Jupiter Oxygen

Annual NETL CO2 Capture Technology for Existing Plants R&D Meeting.

March 25th, 2009

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Director of Development

Jupiter Oxygen Corporation

Presentation Outline

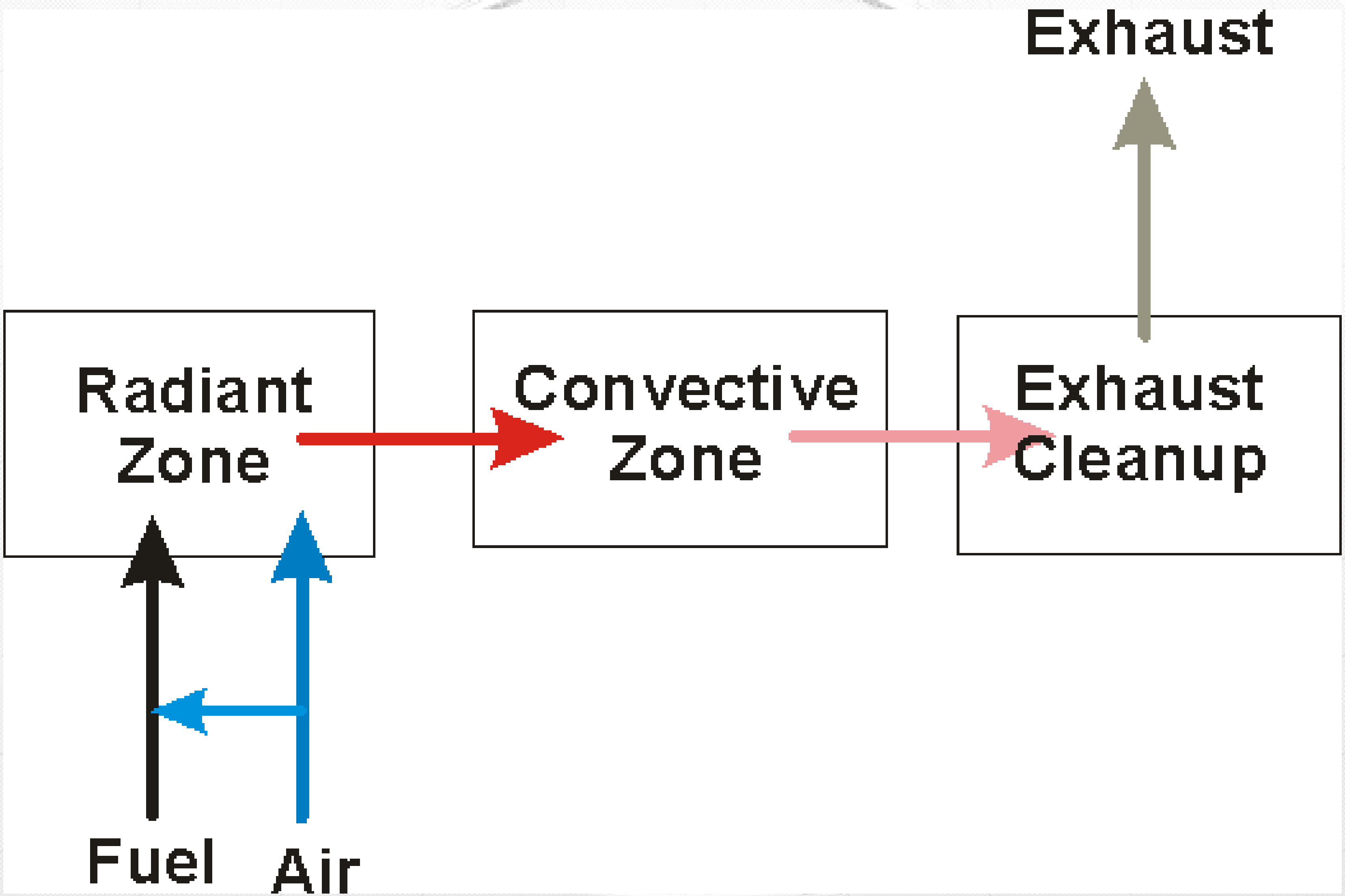
- Project Team and project costs
- Discussion on unique approach of project
  - Jupiter Oxygen High Flame temperature
  - IPR system
- Facility Design and Layout
- Testing with Natural Gas
  - Test conditions
  - Testing results
- Coal testing initial trials (August of 2008 to December of 2008)
  - Testing Hypothesis approach
  - Testing results
    - Burner operation
    - Boiler operation
    - Slagging and fouling
    - IPR
- Next Steps
  - Equipment modifications
  - Test plan
- Summary

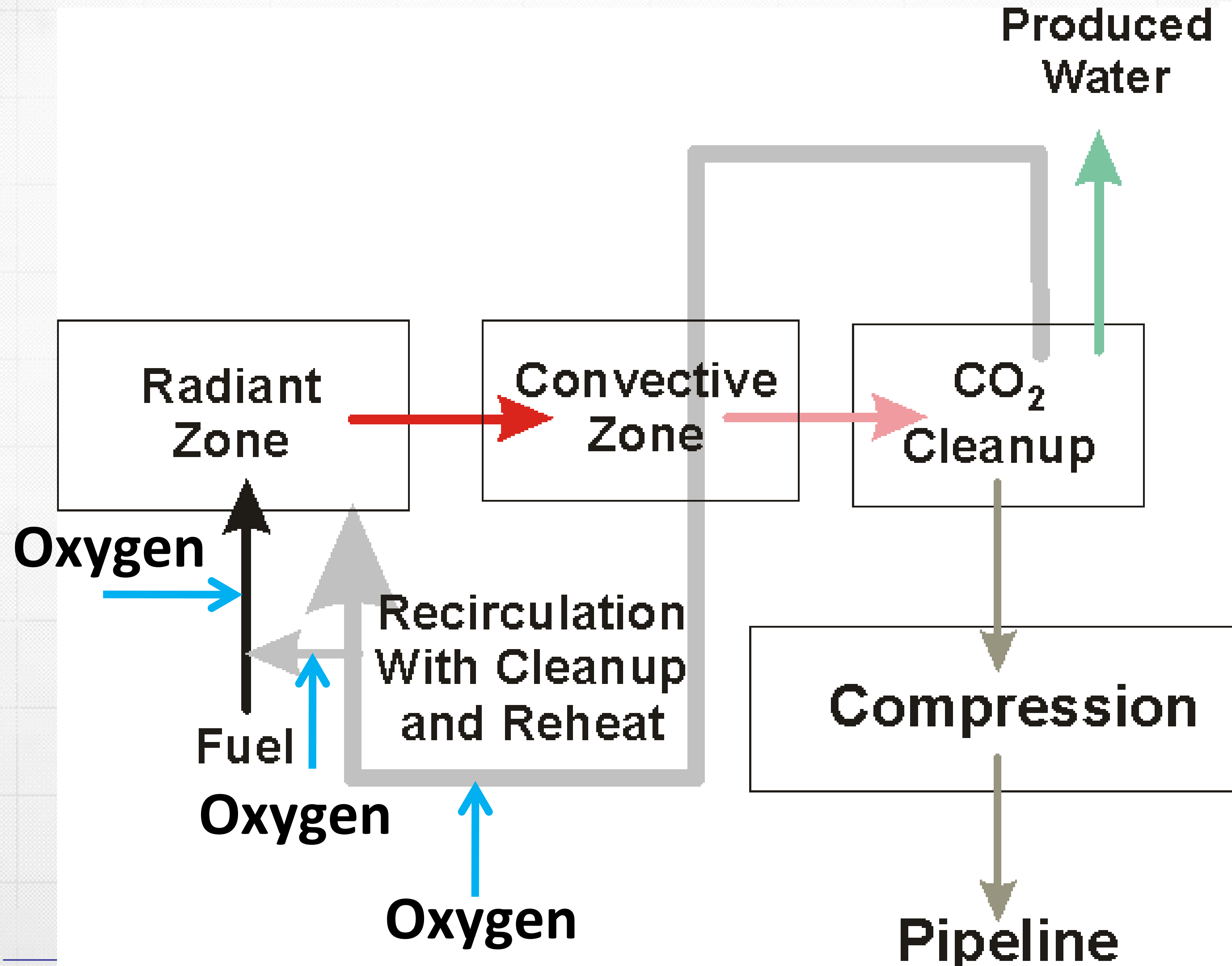
Project Team and Project Cost

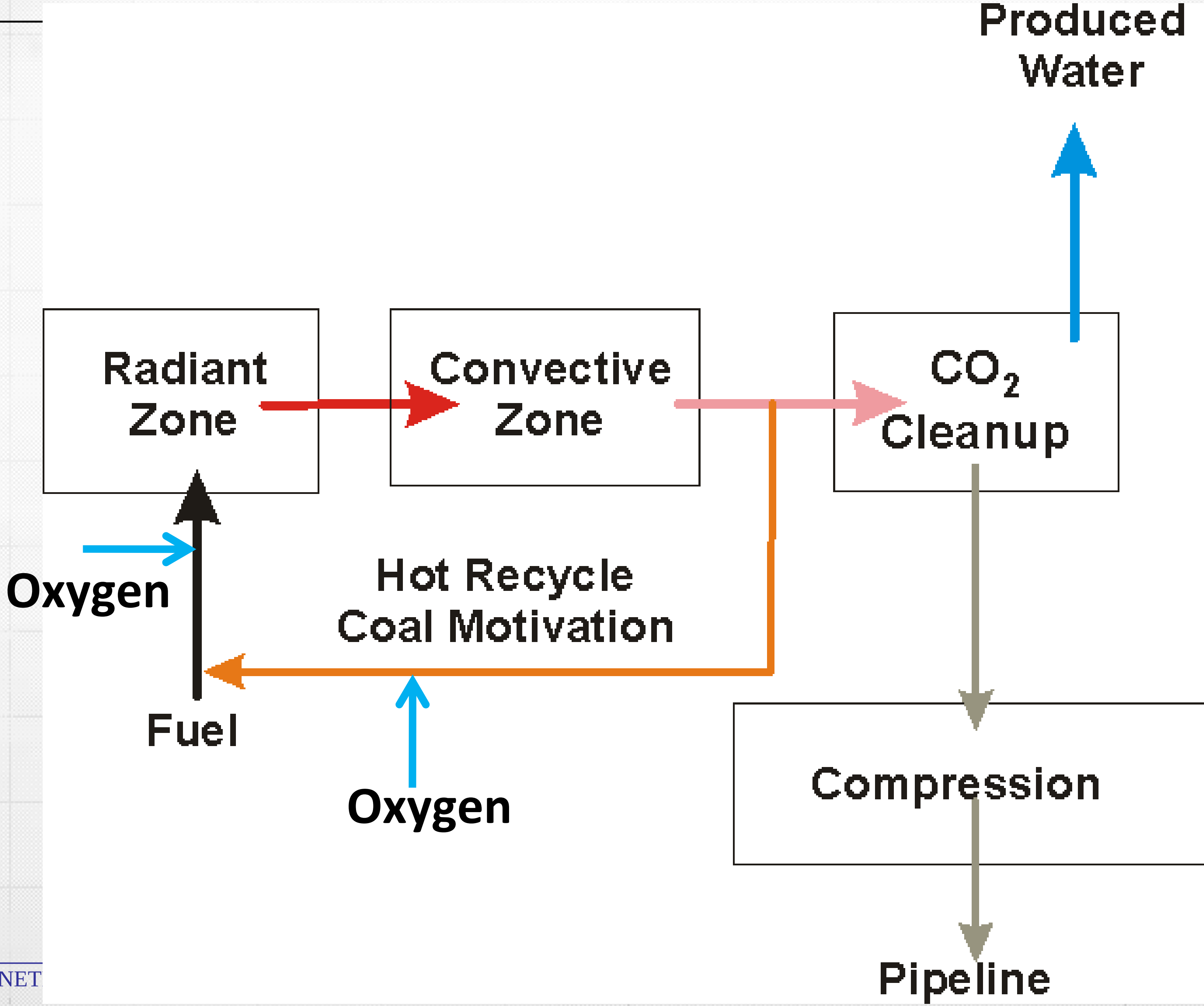
- **Lead: Jupiter Oxygen**
  - Technology Provider
  - Site builder
  - Site Operator
  - Data Collection and Analysis
- **NETL**
  - Technology Provider
  - Data Collection and Analysis
  - Low Pressure IPR system
- **CoalTeck LLC**
  - Chief Consultant
- **Maxon Coporation**
  - Burner provider
- **Doosan Babcock US LLC**
  - Slagging and Fouling studies
- **Other project team members**
  - Purdue Univeristy
  - University of Wyoming
  - Michigan State University
  - EPRI
- **Project Cost**
  - DOE Share $3,024,344
  - Cost Share $760,617

Jupiter Oxygen Differences in Oxy-fuel

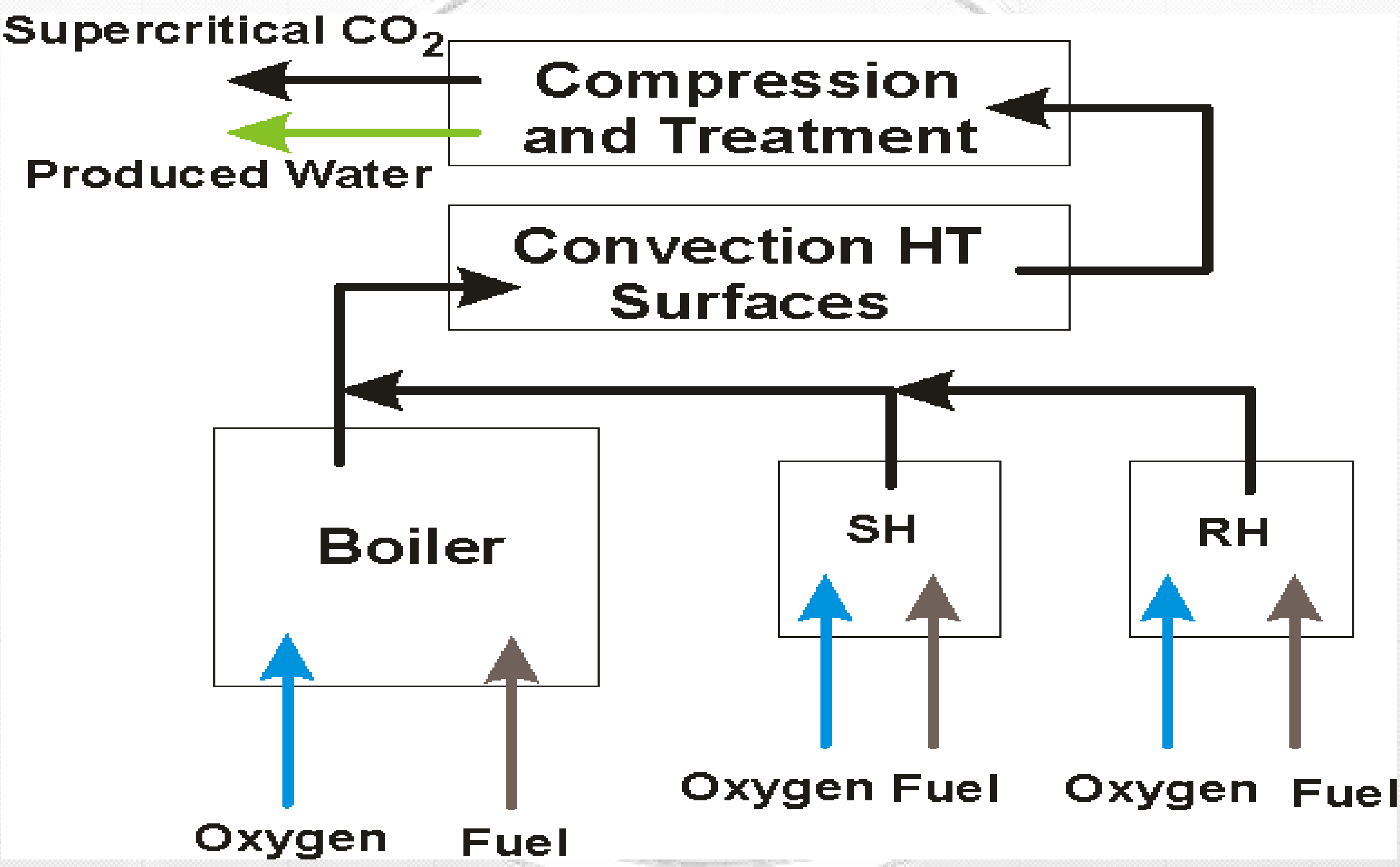
- Jupiter's process
  - High flame temperature – improved radiant transfer in the radiant zone
- Most oxyfuel processes
  - Lower flame temperature = as air firing
- Recycle outside of flame envelope to maintain high flame temperature
- Flame with good turndown and stability
- Not mixing oxygen with recycled flue gas
- Modeling Indicates (GE Gate Cycle) reduced fuel usage


Exhaust
Radiant
Zone
Convective
Zone
Exhaust
Cleanup
Fuel
Air


Produced Water
Radiant Zone
Convective Zone
CO_2 Cleanup
Oxygen
Recirculation With Cleanup and Reheat
Compression
Fuel
Oxygen
Oxygen
Pipeline

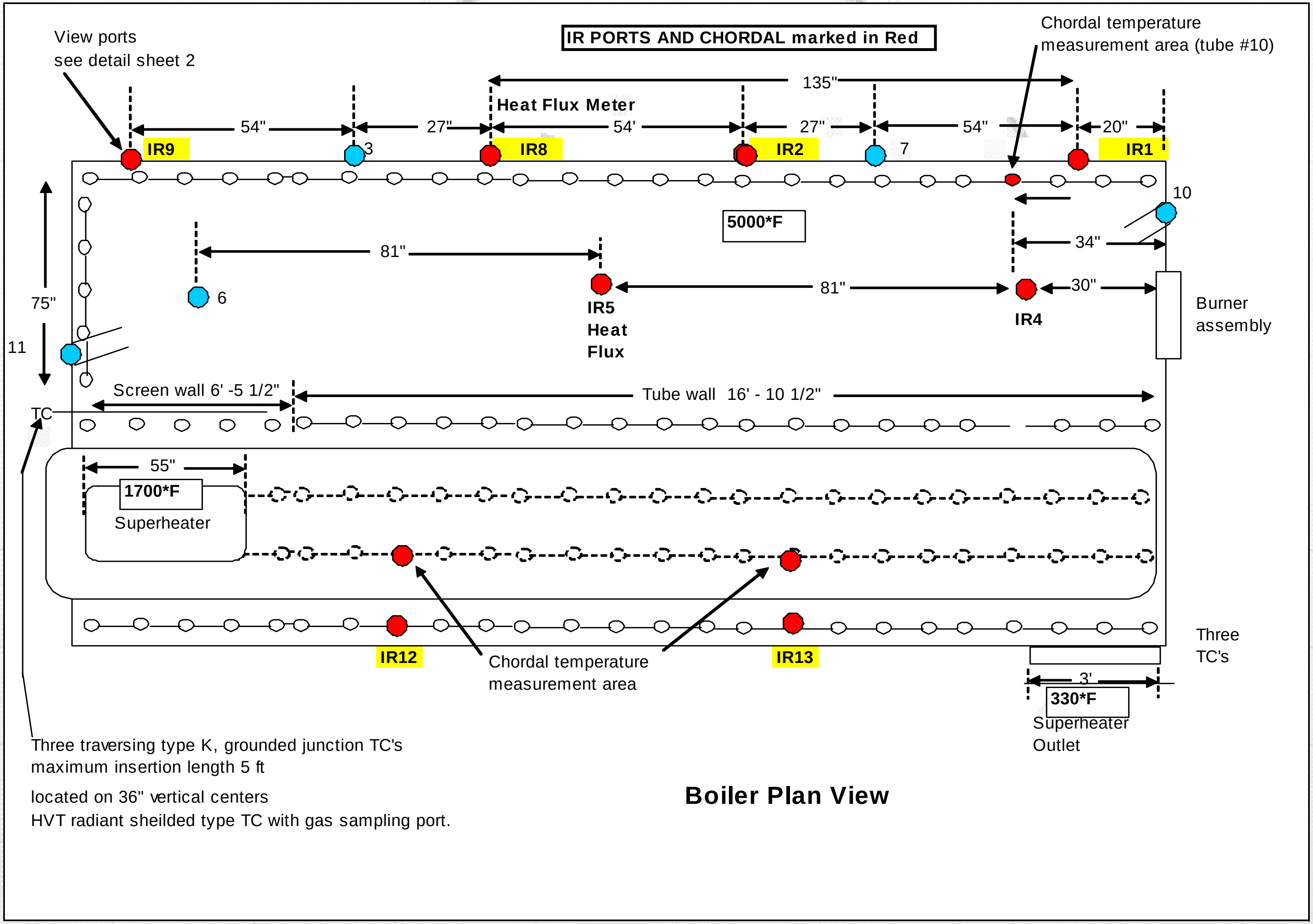

Produced Water
Radiant Zone
Convective Zone
CO_2 Cleanup
Oxygen
Hot Recycle Coal Motivation
Fuel
Oxygen
Compression
Pipeline

Advanced Greenfield Oxy-fuel or repowering

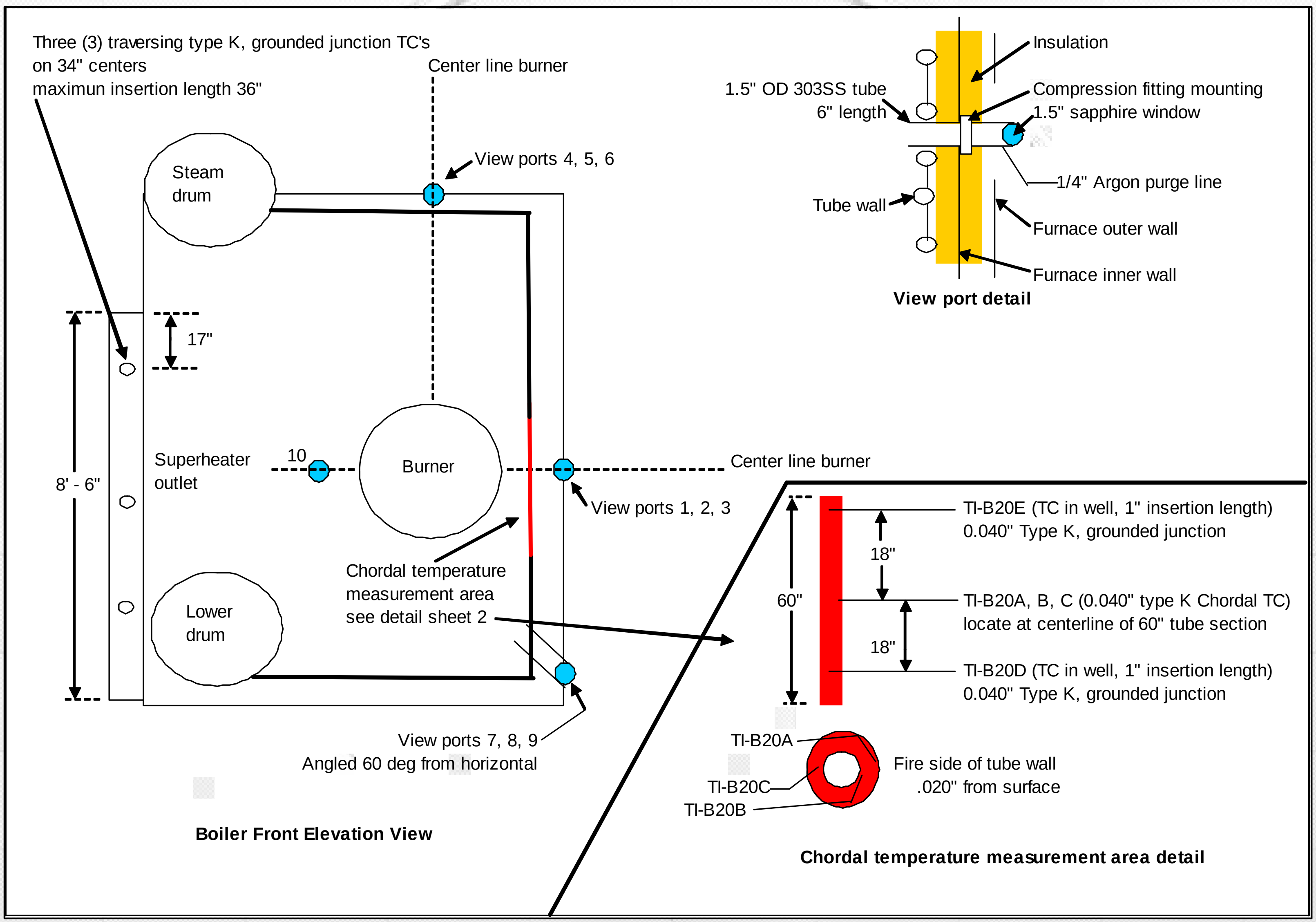


Jupiter Oxygen – Hammond Indiana 15 MWth Test Facility

15 MWth Boiler Plan View



15 MWth Boiler Front View

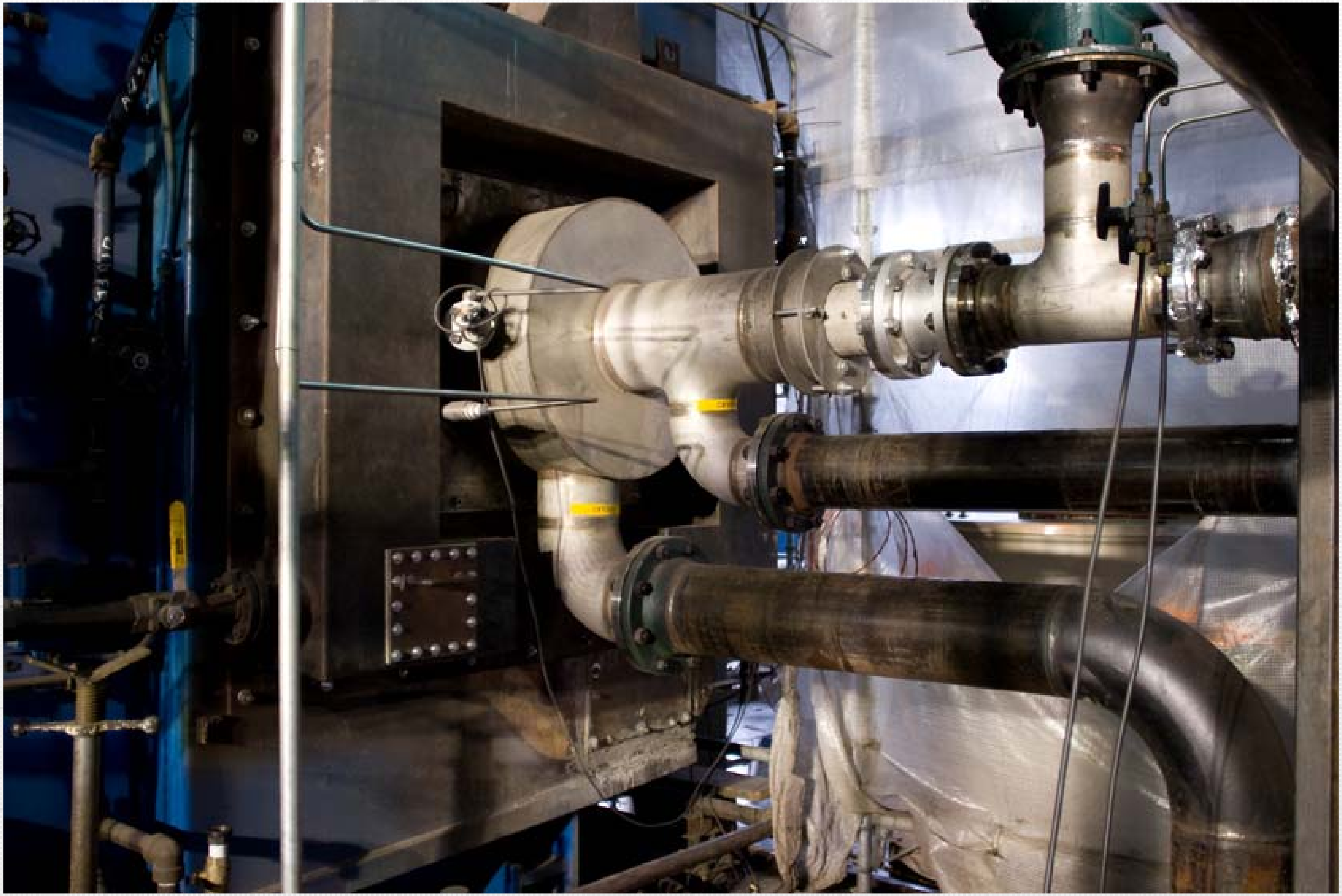


15 MWth Test site

15 MWth Test site

15 MWth Test site

15 MWth Test site



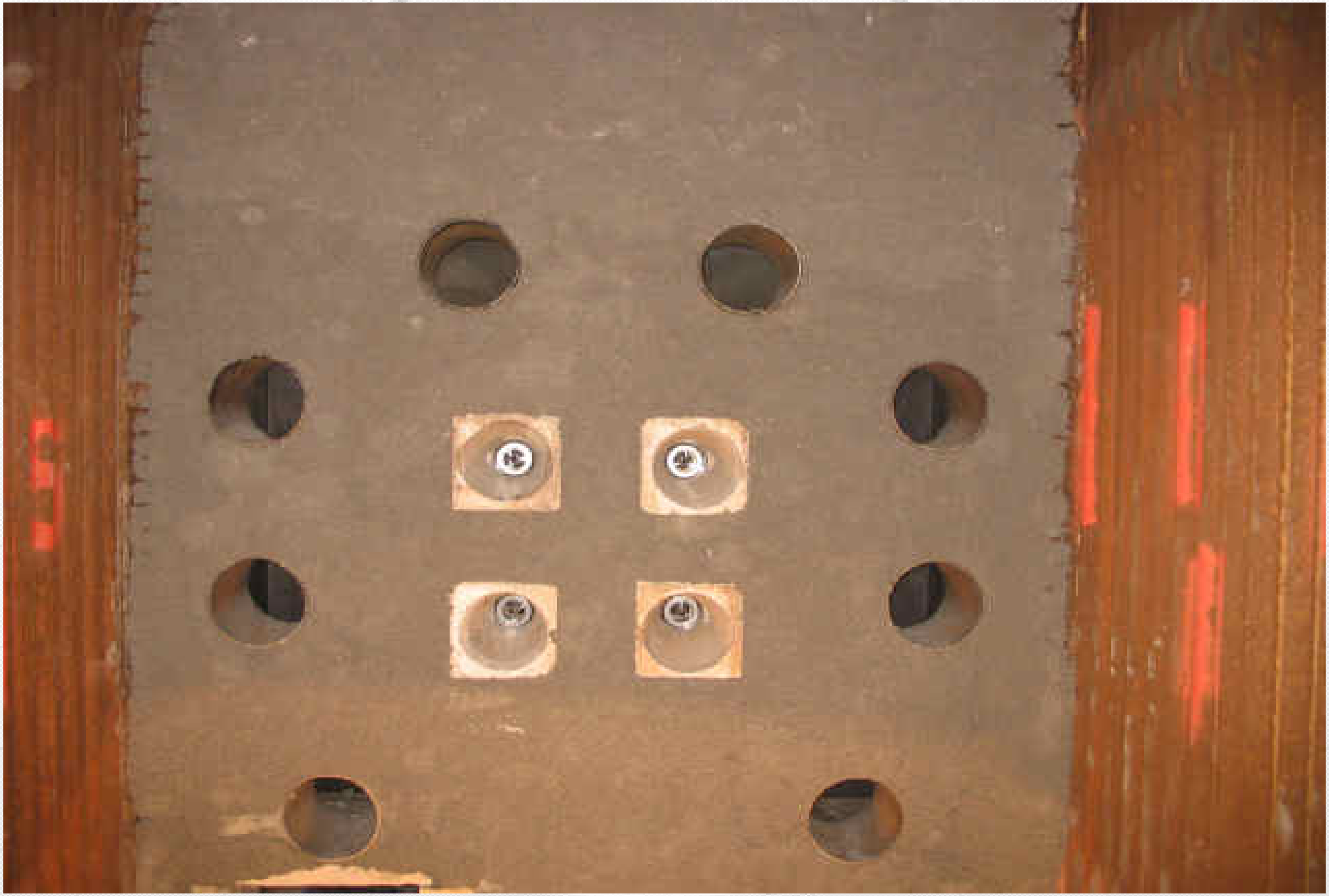
Natural Gas Testing

Background: There are two different approaches to Oxy-fuel firing. Jupiter's approach is to have a "high" flame temperature, that is not tempered with either nitrogen, CO_2 or other gas and there is a "low" flame temperature approach which uses large amounts of CO_2 recycled through or at the burner to "cool" the flame to temperatures near air firing.

Tests: Jupiter performed 4 tests at the 15 MWth test facility to collect data under each condition

1) Oxy – fuel firing with high flame temperature using only oxygen and natural gas at the burner
2) Oxy – fuel firing with high flame temperature using only oxygen and natural gas at the burner while recycling flue gas and not cooling the flame by keeping the recycled flue gas away from the burner.
3) Air Firing – Using a Gordon Piatt 42 MMbtu / hr. burner operating at manufacturer specifications for excess air.
4) Using the Gordon Piatt burner operating with the recycled flue gas and oxygen mixed entirely through the burner thus cooling the flame with recycled flue gas

Maintaining the High Flame Temperature



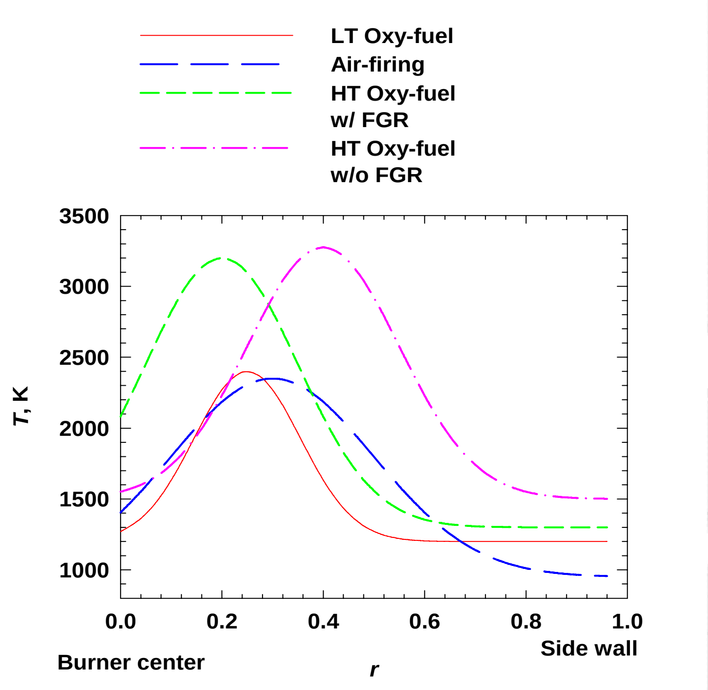
Measure Steam Balance using energy in versus energy out of the boiler (energy difference in water in / steam out vs. fuel in)

			Jupiter High Temp Oxy-fuel no recycle	Air Firing	Efficiency Increase	Estimated Fuel Savings
Efficiency Calculations						
Steam balance duty/HHV duty			94.8%	88.4%	6.4%	6.7%

			Jupiter High Temp Oxy-fuel no recycle	Jupiter High Temp Oxy-fuel with recycle	Air Firing	Low temp Oxy-fuel with recycle
Inputs Fuel, Oxidant, FGR, Air						
NG	Lb-mole/hr		86.8	84.9	82.9	84.2
O2	Lb-mole/hr		196.5	194.8	0.0	173.2
FGR	Lb-mole/hr		0.0	309.2	0.0	273.7
Air	Lb-mole/hr		0.0	0.0	854.5	0.0
		Total	283.3	588.9	937.4	531.1

Temperature of Flames

Flame Temperature (PEAK)			Jupiter High Temp Oxy-fuel no recycle	Jupiter High Temp Oxy-fuel with recycle	Air Firing	Low temp Oxy-fuel with recycle
Purdue Calculation Inversely estimated F			5435	5300	3758	3851
NETL - Wien's Displacement peak particle F			4924	4930	NA	NA
Adiabatic By HYSIS F			5174	5159	3444	4131



Discussion on Flame Temperature

Discussion:

Flame- temperature is typically a calculated number (adiabatic) while direct measurement of flame temperature can be difficult. With air fired combustion the nitrogen in the air acts as a "tempering" agent for the flame temperature. Without the tempering of the nitrogen in the air there would be a "high" flame temperature. The approach of Jupiter Oxygen is to remove the nitrogen from air prior to combustion and burn the fuel in a properly designed mixing device thus producing a high flame temperature.

The low flame temperature oxy-fuel testing replaces the flame tempering affect of the nitrogen with the flame tempering affect of recycle flue gas. Thus theoretically the flame temperature is lowered.

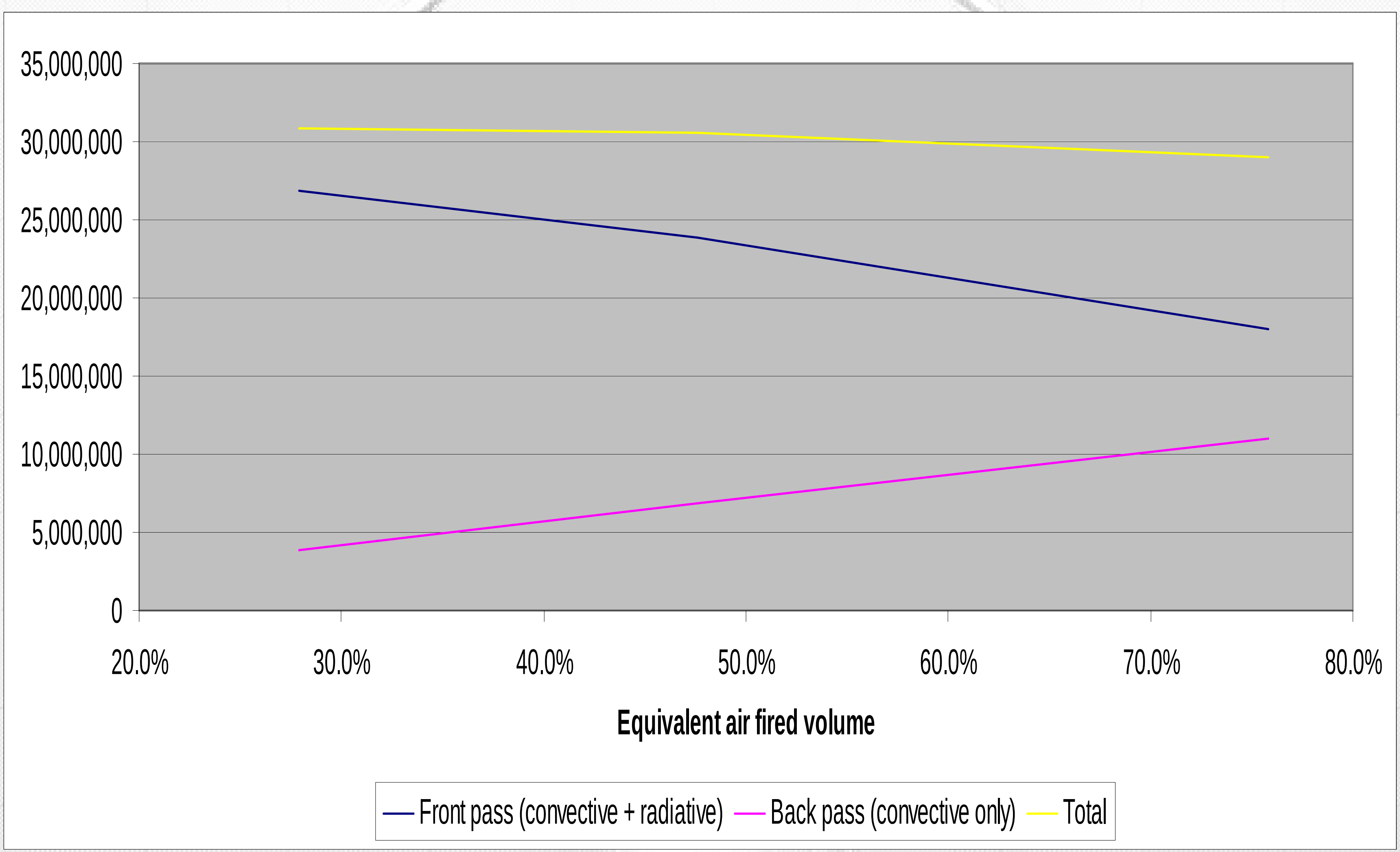
Conclusions:

- **By having a higher oxygen concentration at the flame (ie non-tempered) by either nitrogen or CO_2) the flame temperature rises to more than 1700F greater than in air firing.**
- **With recycle separating the flue gas stream from the burners (not recycle through the burner, but in additional separate ports near the burners) Jupiter Oxygen was able to maintain the high flame temperature while recycling the flue gasses back to the boiler.**
- **There are two measurements that are established and can be used to estimate via direct measurement the temperature of the flame in operation in a boiler. Those temperature measurements are on the order of the calculated adiabatic measurements.**
- **By mixing the flue gas with the oxidant prior to combustion the flame temperature is lowered. The more flue gas that is mixed with the oxidant the lower the flame temperature becomes.**
- **Soot particle radiation tracks adiabatic flame temperature.**

Recycle can control back pass heat transfer:

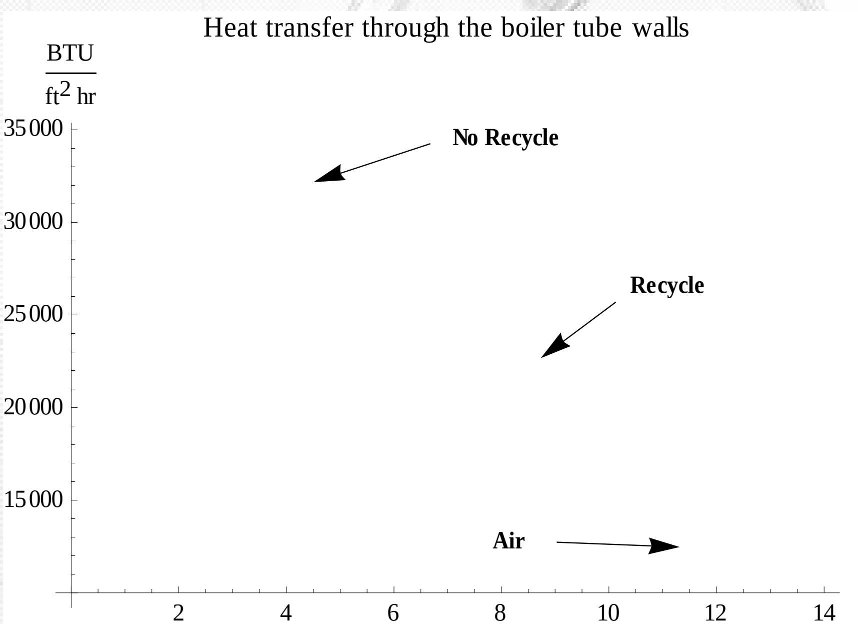
			Jupiter High Temp Oxy-fuel no recycle	Jupiter High Temp Oxy-fuel with recycle	Air Firing	Low temp Oxy-fuel with recycle
Steam Output						
Total combustion duty calculated by HYSIS	BTU/hr		29,081,488	28,191,728	26,181,202	28,073,789
		% of total	87%	71%	61%	81%
Front Pass duty calculated by HYSIS	BTU/hr		25,174,396	20,039,841	15,921,674	22,715,814
		% of total	13%	29%	39%	19%
Back Pass duty caluclated by HYSIS	BTU/hr		3,907,092	8,151,887	10,259,528	5,357,976

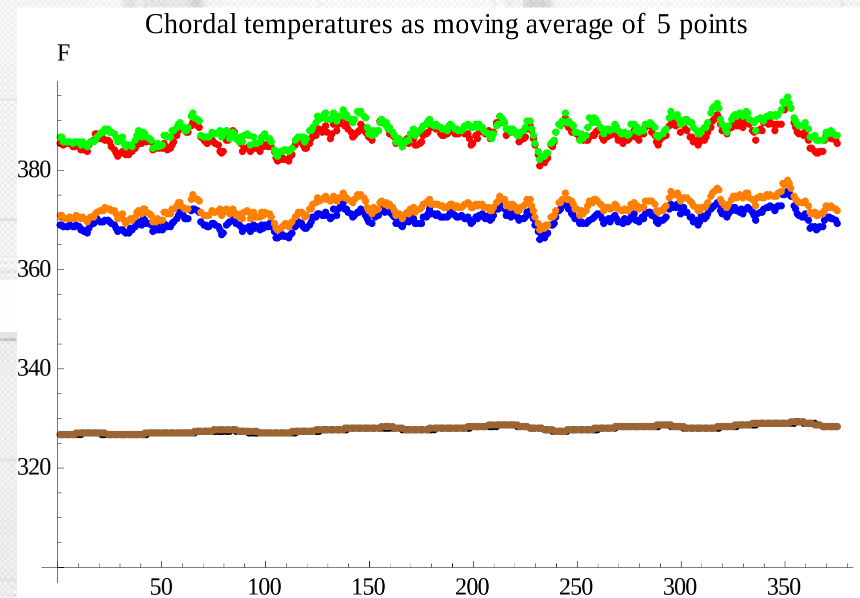
Hammond Test Unit
Boiler Duty (BTU/Hr) vs. Equivalent Air Volume



Tubes and Heat Transfer

Condition	Mean surface temp
Air firing	352°F
Oxy-NG with recycle	370°F
Oxy-NG without recycle	387°F





Coal Testing Hypothesis

1. Can increase heat transfer in radiant section from increased flame temperature
2. The increased flame temperature does not damage boiler tubes
3. Performance and geometry of flame
4. IPR can capture both sensible and latent heat from the exhaust gases
5. IPR can recover sensible and latent heat during compression
6. IPR can remove SOx during spray treatment

Scientific Measurements: 1. Can increase heat transfer in radiant section from increased flame temperature

- **Research concepts**
  - T to the 4th
  - Coal particle
  - CO_2 and Water
  - Residence time
- **Data measurements**
  - Traversing thermocouples
    - Positions in, midstream, out
      - » 5 minutes per position
    - 10” from wall minimum – hose clamp stop at end
    - At boiler exit and screen wall start – physically verified location from internal inspection
  - UV/VIS/NIR
    - positions IR2 – 3 positions
      - » 5 minutes per position
    - Tom Ochs – data analysis

- Spectraline
  - position IR2 – 3 positions
    - » 5 minutes per position
  - Purdue – analysis
- Chordals
  - Labview continuous data
  - 3 positions around boiler radiant section
- Video / sonic readings
  - position various ports – high speed camera
  - accelerometers – 3 (2 on boiler shell, 1 on burner)
  - low speed camera in back port
- Heat Balance (calculation based on data)
  - Fuel (hand recorded), oxygen, water – LabView and data sheet (PLC)
  - Steam – LabView continuous (PLC)
- Total radiometer measurements
  - positions IR2 (center), IR9
- Gardon gauges
  - LabView continuous
  - Near IR2 (2 positions

Scientific Measurements: 2. The increased flame temperature does not damage boiler tubes

Research Concepts

- Hot Spotting
- Soot Particle heat distribution
- Slagging and fouling studies

Data Measurements

- Chordals (primary)
- Total Radiometer (secondary)
- Gardon (secondary)
- Heat Balance (calculation based on data)
- Coupons (installed during final testing?)
- Corrosion sample of boiler tube (before and after testing – Destructive testing)
- Physical Inspection (between testing runs)
- Slag samples from various boiler locations to Doosan Babcock
- Tube fouling dust from various locations to Doosan Babcock

Scientific Measurements: 3. Performance and Geometry of flame

Research Concepts

- Low excess oxygen levels (near stoichiometric)
- Low NOX
- High concentration of water and CO2
- Length of flame
- Diameter of flame
- Flame intensities at different view points

Data Measurements

- Excess Oxygen, CO readings (combustion analyzer, ACSI)
- NOx,SOx,CO2, and H20 (Clean Air, after cyclone)
- Flue gas analysis (samples collected and tested by NETL)
- UV/VIS/NIR
- Spectraline
- Video (visual record)
- Visual observation (notes about appearance)
- Heat Balance (calculation based on data)
- Flyash samples (boiler internal, cyclone, and baghouse evaluated by Doosan Babcock)

Scientific Measurements: Scientific Measurements: IPR

4. IPR can capture both sensible and latent heat from the exhaust gases

- **Research Concepts**
  - Exhaust gases carry sensible and latent heat which is where thermal efficiency is lost. IPR is designed to capture both.
- **Data measurements**
  - Gas properties (temperature, pressure, flow, composition)
  - Spray tower water properties (temperature, flow, composition)

5. IPR can recover sensible and latent heat during compression

- **Research concepts**
  - Compression requires power and heats the compressed gases. IPR is designed to recover some of the power used in compression as heat in feedwater.
- **Data measurements**
  - Gas properties (temperature, pressure, flow, composition)
  - Water properties (temperature, pressure, flow) in heat exchangers

Scientific Measurements: 6. IPR can remove SO_X during spray treatment

Research concepts

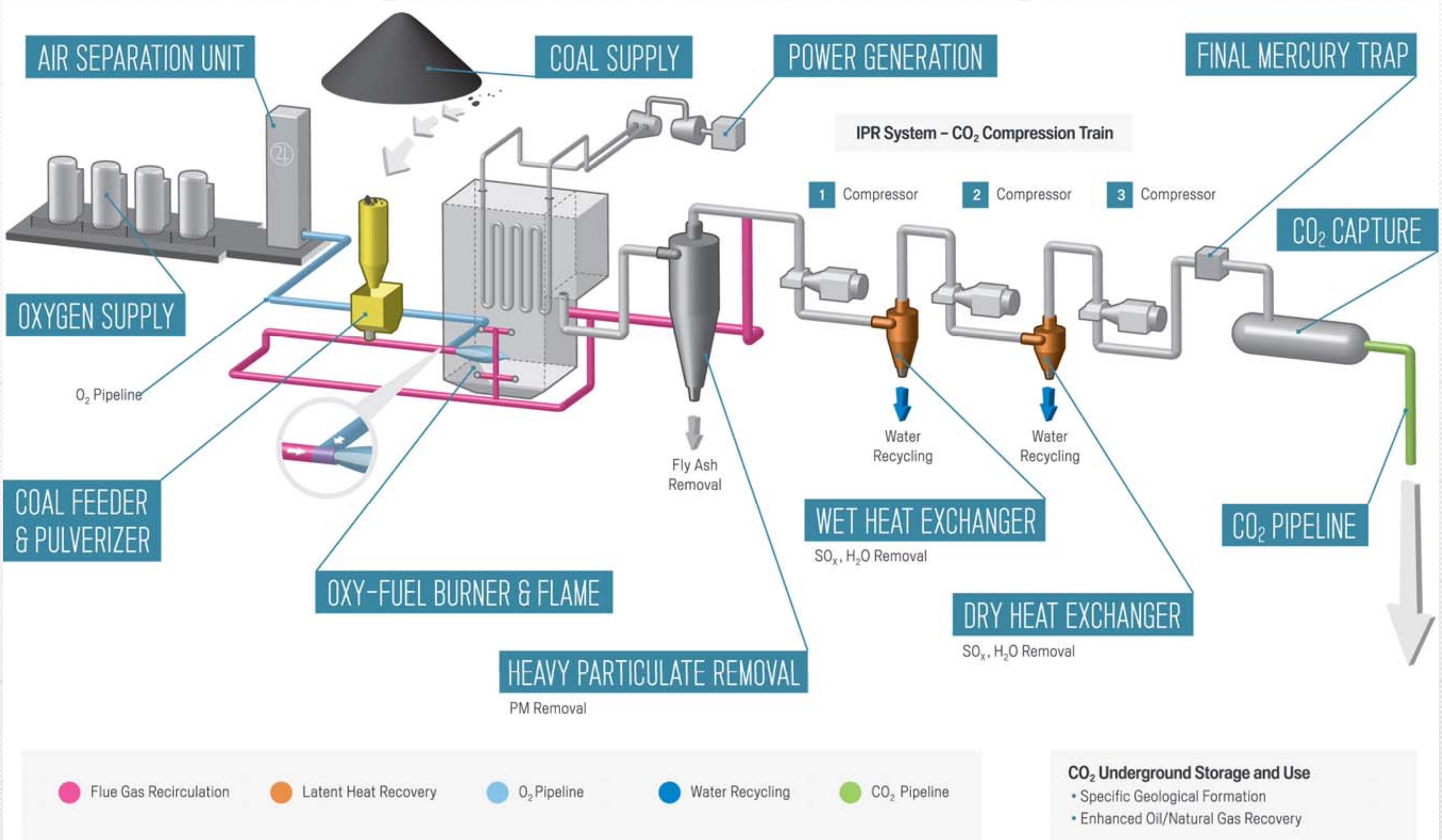
- Reactant in the spray interacts effectively to remove SOx from the flue gas.

Data measurements

- Ash composition
- Composition of spray water before and after contact with flue gas
- Composition of reagent added to spray
- Flow of spray and reagent
- Composition of flue gas before and after contact with spray

JOC OXY–FUEL IPR* SYSTEM DETAIL: CLEAN COAL POWER GENERATION

*Integrated Pollutant Removal (IPR™) System, NETL US DOE



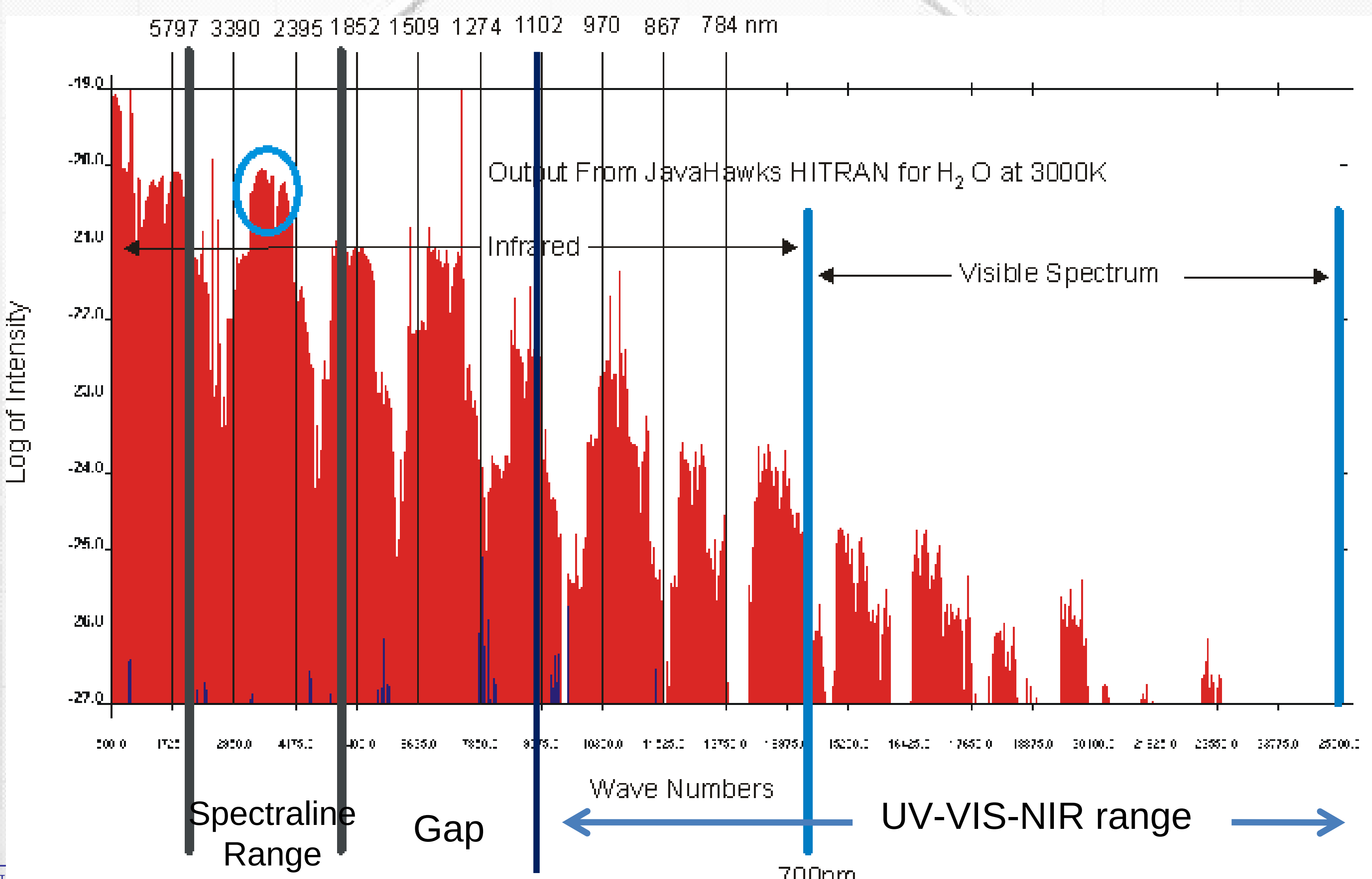
Illinois Coal Used Prairie Power Inc.'s Pearl Station

	Coal Analyses (all %)						
Date	Moisture	Ash	Sulfur	BTU/lb (w)	Carbon	Hydrogen	Nitrogen
10/27/2008	5.02	5.98	3.5	12301	68.05	4.47	1.37
dry	0	6.3	3.68	12951	71.65	4.71	1.44
10/31/2008	3.45	10.77	3.45	11920	66.11	4.48	1.31
dry	0	11.15	3.57	12346	68.47	4.64	1.36
12/9/2008	3.98	13.66	3.6	11754	65.51	4.48	1.31
dry	0	14.23	3.75	12241	68.23	4.67	1.36
12/11/2008	4.28	13.08	3.77	11900	65.96	4.58	1.33
dry	0	13.67	3.94	12432	68.91	4.78	1.39
12/12/2008	3.87	13.73	3.57	11890	65.71	4.49	1.31
dry	0	14.28	3.71	12368	68.36	4.68	1.36

General notes on testing to date

- **Burner modifications**
  - **From 9 port design to 6 port design**
  - **Nozzle change for better mixing**
- **Motive coal**
  - **Eliminate as practical the screw feed pulsing (change screw)**
  - **Change velocities of the coal motive to the burner**
  - **Move mixing T back from the boiler in order to have more mixing time**
- **Test set up**
  - **Better sample collection of ash from cyclone in order to eliminate transient test times**
  - **Dedicated FTIR system for more information during routine operation rather then tests**
- **Results**
  - **Burner has excellent turndown and stability**
  - **Sustained operation of burner with excess oxygen levels of 2.5% or less**
  - **Preliminary results show no issues with slagging or fouling**

Water vapor

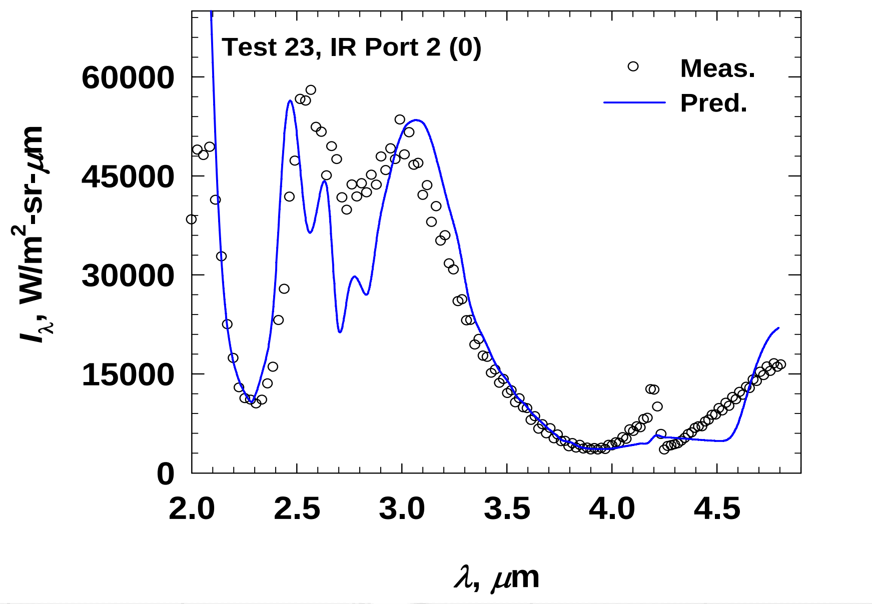


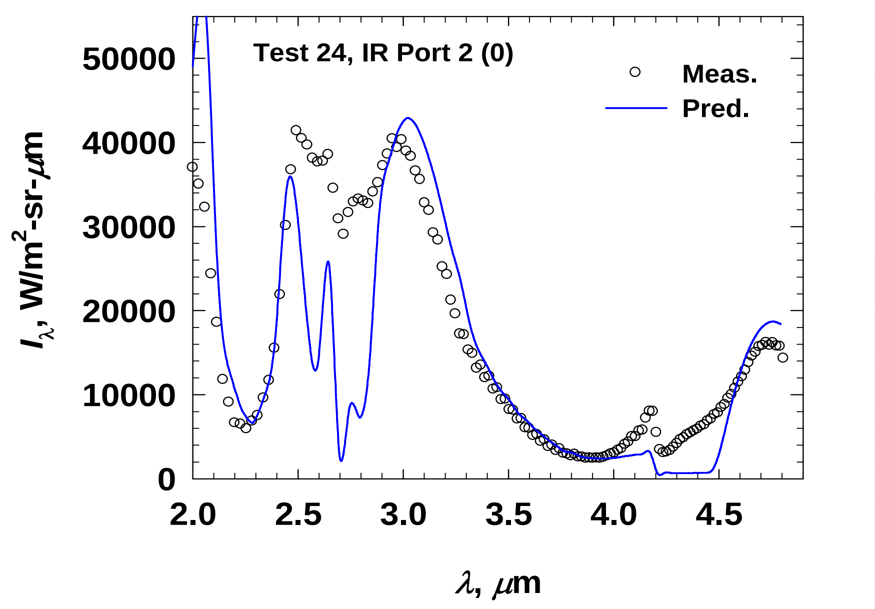
5797 3390 2395 1852 1509 1274 1102 970 867 784 nm
Output From JavaHawks HITRAN for H_2O at 3000K
Infrared
Visible Spectrum
Log of Intensity
-19.0
-20.0
-21.0
-22.0
-23.0
-24.0
-25.0
-26.0
-27.0
Wave Numbers
Spectraline Range
Gap
UV-VIS-NIR range
700nm

Measured spectral radiation intensities – Purdue University

Test 23 high temperature oxy-fuel without recycled flue gas

Test 24 high temperature oxy-fuel with recycled flue gas

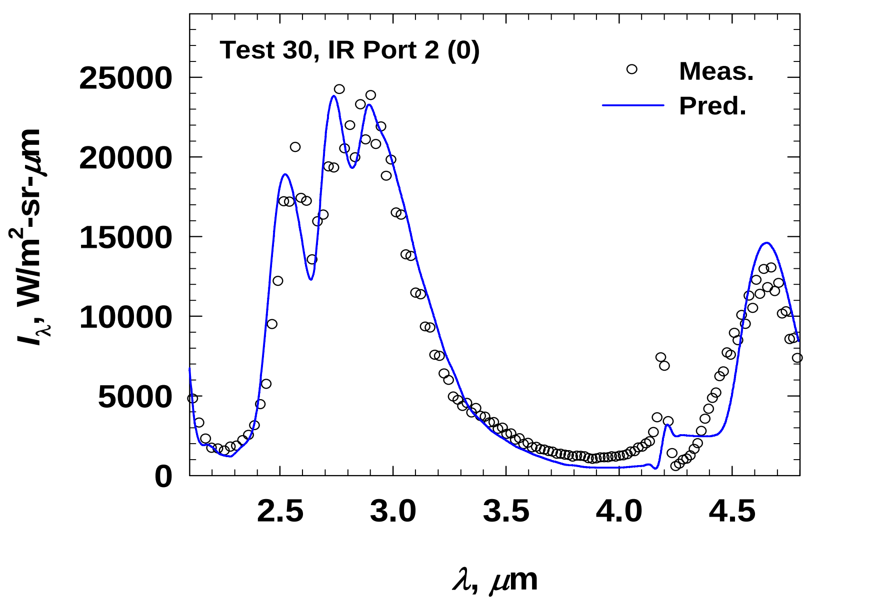


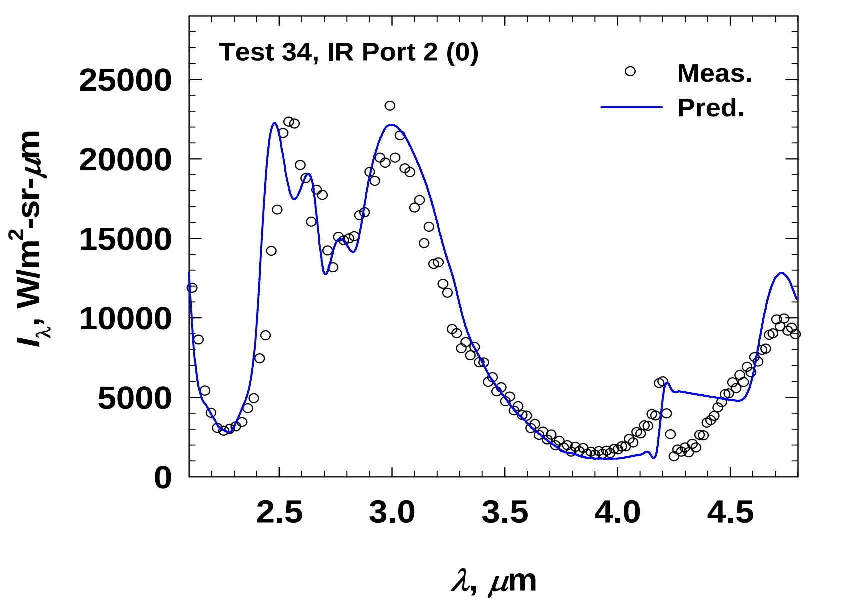


Measured spectral radiation intensities – Purdue University

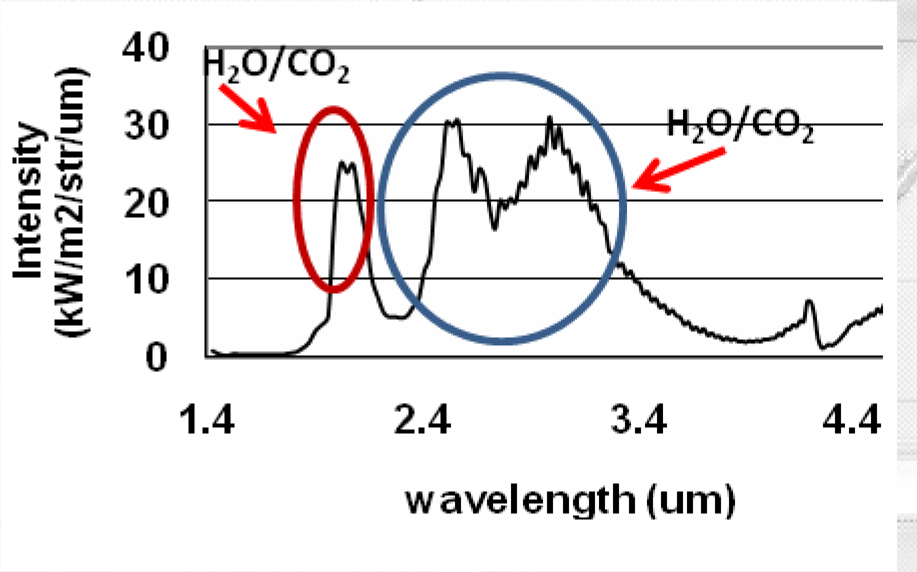
Test 30 Air Firing

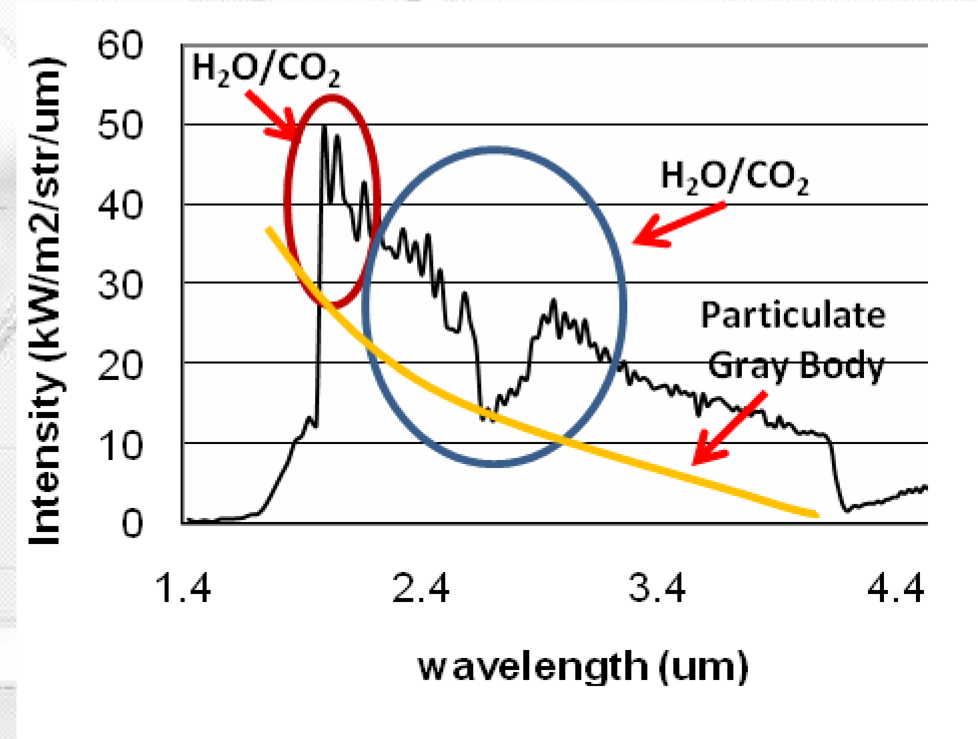
Test 24 Low temperature oxy-fuel with recycled flue gas





Mid-IR spectrum of oxy-natural gas flame and oxy-coal





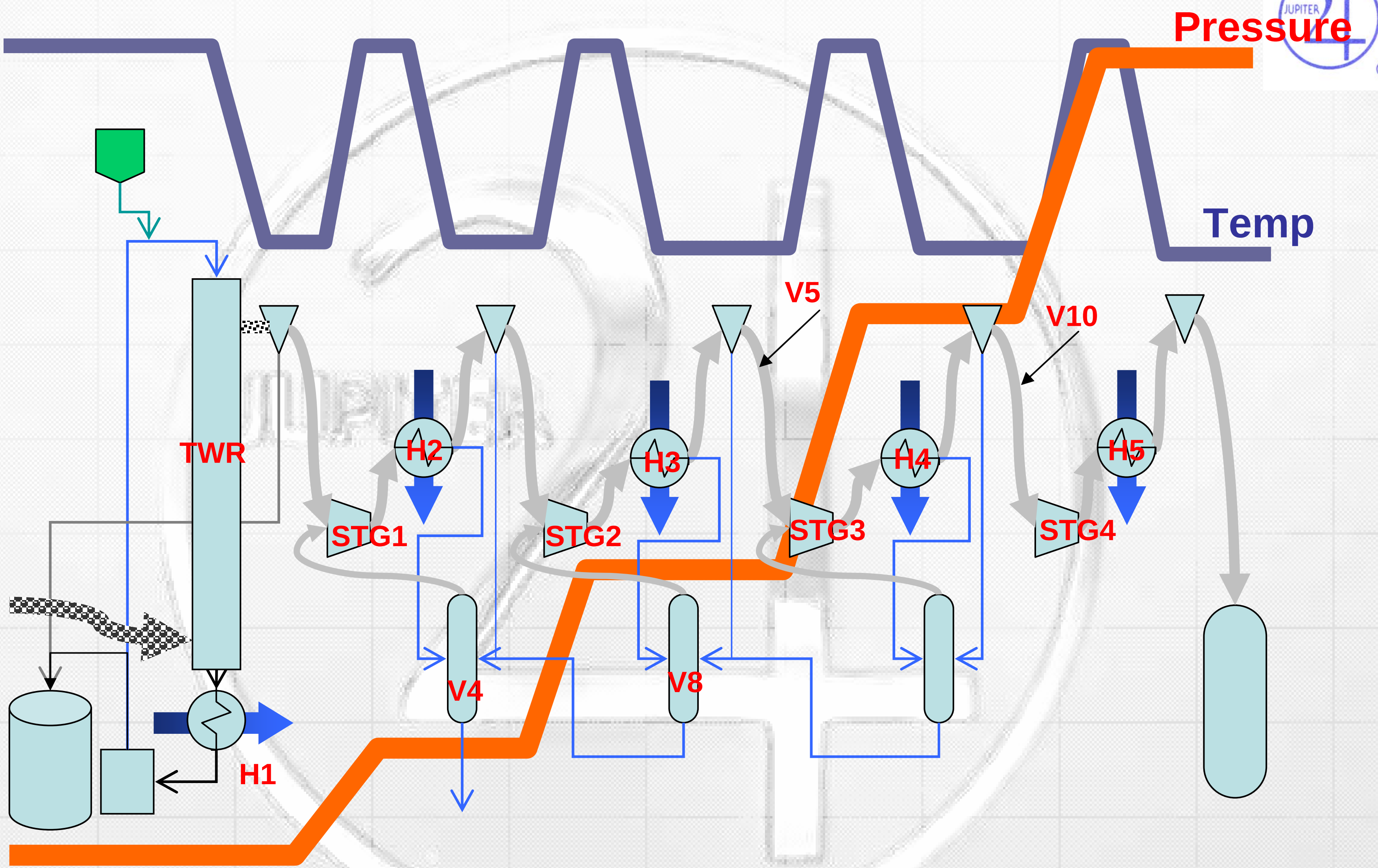
Slag and Ash Samples

Slag and Ash samples from inside the test boiler 12-16-08

Sample	Location	Type	SiO2 %	Al2O3 %	TiO2 %	Fe2O3 %	CaO %	MgO %	K2O %	Na2O %	SO3 %	P2O5 %	SrO %	BaO %	MnO2 %	Silica %	Base Acid Ratio	T 250 deg F	Foul Index
12/16/2008	sight port	coke	48.03	17.44	0.76	22.33	5.34	0.88	1.81	0.38	2.85	0.06	0.01	0.05	0.06	62.76	0.46	2342	0.18
12/16/2008	screen	slag	47.51	17.18	0.81	23.55	5.09	0.88	1.82	0.40	2.57	0.07	0.01	0.05	0.06	61.68	0.48	2323	0.19
12/16/2008	back floor	ash	48.28	17.37	0.70	21.58	5.12	0.88	1.80	0.47	3.63	0.06	0.01	0.04	0.06	63.64	0.45	2356	0.21
Average			47.94	17.33	0.76	22.49	5.18	0.88	1.81	0.42	3.02	0.06	0.01	0.05	0.06	62.69	0.46	2340	0.19

Two Samples to use for comparison (Coal from sample taken at the mine, ash from Pearl power plant)

Sample	Location	Type	SiO2 %	Al2O3 %	TiO2 %	Fe2O3 %	CaO %	MgO %	K2O %	Na2O %	SO3 %	P2O5 %	SrO %	BaO %	MnO2 %	Silica %	Base Acid Ratio	T 250 deg F	Foul Index
4/14/08	coal	ash	48.86	18.10	0.94	18.68	7.27	0.94	2.13	0.45	2.34	0.15	0.02	0.07	0.05	64.50	0.43	2372	0.20
12/18/08	Pearl bottom	ash	48.32	18.63	0.86	21.00	4.80	0.99	1.92	0.78	2.43	0.16	0.02	0.04	0.05	64.33	0.43	2371	0.34


Pressure
Temp
TWR
H1
H2
H3
H4
H5
STG1
STG2
STG3
STG4
V4
V5
V8
V10

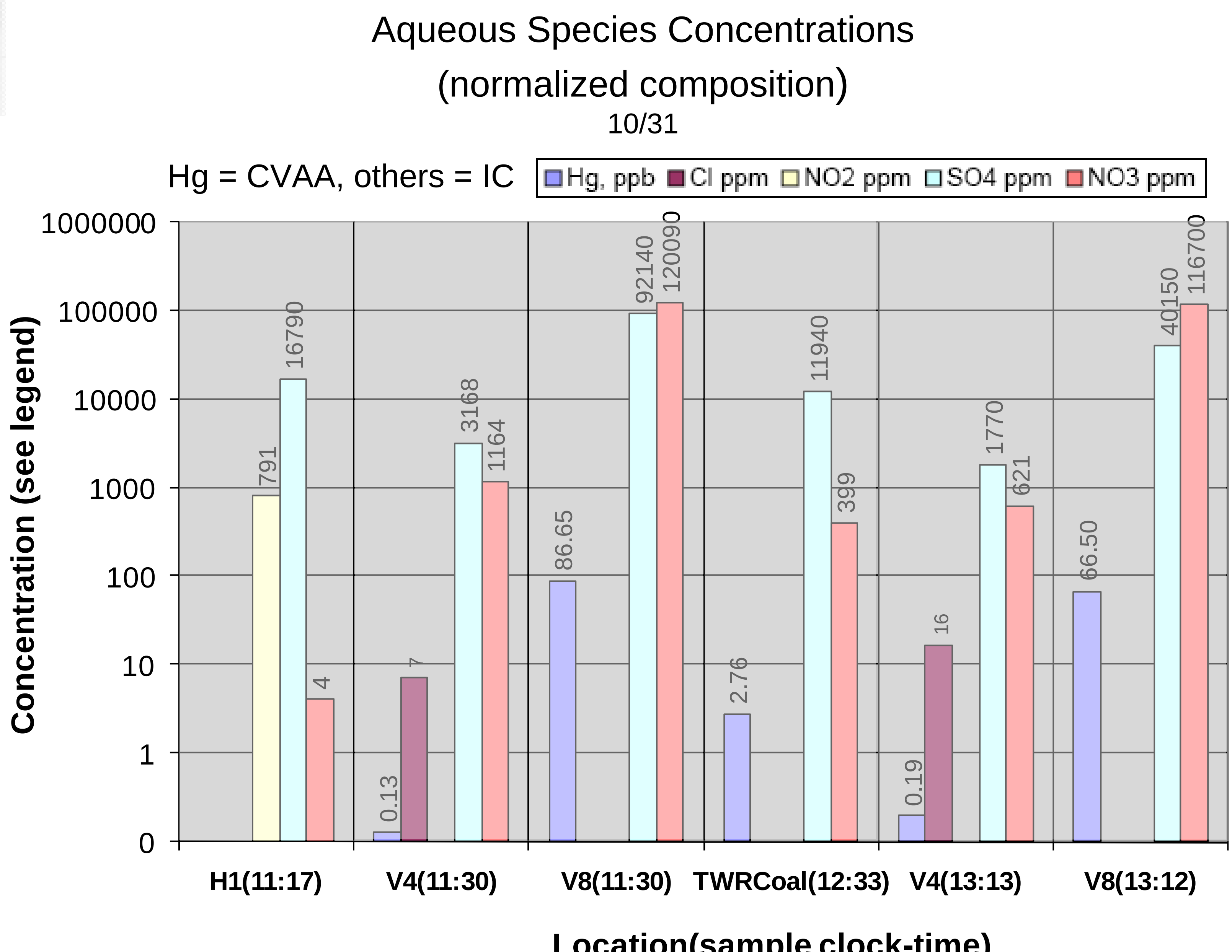
Samples and Measurements

Chemical composition

- **Gas sampling**
  - Continuous emissions monitoring
    - NDIR, UVA, Chemiluminescence, Gas Filter Correlation
  - Periodic tap to sample cylinder
    - GC
  - Bulk capture of treated flue-gas at IPR target pressure
    - GC + UV SO_2 Analyzer
- **Liquid product sampling**
  - Periodic tap of liquid-gathering points
    - IC, CVAA (for Hg), ICP
- **Solid sampling**
  - Ash from boiler cyclone
  - Ash captured in IPR Tower

Thermodynamic State

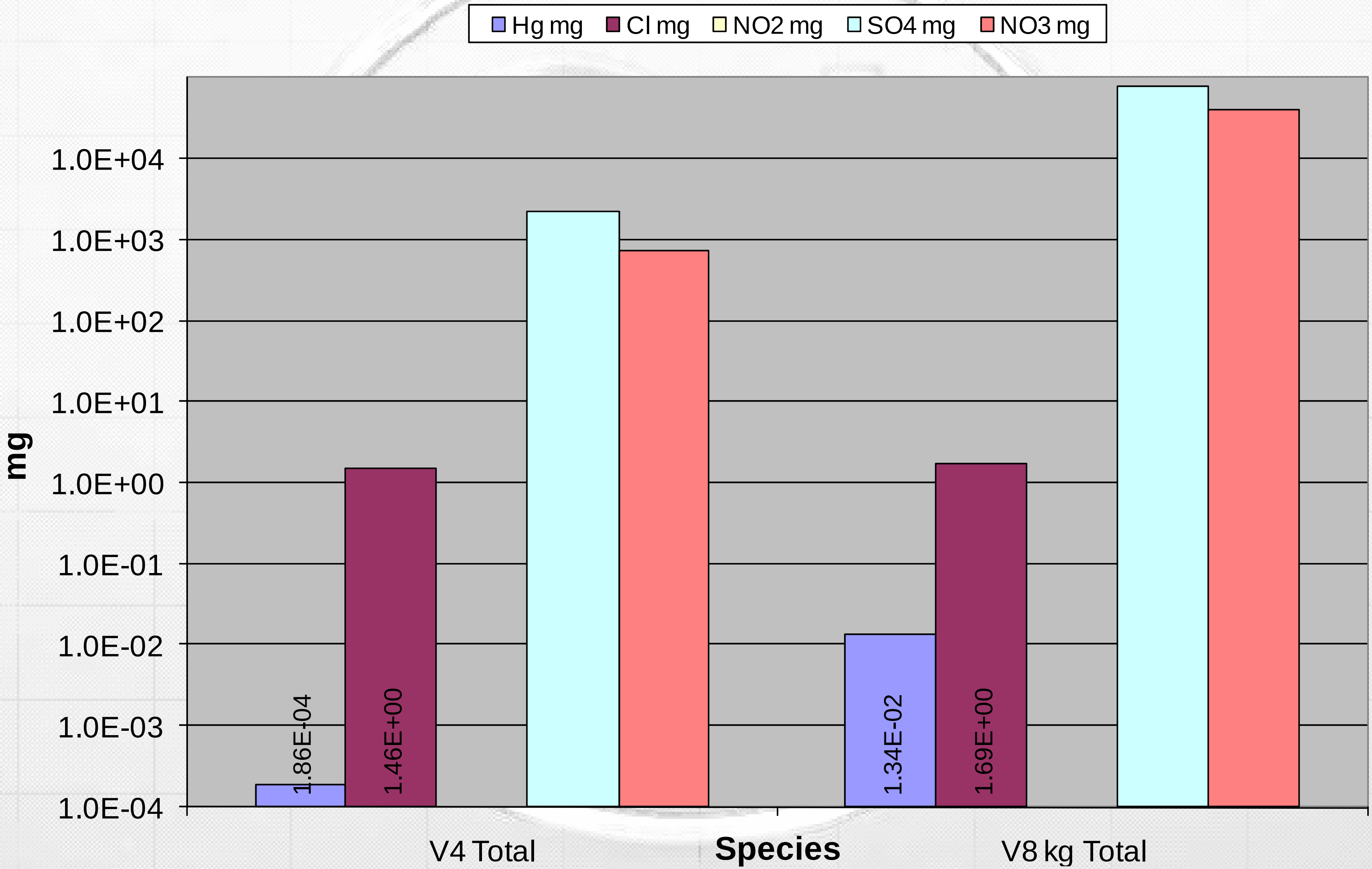
- **Measurements**
  - In-stream temperatures
  - Selected surface temperatures
  - In-stream static pressure
  - In-stream volumetric flow rate
- **Calculations**
  - Enthalpy
  - Density
  - Mass flow



Aqueous Species Concentrations
(normalized composition)
10/31
Hg = CVAA, others = IC
Hg, ppb
Cl ppm
NO2 ppm
SO4 ppm
NO3 ppm
1000000
100000
10000
1000
100
10
1
0
Concentration (see legend)
791
16790
4
0.13
7
3168
1164
86.65
92140
120090
2.76
11940
399
0.19
16
1770
621
66.50
40150
116700
H1(11:17)
V4(11:30)
V8(11:30)
TWRCoal(12:33)
V4(13:13)
V8(13:12)
Location(sample clock-time)

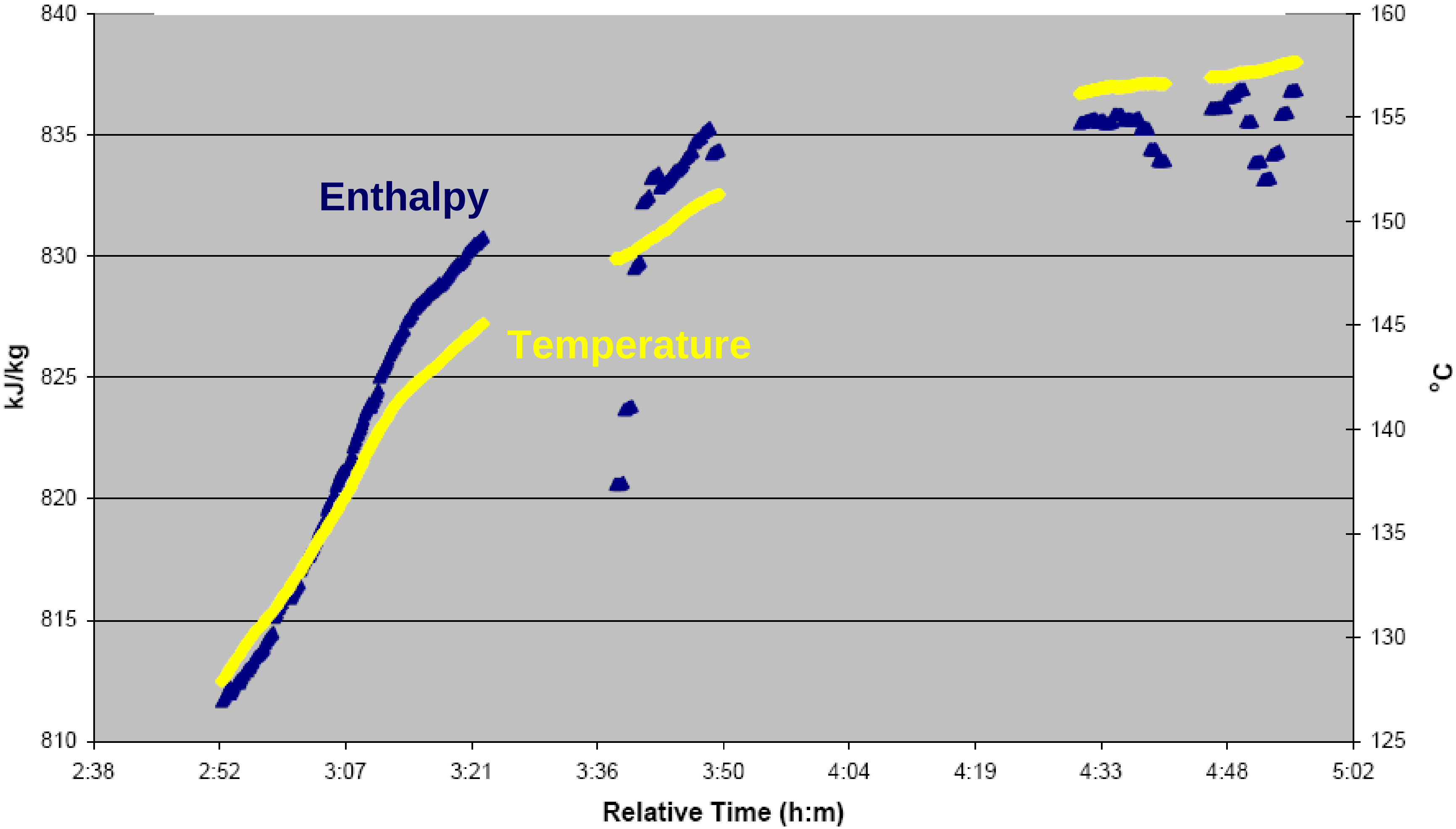
Aqueous Species Integrated over Volume (normalized composition)

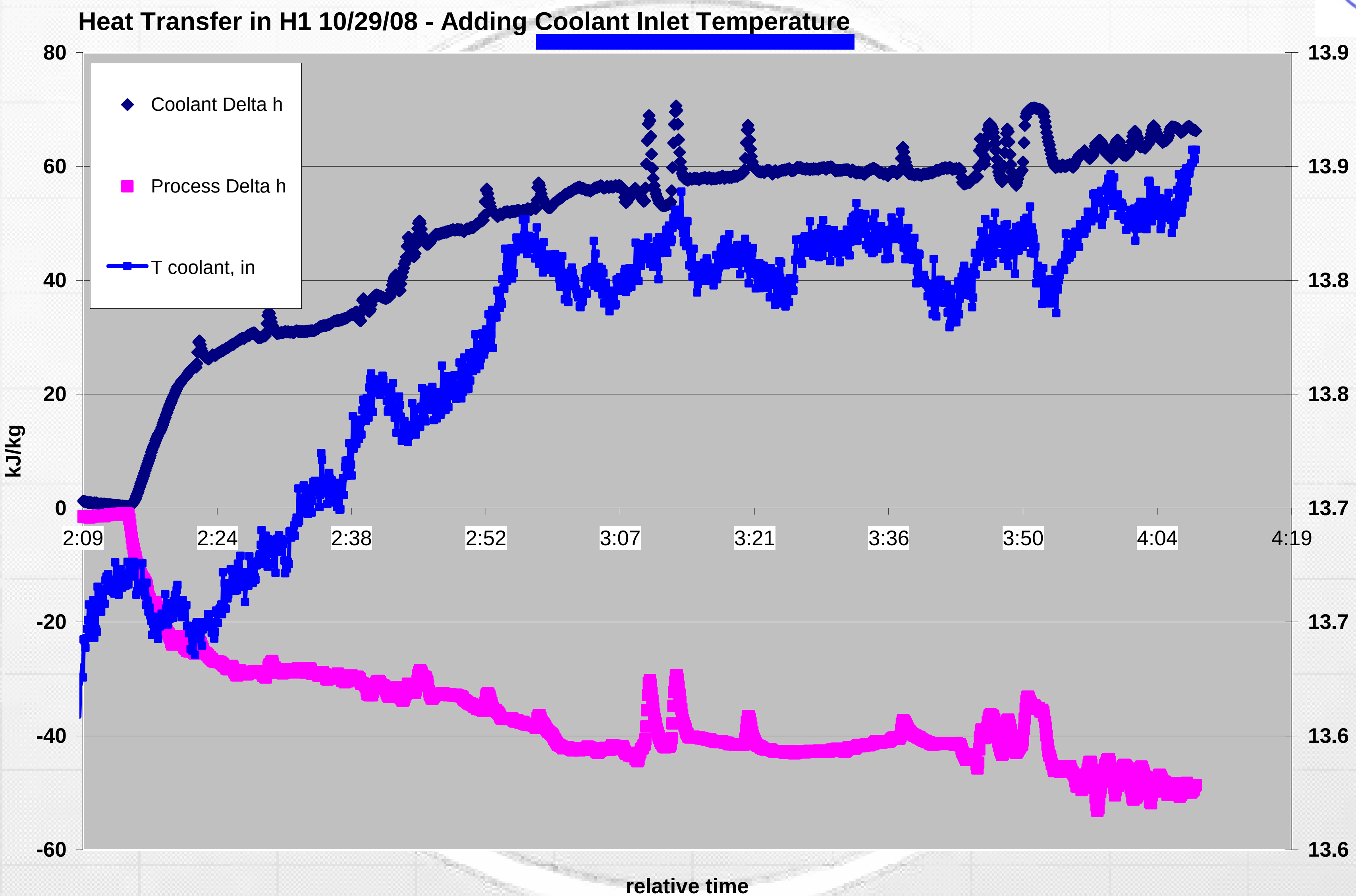
10/29



Temperature with Calculated Enthalpy of FGR gas (at IPR-inlet P&T)

10/29/08




Heat Transfer in H1 10/29/08 - Adding Coolant Inlet Temperature
Coolant Delta h
Process Delta h
T coolant, in
80
60
40
20
0
-20
-40
-60
kJ/kg
13.9
13.9
13.8
13.8
13.7
13.7
13.6
13.6
°C
2:09
2:24
2:38
2:52
3:07
3:21
3:36
3:50
4:04
4:19
relative time

Near Term Next Steps

- **Hammond Testing Current Project**
  - **Receive New Screw feeder for burner**
  - **Vary coal motive velocity**
  - **Install rotary lock on cyclone for ash collection**
  - **Re-test base matrix – burner output**
  - **Performance tests with IPR system**
  - **Finish Slagging and fouling studies**
  - **Develop full data summaries**
  - **Economic Analysis**
    - Work with NETL for Data requirements
      - Develop data summaries
  - **Modeling Groups**
    - Work with NETL for Data requirements
      - Develop data summaries
- **Ready for large scale**

There is a high flame temperature oxyfuel – IPR pathway for Carbon Capture
www.jupiteroxygen.com