Application of Spouting Fluidized Bed to Coal-fueled Pressurized Chemical Looping Combustion (PCLC)

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Chemical Looping Combustion Project Overview

Funding & Performance Dates

		Task Name	Start	Finish	Task Cost
	1.0	Project Management and Planning	9/1/2015	9/30/2018	$211,951
Budget Period 1	2.0	Detailed Engineering Design	9/1/2015	2/29/2016	$61,269
	3.0	Large Quantity OC Production	11/16/2015	12/31/2016	$79,481
	4.0	Fabrication, Installation, & Commissioning of PCLC facilities	3/1/2016	12/31/2017	$449,330
Budget Period 2	5.0	Performance Verification of Major Components	1/1/2018	3/31/2018	$69,925
	6.0	Parametric Testing	4/1/2018	6/30/2018	$61,544
	7.0	Long Term Testing Campaign	7/1/2018	9/30/2018	$39,649
	8.0	Fate of Sulfur & Fuel Nitrogen Transfer	4/1/2018	9/30/2018	$27,630

Main Objectives

- ❑ Validate the coal-fueled PCLC technology that adopts a novel spouted bed to avoid OC (oxygen carrier) agglomeration, to improve plant efficiency, and to reduce process complexity
- ❑ Demonstrate an integrated coal-fueled PCLC facility at lab-scale, and via design, fabrication, commissioning, hot testing, and performance validation to address the major technical gaps that impede the application of PCLC in solid fuel power generation

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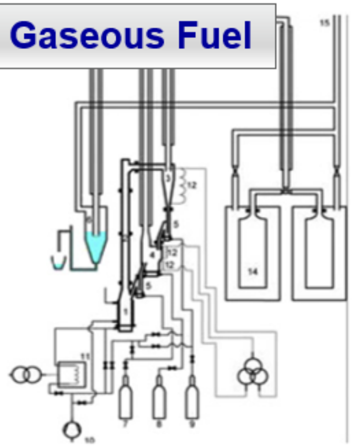
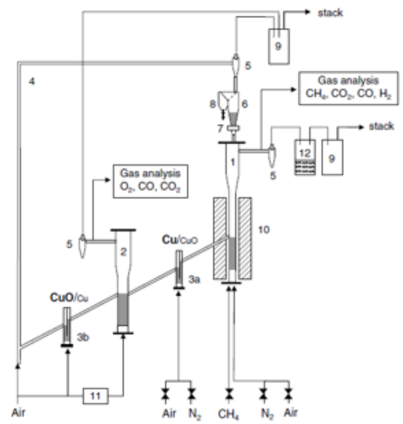
The Core Technology for CLC

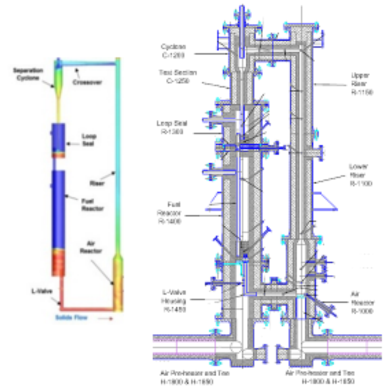
Gaseous Fuel



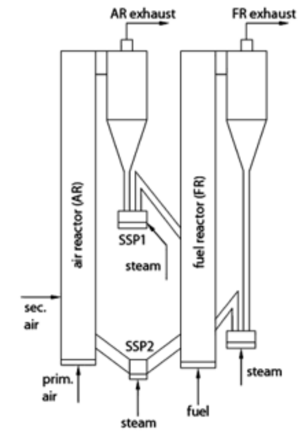
10 kWth at Chalmers



10 kWth at C.S.I.C.

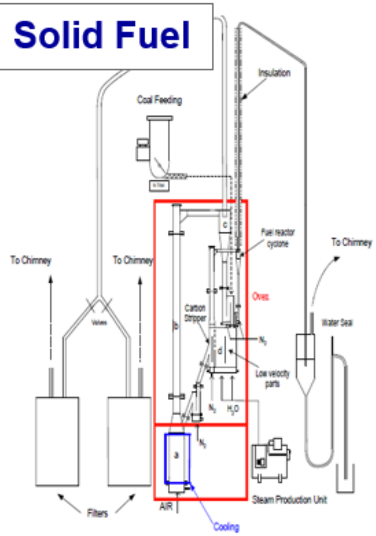


50 kWth at US-NETL



140 kW (Vienna Univ. of Tech.)

Solid Fuel



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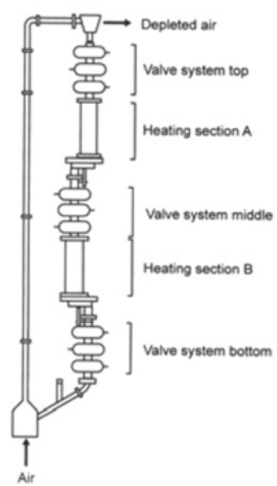
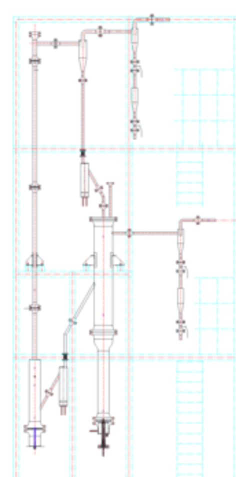
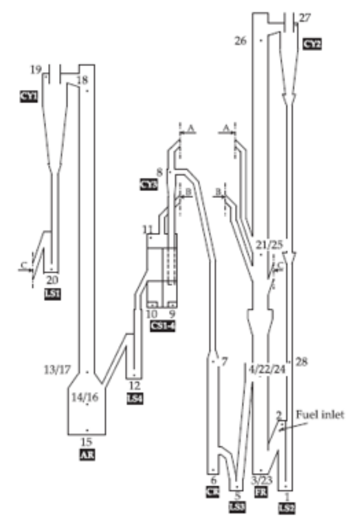


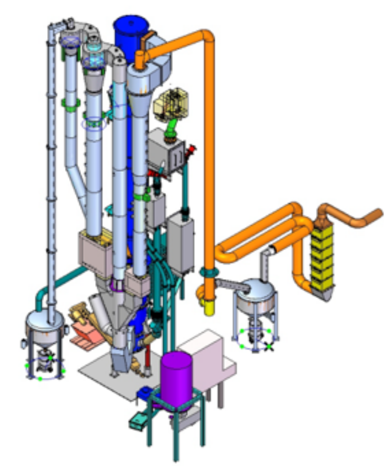
25 kWth at OSU



50 kWth at UKy



100 kWth at Chalmers



3 MWth at ALSTOM

[4] Juan Adanez, Progress in Energy and Combustion Science 38 (2012) 215-282

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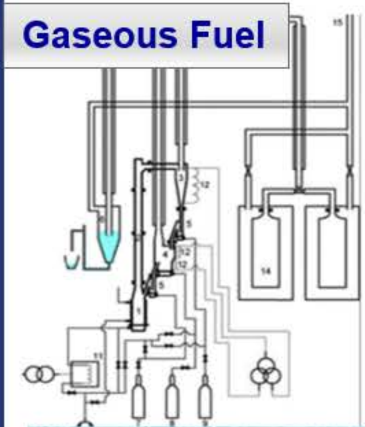
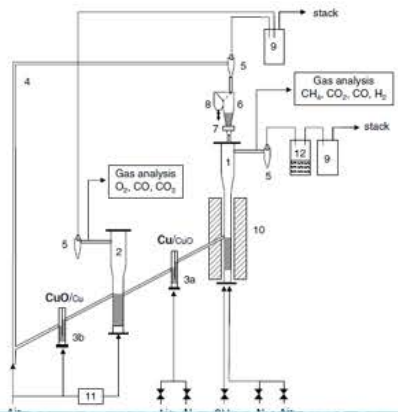
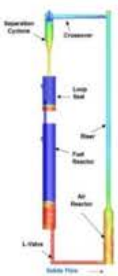
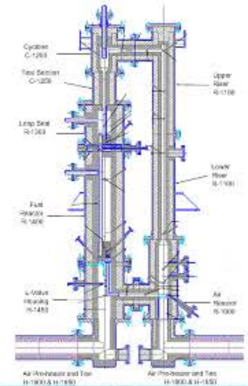
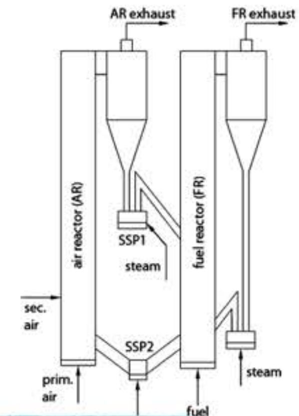
Gaseous Fuel











Mature Fluidized Bed (FB) Technology

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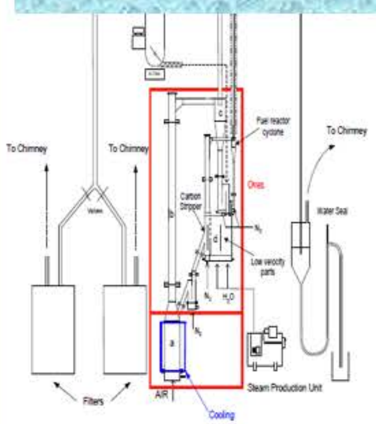

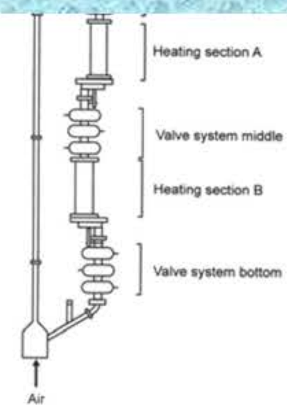

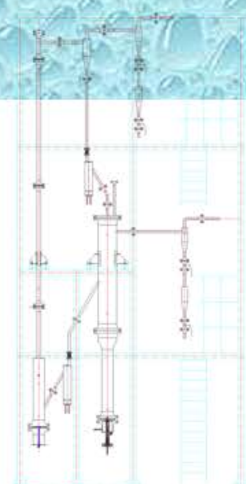

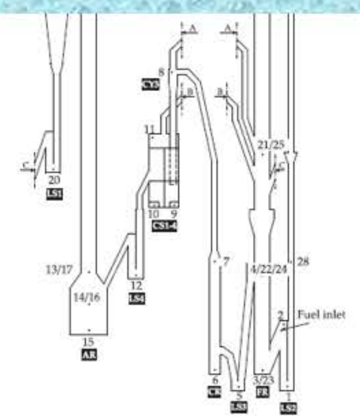

10 kWth at Chalmers | 25 kWth at OSU | 50 kWth at UKy | 100 kWth at Chalmers | 3 MWth at ALSTOM

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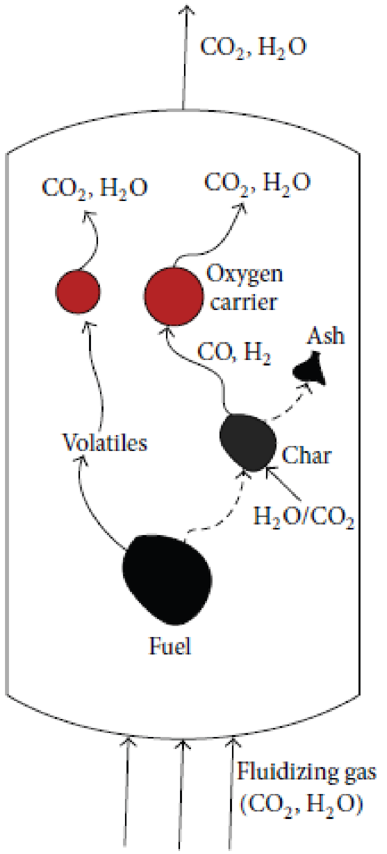
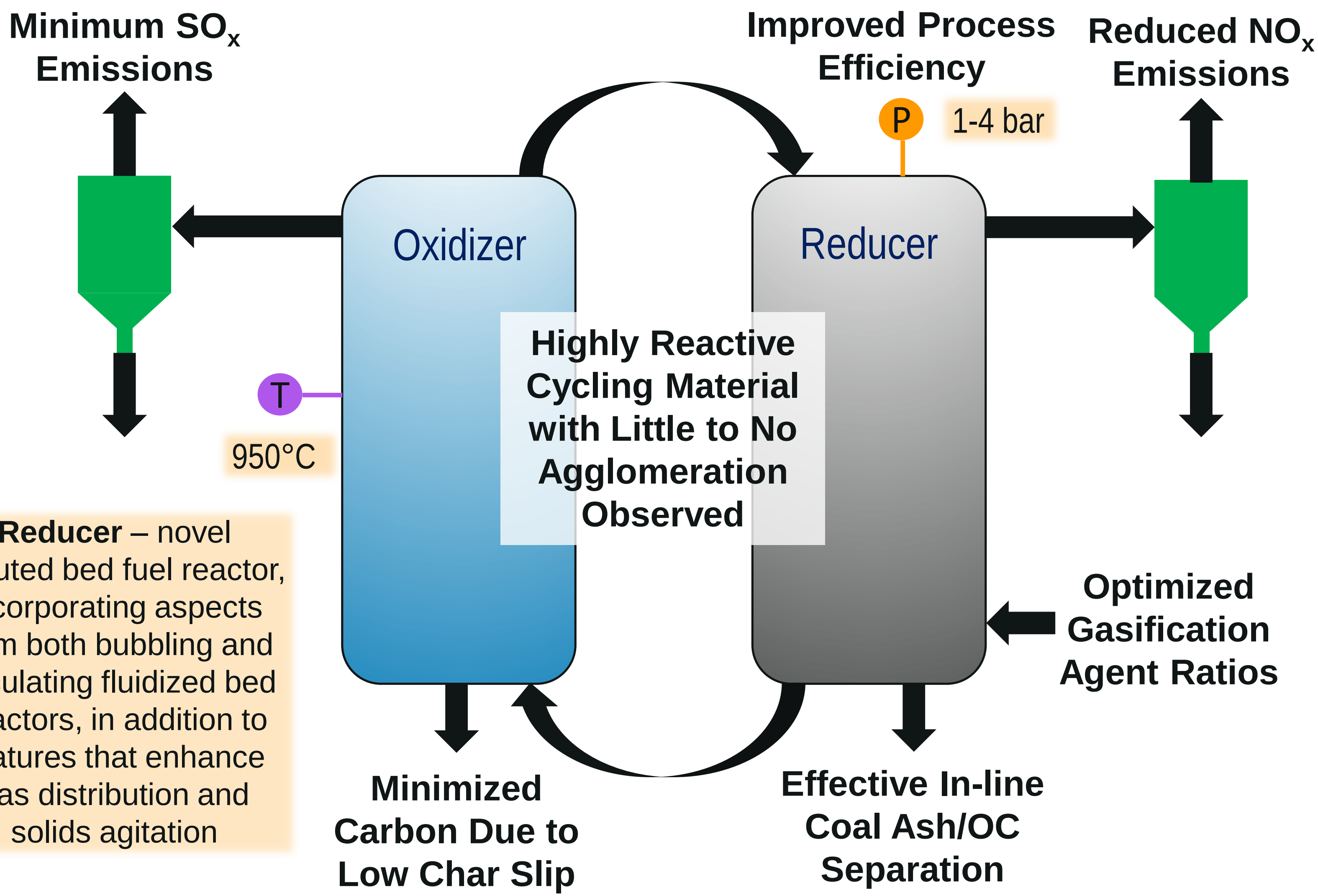
Challenges for CF-CLC

- **Slow Gasification**
- **Catalyst-Oxygen Carrier**
  - *Oxygen & heat carrier (Reactivity, oxygen transport)*
  - *Production cost*
  - *Stability, agglomeration, sintering, attrition*
- **Heat Balance**
  - *Spontaneous process without the requirement of any external heat sources*
- **Fuel Reactor**
  - *Mixing between OC and fuel particles*
  - *High solid fuel conversion*
  - *Controlling OC reduction*
  - *Heat transfer*



Technology Background



Reducer – novel spouted bed fuel reactor, incorporating aspects from both bubbling and circulating fluidized bed reactors, in addition to features that enhance gas distribution and solids agitation

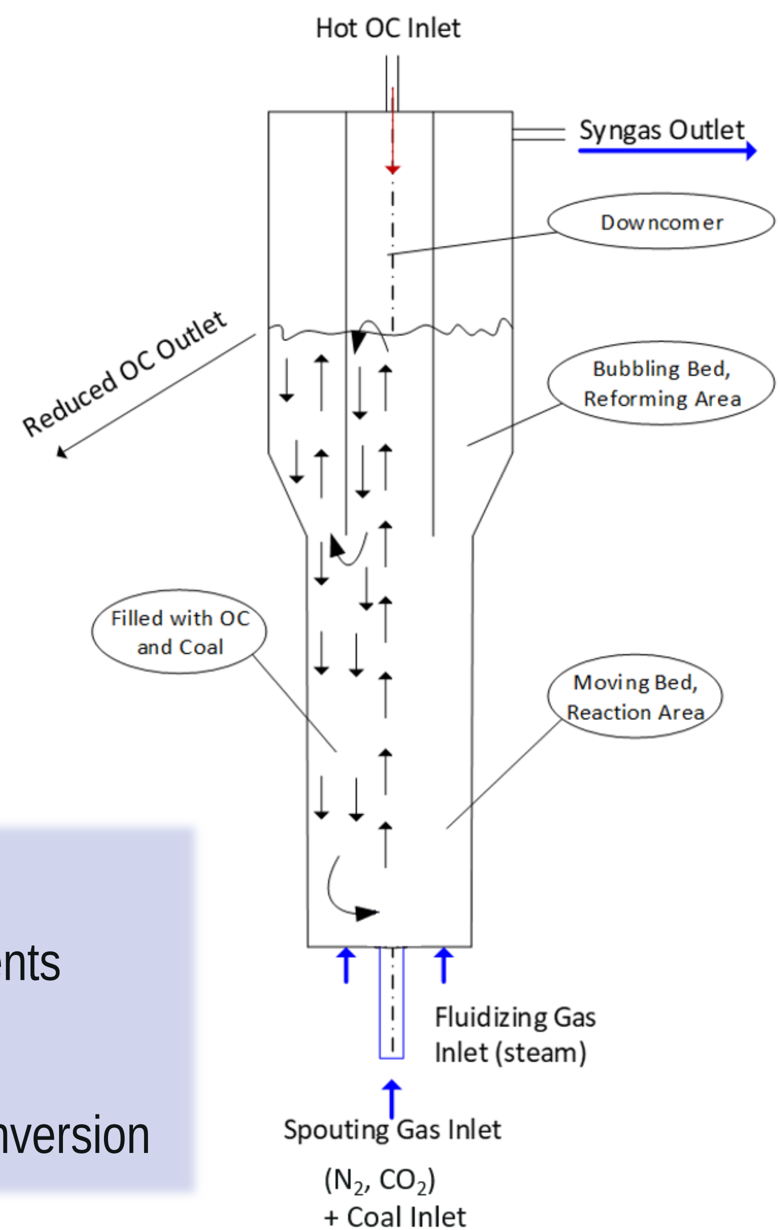
CAER Approach – Coal Feeding

Catalytic Oxygen Carrier

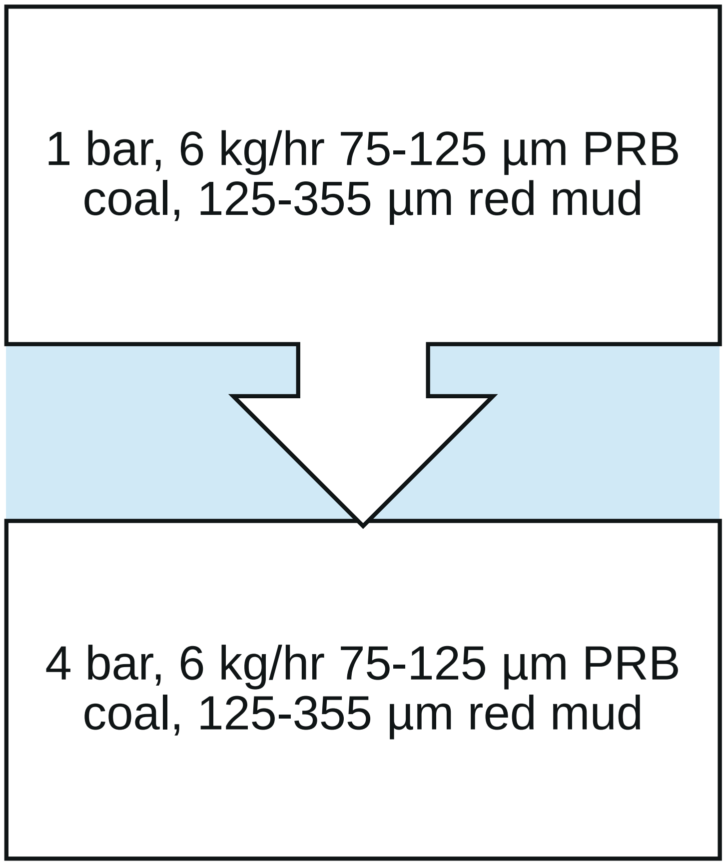
- ✓ Re-use of aluminum industry byproduct
- ✓ Lowers the reaction temperature from 1200-1300°C to 950°C
- ✓ Excelerates gasification and syngas/tar reforming
- ✓ Verified CuO addition to facilitate autothermal operation

Spouted Bed Fuel Reactor

- ✓ Promotes fast pyrolysis, tar cracking and prevents particle agglomeration
- ✓ Reasonable residence time for high carbon conversion



Technical Approach/Project Scope



Long-term Test Campaign Conditions in Order of Operation

Performance Evaluation:

- Percent of carbon slips from fuel reactor to air reactor & carbon capture efficiency
- Combustion efficiency of solid fuel
- Fate of sulfur and nitrogen species
- OC characterization (reactivity, attrition, morphology prior and post operation)
- Ash distribution and interaction with OC
- Solids agglomeration

Additional Areas of Investigation:

- Temperature and pressure distribution along reactor heights
- Mass and energy balances
- Fly ash production and OC attrition rates
- Loopseal fluidization information
- Carbon and OC conversion
- Ash/OC separation

Technical Approach/Project Scope

	Success Criteria
Budget Period 1	Detailed engineering design package (P&ID, general layout/arrangement, blueprint for Reducer, material and instrument selection, et.al)
Budget Period 1	Large quantity OC production yields in total 2000 lb OC.
Budget Period 1	Fabrication, installation & commissioning of the 50 kWth PCLC facilities is complete.
Budget Period 2	During performance verification & parametric testing five independent parameters will be studied: (1) type of coal/PSD; (2) type of OCs; (3) effect of operation pressures; (4) H_2O/CO_2 ratio of the gasification agent; (5) carbon/OC ratio and OC inventory.
Budget Period 2	NOx and sulfur-containing gas profile in long term testing campaign and parametric testing.
Budget Period 2	Achieve 24 hour steady and continuous operation in the long term testing campaign.

Red Mud OC Produced in Rotary Kiln

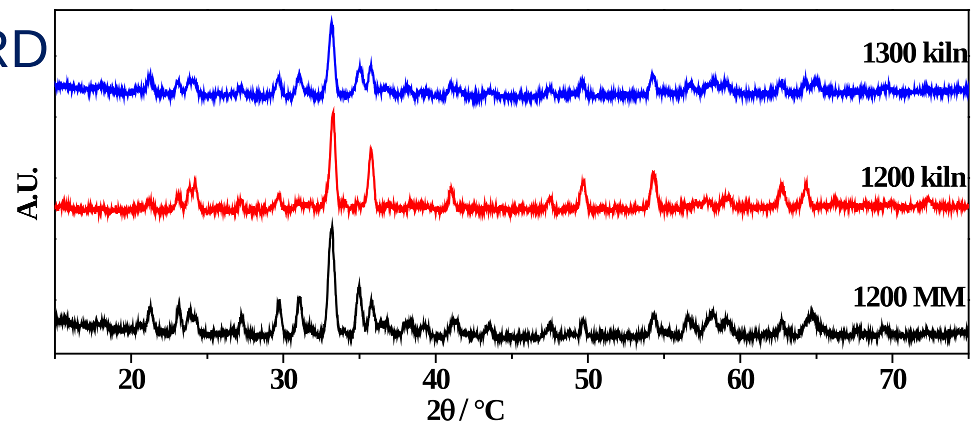
1300 kiln

Crush strength (N)

Raw	0.10
kiln	3.10
Reference	2.32

(125-355 μm)

XRD



1200 kiln: Non-formation of spinel phases

- $Fe_3Al_2(SiO_4)_3$, $Na(Fe_{0.25}Al_{0.75})O_2$

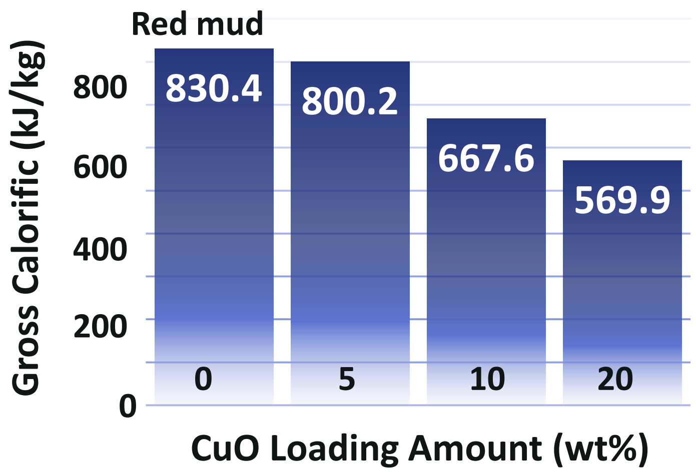
Heat Balance inside FR

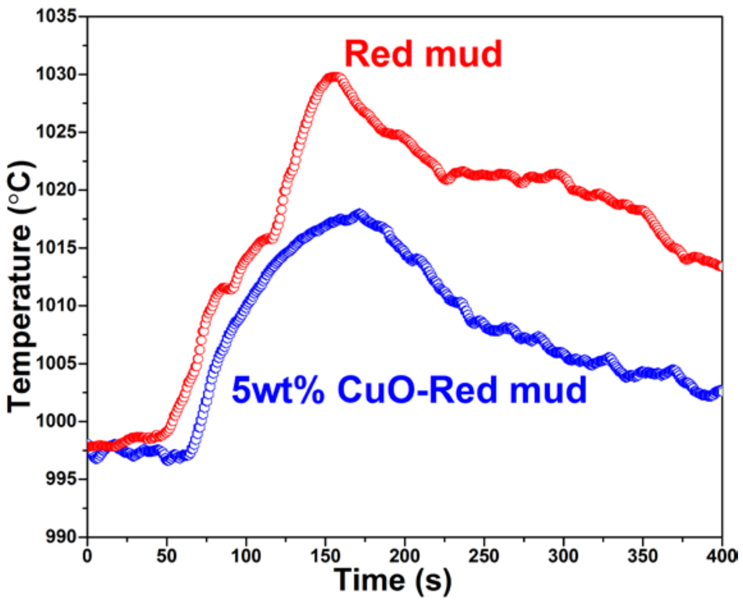
- Thermodynamics
  - Hc/O_2: heat of combustion of fuel or OC per O_2, for example (at 1000°C):

Fuel	Hc/O_2	OC	Hc/O_2
CO	-563	$Fe_2O_3 \rightarrow Fe_3O_4$	480
CH_4	-403	$Fe_2O_3 \rightarrow FeO$	535
Coal	-416	$NiO \rightarrow Ni$	468
H_2	-498	$CuO \rightarrow Cu$	372
C	-395	$CuO \rightarrow Cu_2O$	260

  - Heat must be balanced
    - by circulated OC or tune the OC composition
    - Avoid High excess heat ($\Delta Hc/O_2$) to minimize OC circulation

Copper Modified RM OC Performance

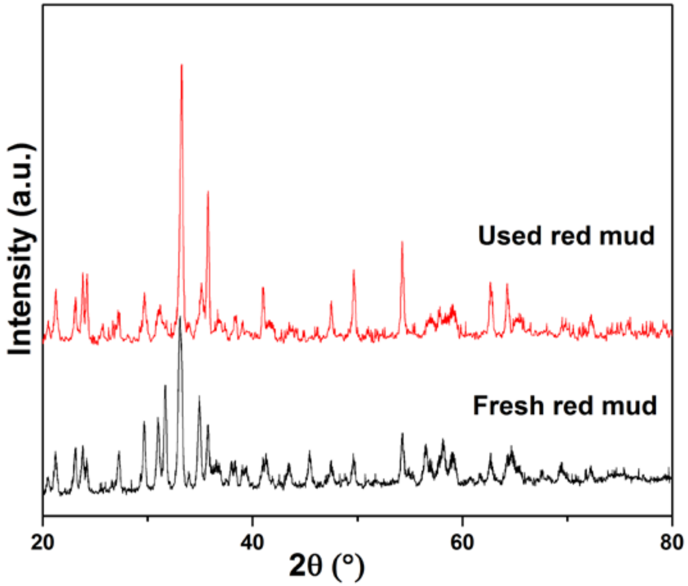




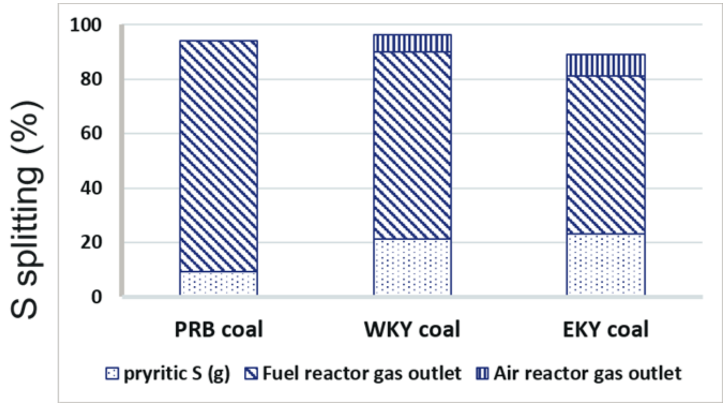
- Addition of CuO enhanced the oxygen transfer capacity
- Heat balance and circulation rate between AR and FR could be brought down

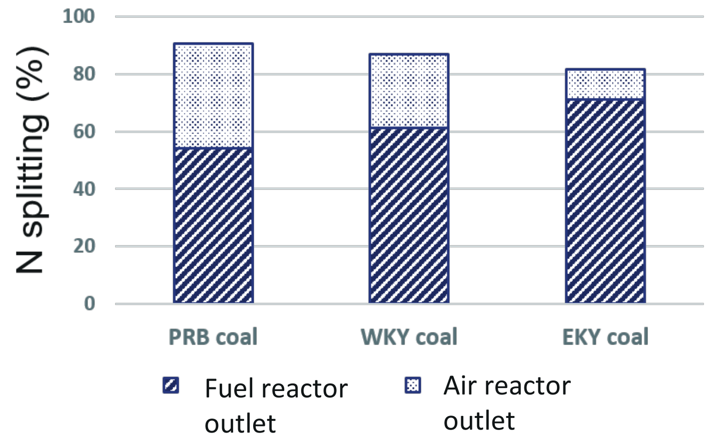
Progress: Fate of Coal Impurity Present in Fuel

- Experimental: bituminous and sub-bituminous fuel, 125-355 µm red mud oxygen carrier, 1 kWth batch unit, 950°C, 50+ hours
- Majority (>70 %) of the sulfur introduced with the fuel emitted as SO_2 at the fuel reactor
- Most of the nitrogen present in coal was found as NO from the fuel reactor



XRD Patterns of Used & Fresh Red Mud





Mass Balance of S & N of 3 Types of Coals

- Red mud shown to not react with the impurities to form stable compounds, such as metal sulphides or sulphates

Progress: Installation & Commissioning of the Pilot-scale 50 kWth PCLC Facility

1) Coal and Oxygen Carrier Loading System

2) Vibration Coal Feeder

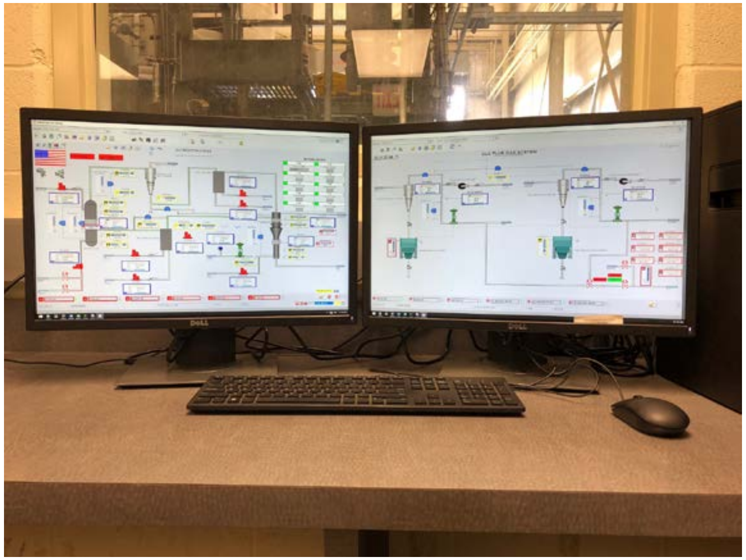
3) Superheated Steam Generation

4) Oxygen Carrier Loop

Progress: Installation & Commissioning of the Pilot-scale 50 kWth PCLC Facility

5) Flue Gas & Spent Air Conditioning

6) Sample Gas Conditioning & Analysis



7) Distributed Control System

Acknowledgement

- DOE/NETL
- State of KY via DEDI
- LGE and KU
- Duke
- EPRI
- AEP via KY Power
- EKPC
- State of WY
- Liangyong Chen, Fang Liu and Jinhua Bao