Staged, Pressurized Oxy-Combustion (SPOC)

Kickoff Meeting

NETL, Morgantown WV

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EPRI

OUTLINE

- **Introduction**
- Project Overview
- Technology Overview
- Progress to Date
- Future Plans

About WUStL

Department of Energy, Environmental & Chemical Engineering

- **140** Undergraduate students
- **27** Master of engineering students
- **70** PhD students
- **16** Full-time faculty

Brauer Hall

Laboratory for Combustion & Energy Research (LACER)

- Fundamentals of coal combustion
- Oxy-combustion
- Flame design
- Materials synthesis

Consortium for Clean Coal Utilization

Founded in January of 2009, the Consortium is dedicated to addressing the scientific and technological challenges of ensuring that coal can be used in a clean and sustainable manner.

Approach

- Research projects are being supported at Washington University in collaboration with Partner Universities around the world.
- State-of-the-art clean coal facilities have been established.
- A motivated work force is being educated to address the challenges associated with clean utilization of coal in the 21st century.

Sponsors

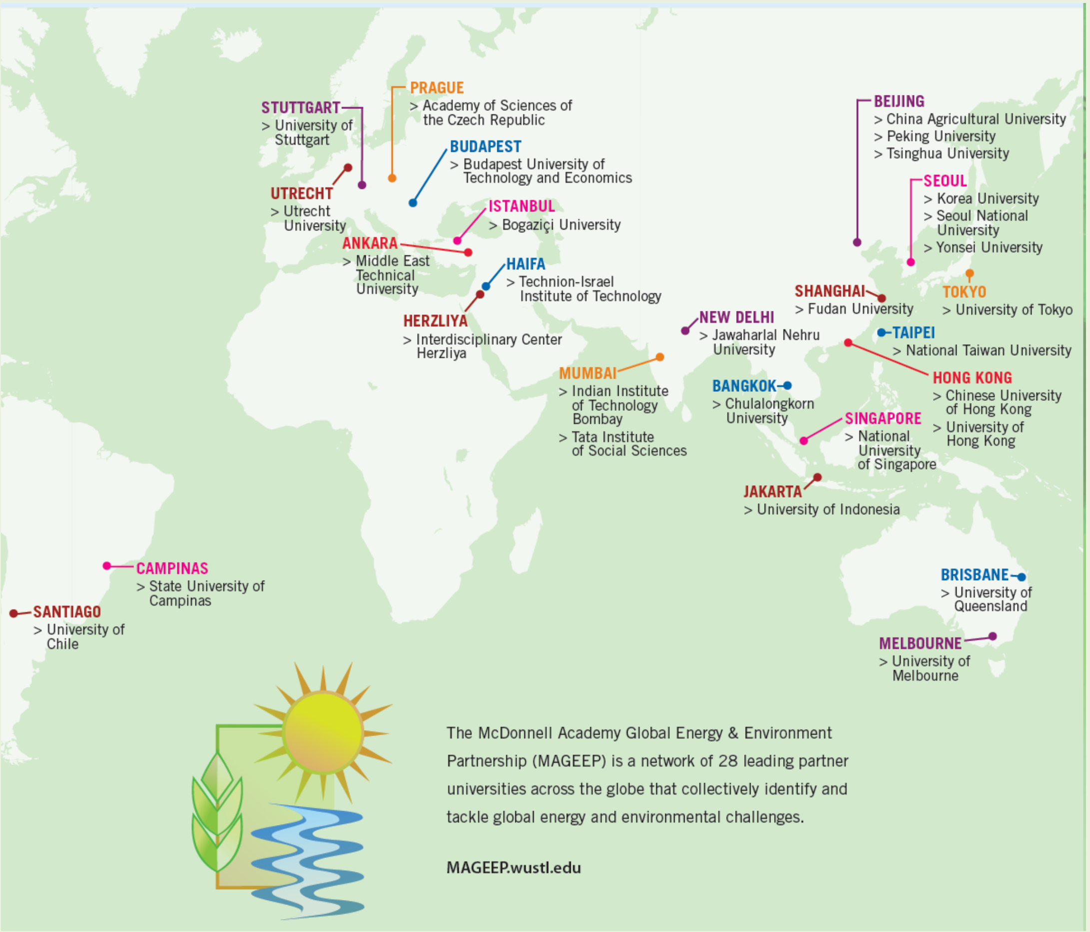
Peabody Energy

Arch Coal

Ameren

CCCU Research Portfolio

- Carbon Dioxide Capture
  - Oxy-combustion
  - Post combustion capture
- Carbon Dioxide Utilization
  - Chemical conversion
  - Algae
- Geological Sequestration
  - Injection/storage modeling
  - Chemical interactions
  - CO_2 Imaging
- Mercury and HAPS control
- Fly Ash Utilization



The McDonnell Academy Global Energy & Environment Partnership (MAGEEP) is a network of 28 leading partner universities across the globe that collectively identify and tackle global energy and environmental challenges.

MAGEEP.wustl.edu

International Partner Institutions

Advanced Coal & Energy Research Facility

ACERF:

- 1 MWth capacity
- Configured for oxy-combustion
- Full suite of emissions monitoring

Additional Facilities:

- 30kW lab-scale test furnace
- Drop tube furnace
- Fuel/ash characterization

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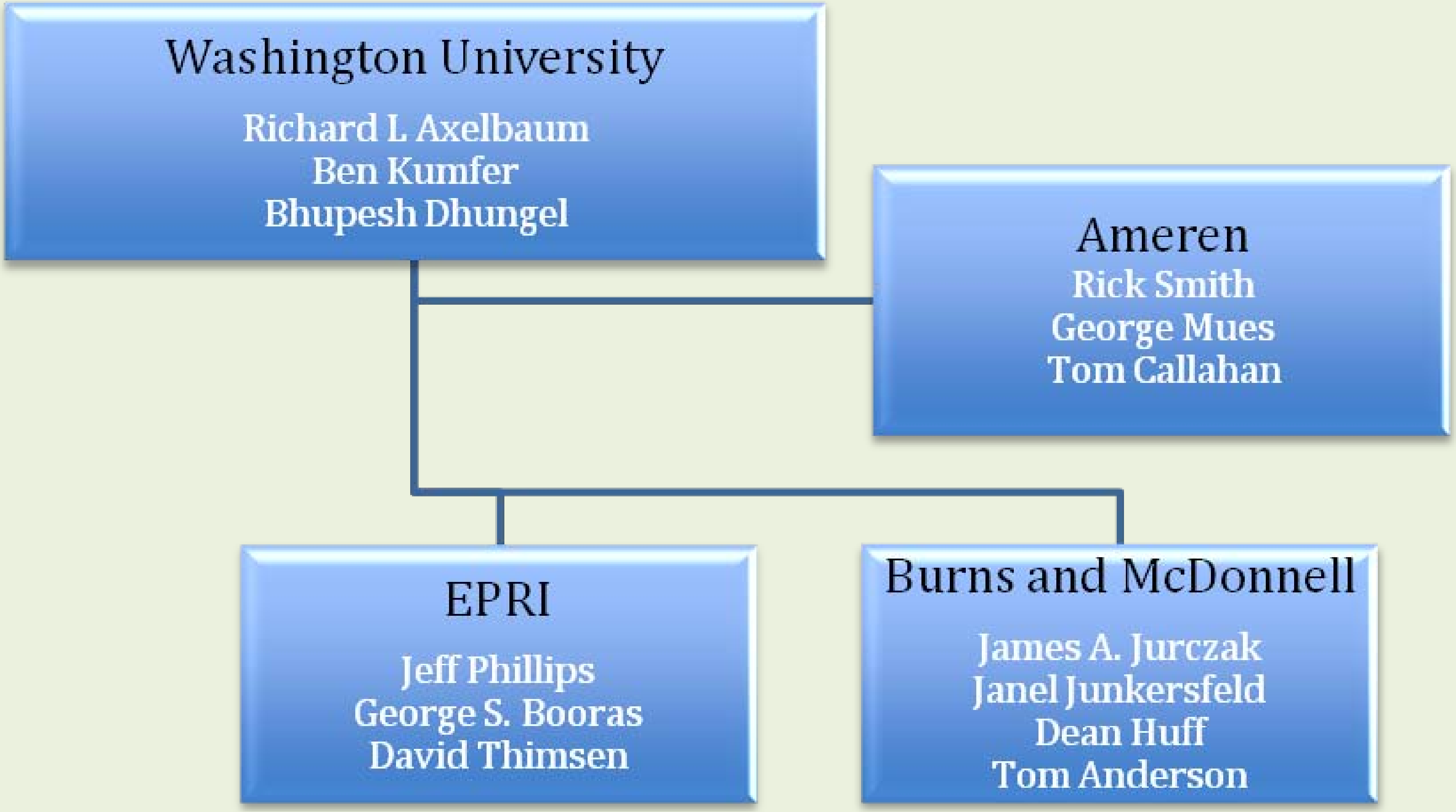
Project Goals

- Develop a novel pressurized oxy-combustion process capable of achieving 90% carbon dioxide capture at no more than a 35% increase in cost of electricity (COE) (<\$25/ton CO2 captured)[1]
- Optimize the design through process modeling to minimize COE
- Identify and analyze potential technical barriers and determine possible solutions

1. Research and Development Goals for CO2 Capture Technology DOE/NETL-2009/1366

Project Team



Washington University

Richard L Axelbaum
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Rick Smith
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Tom Callahan

EPRI

Jeff Phillips
George S. Booras
David Thimsen

Burns and McDonnell

James A. Jurczak
Janel Junkersfeld
Dean Huff
Tom Anderson

Team Member Roles

Task	Team Member
Management & Reporting	*Wash U*
Process Modeling	*Wash U*
Key Technology Selection	*Wash U, EPRI*
Schematic Boiler Design	*Wash U, EPRI, Burns & McDonnell*
Lab Experiments, CFD Simulation	*Wash U*
Balance of Plant Specs	*Burns & McDonnell*
Economic Analysis	*Burns & McDonnell, EPRI*
Utility Advisory	*Ameren*

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Pressurized Oxy-Combustion

- The requirement of high pressure CO_2 for sequestration enables pressurized combustion as a tool to increase efficiency and reduce costs
- Combustion occurs at 10-40 bar
- Benefits:
  - Latent heat of flue gas moisture can be utilized
  - Reduces flue gas volume, potentially translating into lower capital costs
  - Avoids air ingress
  - Increases convective heat transfer (for a given velocity)
  - Increases char burning rates

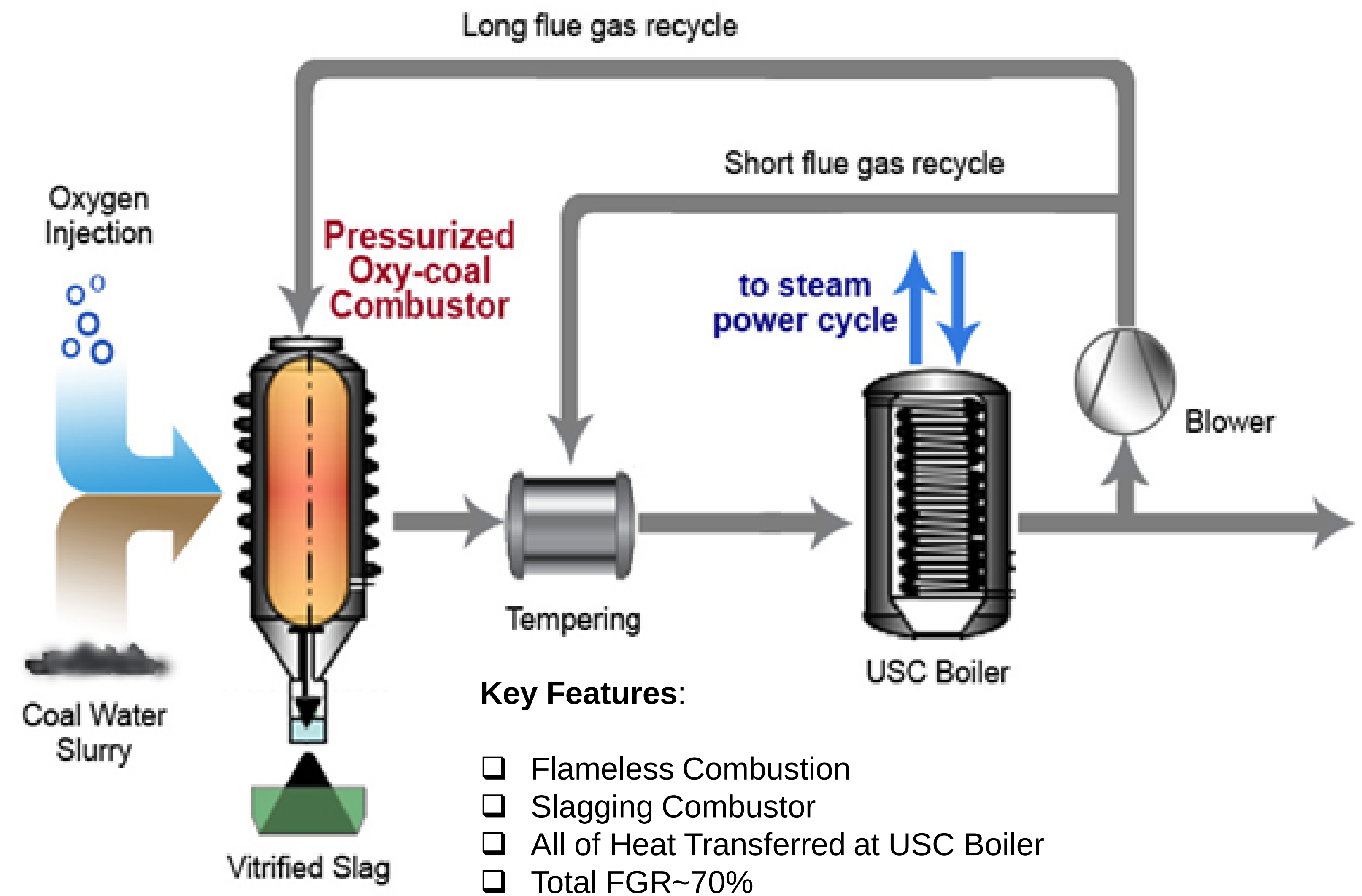
Advanced Oxy-Combustion Rankine Cycle

To achieve project goals, capital and operating costs must be reduced over those of 1st generation oxy-combustion or other approaches to pressurized oxy-combustion

- Capital Costs
  - Minimize heat transfer surface area
  - Minimize auxiliary equipment size (CPU, filters, fans)

- Operating Costs
  - Maximize efficiency
    - Recover latent heat in flue gas
    - Use a high temperature & pressure steam cycle
    - Minimize parasitic loads
  - Minimize excess oxygen requirements

Example: Unity Power Alliance



Key Features:

☐ Flameless Combustion
☐ Slagging Combustor
☐ All of Heat Transferred at USC Boiler
☐ Total FGR~70%

Coal Slurry vs. Dry Feed

Case A: coal slurry

(50wt% dry coal, 50% H_2O)
+ O_2, **λ = 1.065**

→ combustion →

39.3% CO_2
56.8% H_2O
3.0% O_2
0.6% S
0.3% N

→ moisture removal → to CPU

90.9% CO_2
7.1% O_2
1.3% S
0.8% N

Case B: pulverized coal

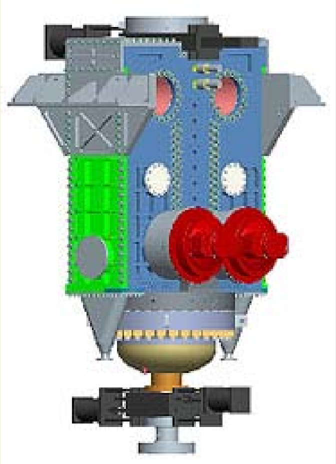
(as received, 11wt% H2O)
+ O_2, **λ = 1.041**

→ combustion →

62.2% CO_2
33.3% H_2O
3.0% O_2
0.9% S
0.5% N

→ moisture removal → to CPU

93.3% CO_2
4.5% O_2
1.4% S
0.8% N

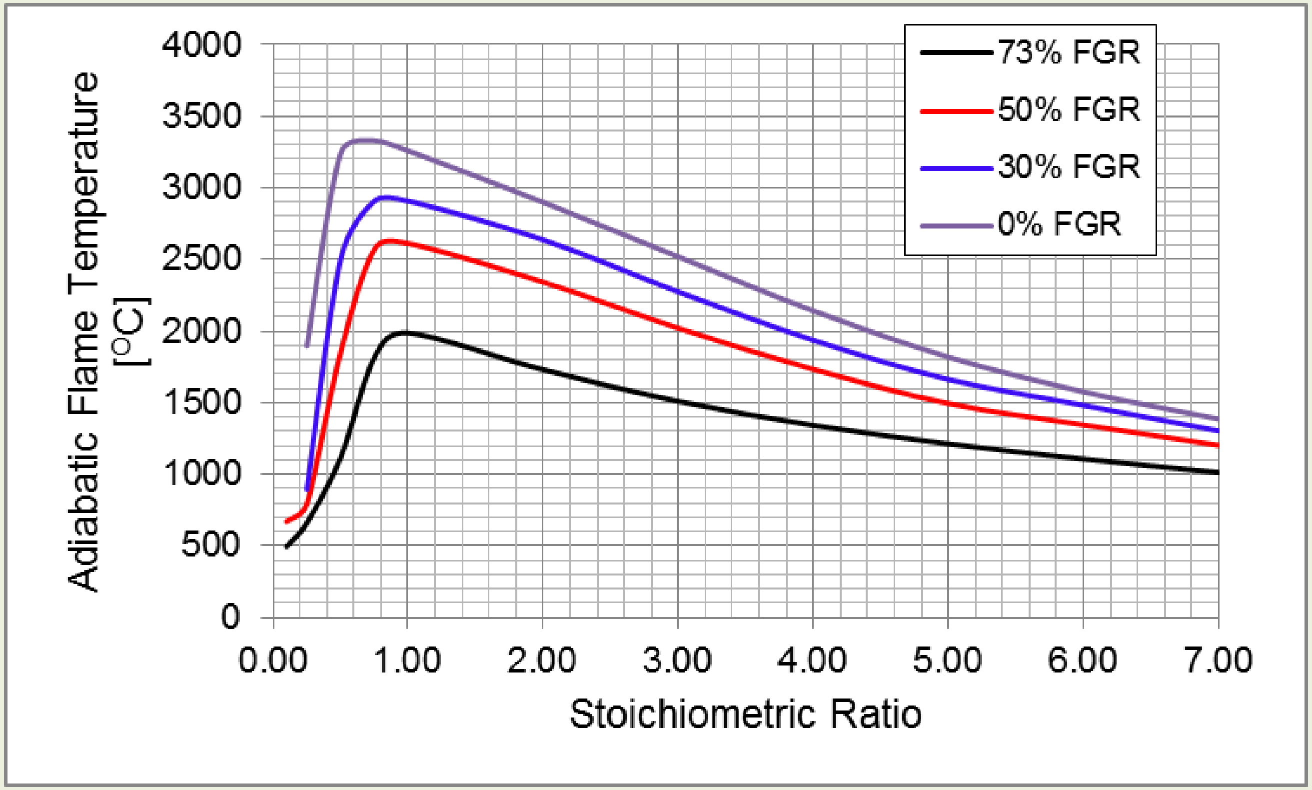


Pratt & Whitney Rocketdyne dry solids feed pump

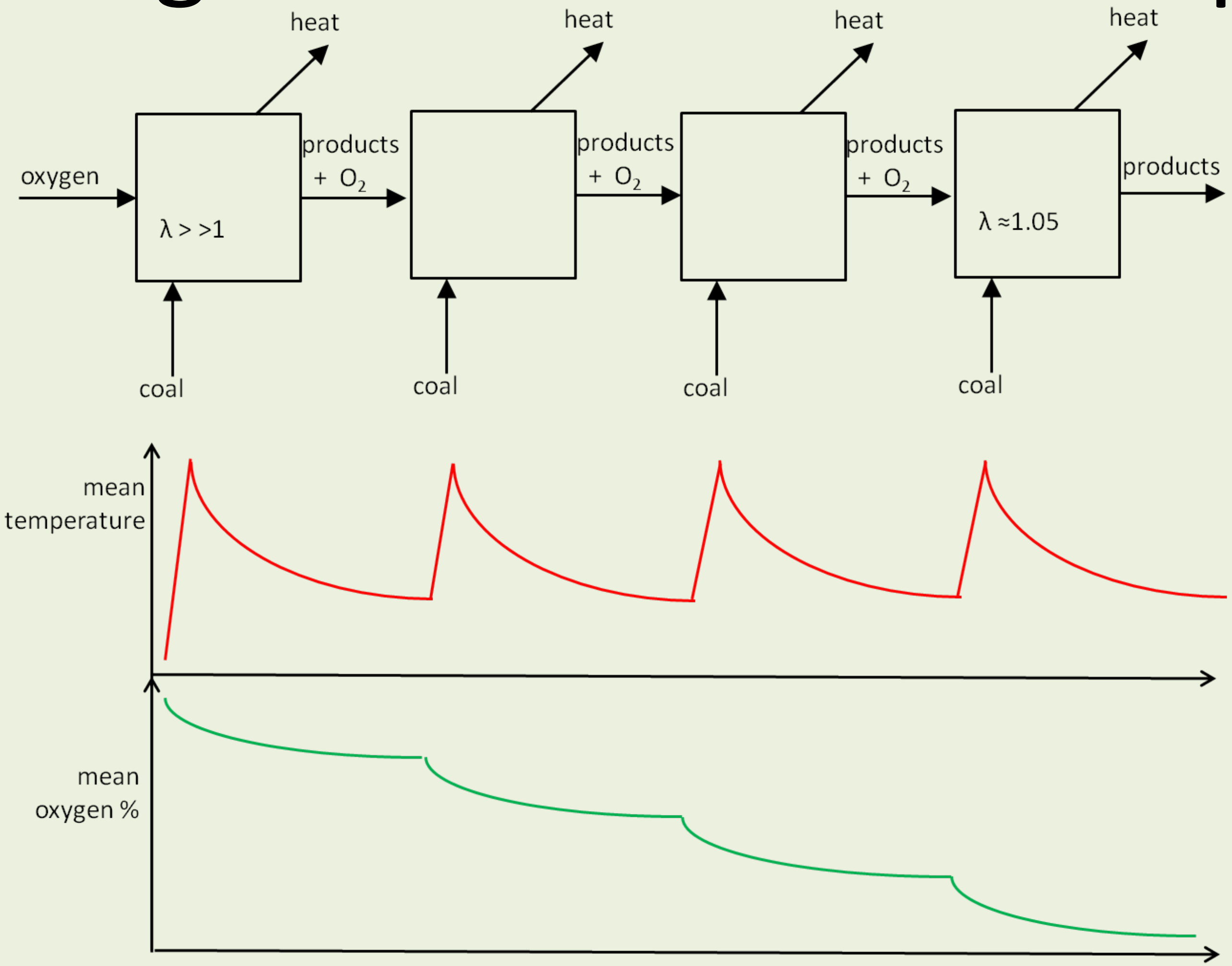
- Less O_2 required from ASU
- Less O_2 removal in CPU

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

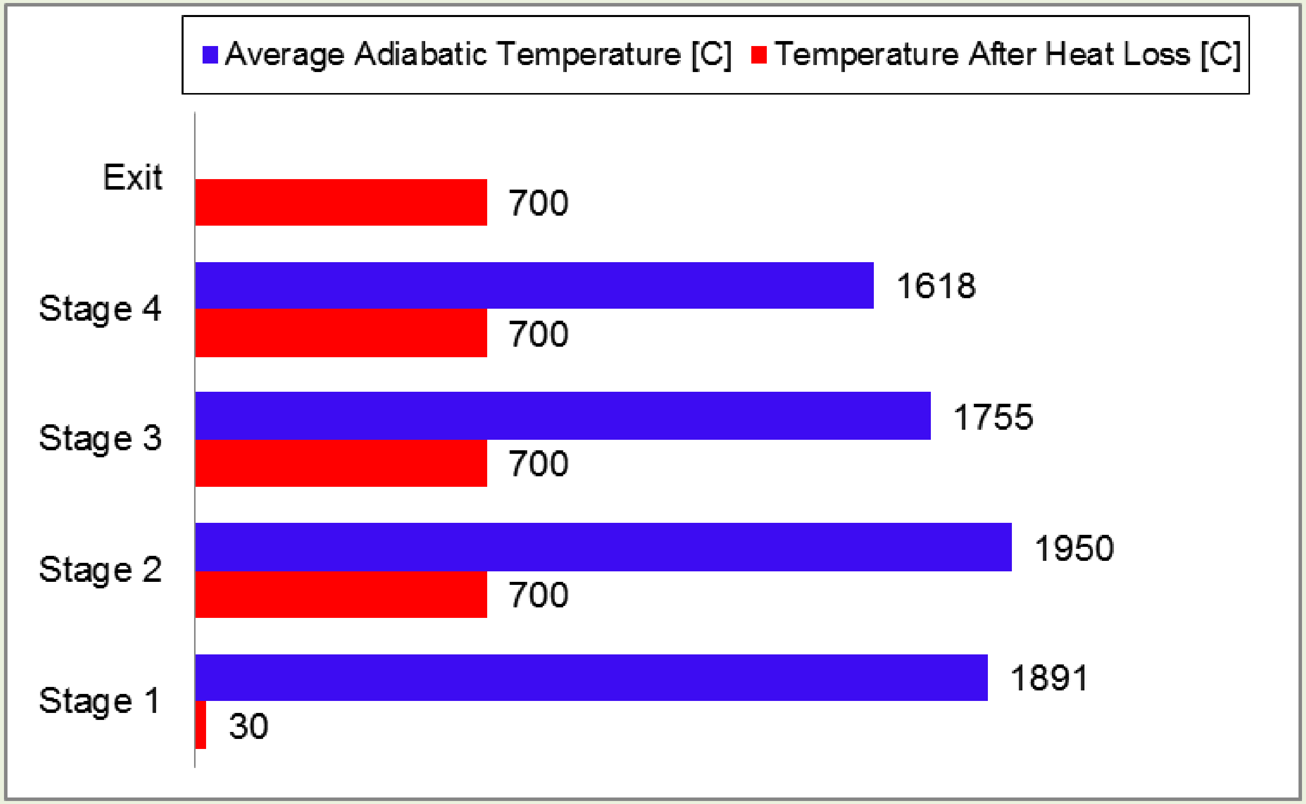


Staged Combustion Concept



- Employ high stoichiometric ratio in early stages to control mean temperature
- Cooled products from early stages (CO2, H2O) assist in controlling temp downstream

Progression of T and Gas Composition



	Vol. % wet	Vol. % wet	Vol. % wet	Vol. % wet	Vol. % wet
End of Stage	**CO2**	**H2O**	**SO2**	**N2**	**O2**
Stage 1	23.4	8.8	0.2	5.1	62.5
Stage 2	41.4	15.6	0.4	4.6	38.0
Stage 3	55.6	20.9	0.6	4.2	18.7
Stage 4	67.1	25.2	0.7	3.9	3.0

Schematic Process Flow Diagram

Proprietary material removed

Boiler Temperature Distribution

Proprietary material removed

Benefits of Staged Combustion

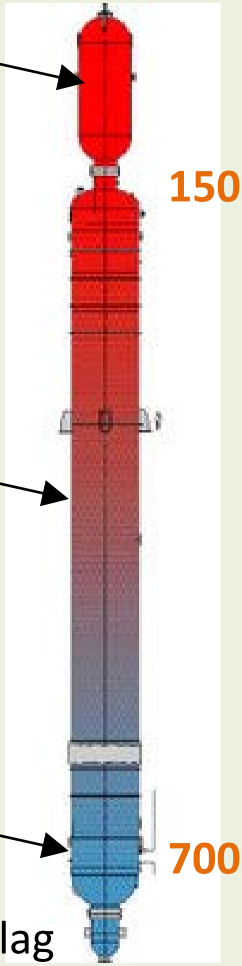
- Near-zero flue gas recycle
  - Minimizes flue gas volume
  - Minimizes equipment size
  - Minimizes parasitic loads and pumping costs associated with RFG
  - Minimizes oxygen requirements
- Higher peak temperature
  - Increased radiation heat transfer
  - With proper design, can ensure maximum and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

Project Goals

Goal	**Approach**
Capital Costs	
Minimize heat transfer surface area	Staged Combustion
Minimize auxiliary equipment size	Staged Combustion/Pressurize Combustion
Operating Costs	
Recover latent heat in flue gas	Pressurized Combustion
Operate at high steam T and P	Advanced boiler tube materials
Minimize parasitic loads	Staged Combustion
Minimize oxygen requirements	Staged Combustion w/ dry coal feed

Boiler Design:
Radiant Syngas Cooler Analog

ALSTOM Power Energy Recovery



Gasifier/ Combustor

1500 °C

Radiant Syngas Cooler

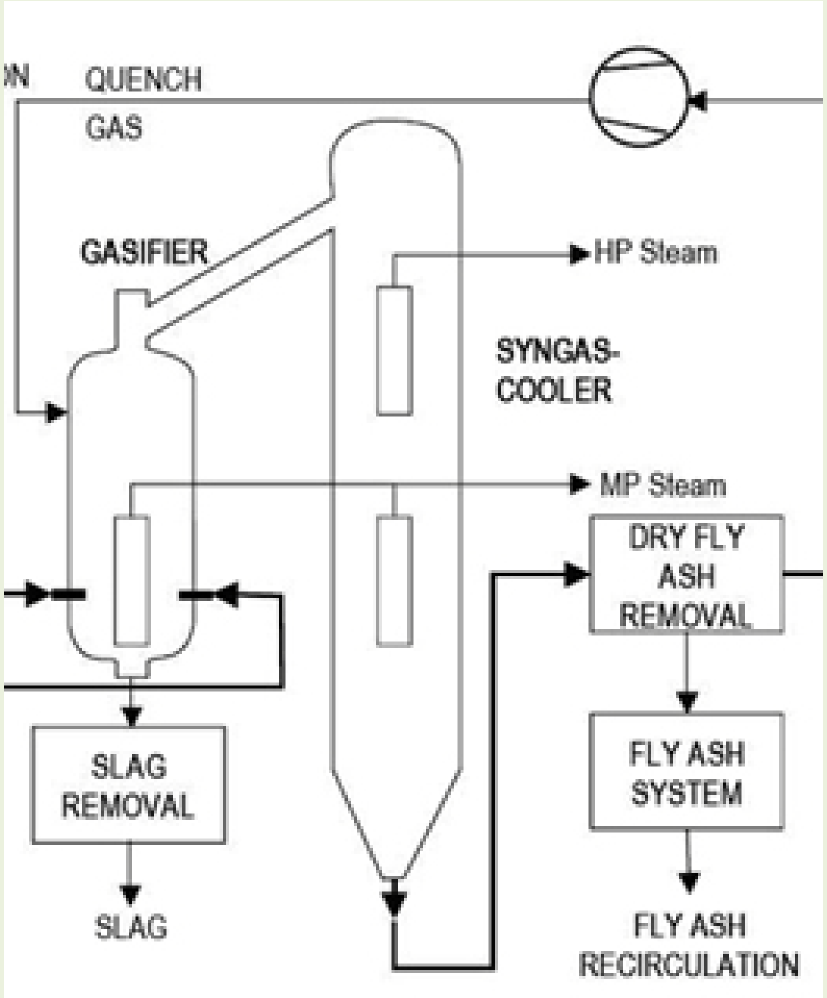
Gas Outlet

700 °C

Slag Removal

(~ 70% of total ash)

Shell Gasifier



Coal Feed

http://www.shg-schack.com

http://www.netl.doe.gov

Anticipated Technical Challenges

- Heat flux limitations
- Avoidance of hotspots & flame impingement
- Boiler materials performance under high P_{O2}
- Ash and slag handling
- Corrosion due to high sulfur

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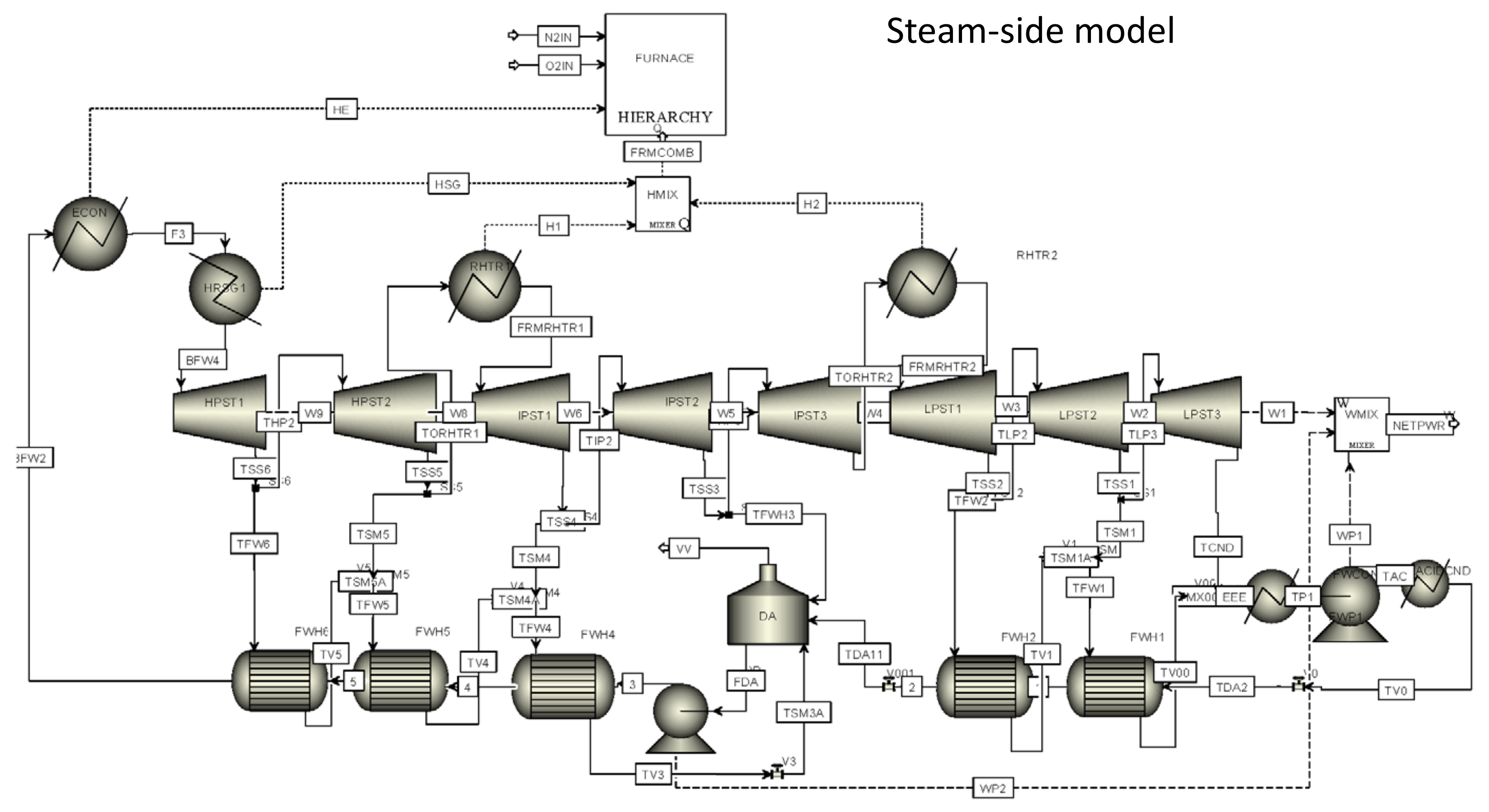
Design Basis

Case #	**Fuel**	**Site**	**Steam Conditions**	**Oxygen Source**	**De-SOx/NOx**	**Sequest. Site**
1	Illinois #6	Midwest ISO	supercritical	cryogenic ASU	Scrubber/SCR	Saline Aquifer
2	Illinois #6	Midwest ISO	supercritical	**ITM**	Scrubber/SCR	Saline Aquifer
3	Illinois #6	Midwest ISO	supercritical	best option	**lead chamber**	Saline Aquifer
4	Illinois #6	Midwest ISO	**advanced USC**	best option	best option	Saline Aquifer
5	**Wyoming PRB**	Wyoming	advanced USC	best option	best option	Saline Aquifer
6	Wyoming PRB	Wyoming	advanced USC	best option	best option	**EOR**

supercritical = 24.1MPa/593°C/593°C (3,500 psig/1,100°F/1,100°F)

“advanced” ultra-supercritical = 27.6 MPa/732°C/760°C (4,000 psig/1,350°F/1,400°F)

AspenPlus Modeling


Steam-side model

CFD Modeling

Proprietary material removed

Radiation Profile

Proprietary material removed

Summary of Tasks to be Completed

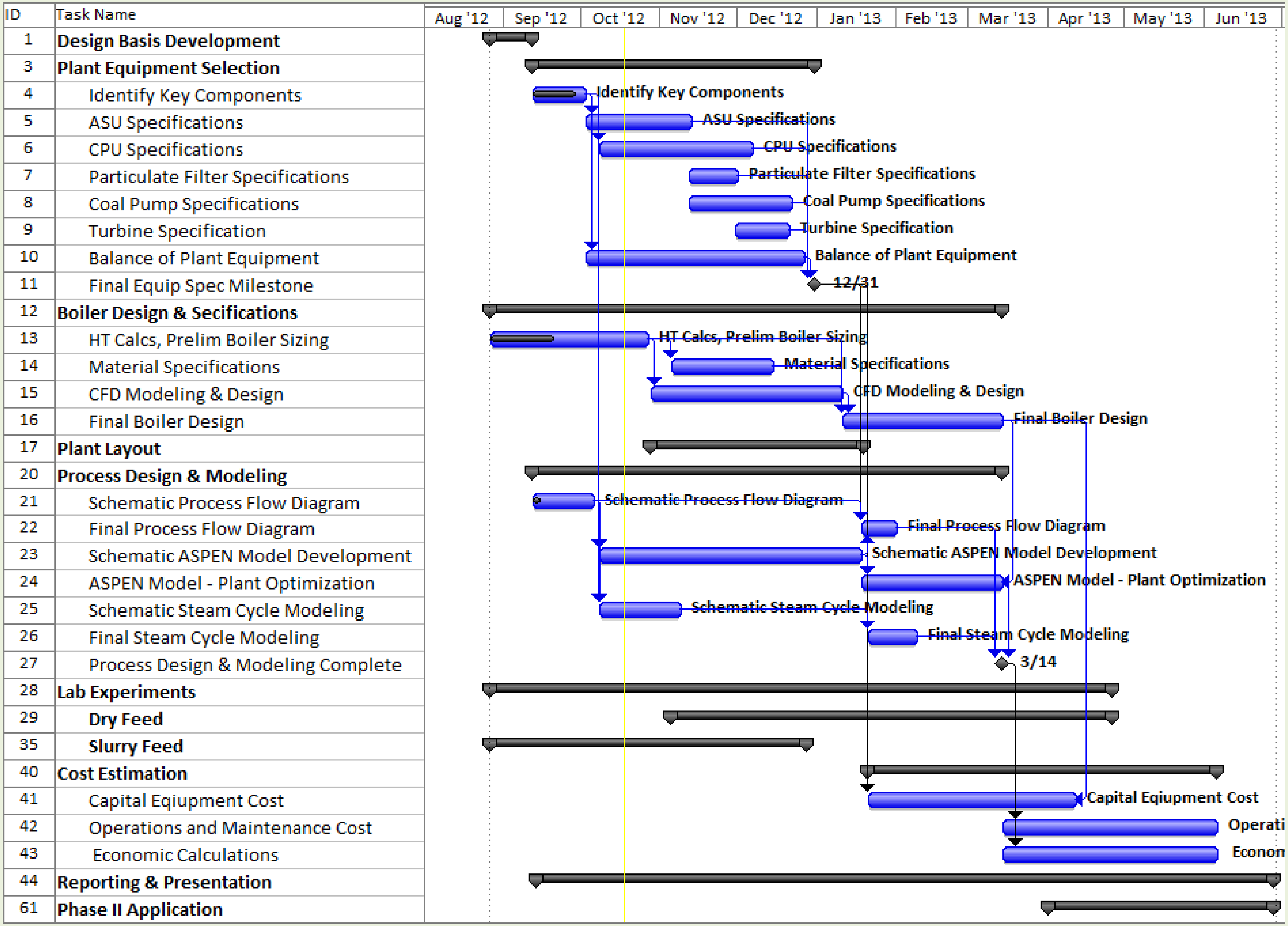
- Develop pre-engineering design of combustor/radiant coolers for cost estimation using
  - CFD modeling
  - Pressure vessel design standards & syngas cooler analogs

- Process Design & Modeling
  - Determine optimum number and sizes of stages
  - Maximize efficiency using Aspen

- Laboratory Experiments
  - Reproduce first and last stages in lab-scale furnace
  - Make radiation measurements to validate CFD model

- Cost estimation

Project Timeline



ID	Task Name
1	**Design Basis Development**
3	**Plant Equipment Selection**
4	Identify Key Components
5	ASU Specifications
6	CPU Specifications
7	Particulate Filter Specifications
8	Coal Pump Specifications
9	Turbine Specification
10	Balance of Plant Equipment
11	Final Equip Spec Milestone
12	**Boiler Design & Secifications**
13	HT Calcs, Prelim Boiler Sizing
14	Material Specifications
15	CFD Modeling & Design
16	Final Boiler Design
17	**Plant Layout**
20	**Process Design & Modeling**
21	Schematic Process Flow Diagram
22	Final Process Flow Diagram
23	Schematic ASPEN Model Development
24	ASPEN Model - Plant Optimization
25	Schematic Steam Cycle Modeling
26	Final Steam Cycle Modeling
27	Process Design & Modeling Complete
28	**Lab Experiments**
29	**Dry Feed**
35	**Slurry Feed**
40	**Cost Estimation**
41	Capital Eqiupment Cost
42	Operations and Maintenance Cost
43	Economic Calculations
44	**Reporting & Presentation**
61	**Phase II Application**