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

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NETL CO2 Capture Technology Meeting
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CONSORTIUM FOR CLEAN COAL UTILIZATION

Project Overview

Objectives

Demonstrate, evaluate, and improve on a novel pressurized oxy-combustion concept, incorporating fuel staging to eliminate flue gas recycle

- 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

Funding

Total award: $5,243,789

- DOE share: $4,137,184
- Cost share: $1,106,614

Duration

10/01/2012-09/30/2016

Project Participants

WUSTL (Lead)	Partners	Advisory	Services
PI: Rich Axelbaum Pratim Biswas Ben Kumfer Gregory Yablonski Postdocs Zhiwei Yang Bhupesh Dhungel* Grad Students Akshay Gopan Adewale Adeosun Matthew Pollard Phillip Johnson Fei Xia* Lab Technician George Pires Admin Natalie Goodwin-Frank Lesley Smith	EPRI Jeff Phillips David Thimsen John Shingledecker Steven Kung Oak Ridge National Lab Bruce Pint	Ameren Rick Smith George Mues Tom Callahan Praxair Lee Rosen	Facility Construction Team: WUSTL Facilities & Management McCarthy KJWW KPFF Becht Gillespie & Powers

* past team member

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

Motivation for SPOC

Key Features:

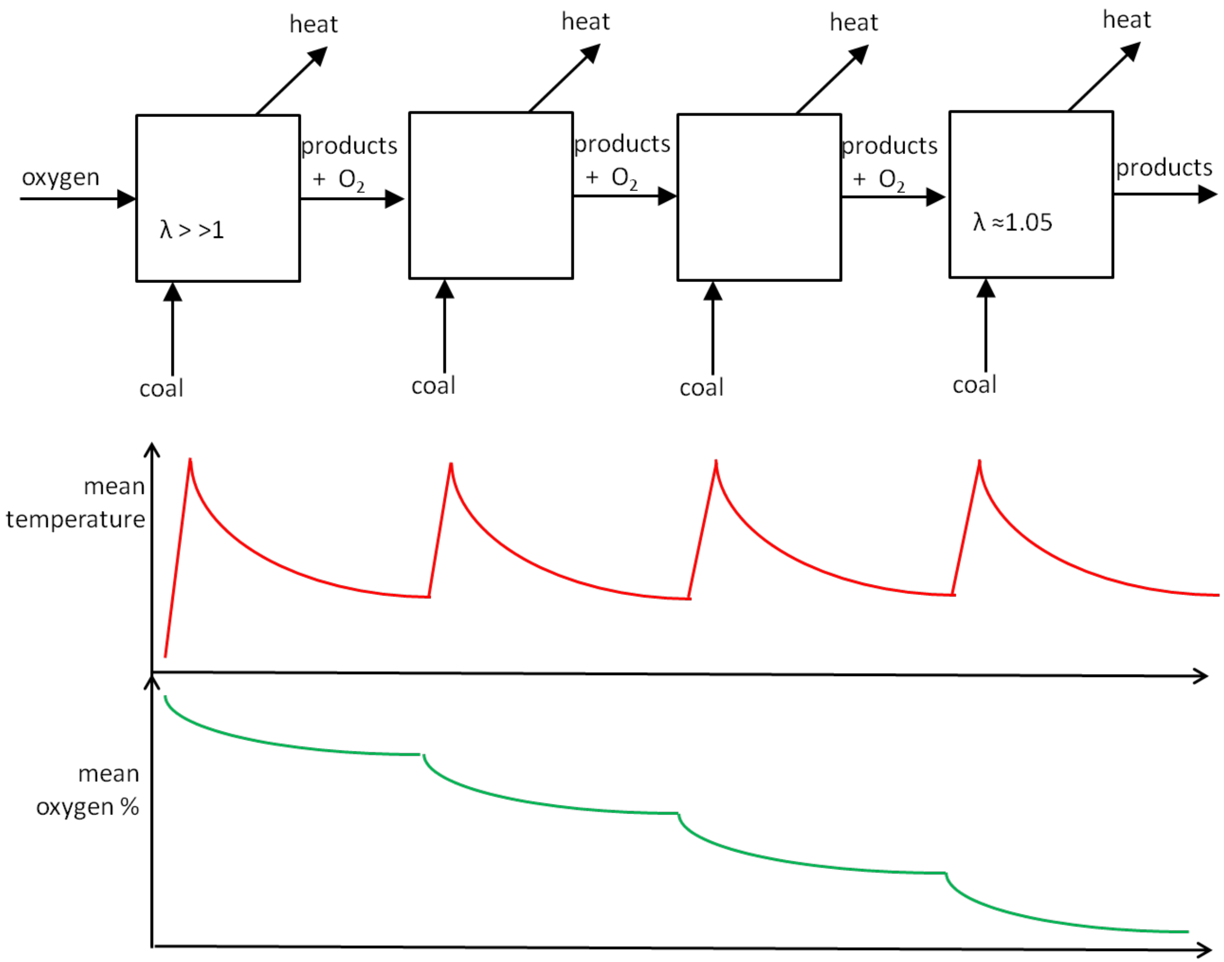
Improve capital costs by:

- 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:

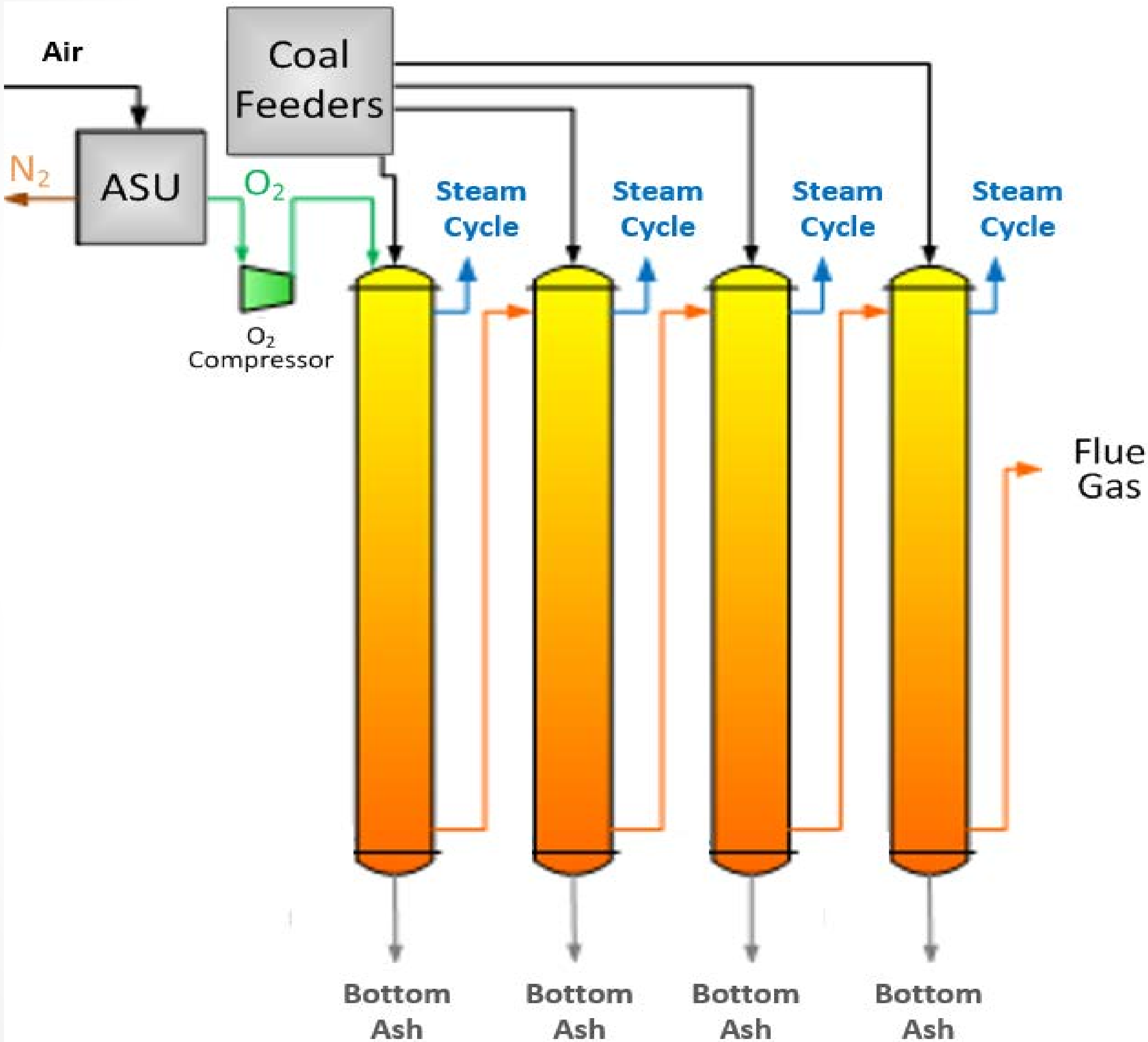
- Maximizing boiler efficiency
- Minimizing parasitic loads associated with RFG
- Utilizing "lead chamber" process for SOx & NOx removal
- Minimizing oxygen requirements
- Maximizing efficiency through dry feed
- Increasing performance of wet, low BTU fuels

Fuel-Staged Oxy-Combustion



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

Schematic Process Diagram for SPOC



ASPEN modeling shows *6%-pts improvement in plant efficiency*

29.3% ⟹ **35.7%**

Gopan A, et al., Applied Energy. 2014;125:179-88.
Hagi, et al. Energy Procedia 2014

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 condensor
6. Re-evaluation of boiler design
7. Update process model and techno-economic analysis

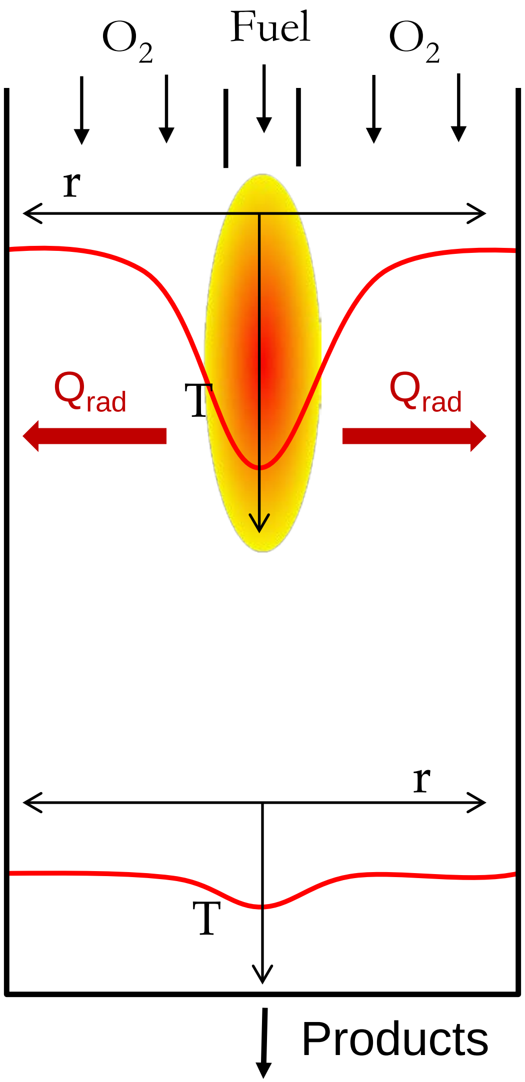
Projected Phase 2 Outcomes

- 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 formation/deposition mechanism in pressurized oxy-combustion conditions
- Knowledge of performance of boiler tube materials under SPOC conditions
- Improved estimate of SOx, NOx removal efficiency in direct contact condenser
- Reduced uncertainty and contingencies → improved COE

Boiler temperature distributions

First Stage:

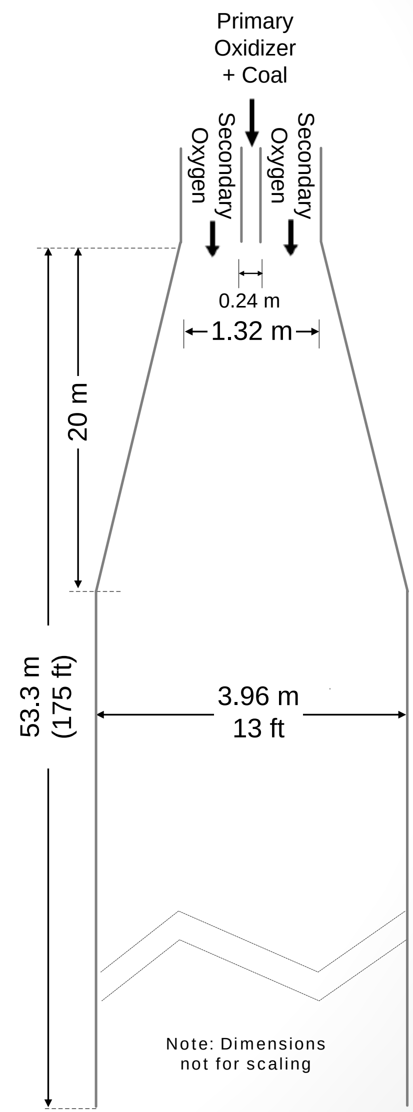
$\lambda \gg 1$



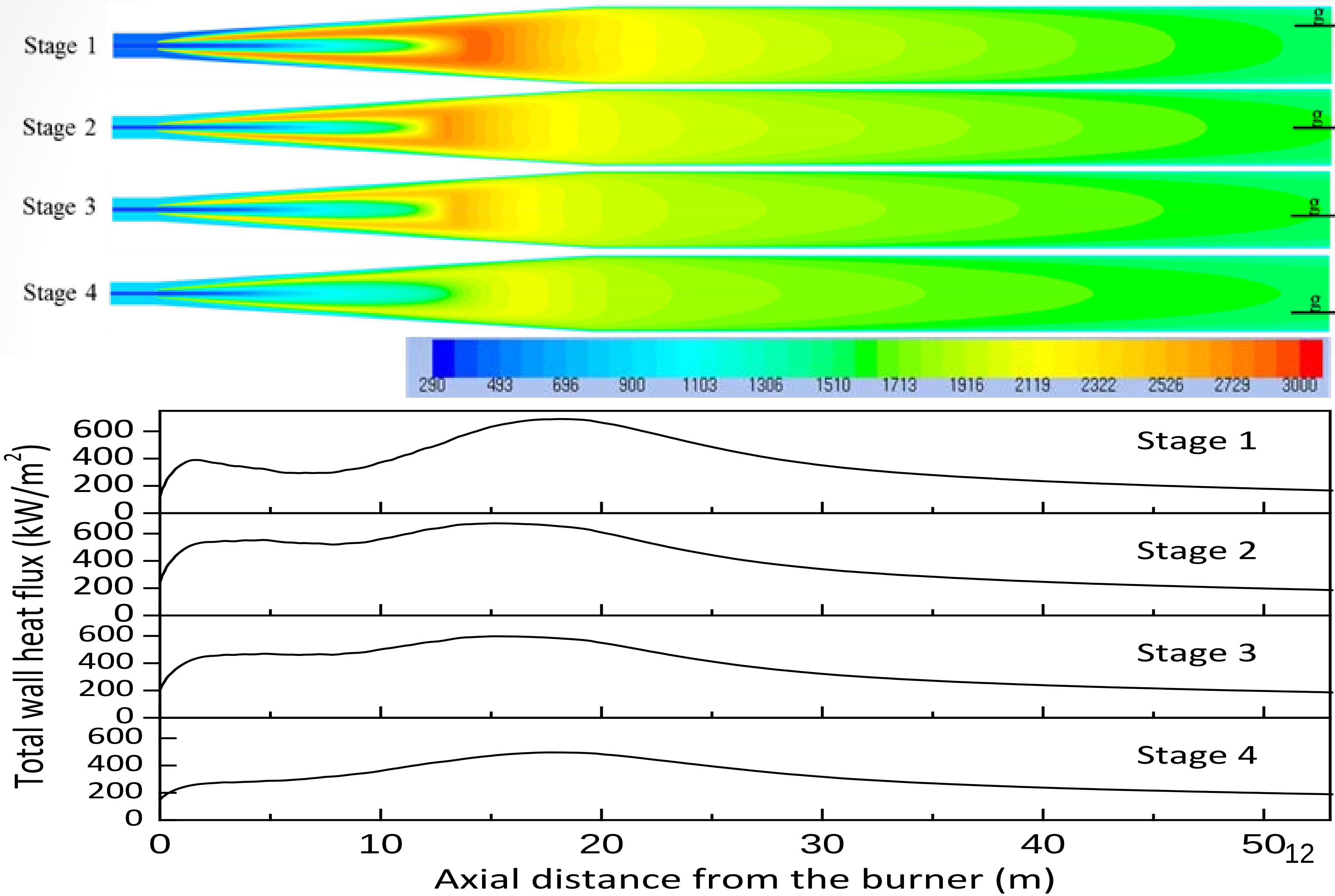
Design a burner to control flame and wall heat flux.

Burner/Boiler Design

- Avoid external recirculation and slow down mixing to get longer flame
  - High Tring-Newby parameter
- Maintain high velocity to keep high Richardson number and reduce buoyancy effect
  - Tapered design

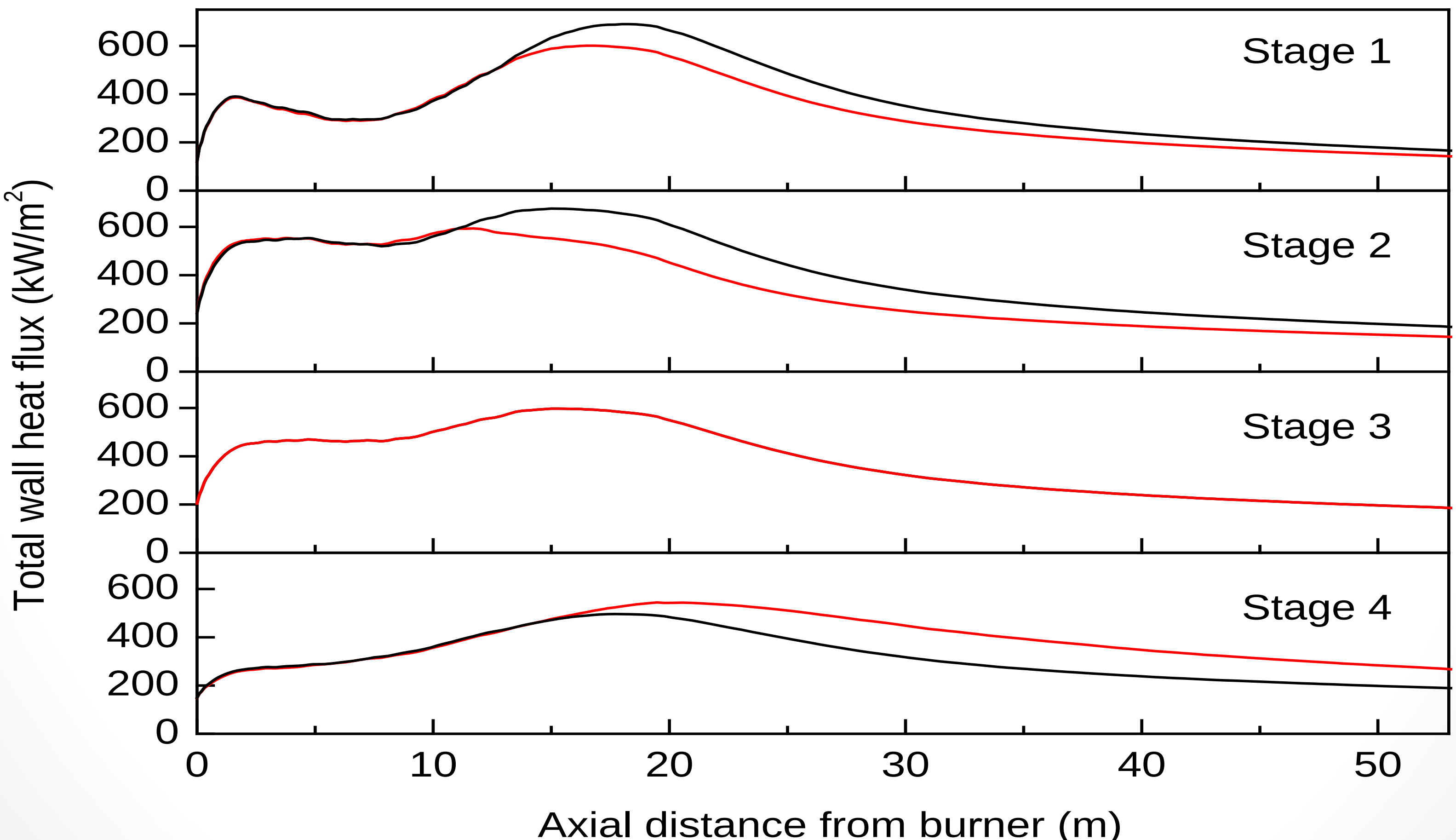


Simulation results for SPOC reactors with 1540 MW_{th} in total

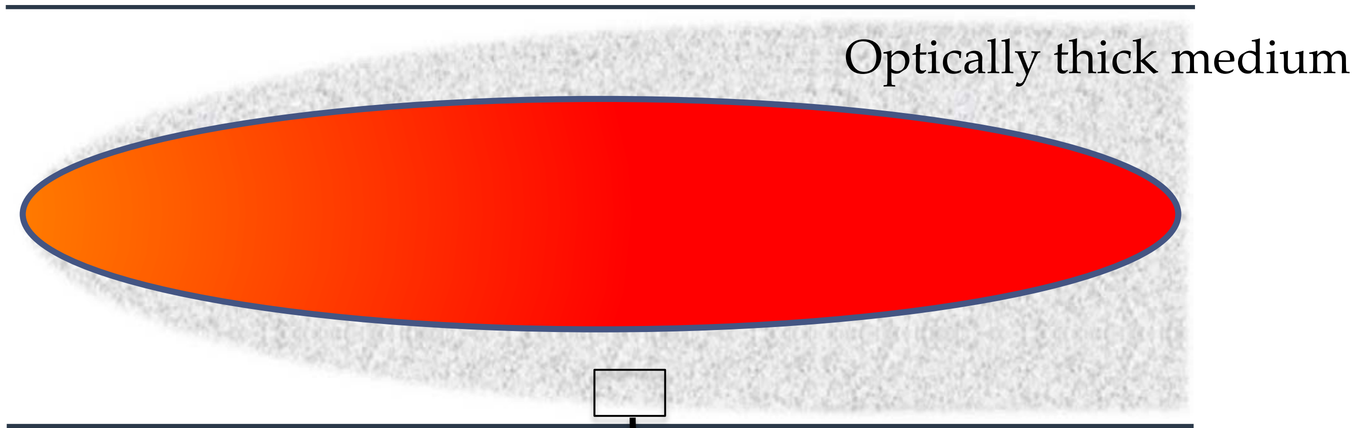


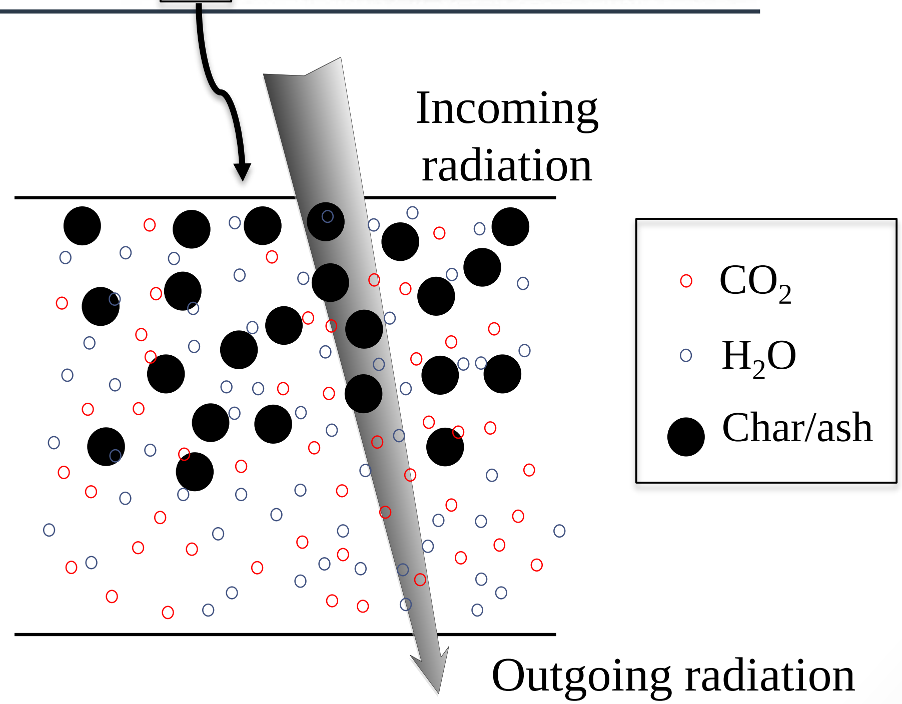
Redistribute the thermal input

	Stage 1	Stage 2	Stage 3	Stage 4
Uniform thermal input	385 MW	385 MW	385 MW	385 MW
Redistributed thermal input	340 MW	302 MW	385 MW	513 MW

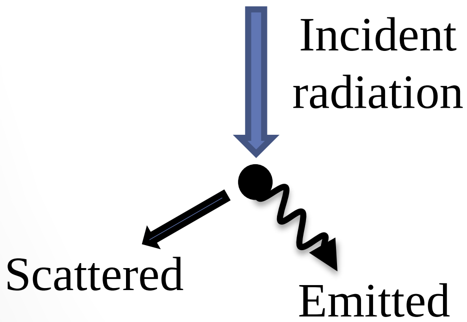


Radiant Heat Transfer

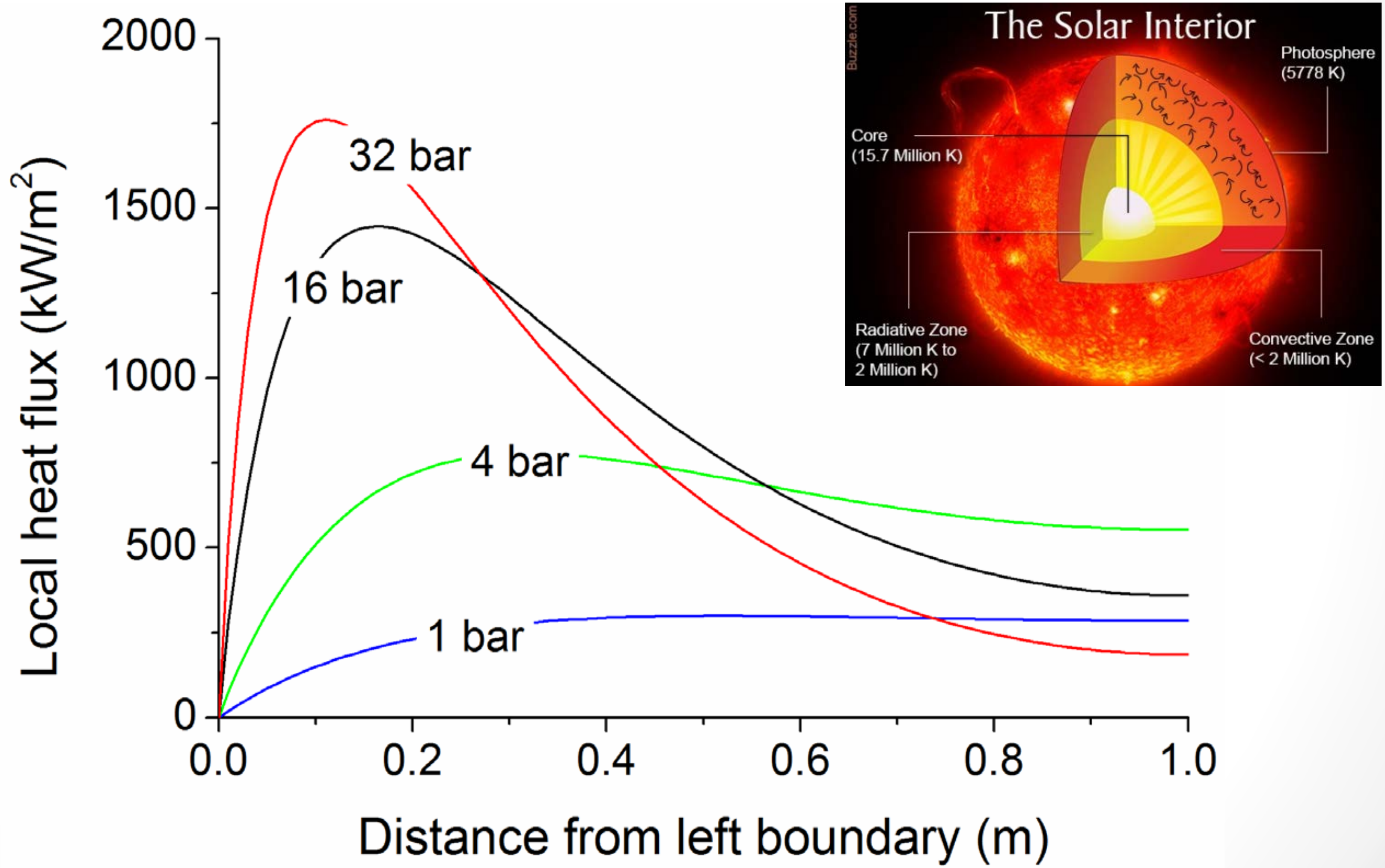




Add sun

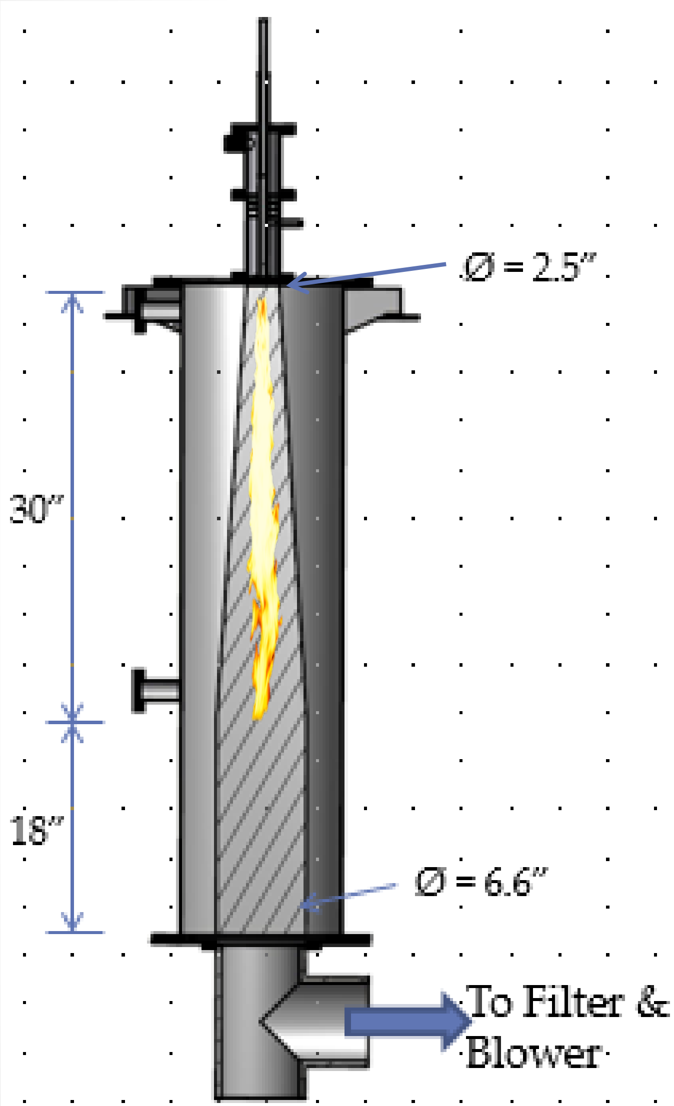


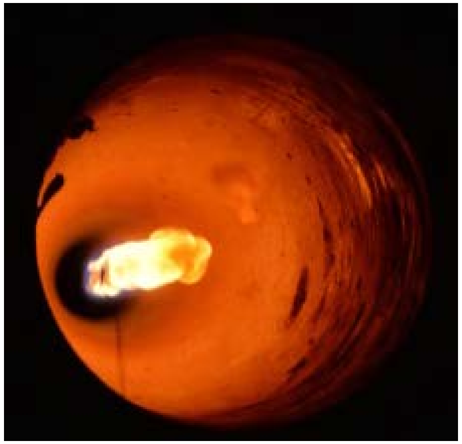
Fundamental study on radiation



1 atm Facility: Burner Testing

Preliminary Test with Propane

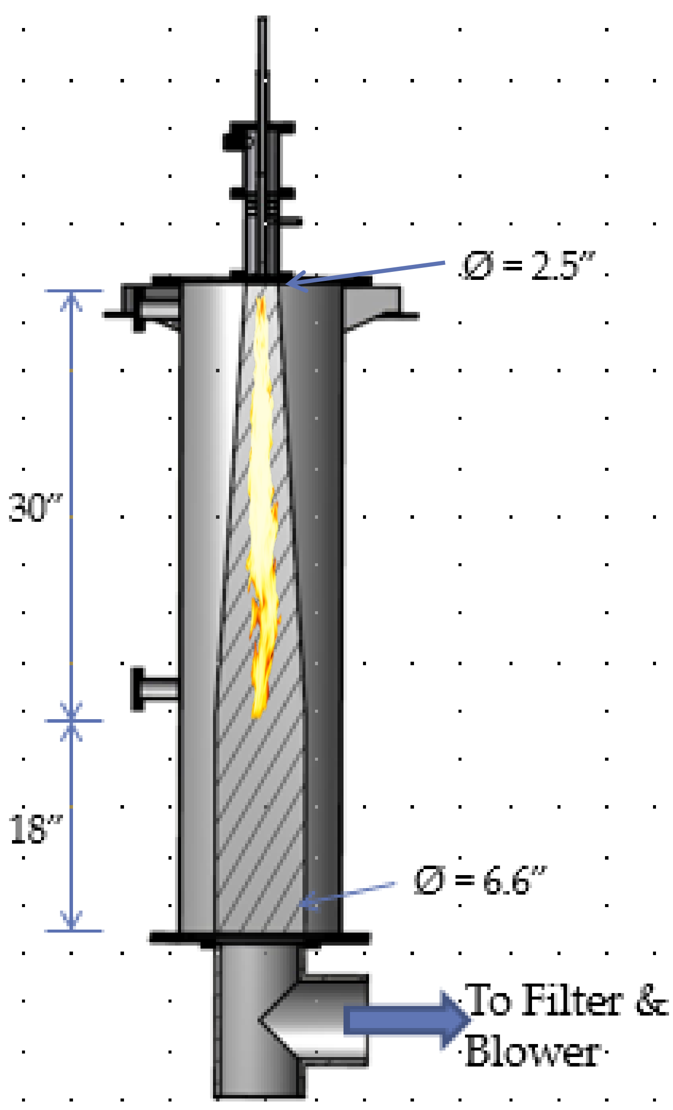


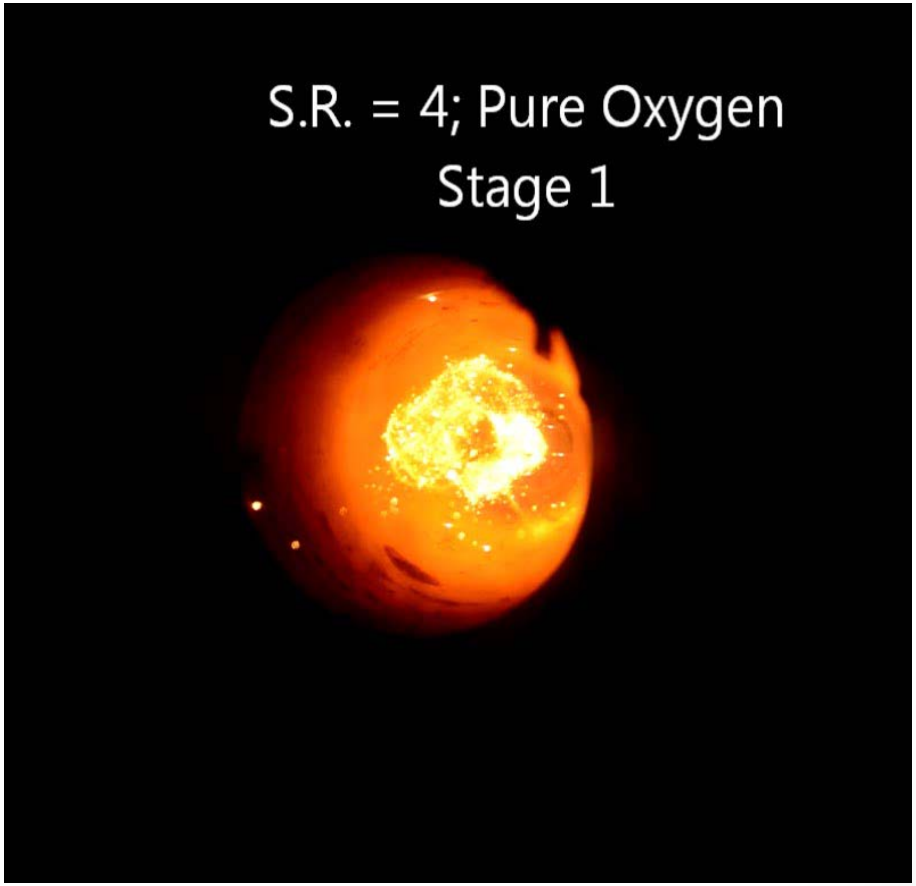


Pure Oxygen

50% Oxygen

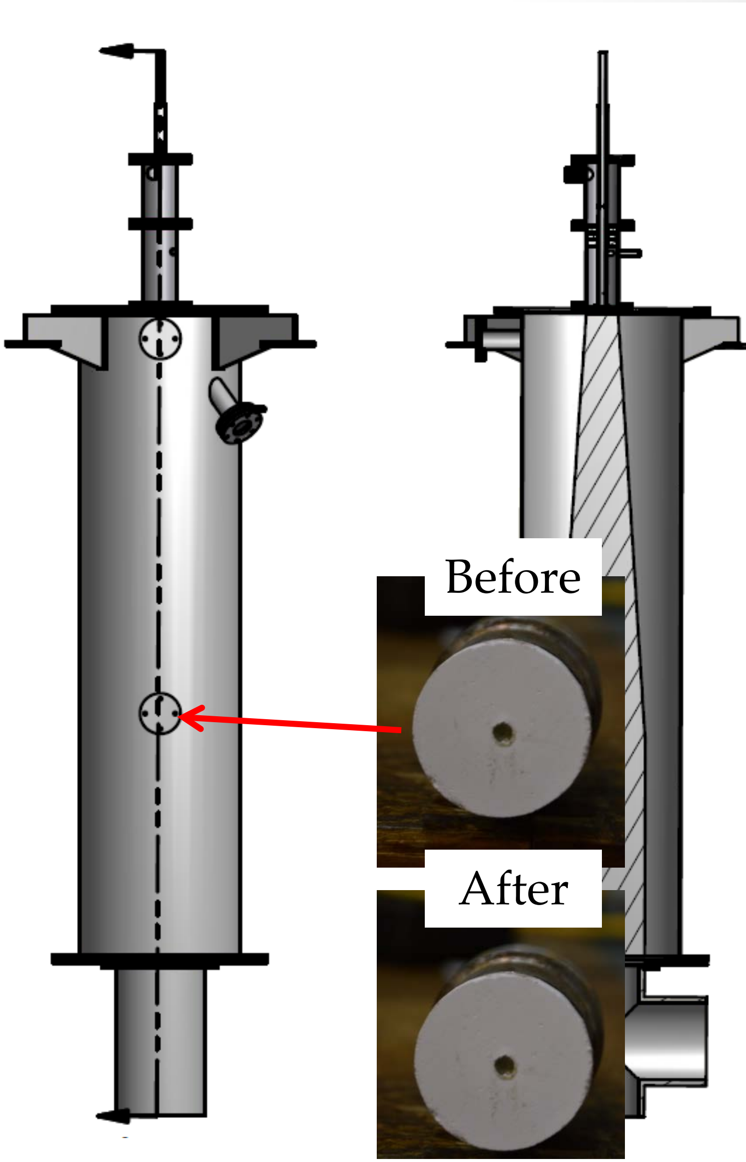
Preliminary Test with Coal





Fuel-Staging with Coal – Ash Deposition on Wall

- 8 kW Coal piloted by propane at 60% oxygen (S.R. = 2.4).
- Ceramic deposition probe – immediately downstream of flame where propensity for deposition is maximum.
- After 2 hours – no detectable wall deposition.



Construction of Pressurized Reactor

Objectives:

- Furnace installed at WUSTL to test under SPOC conditions (high O_2)
- ~100kW, 1-15 bar

Accomplishments:

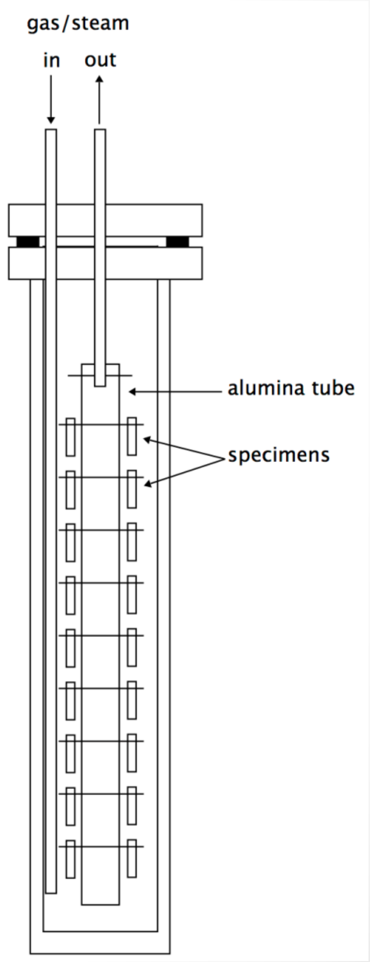
- Completed engineering, PIDs
- Acquired vessel and completed repairs
- Passed hydro pressure test
- Vessel & support structure installed at WUSTL

Ongoing Activities:

- Piping installation
- Design of reactor internals
- Development of operating & HAZOP procedures

Phase 1 SPOC testing at ORNL

Temp.	Environment	1bar	17bar
600°C	$90\%O_2+10\%H_2O$	500h	500h
800°C	$90\%O_2+10\%H_2O$	500h	500h
600°C	$90\%O_2+10\%H_2O+0.1\%$ SO_2	500h	500h
800°C	$90\%O_2+10\%H_2O+0.1\%$ SO_2	500h	336h*



- 600°C: mainly steel candidates + overlays
- 800°C: high strength Ni-base alloys

Side-by-side alloy 230 reaction tubes at 1 and 17 bar with same gas source

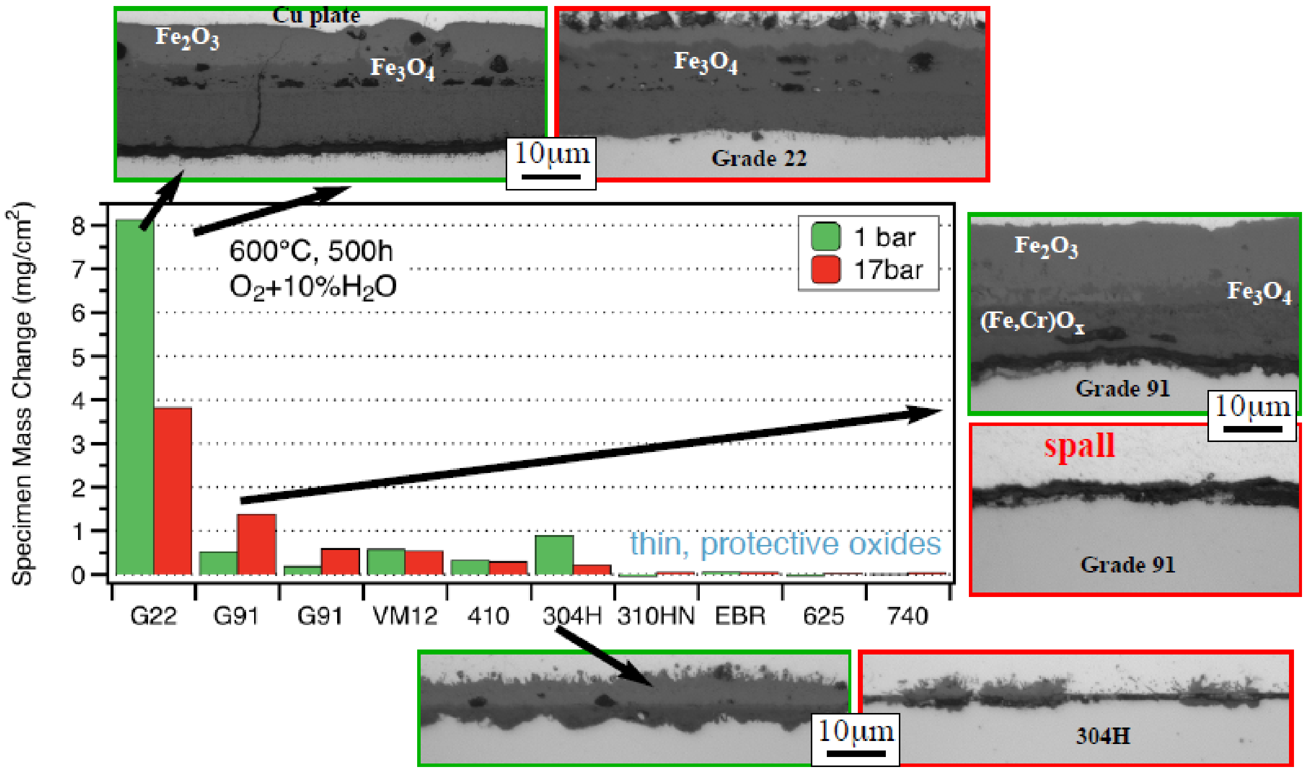
* System plugged due to corrosion product

Bruce Pint, ORNL

$90\%O_2$-$10\%H_2O$

Phase 1: subtle effects of pressure

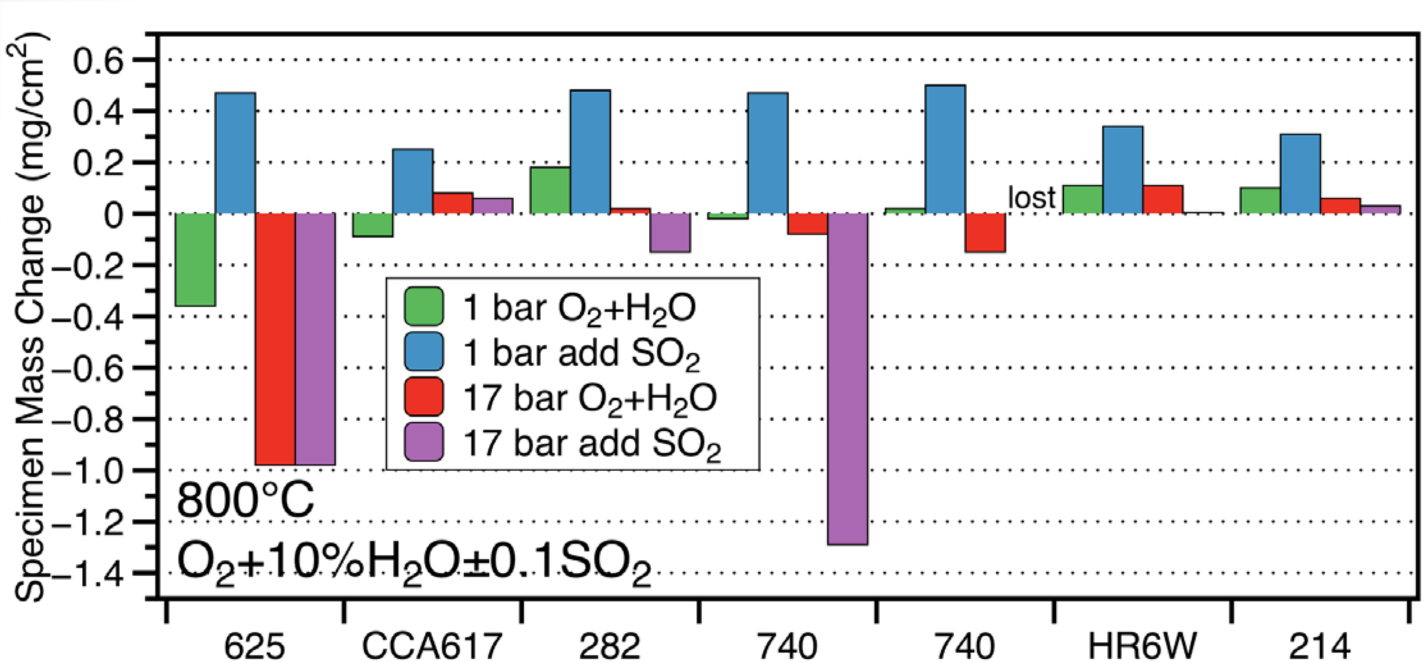
Side-by-side reaction tubes: 1 + 17bar, $90\%O_2$-$10H_2O$



Thick oxides on Fe-Cr spall: mass change unreliable

Higher-alloyed materials: very thin oxide, low mass gains

$90\%O_2-10\%H_2O-0.1\%SO_2$



$0.1\%SO_2$ increased all mass gains at 1 bar, 800°C
At 17 bar, non-uniform response

O_2+H_2O mass loss: Cr + O_2+H_2O -> $CrO_2(OH)_2$ (v)
Metallography in progress for SO_2 specimens

Project Status

Year 1:

- Test facility engineering design
- Component fabrication
- Inspection of major equipment

Year 2:

- Combustion test system installation at WUSTL
- System shakedown, proof of operation.
- First phases of boiler tube materials corrosion testing, identification of most promising materials

Future Plans

- Year 3:
  - High pressure combustion experiments
  - CFD model evaluation
  - Detailed boiler tube materials corrosion analysis
  - Process model and techno-economic analysis reevaluation
- After this project:
  - A proposal entitled "Advanced Combustion Pressurized Oxy-Combustion: Towards Pilot Scale Demonstration" has been submitted to U.S.-China Clean Energy Research Center (CERC-ACTC)
- Scale-up:
  - Results of our study will be used to attract potential industrial partners for pilot-scale demonstration

Thank You!