# A Staged, Pressurized Oxy-Combustion System for Carbon Capture

Ben Kumfer

Washington University in St. Louis

Consortium for Clean Coal Utilization

co-authors:

Wash U: B. Dhungel, A. Gopan, F. Xia, M. Holtmeyer, R. Axelbaum*

EPRI: J. Phillips, D. Thimsen

3rd Oxyfuel Combustion Conference Sept. 11, 2013

# Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

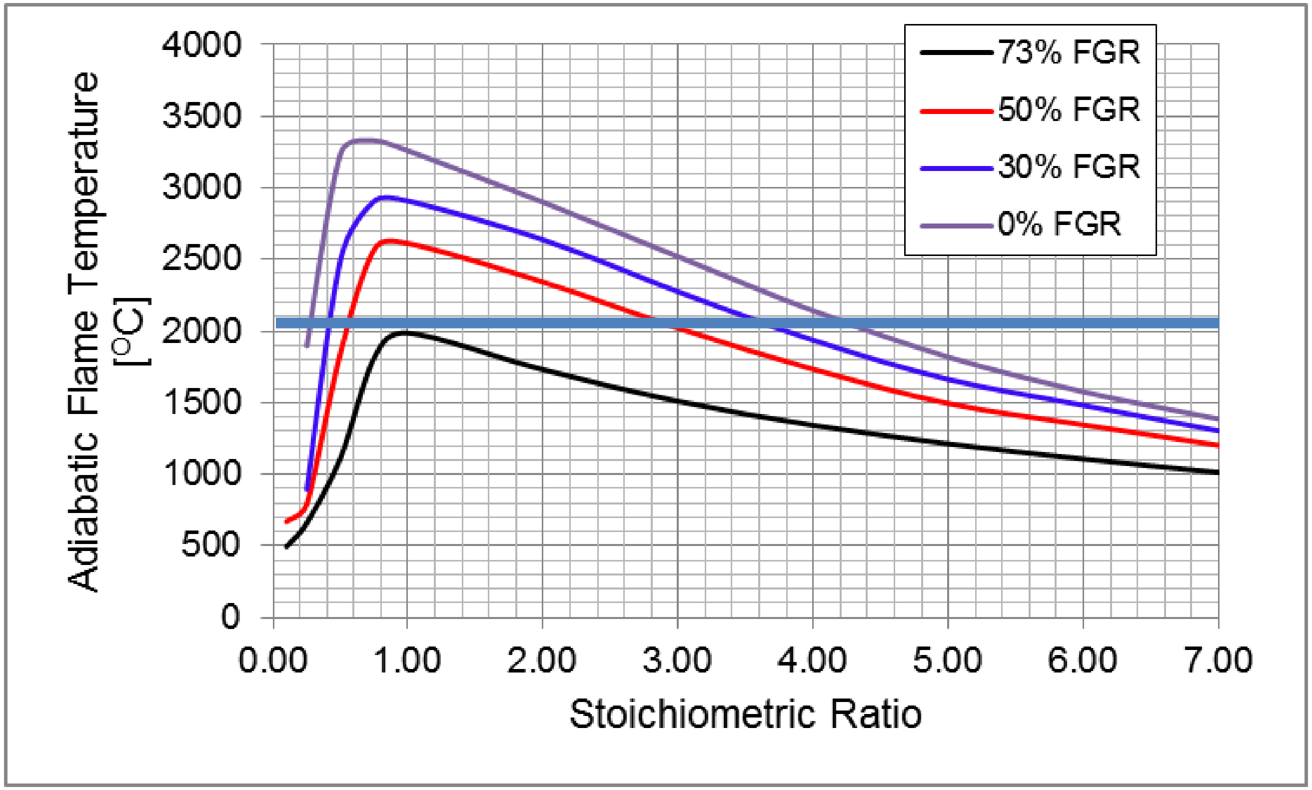
# Pressurized Oxy-Combustion

- The requirement of high pressure $CO_2$ for sequestration enables pressurized combustion as a tool to increase efficiency and reduce costs

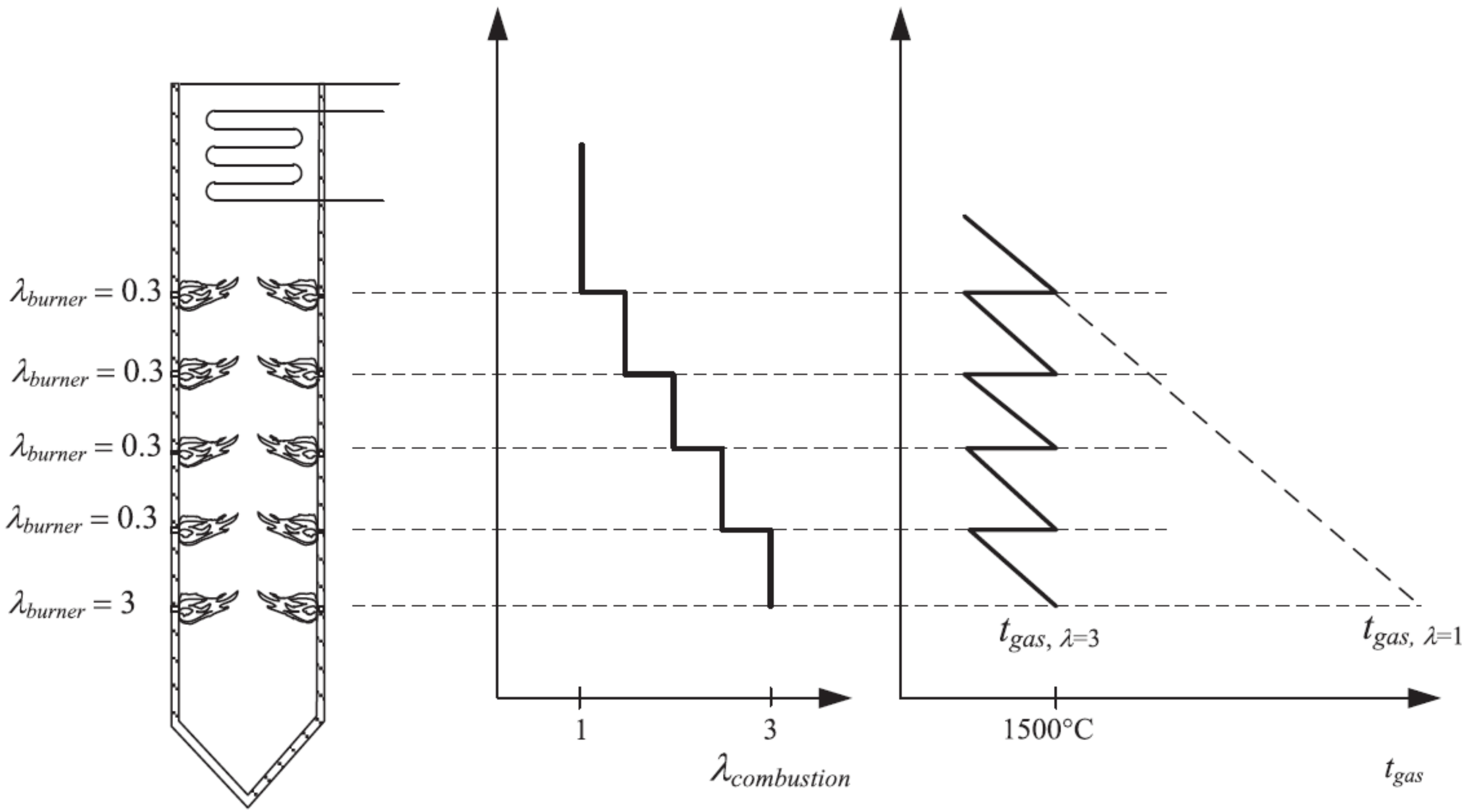
- Benefits:
  - Latent heat of flue gas moisture can be utilized --> increased efficiency
  - Reduces flue gas volume --> lower capital and operating costs
  - Avoids air ingress
  - Reduces oxygen requirements

# First Thoughts on Temperature Control

- Temperature in oxy-combustion is typically controlled by addition of RFG or water (CWS or steam)
- But, global combustion temperature is also a function of stoichiometric ratio



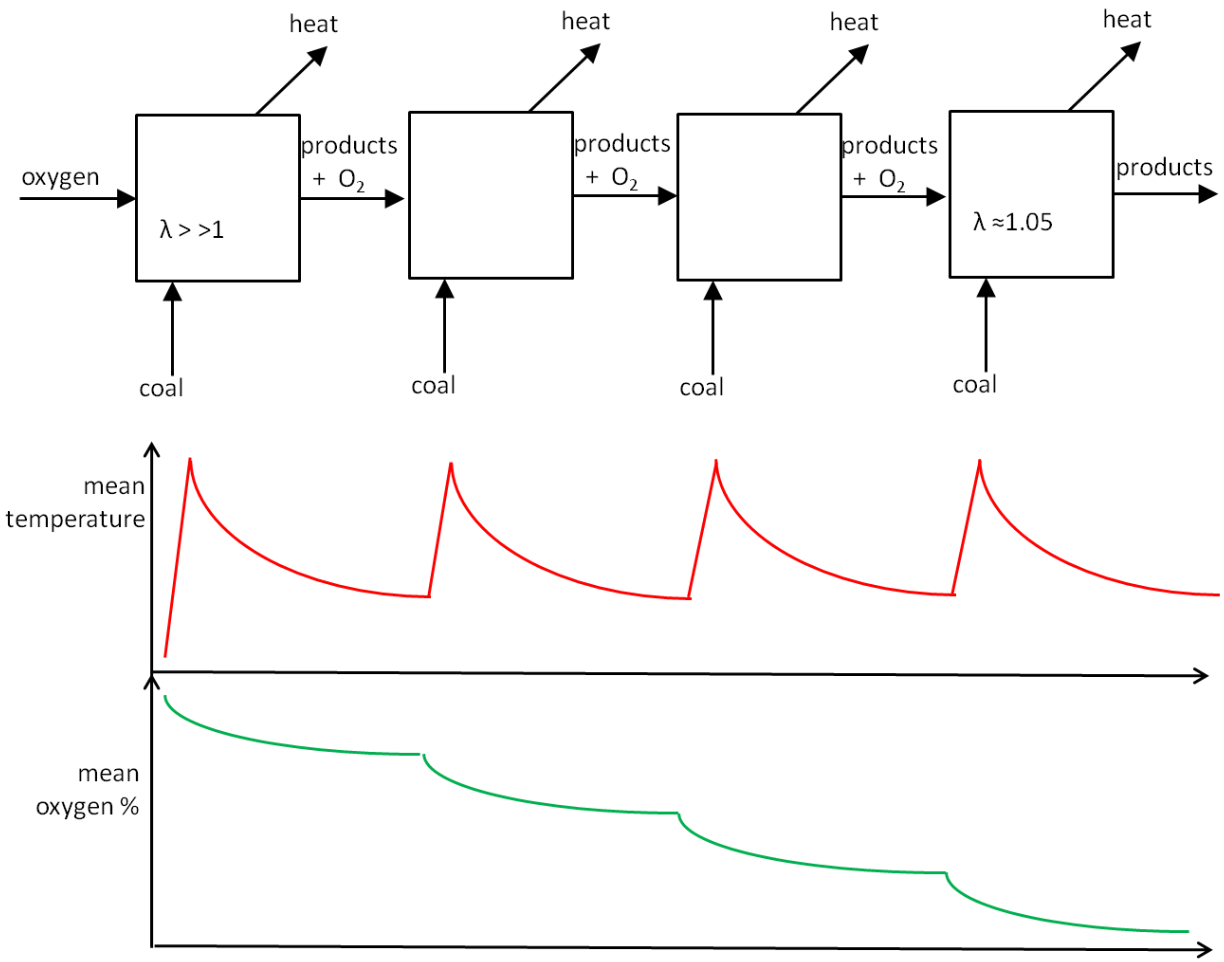
# Fuel Staged Oxy-Combustion




from Becher et al. *Combust. Flame* (2011) 158:1542-52

- Flue gas recirculation reduced to 50%
- Higher heat flux to the wall observed

# Fuel-Staged Oxy-Combustion

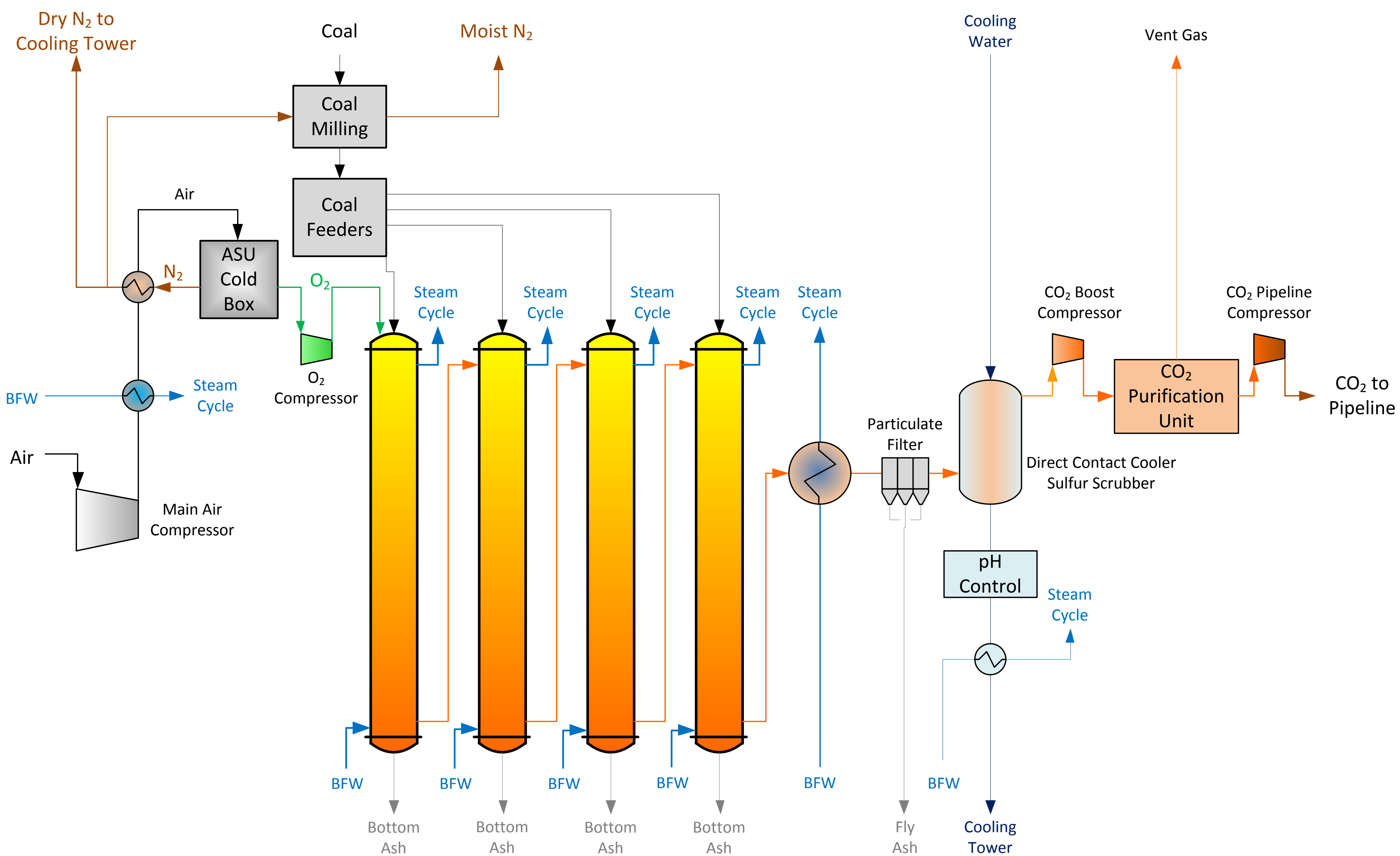



- Multiple boiler modules connected in series w.r.t combustion gas
- Enables near-zero flue gas recycle

# Benefits of Staged Combustion

- Near-zero flue gas recycle
  - Minimizes flue gas volume
  - Minimizes equipment size
  - Minimizes parasitic loads and pumping costs associated with RFG
- Maintain high temperature
  - Increased radiation heat transfer
  - With proper design, can yield maximum and uniform heat flux to the boiler tubes

# Process Flow

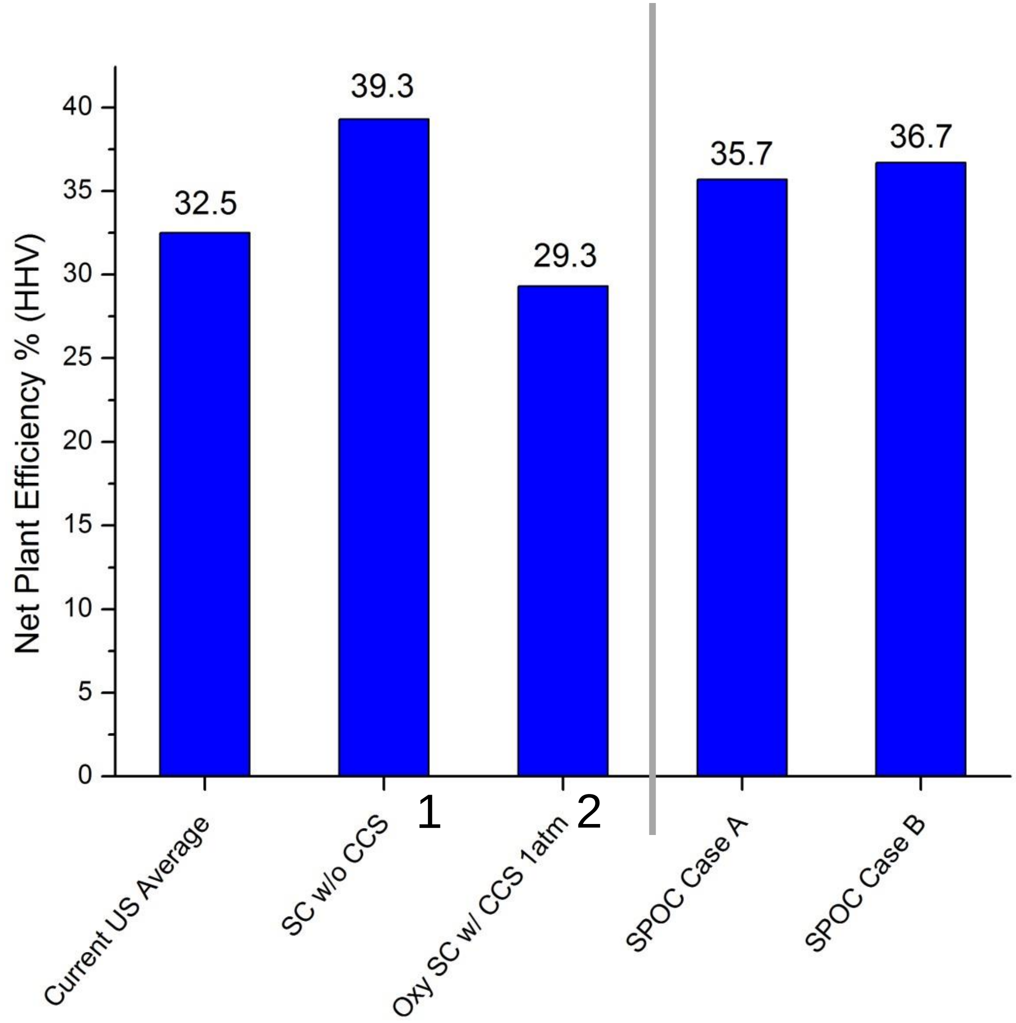


# Modeling Design Basis

- 550 MWe
- Combustion pressure: 16 bar
- Supercritical steam: 3500 psig/1100°F/1100°F (240 bar/600°C/600°C)
- Generic Midwest location, ISO ambient conditions
- PRB Sub-bitum. and Ill #6 bitum. coals considered
- 90% $CO_2$ recovery, EOR-grade $CO_2$: >95%v $CO_2$, < 0.01%v $O_2$
- Follows DOE baseline:

Cost and performance baseline for fossil energy plants volume 1: bituminous coal and natural gas to electricity
DOE/NETL-2010/1397, rev. 2

# ASPEN Plus Results – Plant Efficiency



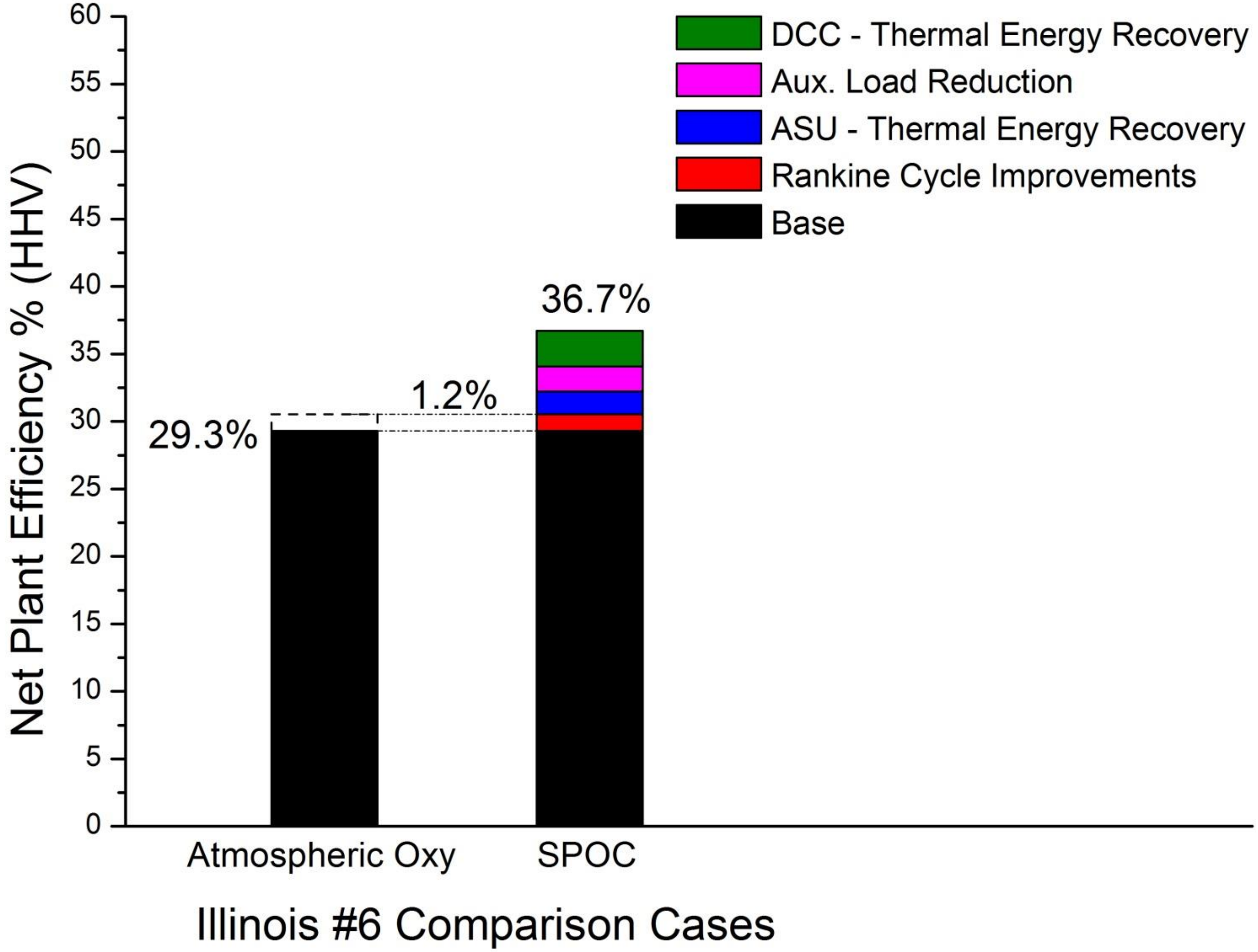

Case A: Subbitum, PRB

Case B: Bitum, Ill #6

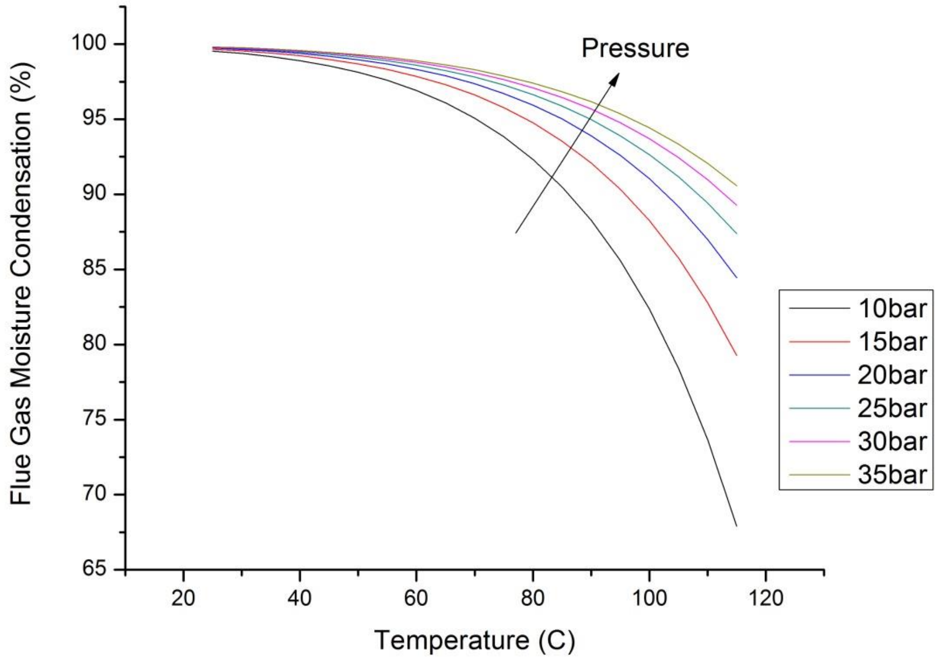
1. Cost and performance baseline for fossil energy plants volume 1: bituminous coal and natural gas to electricity DOE/NETL-2010/1397, rev. 2

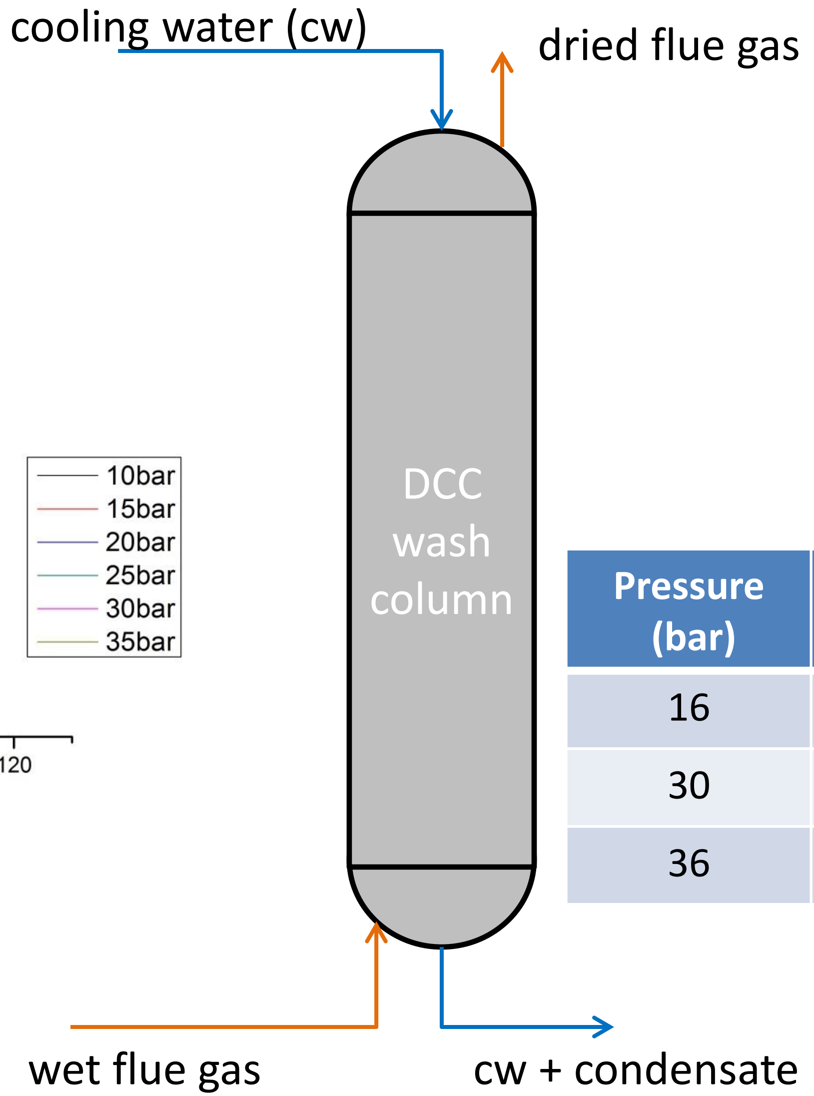
2. Advancing Oxycombustion Technology for Bituminous Coal Power Plants: An R&D Guide. DOE/NETL - 2010/1405

# Efficiency Gain Breakdown



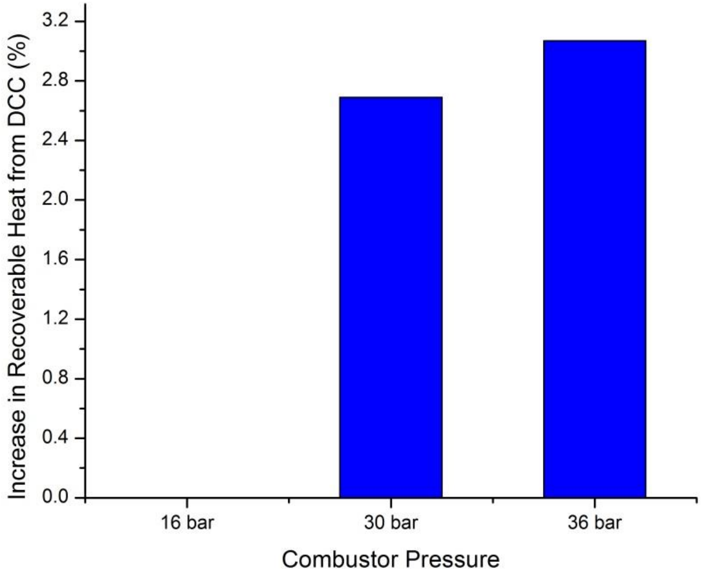
# Latent Heat Recovery

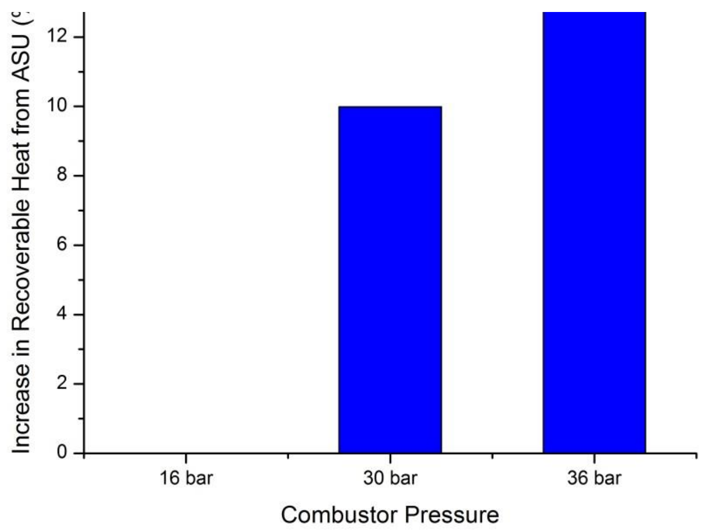


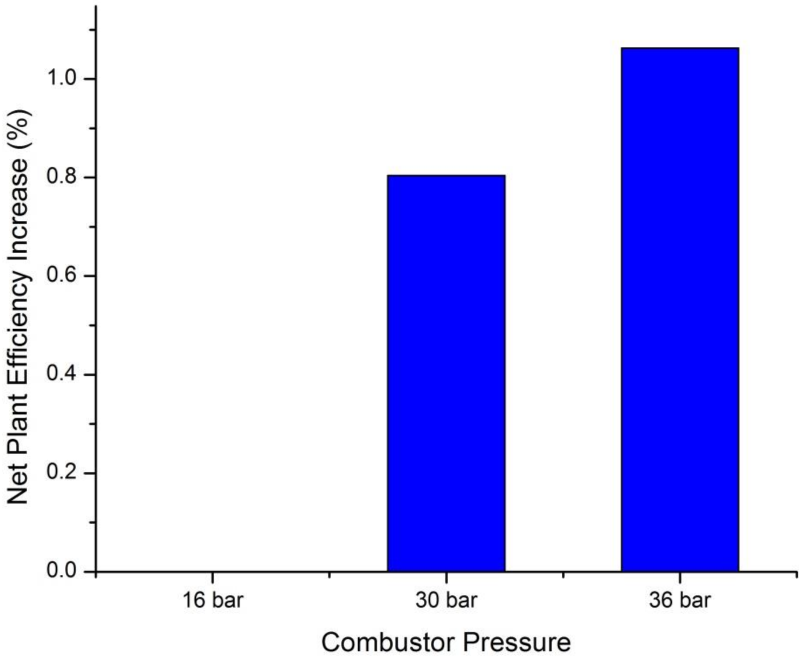




| Pressure (bar) | Exit Temp (C) |
|---|---|
| 16 | 167 |
| 30 | 192 |
| 36 | 199 |

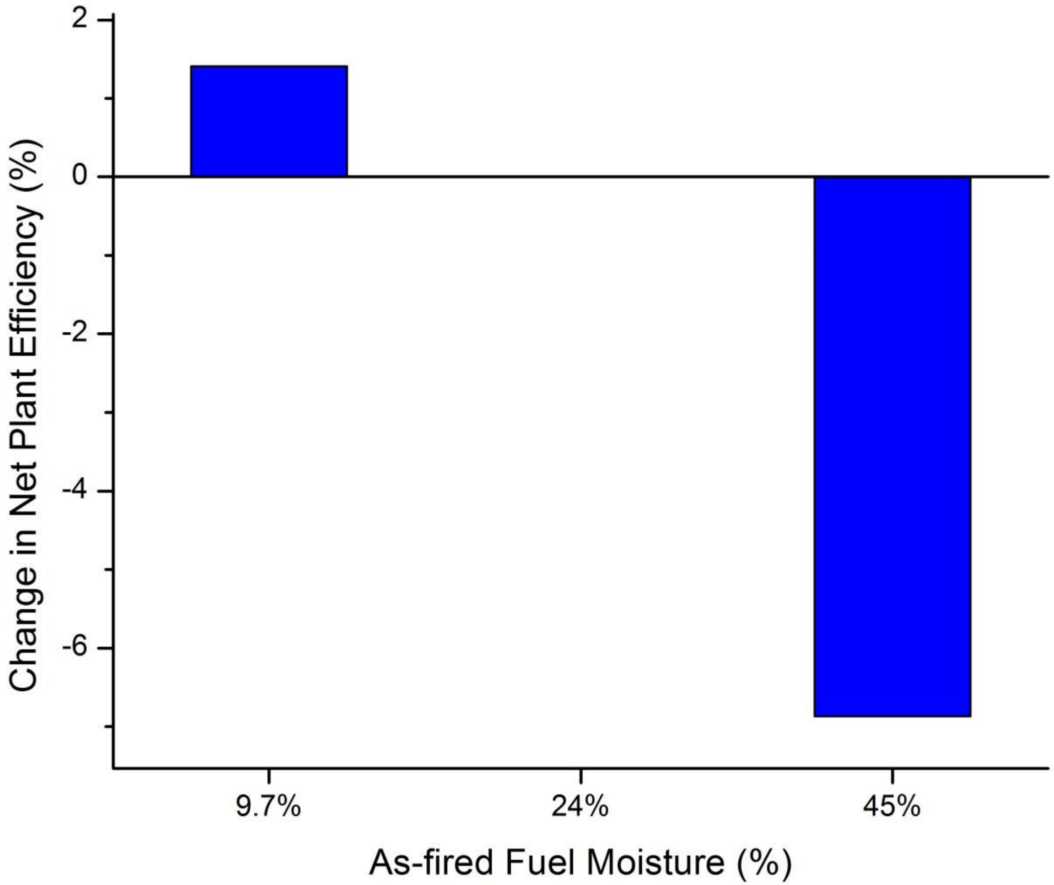
# Effects of Pressure



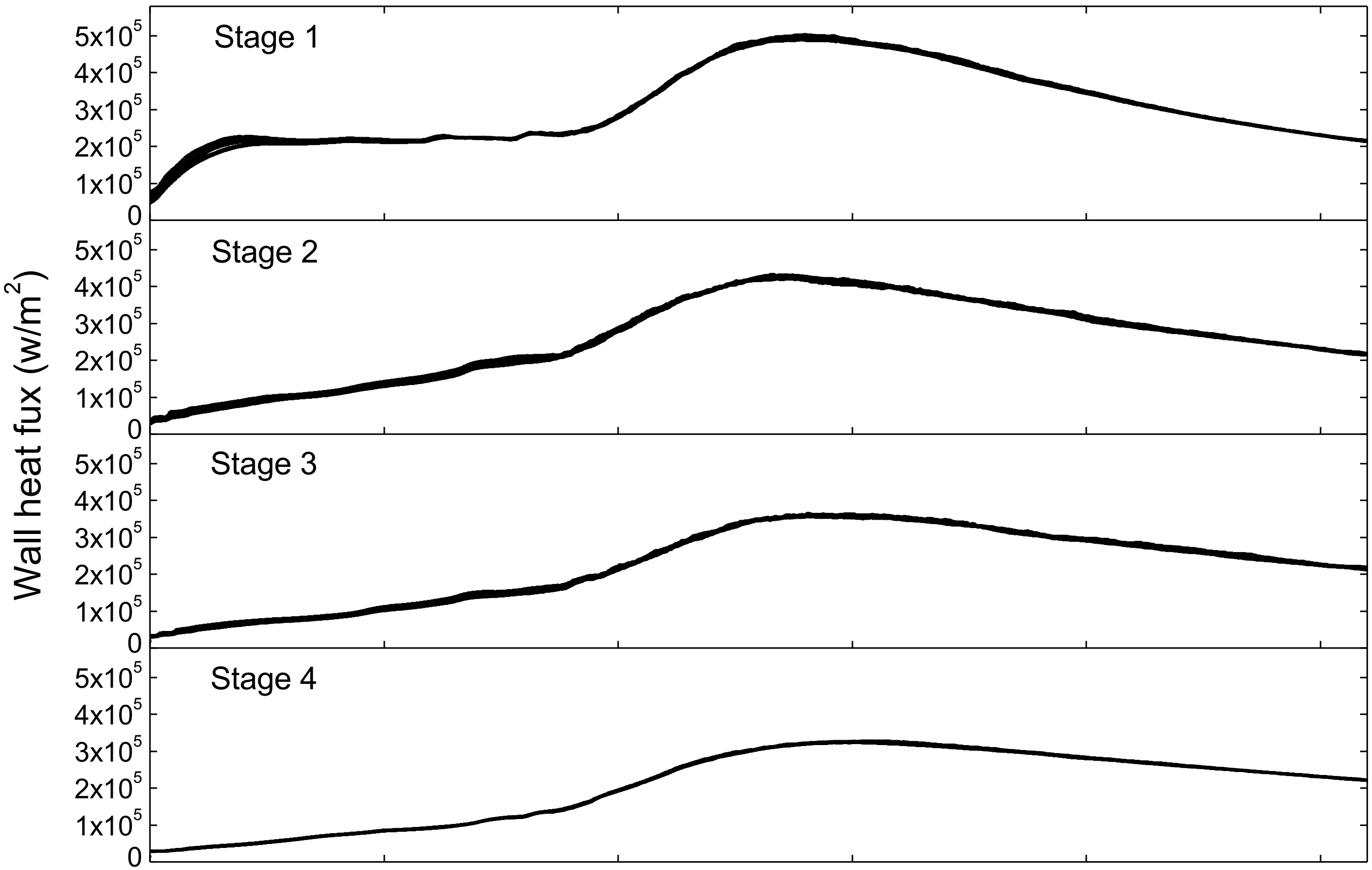



# Effects of Fuel Moisture



# CFD Results - Wall Heat Flux

- 4 vessels of similar design, for 550 MWe plant
- Pressure = 16 bar
- Resulting peak heat flux within limits of traditional SC tube materials



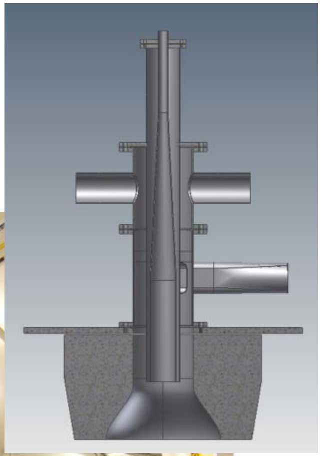
# Experiments – 1 atm

**Advanced Coal & Energy Research Facility (ACERF)**

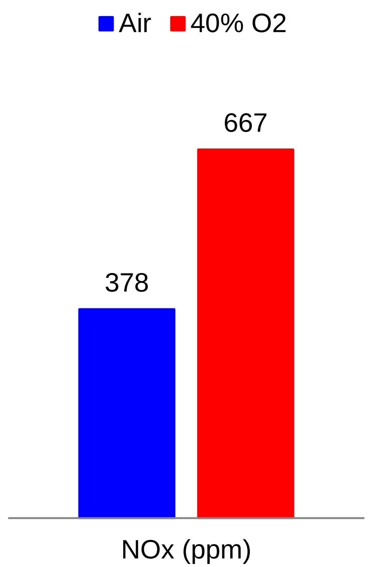
1 MWth capacity

Initial experiments with high O2 concentration:

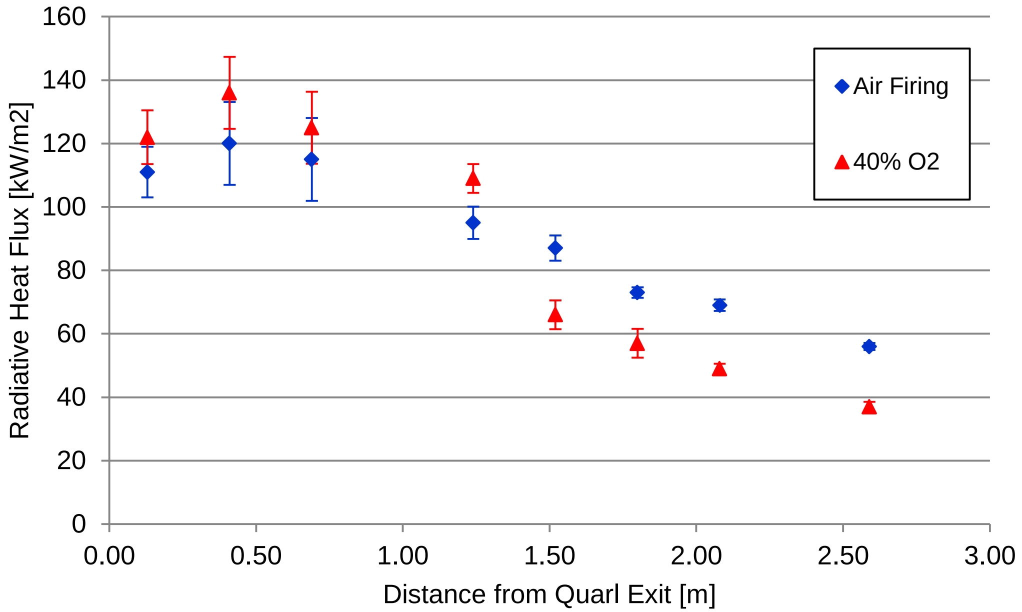
- Once-through, oxygen-enhanced combustion
- O2 injected into secondary stream only, coal is carried using air
- Portion of N2 is replaced by equal volume of O2
  - Increase stoich ratio to mimic staging
  - Adiabatic mixture temp held constant



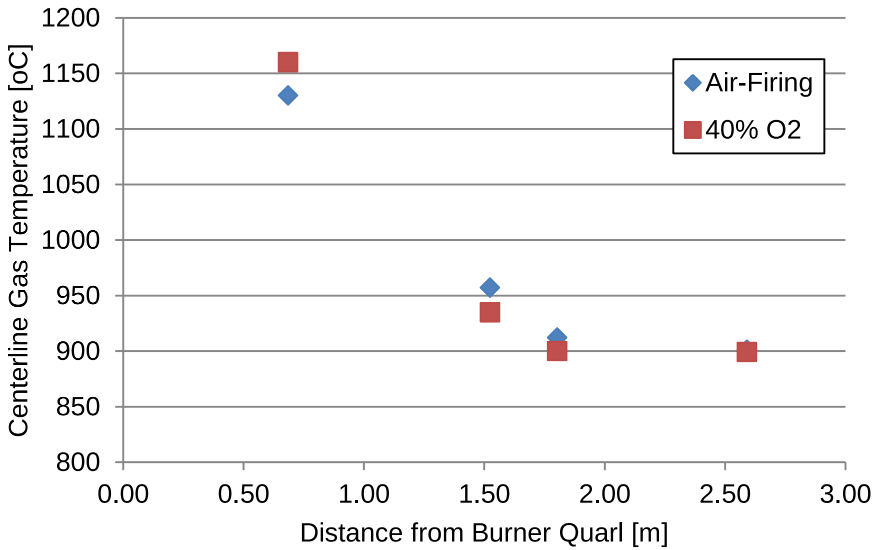
# Results



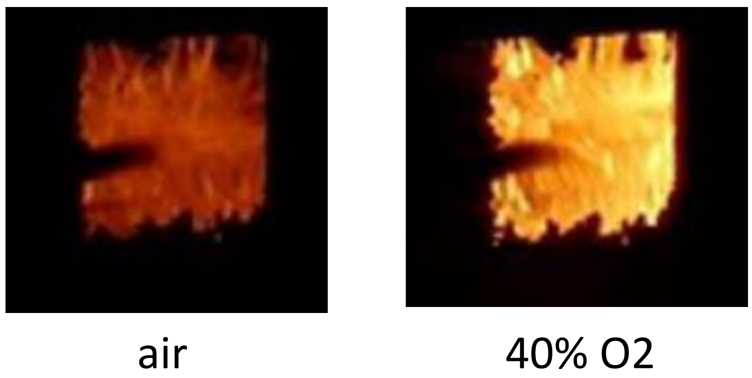
Air
40% O2
667
378
NOx (ppm)

160
140
120
100
80
60
40
20
0
Radiative Heat Flux [kW/m2]
Air Firing
40% O2
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Distance from Quarl Exit [m]

1200
1150
1100
1050
1000
950
900
850
800
Centerline Gas Temperature [oC]
Air-Firing
40% O2
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Distance from Burner Quarl [m]

air
40% O2

# Key Features of SPOC Process

- Increased radiative heat transfer
- Ideal for “lead chamber” process for NOx/SOx removal
- Reduced gas volume
- Modular boiler construction
- Near-zero recycle
- Increased performance of wet, low BTU fuels
- Reduced oxygen demand
- Higher efficiency through dry feed

# Acknowledgements

U.S. Department of Energy:  Award # DE-FE0009702

Advanced Conversion Technologies Task Force, Wyoming

Consortium for Clean Coal Utilization, Washington University in St. Louis

sponsors: Arch Coal, Peabody Energy, Ameren

Ameren:
Rick Smith
George Mues
Tom Callahan

Burns & McDonnell:
Jim Jurzcak
Janel Junkersfeld
Dean Huff
Gary Mouton

# THANK YOU