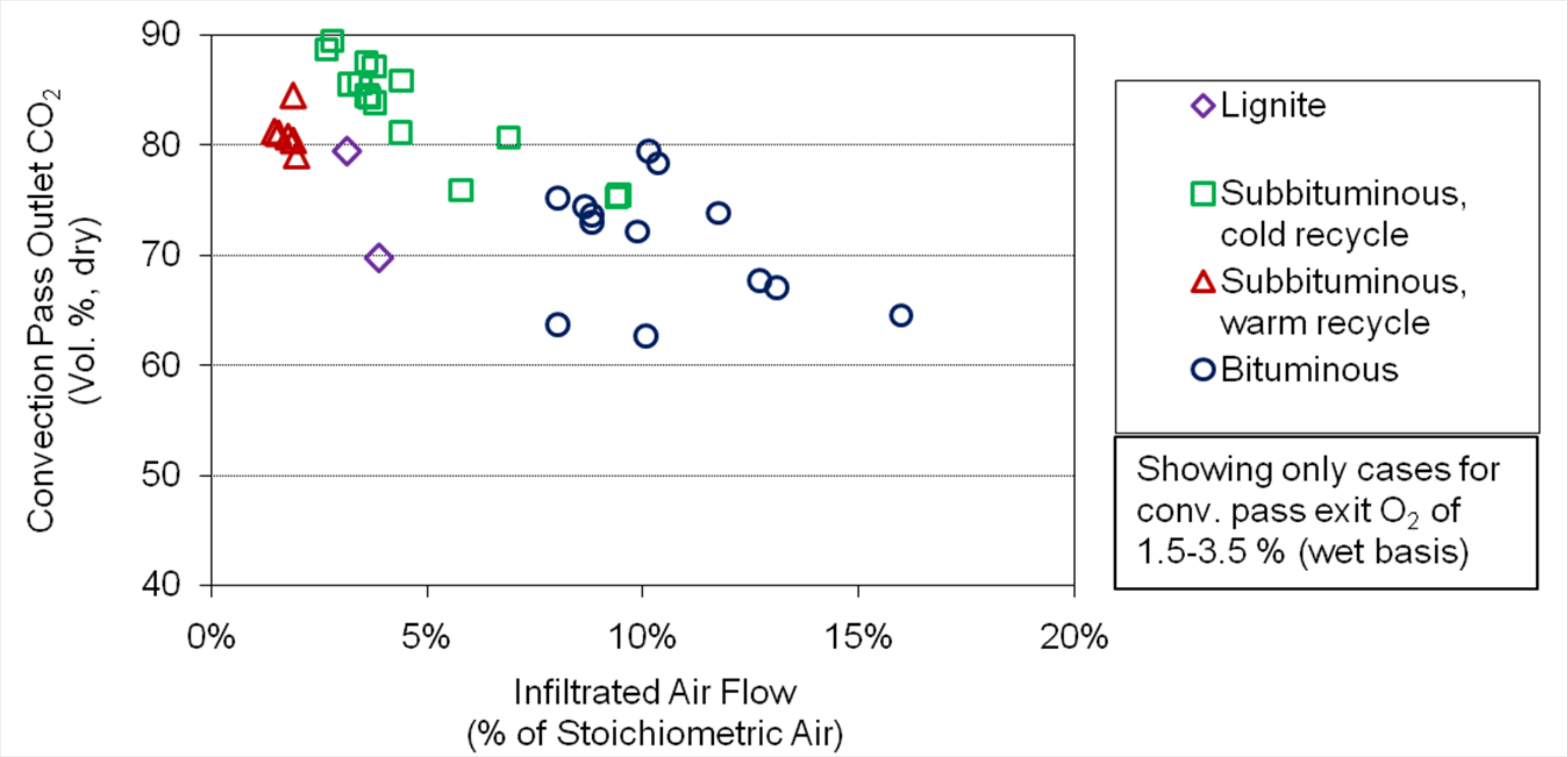


FLAMEVIEW™ Temperature Map – Cyclone Exit



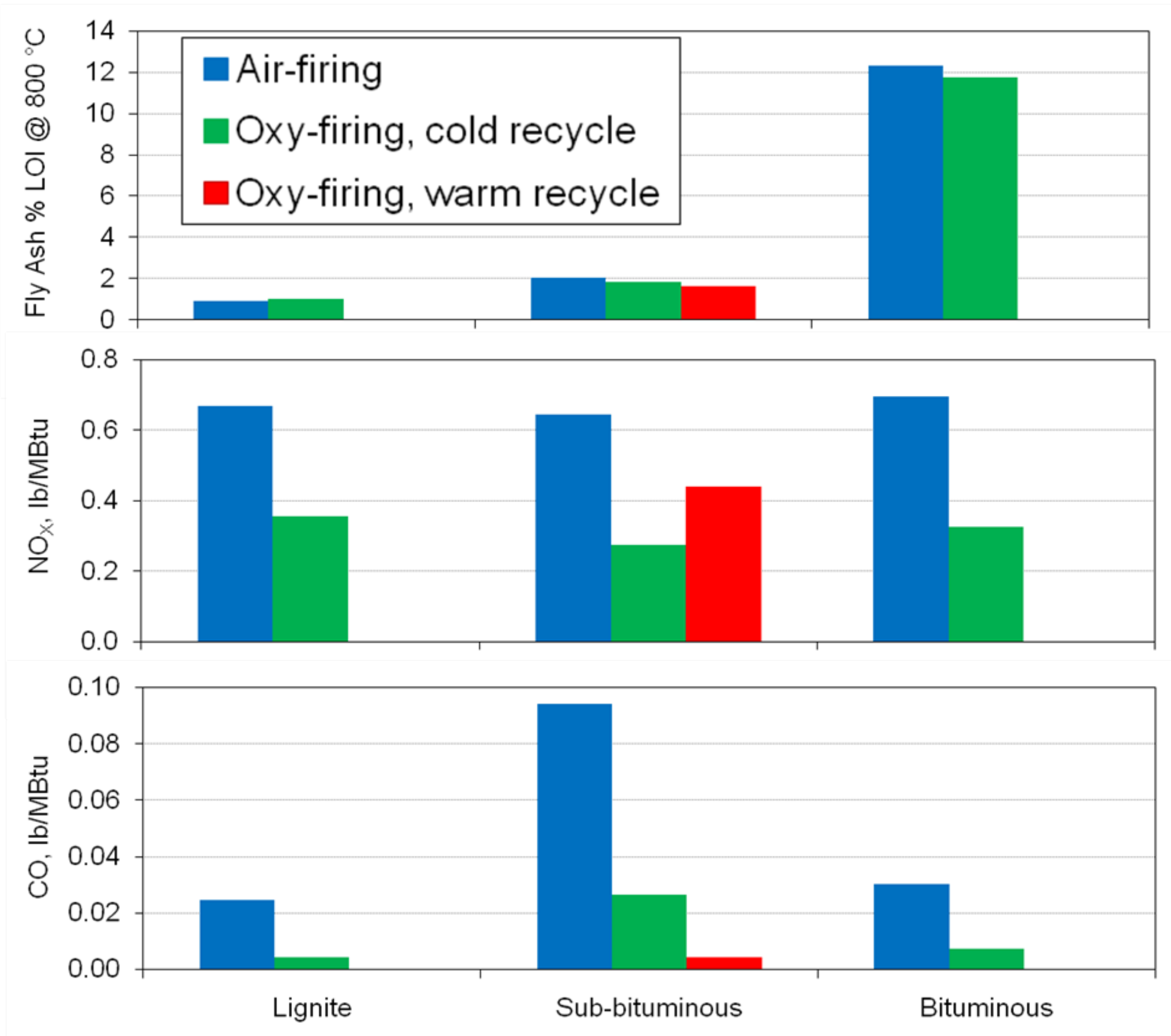
Lignite, air-firing	Lignite, oxy-firing
5.5 MBtu/h	5.4 MBtu/h
Cyclone SR = 0.99	Cyclone SR = 1.04
Overall SR = 1.28	Overall SR = 1.17

Effect of Air Infiltration on CO_2



- High levels of CO_2 achieved by limiting air infiltration

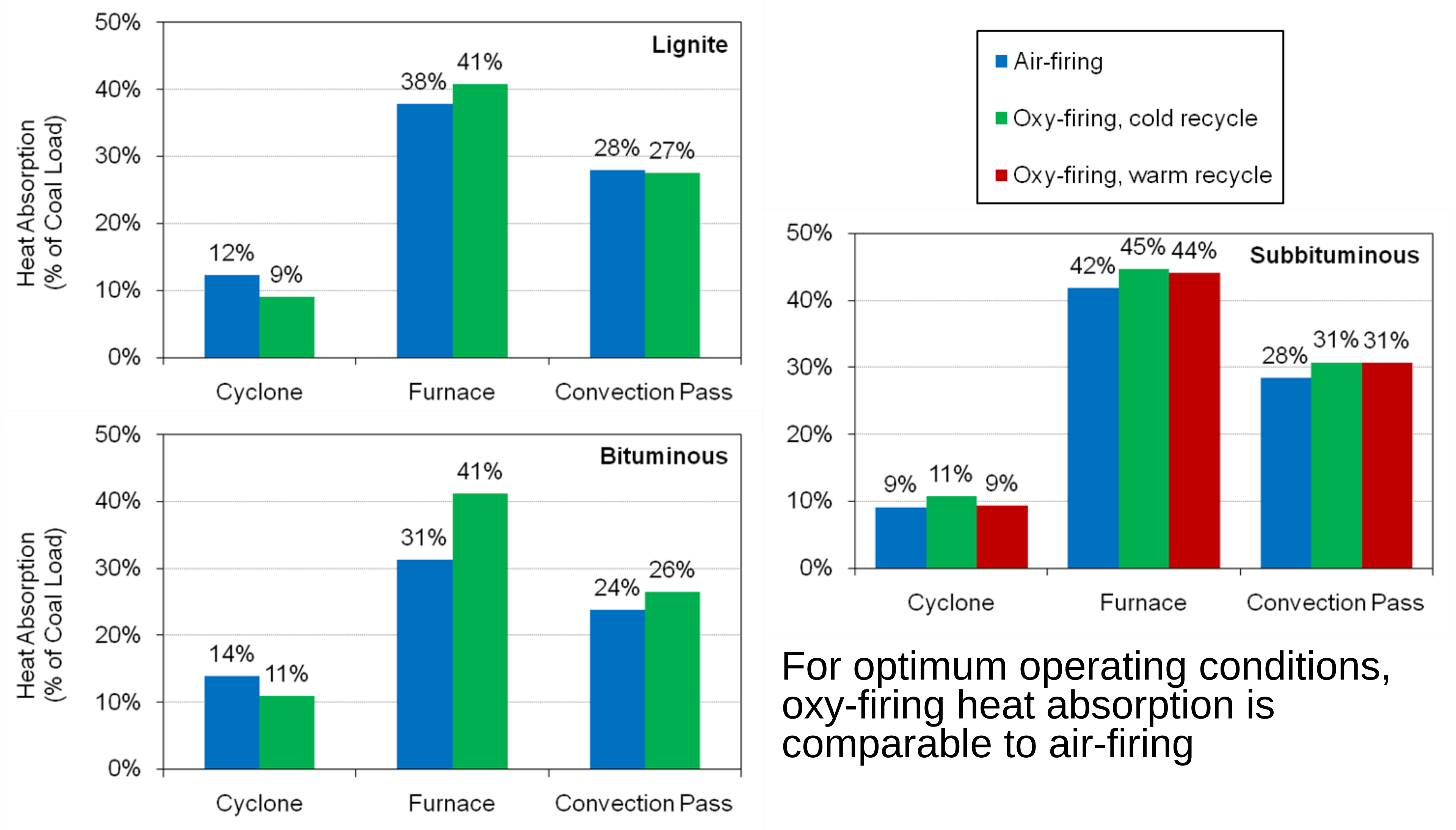
Combustion and Emissions (Boiler Exit)



At optimum operating conditions, oxy-firing is superior to air-firing:

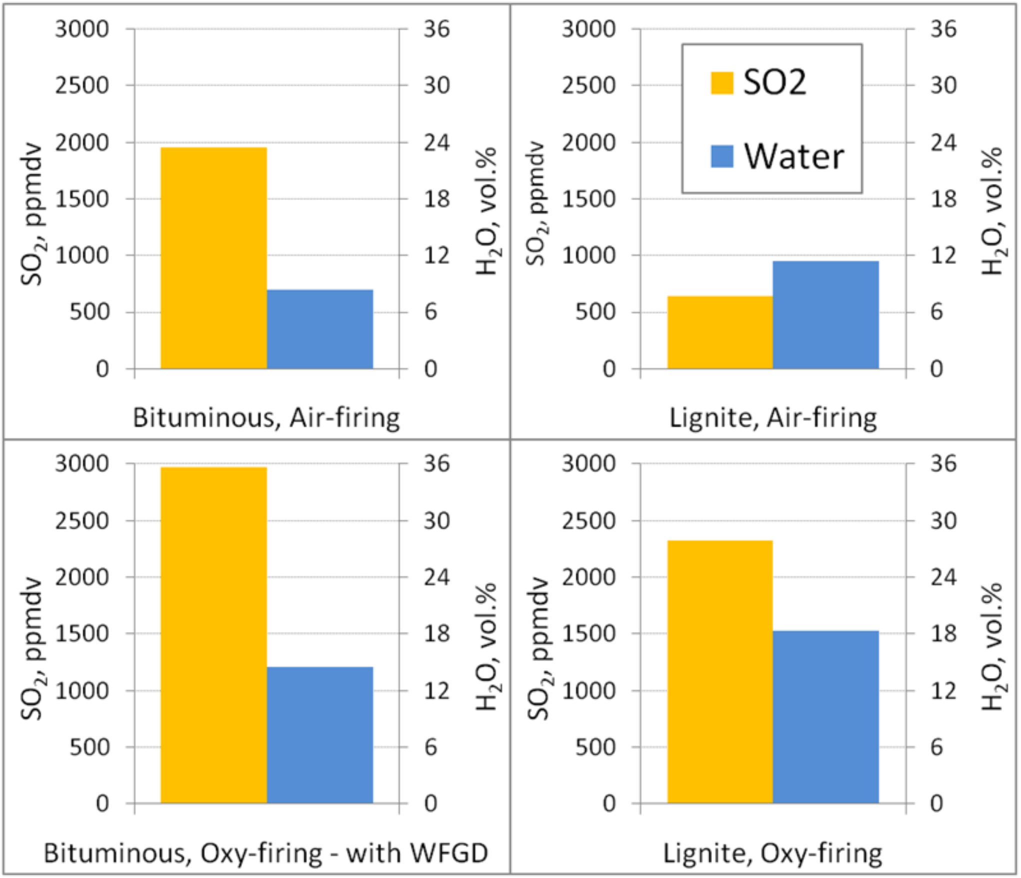
- Lower LOI
- Lower NO_X
- Lower CO

Heat Absorption at Optimum Conditions



For optimum operating conditions, oxy-firing heat absorption is comparable to air-firing

Convection Pass Exit SO_2 and H_2O



← Air-firing

<u>Effect of SO_2 scrubbing</u>

← Oxy-firing

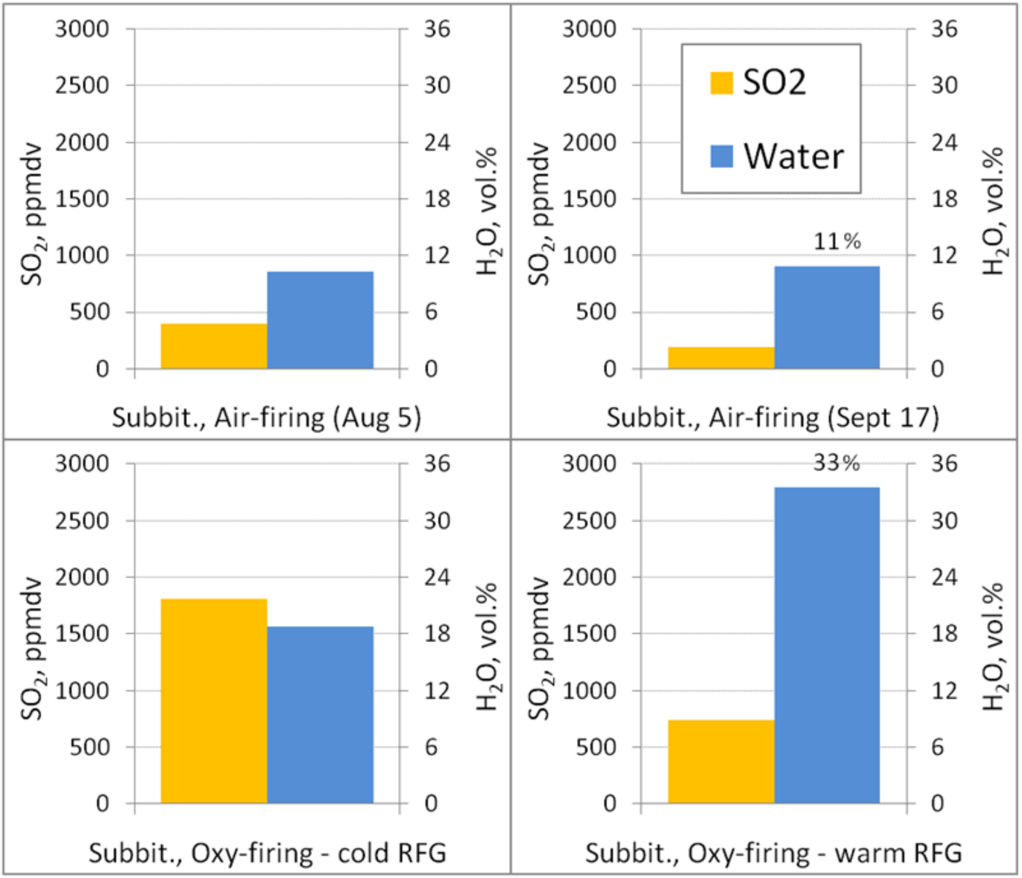
↑ Bituminous with scrubbing

↑ Lignite without scrubbing

When changing from air to oxy:

- Without scrubbing, SO_2 concentration increased by a factor of 3.6-4.5
- Moisture increases by a factor of 1.6-1.8

Convection Pass Exit SO_2 and H_2O



Air-firing

Oxy-firing

Cold recycle test campaign

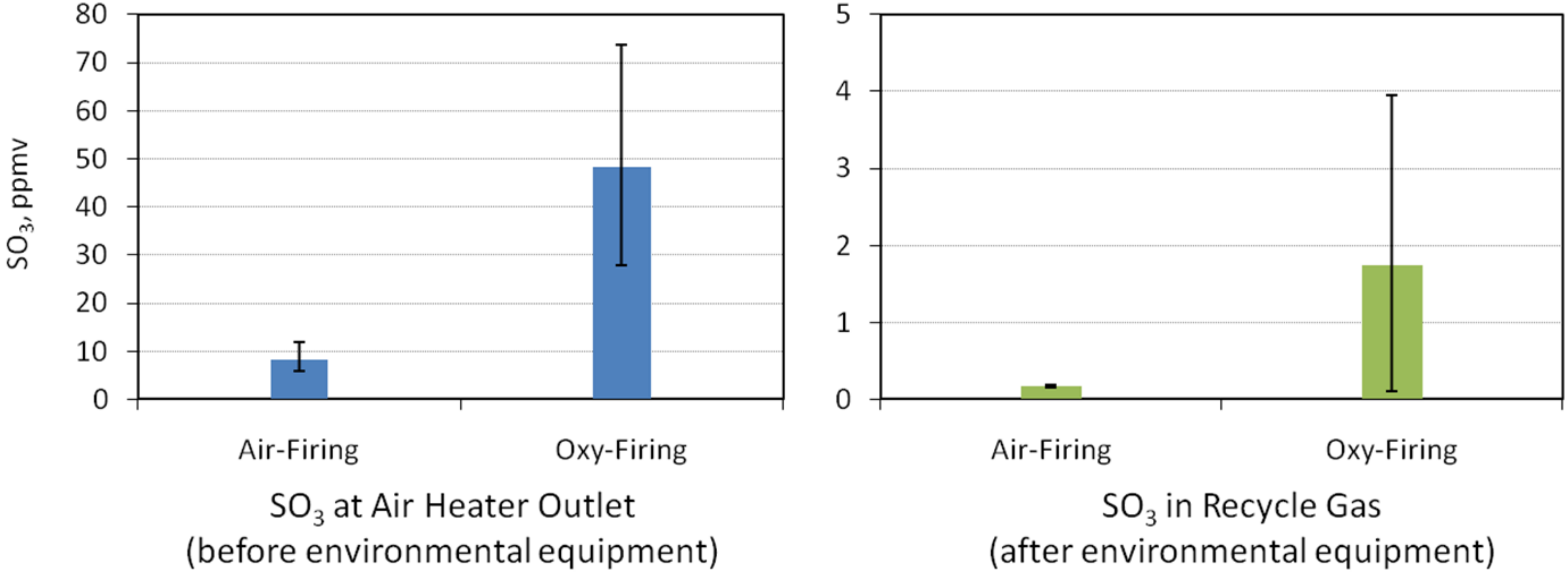
Warm recycle test campaign

Effect of flue gas moisture removal

Effect of warm recycle:

- Significantly higher moisture
- SO_2 not affected

SO_3 – Bituminous Testing



- Oxy-firing produces higher concentrations of SO_3 than air-firing
- Further investigation is necessary to determine the cause, but…
- A combination of baghouse, wet scrubber, and **condensing heat exchanger** was capable of reducing SO_3 to very low levels

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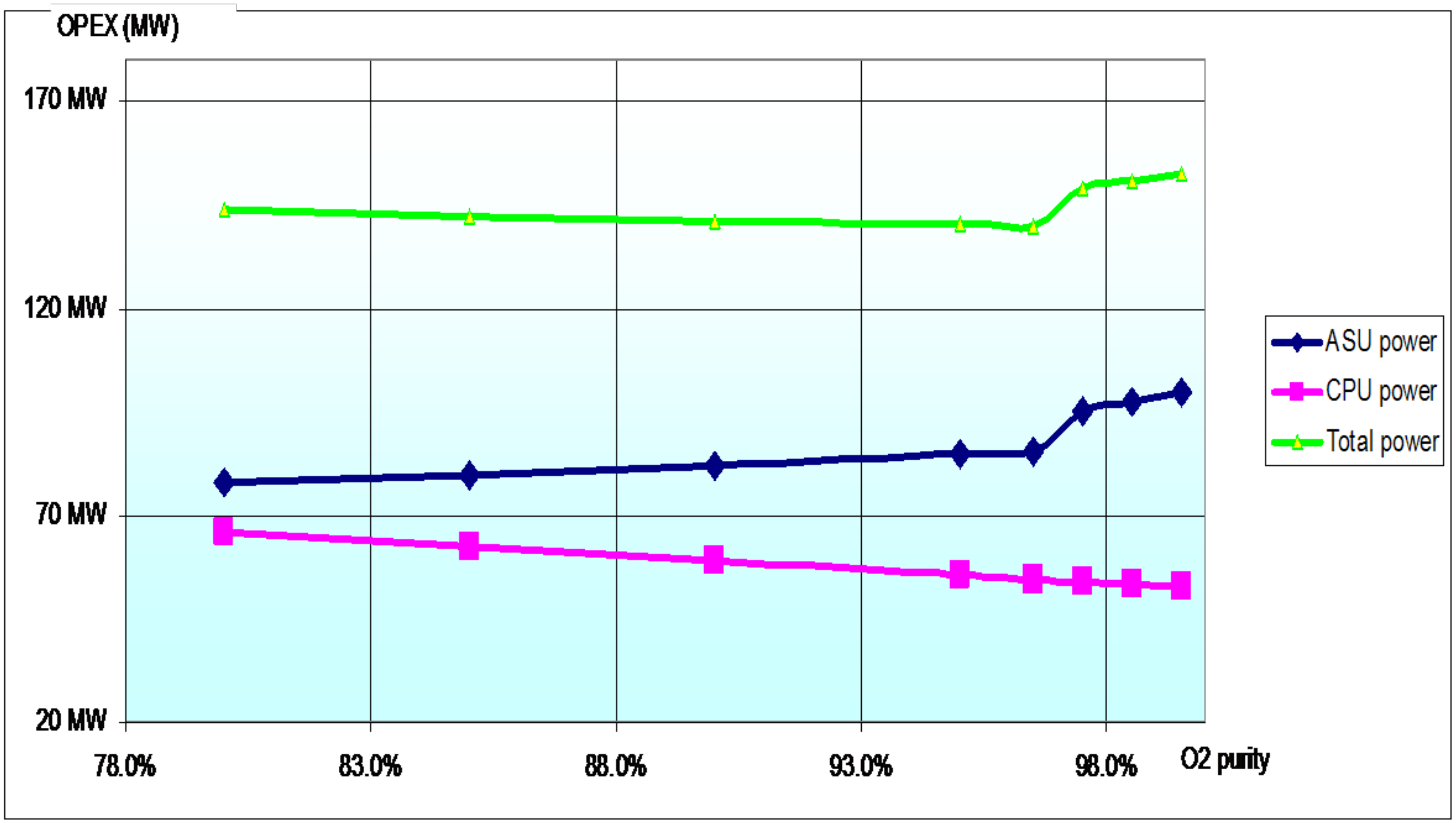
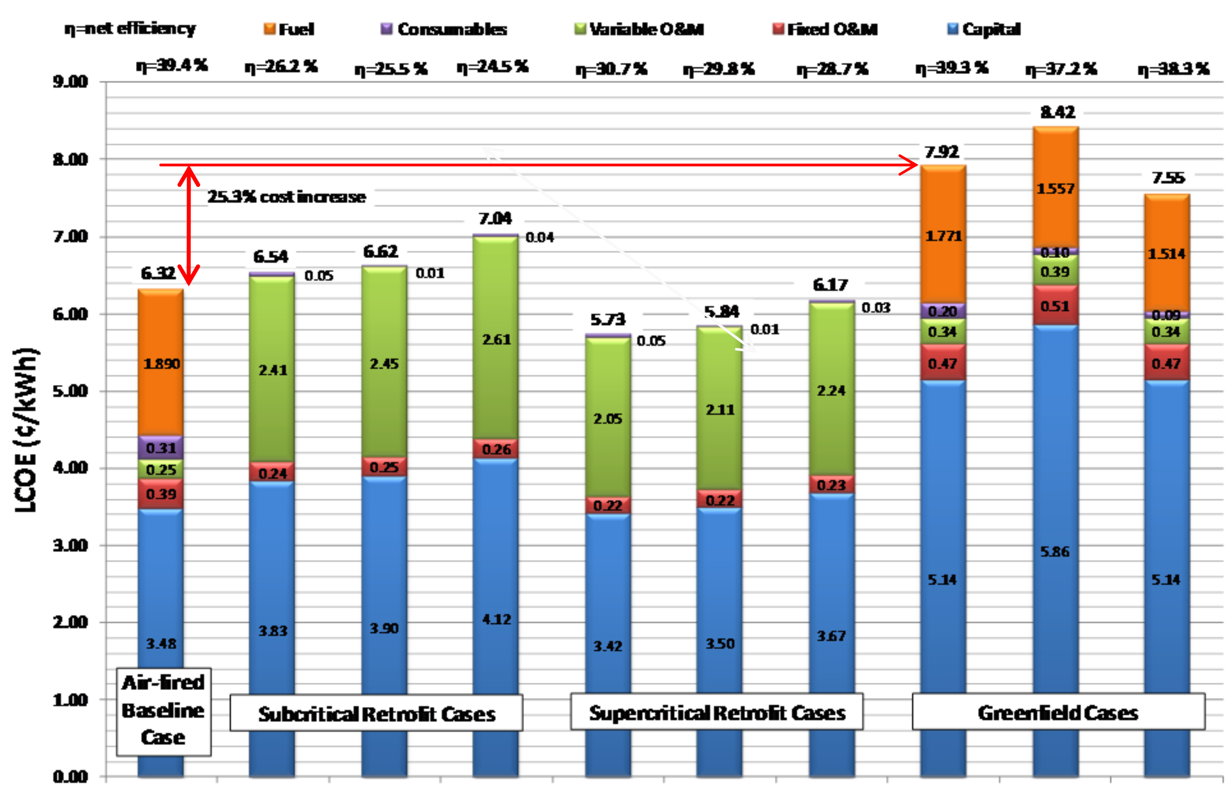
Oxy-firing Optimization: Effect of Oxygen Purity



- Beyond 96.5% O_2 purity, ASU power requirement increases dramatically due to higher energy for O_2/Argon separation
- The increased ASU power requirement more than compensates for the savings in CPU power.
- High purity O_2 is not the optimal solution for oxy-coal combustion with CO_2 capture

Oxy-firing Economics

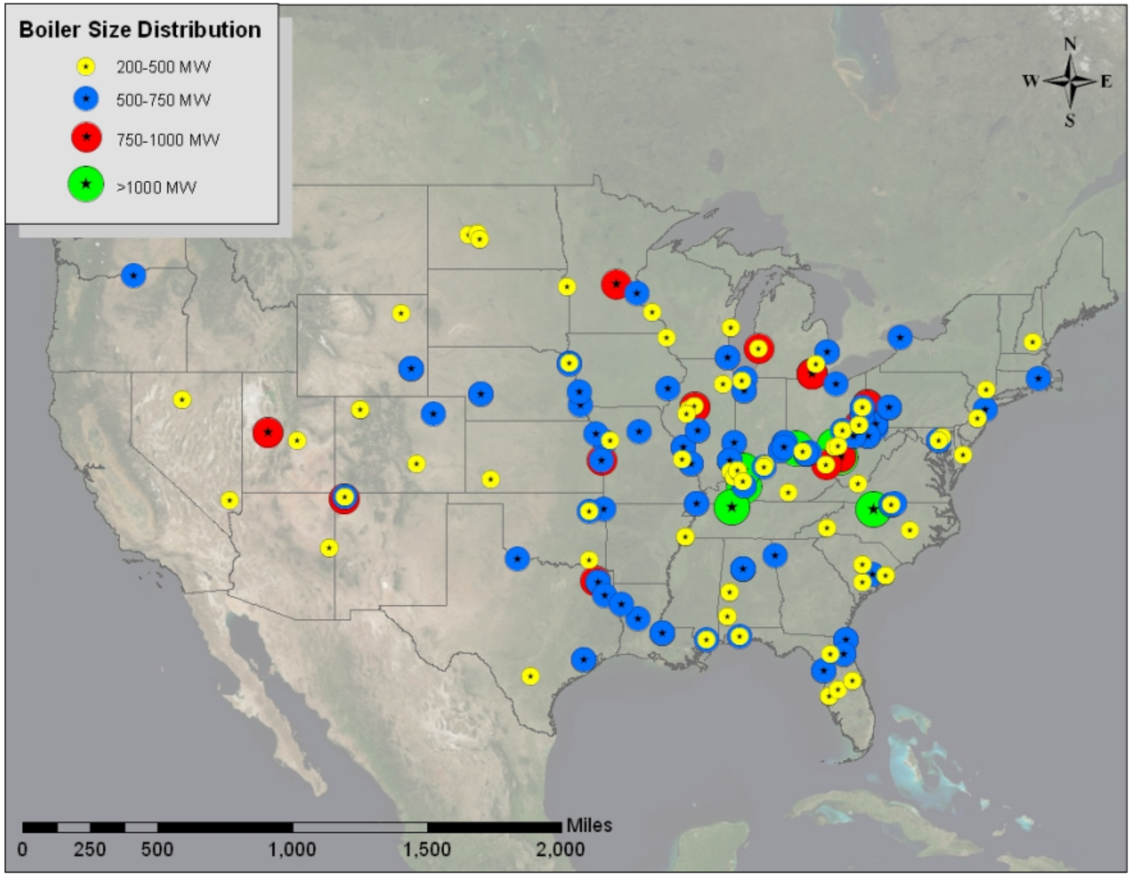


	BASE	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 11	CASE 12	CASE 13
Type	Greenfield	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	Greenfield	Greenfield	Greenfield
Recycle	Air-fired	Cold	Cold	Cold	Cold	Cold	Cold	Warm	Warm	Warm
Steam pressure	SC	SubC	SubC	SubC	SC	SC	SC	USC	USC	USC
Firing System	PC	PC	PC	PC	PC	PC	PC	PC	PC	CYC
Coal	Illinois #6	Illinois #6	Decker	ND Lignite	Illinois #6	Decker	ND Lignite	Illinois #6	Decker	Decker
Existing Scrubber Type	WFGD	WFGD	SDA	SDA	WFGD	SDA	SDA	LI/SDA	SDA	SDA
Polishing Scrubber Stream	NA	PRI+CPU	PRI+CPU	PRI+CPU	PRI+CPU	PRI+CPU	PRI+CPU	PRI+CPU	PRI+CPU	PRI+CPU
Type of ASU	NA	ASU-C	ASU-C	ASU-C	ASU-C	ASU-C	ASU-C	ASU-F	ASU-C	ASU-F
Type of Compression	NA	CPU-C	CPU-C	CPU-C	CPU-C	CPU-C	CPU-C	CPU-F	CPU-C	CPU-F

Reference: DOE/NETL- 1291 Rev. 8/08

Sequestration for Existing Boilers

(Based on NETL's Coal Power Plant Data-base, 2007)



- 251 coal burning wall-fired or cyclone boilers with generator nameplate rating over 200 MW
- 183 boilers within 50 miles of sedimentary basins deeper than 800 m
- 146 boilers qualify within a seismic risk hazard of 1-6 (USGS scale). These are predominantly located in the Ohio River Valley and the Gulf Coast with a few scattered around the inter-mountain West and the Dakotas.
- Boilers located near the Ohio River Valley and the Gulf Coast are especially good sites for potential CCS projects as they are located in areas with heavy CO2 emissions due to power plants and refineries.

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