Staged, High Pressure Oxy-Combustion Technology: Development and Scale-Up

DE-FE0009702

NETL CO2 Capture Technology Meeting

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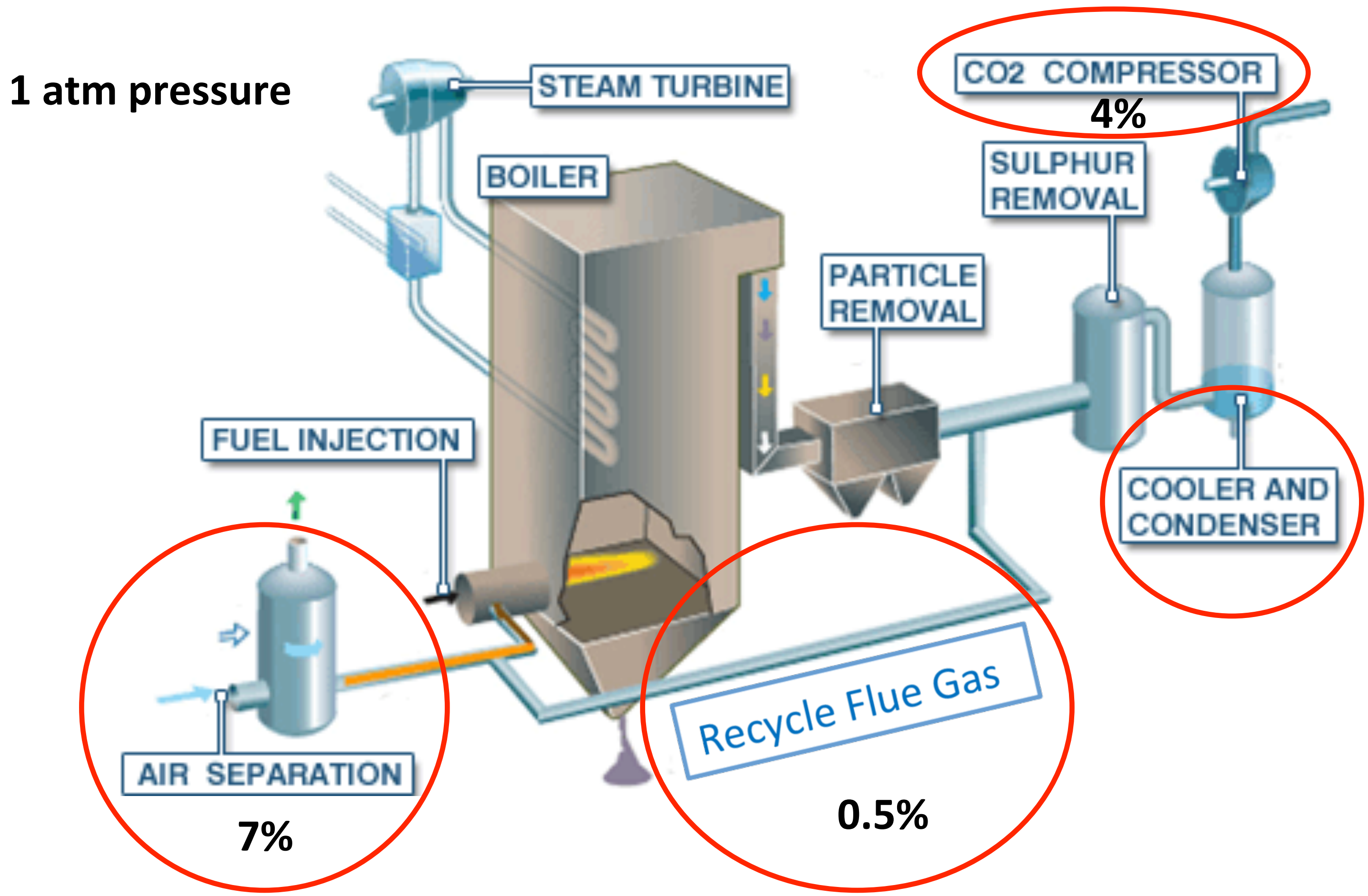
CONSORTIUM FOR CLEAN COAL UTILIZATION

First Generation Oxy-fuel Combustion



http://www.reuk.co.uk/Carbon-Capture-and-Storage.htm

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 of Pressurized Combustion
  - Recover latent heat in flue gas → Increase efficiency
  - Latent heat recovery can be combine with integrated pollution removal → Lower capital and O&M
  - Reduce gas volume → Lower capital and O&M
  - Avoid air-ingress → Lower purification cost
  - Reduce oxygen requirements → Increase efficiency

Project Overview

Objectives

Demonstrate, evaluate, and improve on a novel pressurized oxy-combustion concept, incorporating fuel staging to eliminate flue gas recycle, to achieve carbon capture with reduced costs and higher efficiency, as compared to first generation technologies.

– DOE goals: 90% capture at no more than 35% increase in COE

Project Goals

- Optimize the design through process modeling to minimize COE
- Identify and analyze potential technical barriers and determine possible solutions
- Construct prototype to demonstrate feasibility and address potential technical barriers.

Motivation for SPOC

Key Features:

Improve capital costs by:

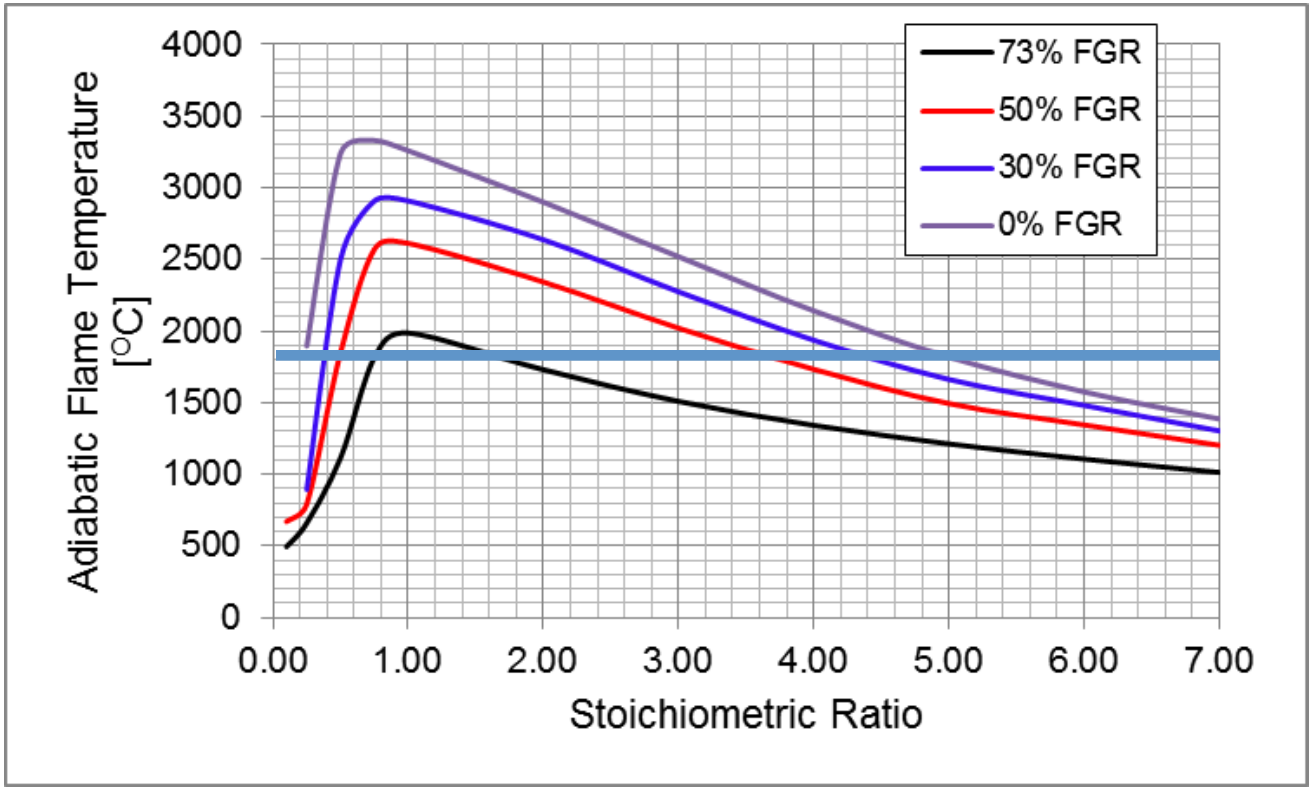
- Optimizing use of radiation to minimizing heat transfer surface area
- Minimizing recycled flue gas (RFG) and, thus, gas volume
- Minimizing equipment size
- Utilizing modular boiler construction

Improve operating costs by:

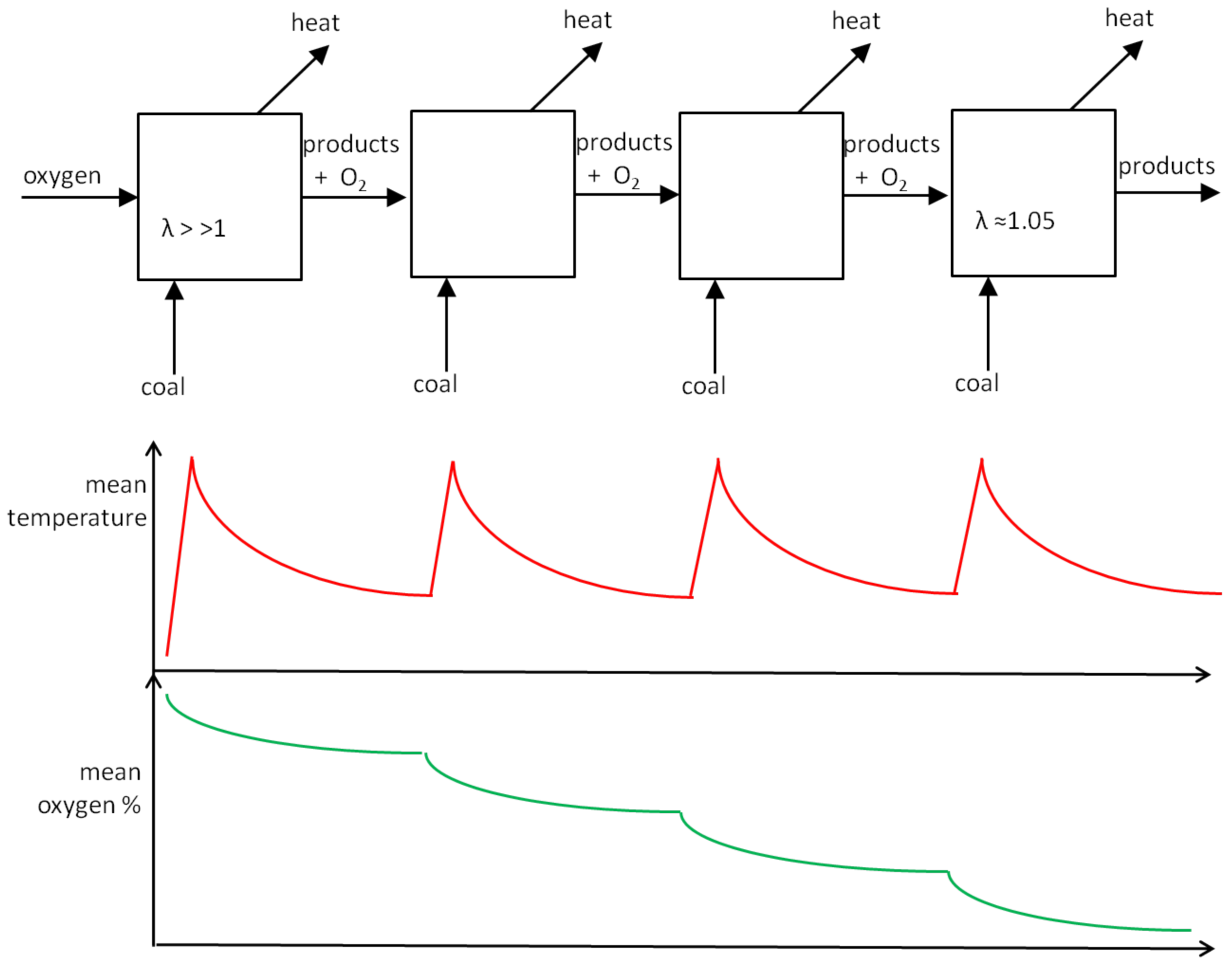
- Maximizing boiler efficiency
- Minimizing parasitic loads associated with RFG
- Utilizing "lead chamber" process for SOx & NOx removal
- Minimizing oxygen requirements
- Maximizing efficiency through dry feed
- Increasing performance of wet, low BTU fuels

Temperature Control w/o FGR

- 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

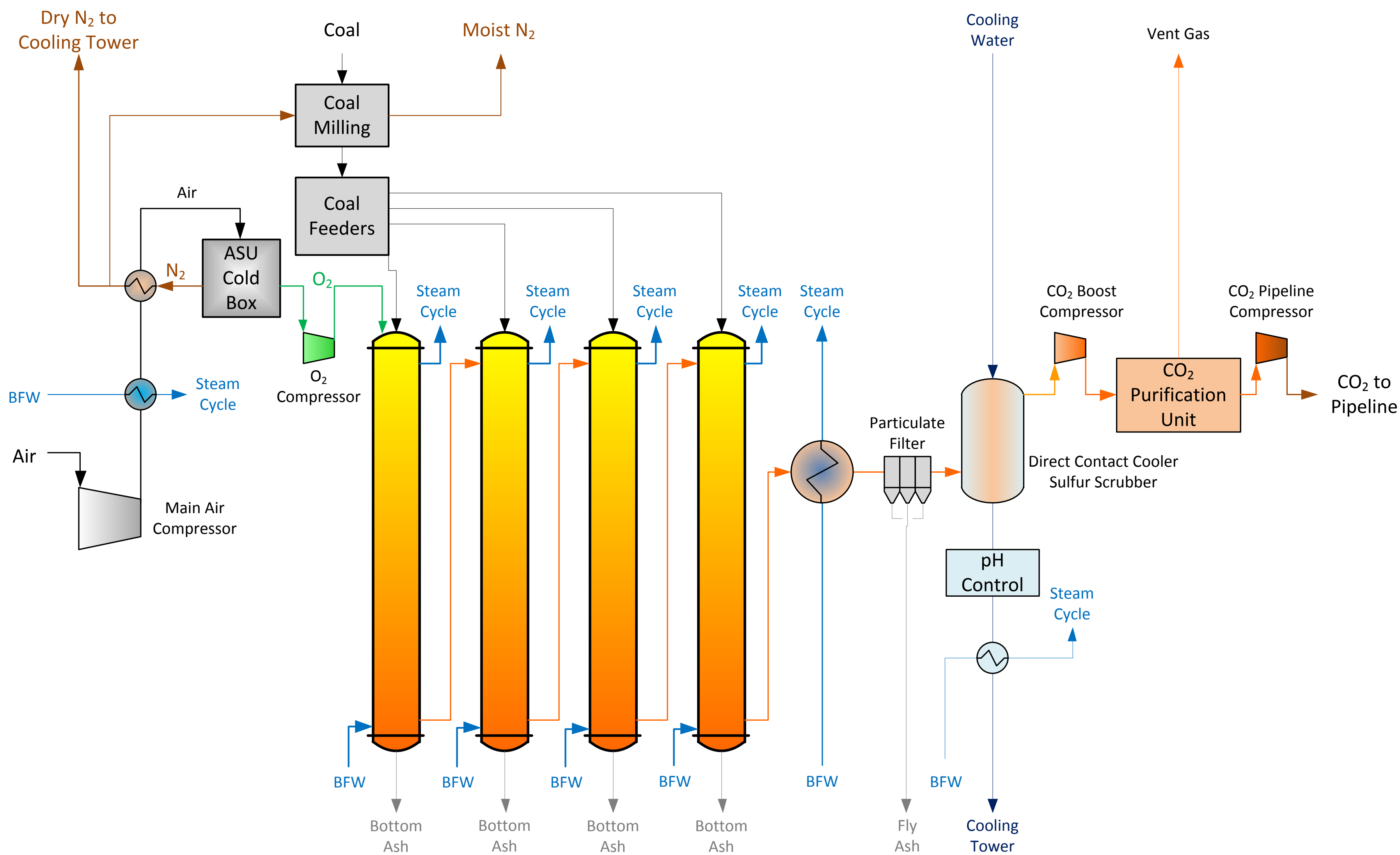


- Multiple boiler modules connected in series w.r.t combustion gas
- Enables near-zero flue gas recycle

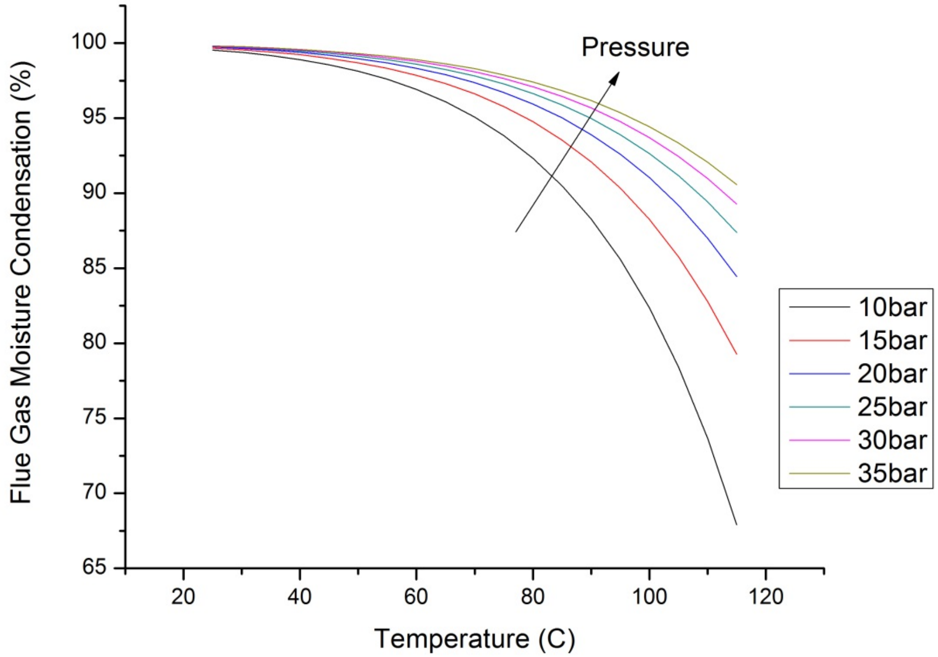
Phase I Objectives

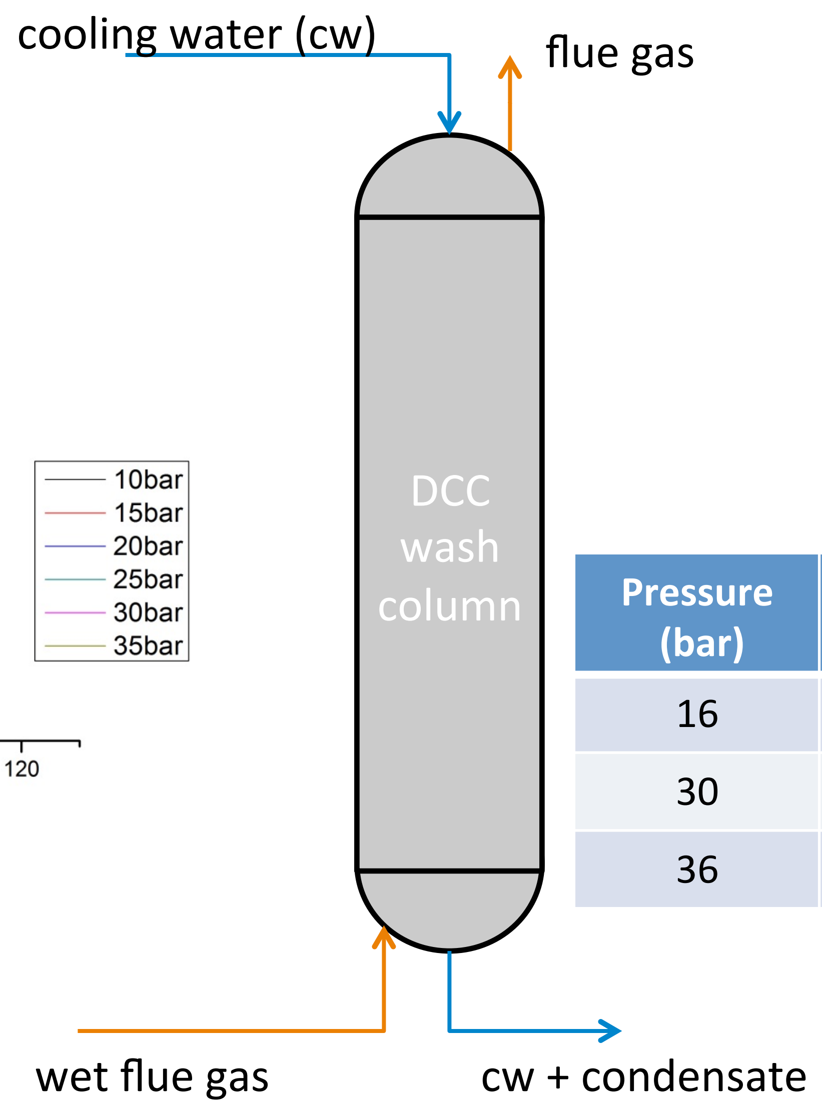
- Conduct a plant-wide technical and economic evaluation
- Conduct CFD-aided design of a novel staged combustion vessel and radiative heat exchanger
- Perform limited lab-scale experiments to simulate staged combustion conditions
- Optimize the system utilizing the ASPEN Plus modeling tool

Process Flow



Latent Heat Recovery – DCC





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

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SOx, NOx and Hg Removal

Follow Air Products approach (without need for compression)

- NO is oxidized to NO_2 at high pressure (>15 bar) which oxidizes SO_2 to H_2SO_4 and NO to HNO_3

- For complete removal $[SO_2]/[NOx]$ ratio must be small, approaching unity.
  - Typically much higher.
  - SPOC is ideally suited.

- Some Hg will also be removed, reacting with the nitric acid that is formed

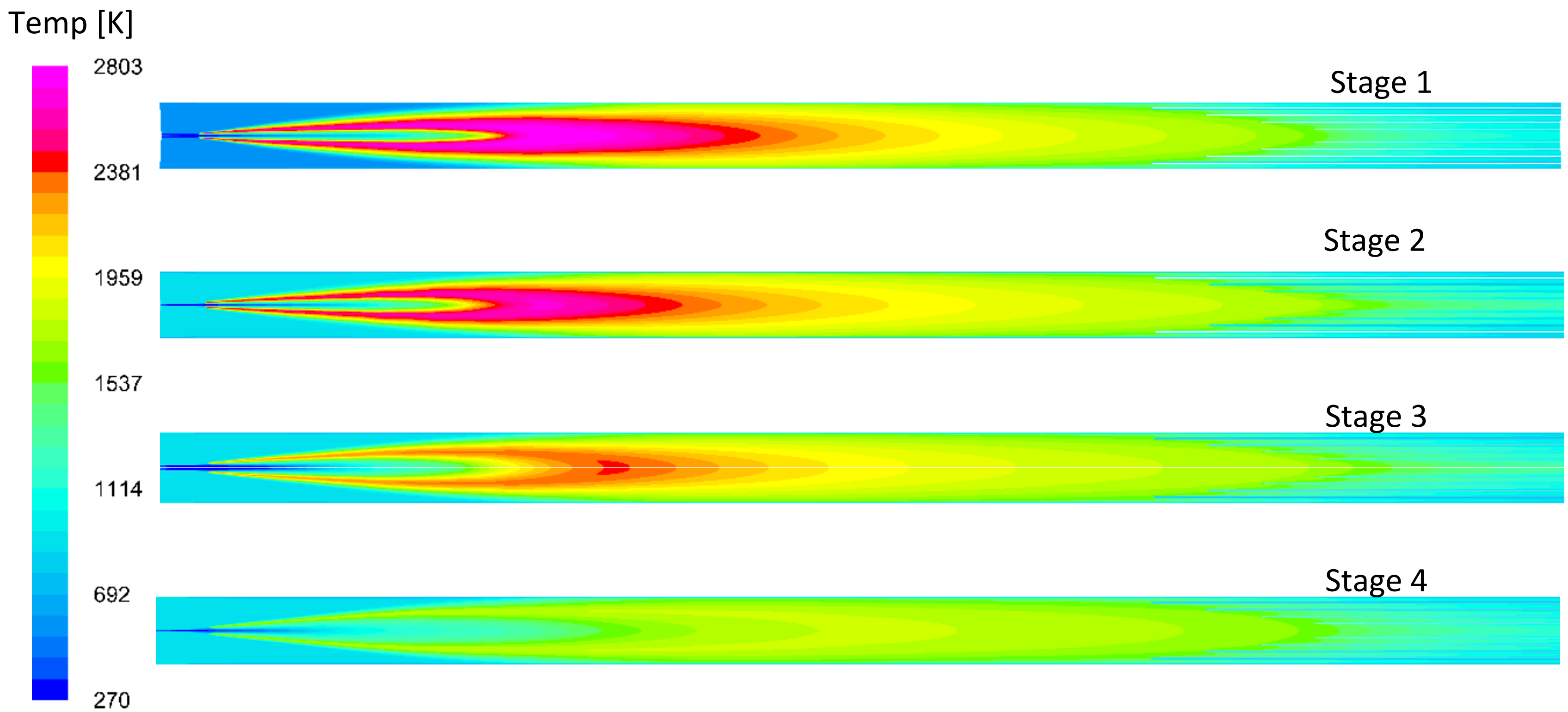
- Combine with DCC to remove SOx, NOx and Hg while recovering latent heat

Reactions Modeled for DCC Chemistry

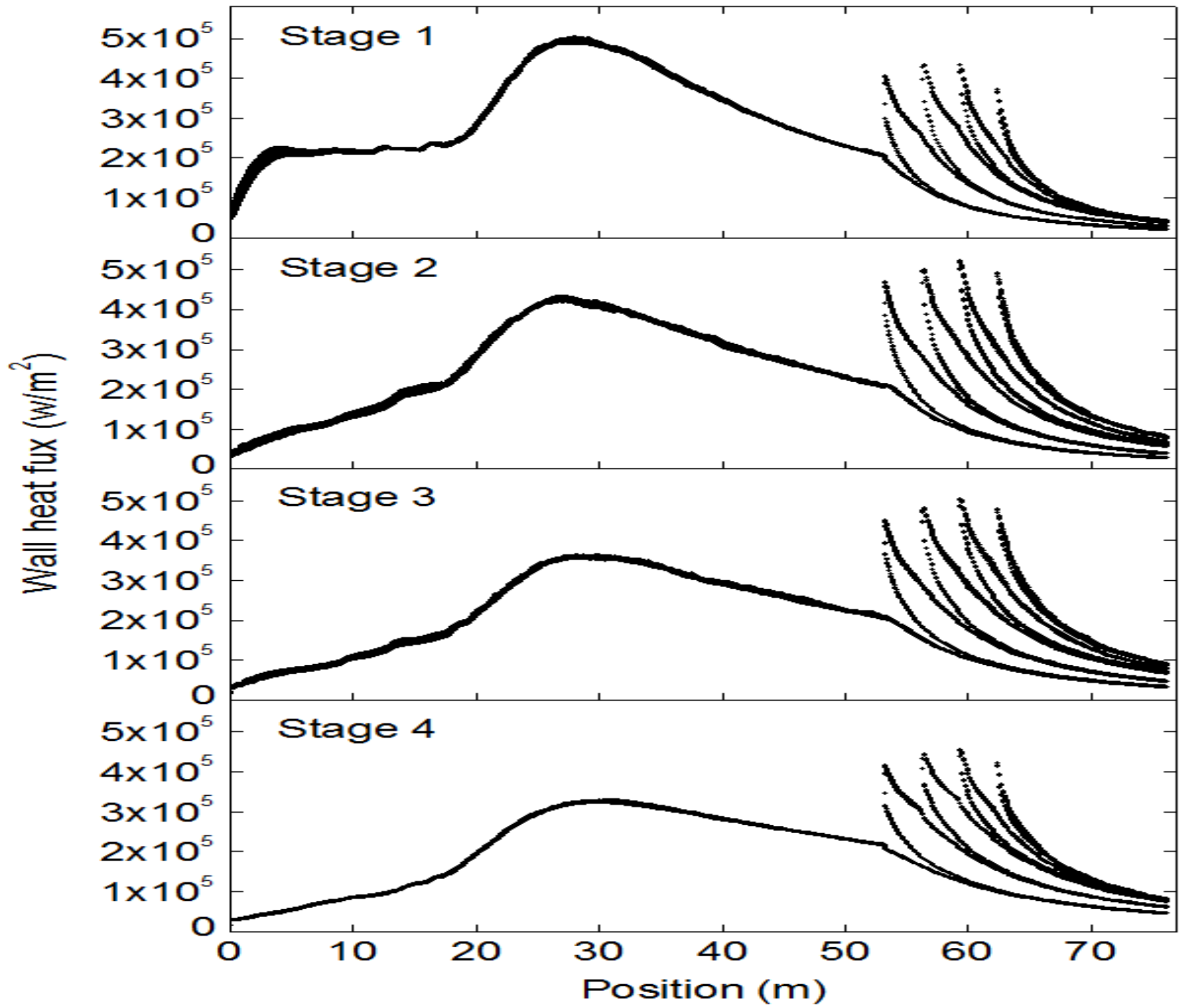
Reaction	Phase	No.
$NO + \frac{1}{2}O_2 = NO_2$	Gas phase	(A)
$NO_2 + SO_2 + H_2O = NO + H_2SO_4$	Gas phase	(B)
$2NO_2 = N_2O_4$	Gas phase	(C)
$N_2O_4 + H_2O = HNO_2 + HNO_3$	Liquid phase	(D)
$3HNO_2 = HNO_3 + 2NO + H_2O$	Liquid phase	(E)
$SO_3 + H_2O = H_2SO_4$	Liquid phase	(F)

- At 15 bar and with SOx/NOx ratio of near unity or lower, nearly complete removal of SOx and NOx has been observed.

CFD Modeling Results - Temperature



CFD Modeling Results – Wall Heat Flux



Wall heat flux (W/m^2) for stages 1-4

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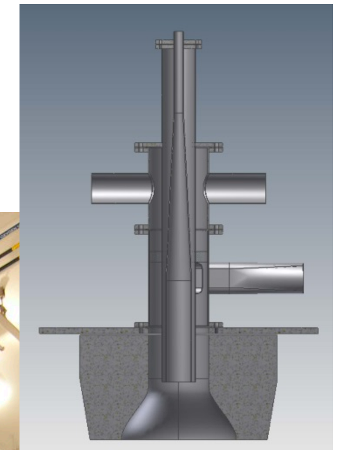
Experiments – 1 atm

Advanced Coal & Energy Research Facility (ACERF)

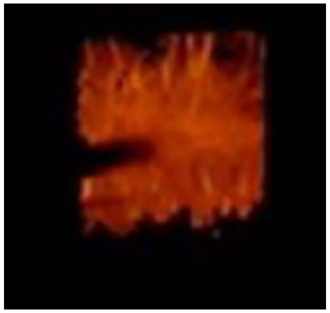
1 MWth capacity



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

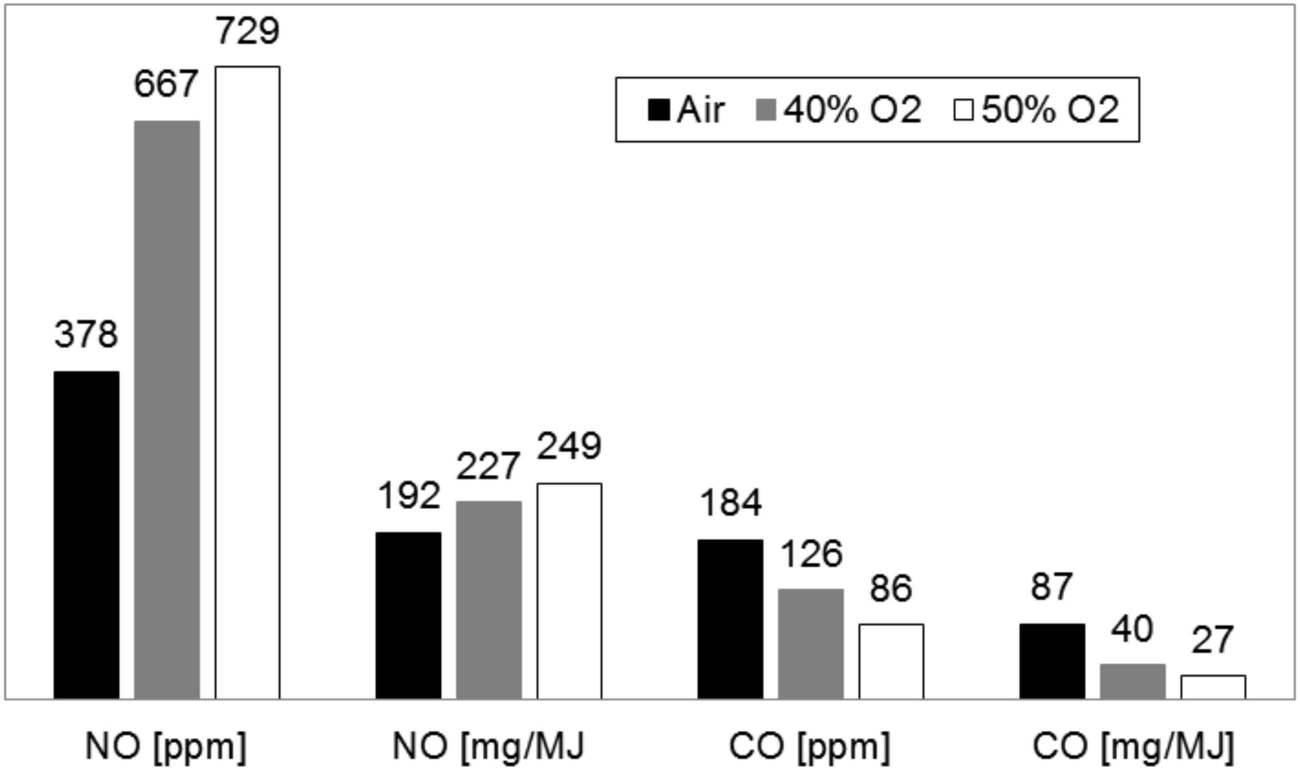
Experimental Results



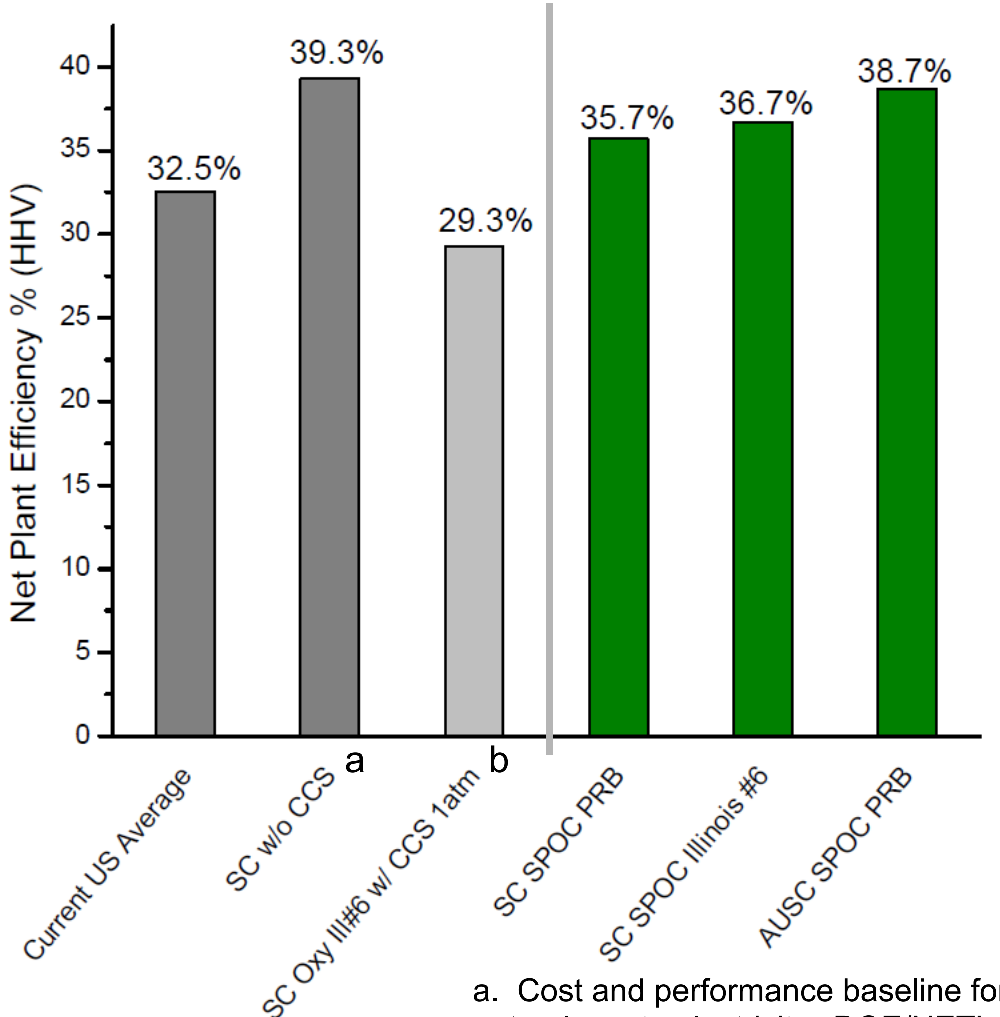
air

40% O2

Furnace exit NO and CO concentrations



ASPEN Plus Results – Plant Efficiency



<u>Net Efficiency</u>:

- SPOC process increases the efficiency up to 6 percentage points over conventional oxy-combustion.
- Efficiency higher than Current US Average.

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

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

Economic Performance Summary

	NETL Baseline Case 11 (no CCS)	NETL Case 12 w/ post combust. capture	SPOC Case A	SPOC Case B
Coal	Illinois #6	Illinois #6	PRB	PRB
Steam Conditions	Supercritical	Supercritical	Supercritical	A-USC
Heat Rate (Btu/kWhr)	8,686	12,002	9,555	8,819
First Year COE ($/MWhr)	80.95	137.28	101.38	102.80
% increase in COE	**0**	**70%**	**25%**	**27%**

- 2011 cost basis
- CO2 purity meets specifications for enhanced oil recover (EOR)
- COE does not include revenue from sale of CO2, or costs for geologic storage.

Phase 2 Work

Objective:

Design and build a laboratory-scale facility and conduct laboratory-scale experiments and complimentary modeling that address the technical gaps and uncertainties identified during Phase 1

Tasks:

1. Project management
2. Design, fabrication and installation of high pressure combustion furnace
3. High pressure combustion experiments (heat flux, temp, ash, deposition)
4. Materials corrosion studies (high O_2 and SO_2 environments)
5. Modeling direct contact cooler
6. Re-evaluation of boiler design
7. Update process model and techno-economic analysis

Projected Phase 2 Outcomes

- Proof of concept demo of coal combustion in O_2, w/o FGR
- Improved understanding of radiation heat transfer in pressurized oxy-combustion conditions
- Improved understanding of ash deposition mechanism in pressurized oxy-combustion conditions
- Knowledge of performance of materials under SPOC conditions
- Improved estimate of SOx, NOx removal efficiency
- Reduced uncertainty and contingencies → improved COE

Project R&D Team

Partners

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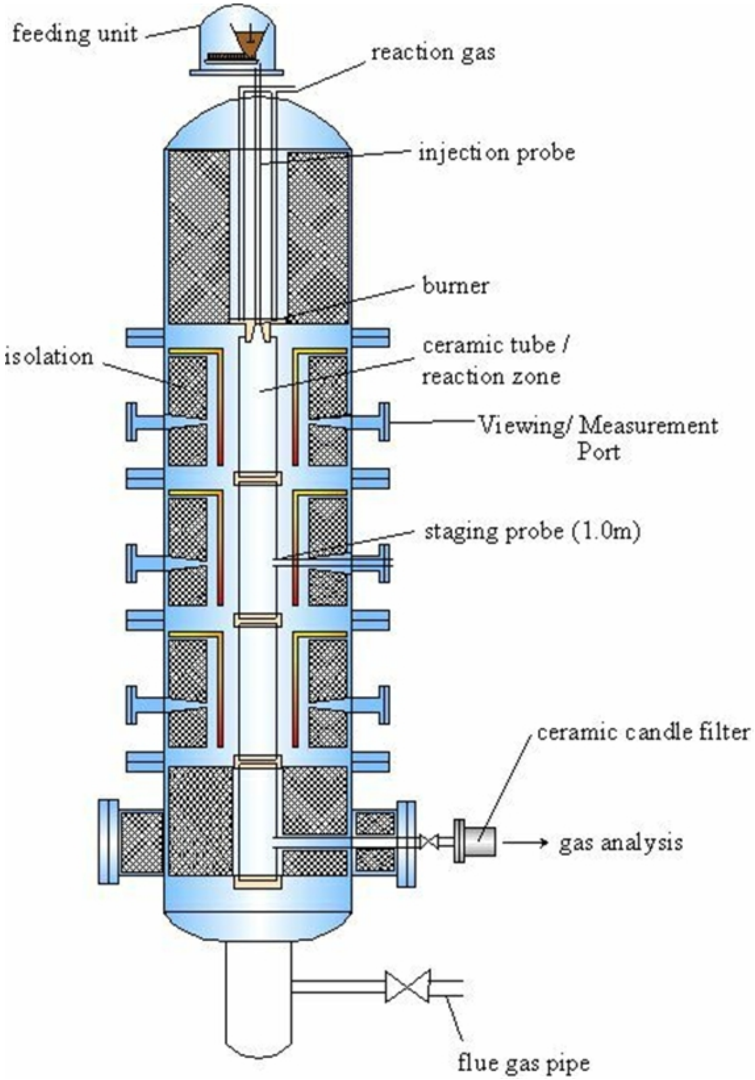
High-Pressure Furnace



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Thank You