Coal-fueled Pressurized Chemical Looping Combustion with a Spouting Fluidized Bed

Award Number
DE-FE0025098

University of Kentucky Research Foundation on Behalf of
Center for Applied Energy Research
University of Kentucky
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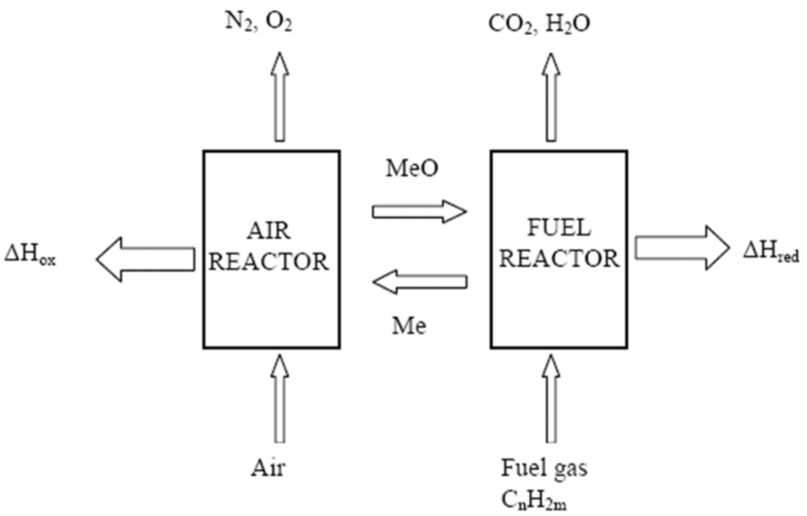
Outline

- Motivation and Development Pathway
- Project Objective
- Technical Approach
- Project Management Plan and Risk Management
- Schedule and Budget
- Progress

Chemical Looping Combustion (CLC)

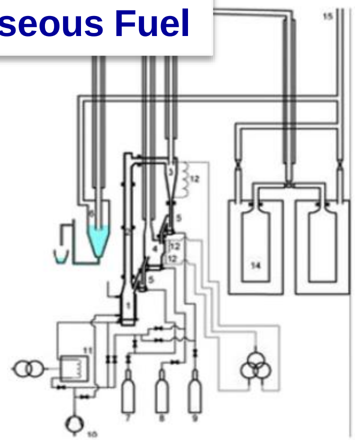
- ✓ *Solid OC circulates between two reactors*
- ✓ *Oxygen carrier (OC): oxygen, heat and fuel energy*
- ✓ *OC pick up O_2 in the Air Reactor (exothermic)*
- ✓ *OC combust fuels in the Fuel Reactor(endothermic)*
- ✓ *Total heat release equal to normal fuel combustion*
- ✓ *OC materials: Fe, Ni, Mn, Cu, Ca, natural materials, solid waste*



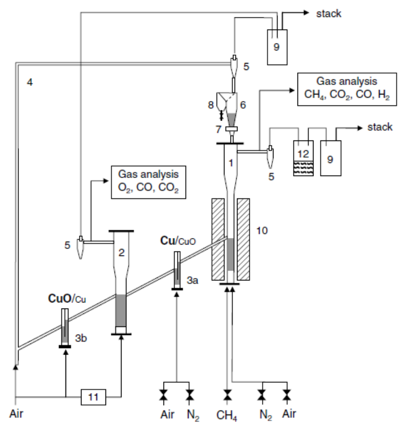
Schematic Diagram of CLC Concept

Today's CLC Facilities

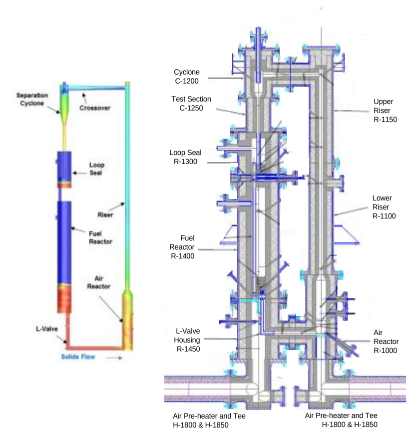
Gaseous Fuel



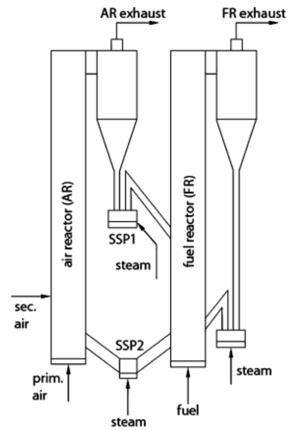
10 kWth at Chalmers



10 kWth at C.S.I.C.

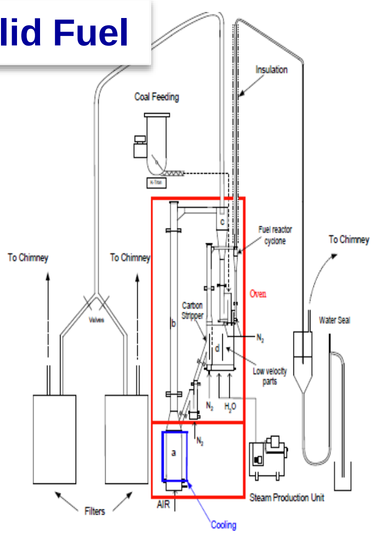


50 kWth at US-NETL

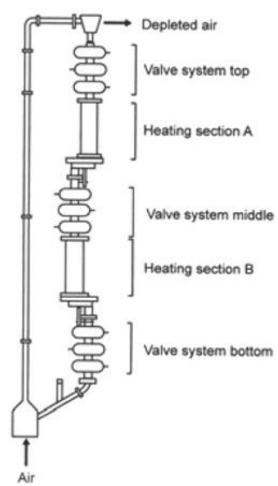


140 kW (Vienna University of Technology)

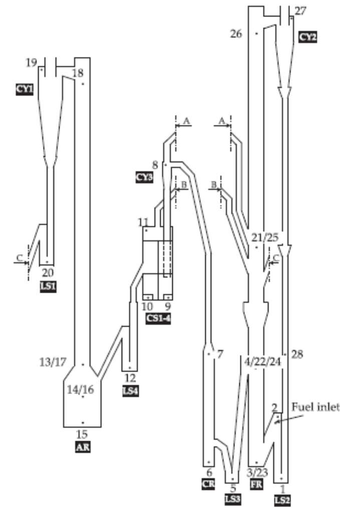
Solid Fuel



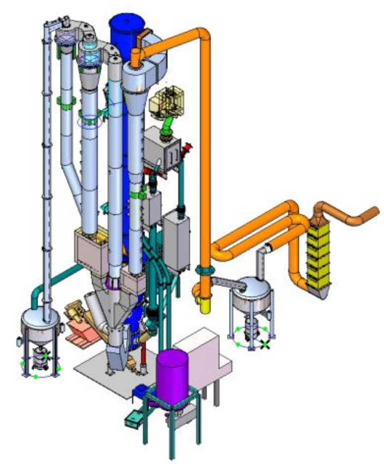
10 kWth at Chalmers



25 kWth at OSU



100 kWth at Chalmers



3 MWth at ALSTOM

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

CLC Development at UK-CAER

- Cost-effective oxygen carrier development:

  - Fe-based: synthesized, ilmenite & solid waste

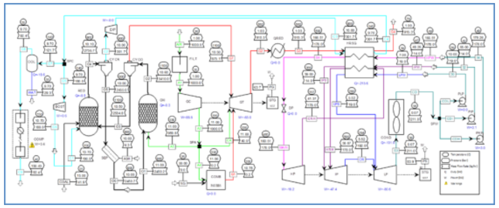
- System design & technical-economic evaluation of PCL for power generation/syngas production

- Demonstration of PCLC/CLG (1-50 kW_{th} fixed bed/fluidized bed/spouted bed)

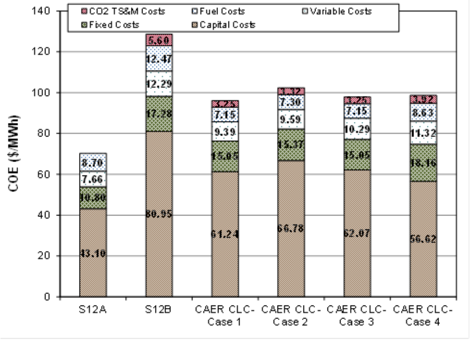
- Fundamental: kinetics of coal char gasification/OC reaction, pollutant formation, interaction between OC and coal ash

TGA-MS

Bench-scale fluidized bed



System Design



Plant Efficiency and COE

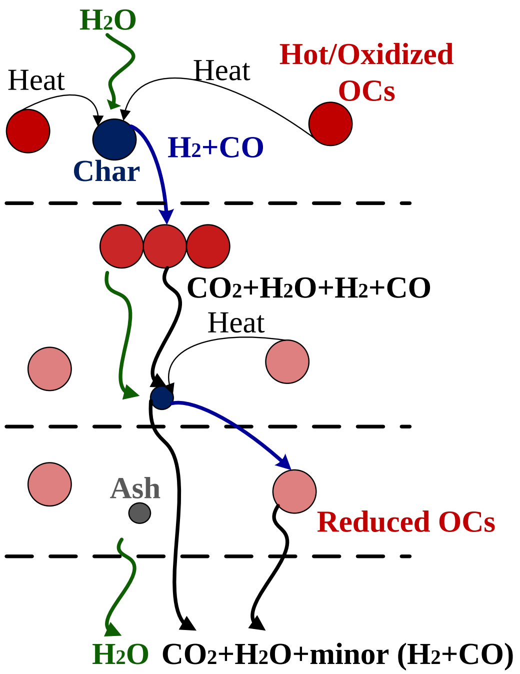
50 KWth Spouted bed reactor

Funded Projects on CLC/G at UK-CAER

- Cost-effective and High Performance OC Development
  - Supported by Carbon Management Research Group consortium at CAER
- Novel Carbon Capture Technology Development for Power Generation Using Wyoming Coal
  - Investigation into the use of Wyoming coal as the feed for Solid-Fueled CLC, State of Wyoming Clean Coal Technologies Research Program
- Solid-fueled PCLC with Flue-gas Turbine Combined Cycle for Improved Plant Efficiency and CO_2 Capture
  - Supported by DOE- Phase I , system design and economic analysis
- Coal-fueled PCLC Combined Cycle for Power Generation and CO_2 Capture
  - Supported by Kentucky Energy and Environment Cabinet, FB
- Application of Chemical Looping with Spouting Fluidized Bed for Hydrogen-Rich Syngas Production from Catalytic Coal Gasification
  - Supported by DOE, CL combined with catalytic gasification

Challenges for CF-CLC

- **Oxygen Carrier**
  - *Oxygen & heat carrier (Reactivity, oxygen transport capacity)*
  - *Production cost*
  - *Stability, agglomeration, sintering, attrition*
- **Slow Gasification**
- **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*



Coal-fueled Pressurized Chemical Looping Combustion with a Spouting Fluidized Bed

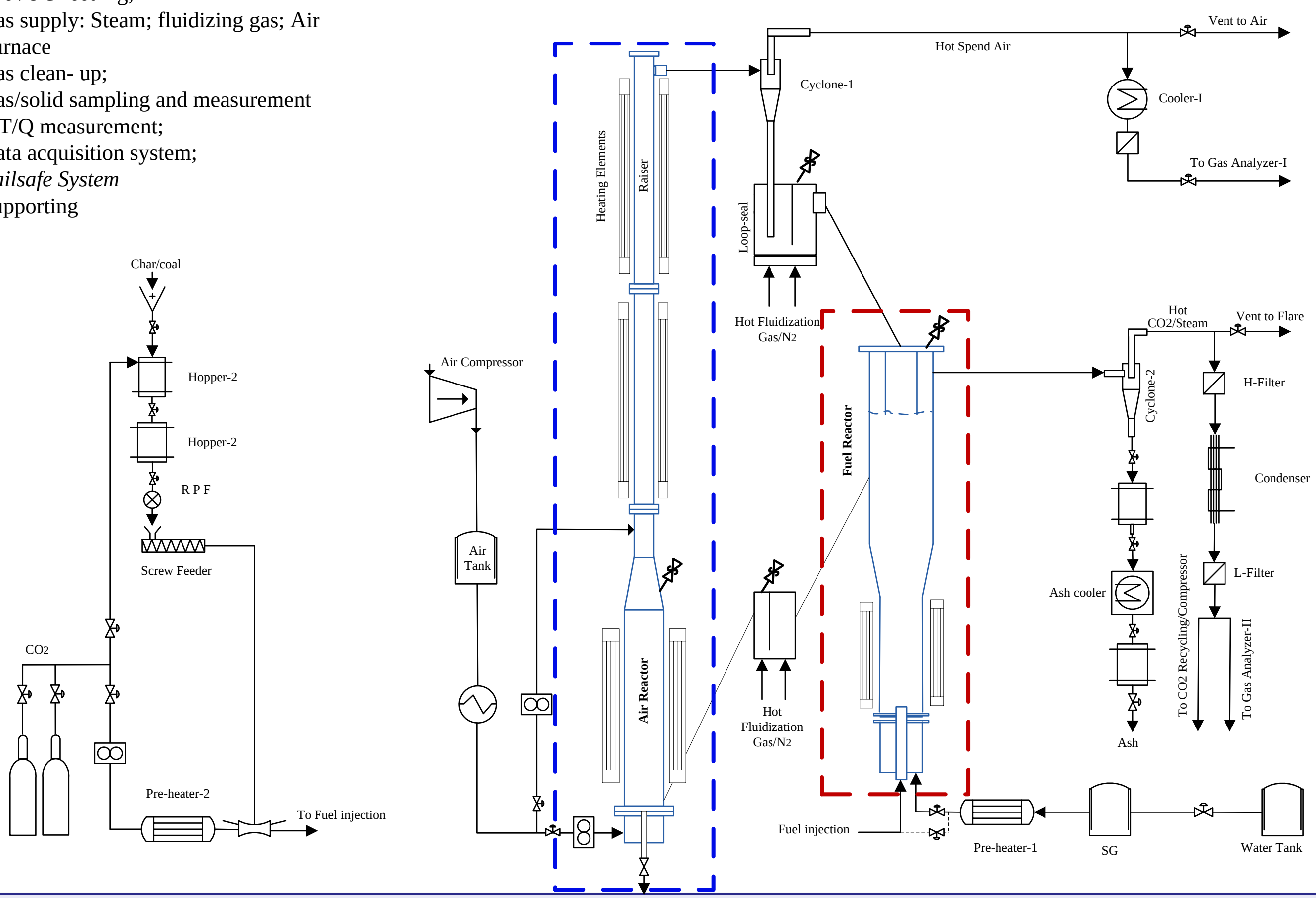
Project Objectives

- Demonstrate an integrated coal-fueled PCLC facility at lab-scale: design, fabrication, commissioning, hot testing, and performance evaluation
- Techno-economic assessment of the UK-CAER PCLC integrated power generation at commercial scale
- Technical gaps need to be narrow or addressed:

  - *Cost-effective materials for OCs (Red mud)*
  - *Overall fast reaction rates in the Fuel Reactor*
  - *Simple & effective ash separation from binary mixtures of OCs & ash*
  - *Suppression of OC agglomeration from the initial coal devolatilization step*
  - *Pollutant mitigation to avoid emission of sulfur/NOx/alkaline metal into the hot spent air stream*

UK-CAER PCLC Facility

1. AR & FR;
2. Fuel/OC feeding;
3. Gas supply: Steam; fluidizing gas; Air
4. Furnace
4. Gas clean- up;
5. Gas/solid sampling and measurement
6. P/T/Q measurement;
7. Data acquisition system;
8. *Failsafe System*
9. Supporting

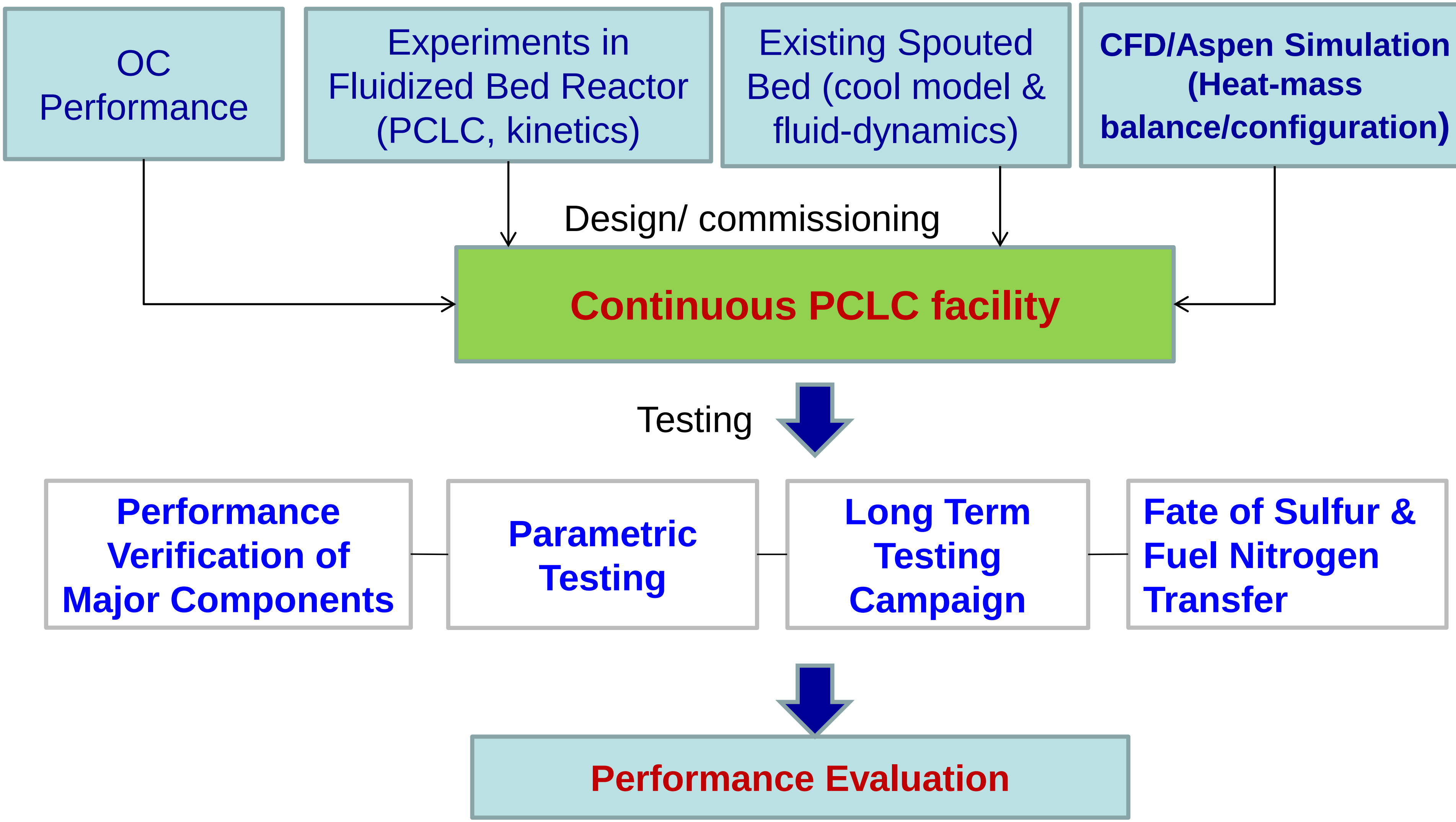


- Demonstrate coal-fueled PCLC tech. at continuous model & data collection
- Narrow the major near-term technical gaps impeding SF-PCLC & its scale up
- TEA of UK-CAER PCLC at commercial scale

Strategy to Achieve the Objectives

- *Cost-effective oxygen carrier from RM*
- *Use of a spouted bed to avoid OC-coal agglomeration and to improve fuel conversion and CO_2 purity*
- *Pulverized fuel injection*
- *Improvement of solid fuel gasification under elevated pressure*
- *CO_2 recycling to save energy consumption*
- *Elimination of external ash separation process*

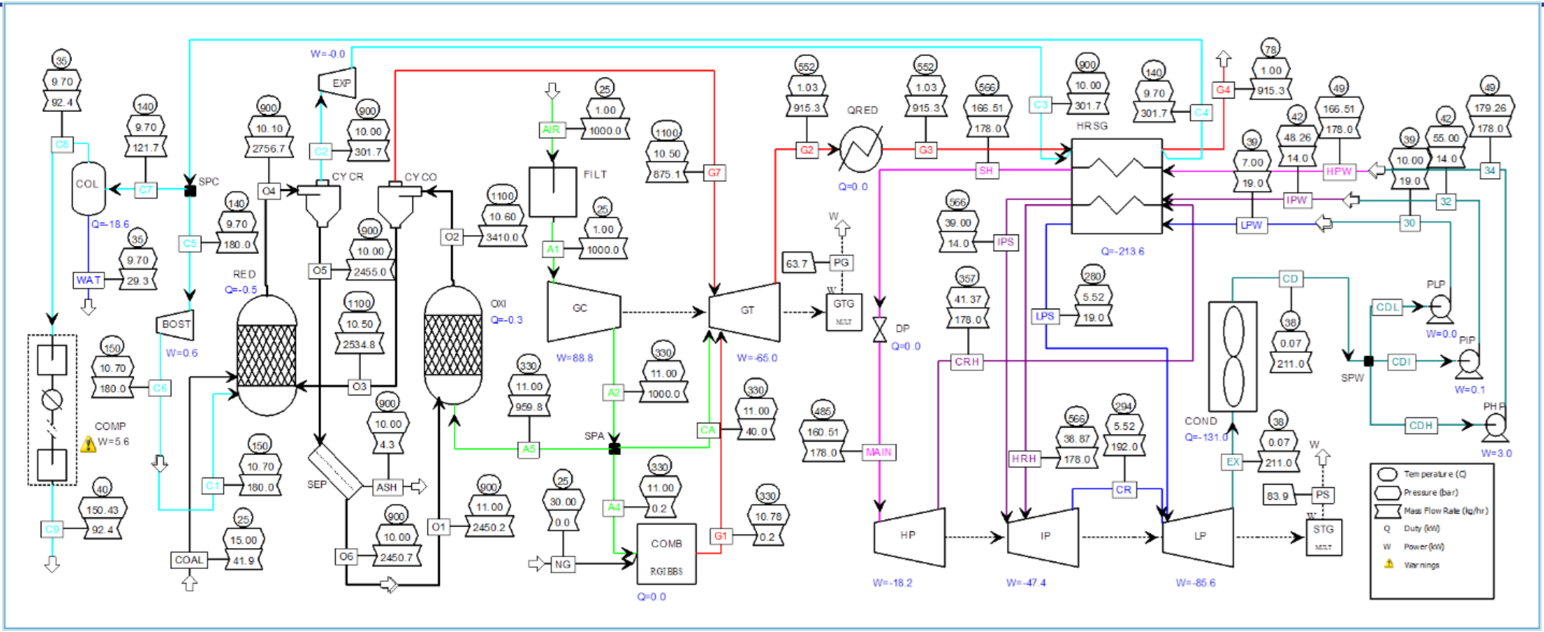
Task & Approach: PCLC facility & testing



CAER CENTER FOR APPLIED ENERGY RESEARCH

Task & Approach- Aspen Model

UK



- PCLC = CC + PFBC + CLC (550 MWe PCLC Power Plant)
  - CC: 3-P combined cycle for high efficiency power generation
  - PFBC: coal utilization
  - CLC: low cost CO_2 removal w/o ASU
- H&MB model on Aspen Plus platform to provide information
  - For plant performance evaluation, and for configuration, integration, and design consideration
- Detailed reactor model
  - Reactor design and size with obtained kinetics

Task & Approach: T-E Analysis

Based on system simulation, key component sizing, and cost estimate of major equipment:

1. *A factored estimate of capital costs for power production and CO_2 capture*
2. *An estimate of operating costs (cooling water, steam, fuel, oxygen carrier etc.)*
3. *An estimate of the energy performance and parasitic energy load of the technology*
4. *An estimate of the cost of CO_2 capture*

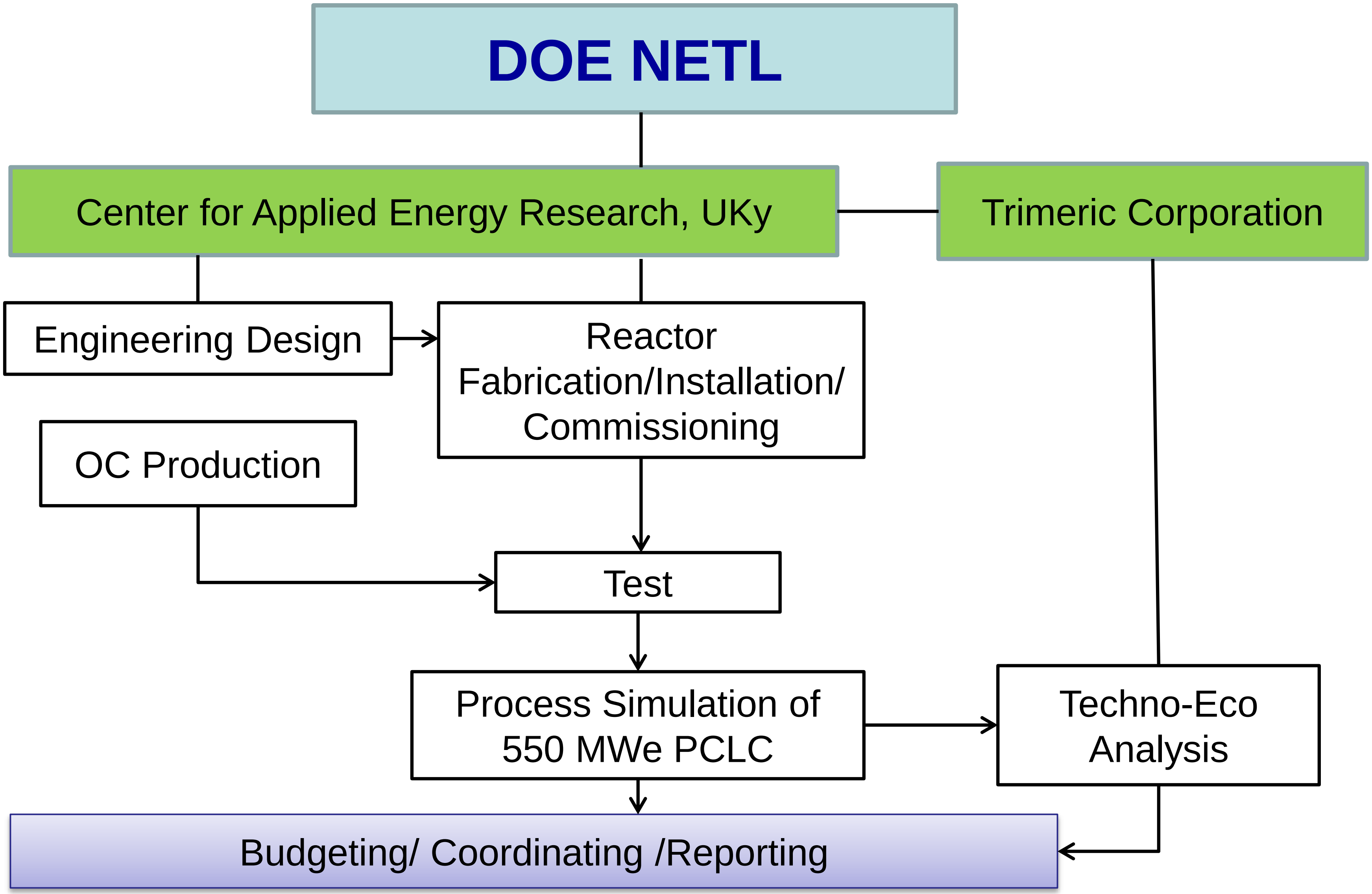
Project Management Plan & Schedule

		Task Name	Start	Finish	Task Cost
	1.0	Project Management & Planning	9/1/2015	8/31/2017	$192,437
Budget Period 1	2.0	Detailed Engineering Design	9/1/2015	2/29/2016	$77,290
	3.0	Large Quantity OC Production	11/16/2015	3/21/2016	$59,060
	4.0	Fabrication, Installation, & Commissioning of PCLC facilities	3/1/2016	8/31/2016	$195,237
	4.1	Modification, fabrication, and installation	3/1/2016	6/30/2016	
	4.2	Commissioning	7/1/2016	8/31/2016	
Budget Period 2	5.0	Performance Verification of Major Components	9/1/2016	12/2/2016	$69,876
	6.0	Parametric Testing	12/2/2016	4/3/2017	$61,907
	7.0	Long Term Testing Campaign	4/4/2017	6/5/2017	$46,901
	8.0	Fate of Sulfur & Fuel Nitrogen Transfer	12/1/2016	5/31/2017	$46,454
	9.0	Process Simulation of 550 MWe PCLC Power Plant	12/1/2016	5/31/2017	$43,843
	10.0	Technoeconomic Assessment	6/1/2017	8/31/2017	$82,775

Deliverables

Task 1	Project Management Plan	10/30/2015
Task 2	The engineering design (including P&ID, general layout, blueprint for Reducer, material and instrument selection, et.al)	02/29/2016
Task 3	Installation & commissioning	08/31/2016
Task 5 & 6	Effectiveness of major components & optimized operation conditions	04/3/2017
Task 7 – 9	Database of pollutants & stream table from simulation	05/31/2017
Task 10	TEA	08/31/2017

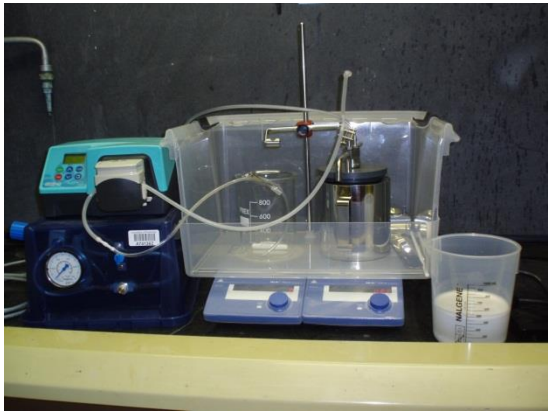
Team Structure



Risk Management

Description of Risk	Probability (Low, Moderate, High)	Impact (Low, Moderate, High)	Risk Management (Mitigation and Response Strategies)
Technical Risks:			
Performance of OC	Low	High	• Addition of supports/additives • Change preparation methods
Catalyst-OC contamination	Moderate	Moderate	• Desulfurization sorbent
Agglomeration in draft tube	Moderate	Moderate	• Re-configuration
Gas leakage between reactors	Moderate	Moderate	• Re-configuration of loop-seal
Solid circulation & flux estimation	Moderate	High	• Developing model for accurate prediction
Resource Risks:			
Air permit	Low	High	• EH&S Team early involvement
Project cost overrun	Low	High	• UKRF Project team assistance
Management Risks:			
Contract agreement delay	Low	High	• Dedicated UKRF staff

Available Instruments & Equipment

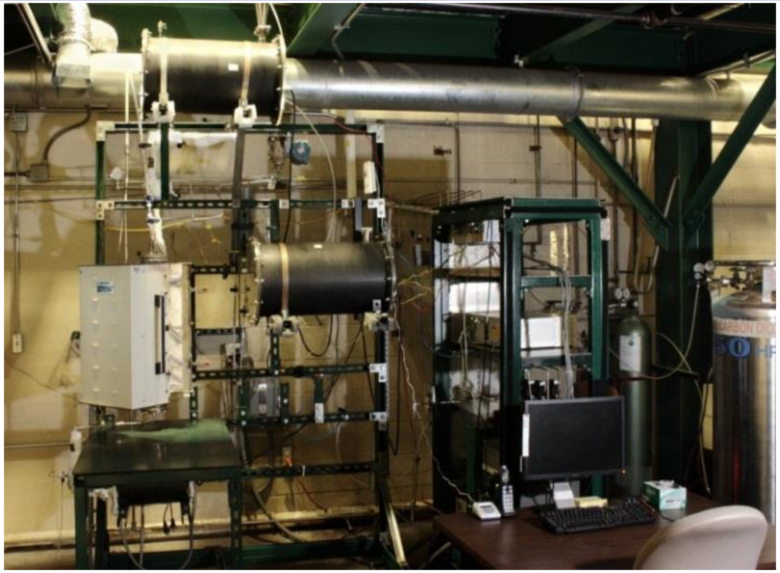


TGA/DSC/DTA/MS with WV Furnace

Hitachi S-4800

Philips X'pert

Available Facilities



Bench Scale Fluidized Bed Facility

Spouted Bed Reactor

Why Red Mud – The Properties

Physical Characteristics

Particle size: **80% particles <10µm**

Concentration: **50-65%**

pH: 12-13.5(need neutralization)

No mechanical grinding & slurry preparation needed

Direct Granulation (spray dry method)

Calcination

Cost-effective OC

No additive needed

Chemical Composition(Dry)

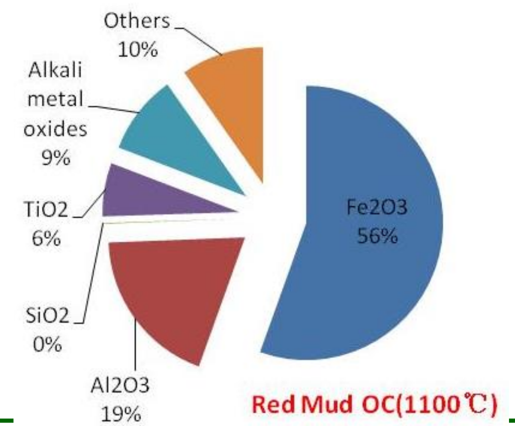
- **Fe_2O_3:30%-60%** → **Active composition**

- Al_2O_3:10%-20%
- SiO_2: 3%-50%
- TiO_2: 2%-25%

→ **Support**

- Na_2O: 2%-10%
- CaO: 2%-8%

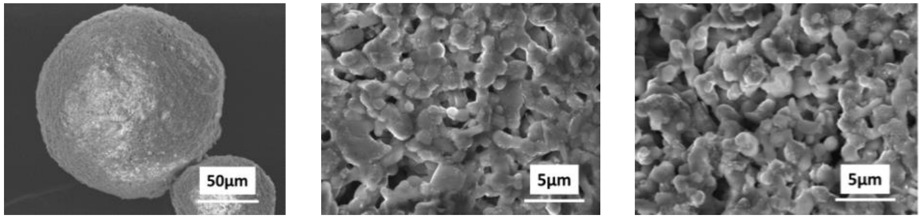
→ **Bonding**



Red Mud OCs

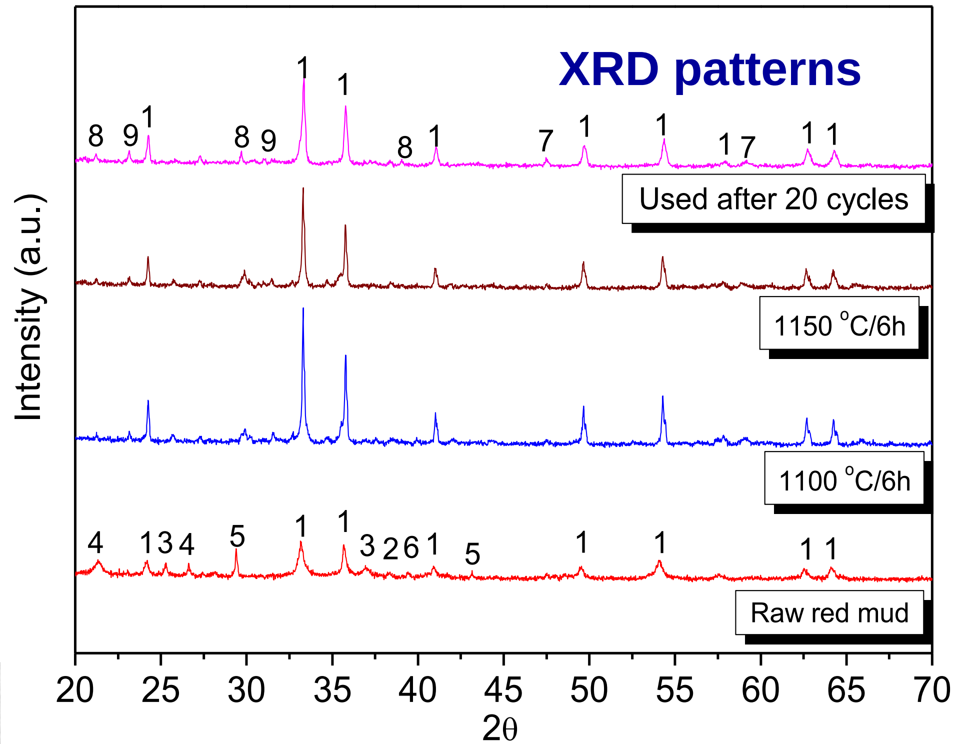
Chemical composition of raw red mud and OC samples

Composite	Raw	Red mud OCs (after calcination) 1100 °C/6h	1150 °C/6h
Fe_2O_3	51.14	50.96	51.56
SiO_2	9.85	10.51	9.98
Al_2O_3	17.92	18.54	18.18
TiO_2	6.44	6.39	6.47
CaO	8.14	7.96	7.77
MgO	0.49	0.52	0.51
Na_2O	1.81	1.91	1.85
K_2O	0.2	0.19	0.18
Balance	4.01	3.02	3.5



(a) Fresh particle (b) Fresh (c) used after 20 redox cycle

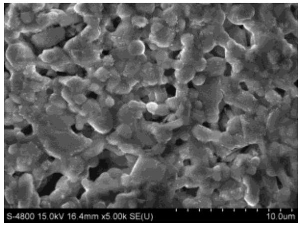
- SEM images

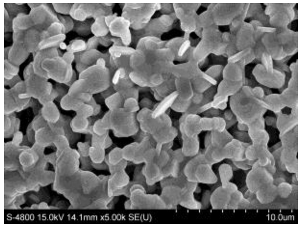


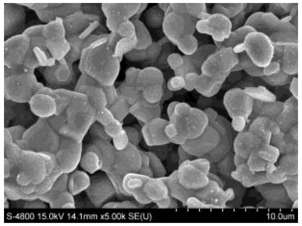
1-Fe_2O_3; 2-AlO(OH); 3-TiO_2; 4-SiO_2; 5-$CaCO_3$; 6-NaOH; 7-$CaTiO_3$; 8-$NaAlSiO_4$; 9-$CaAl_2Si_2O_8$

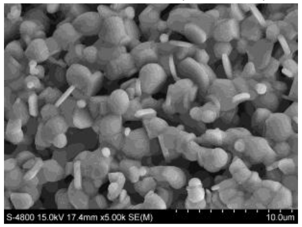
Chemical Stability

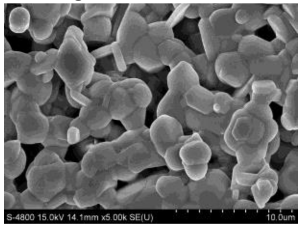
Composite	Original	Red mud OCs (after calcination)						
		1150 ºC/6h	500h	1000h	1500h	2000h	2500h	3000h
Fe_2O_3	51.14	51.56	50.94	51.01	51.43	50.28	51.27	50.83
SiO_2	9.85	9.98	10.44	10.03	10.23	10.33	9.81	10.32
Al_2O_3	17.92	18.18	18.1	18.24	17.95	18.27	18.45	18.35
TiO_2	6.44	6.47	6.39	6.34	6.39	6.35	6.37	6.39
CaO	8.14	7.77	7.79	8.38	7.83	8.35	8.44	8.37
MgO	0.49	0.51	0.44	0.43	0.65	0.66	0.68	0.68
Na_2O	1.81	1.85	1.67	1.58	1.88	1.79	1.60	1.68
K_2O	0.2	0.18	0.18	0.16	0.17	0.15	0.12	0.13
Balance	4.01	3.5	4.05	3.83	3.47	3.82	3.26	3.25

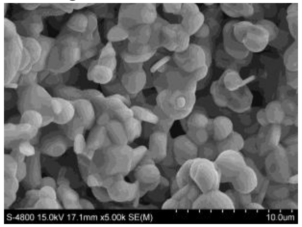

FG-RM-1150/6h(125-300)


Baking under 1100 for 500 h

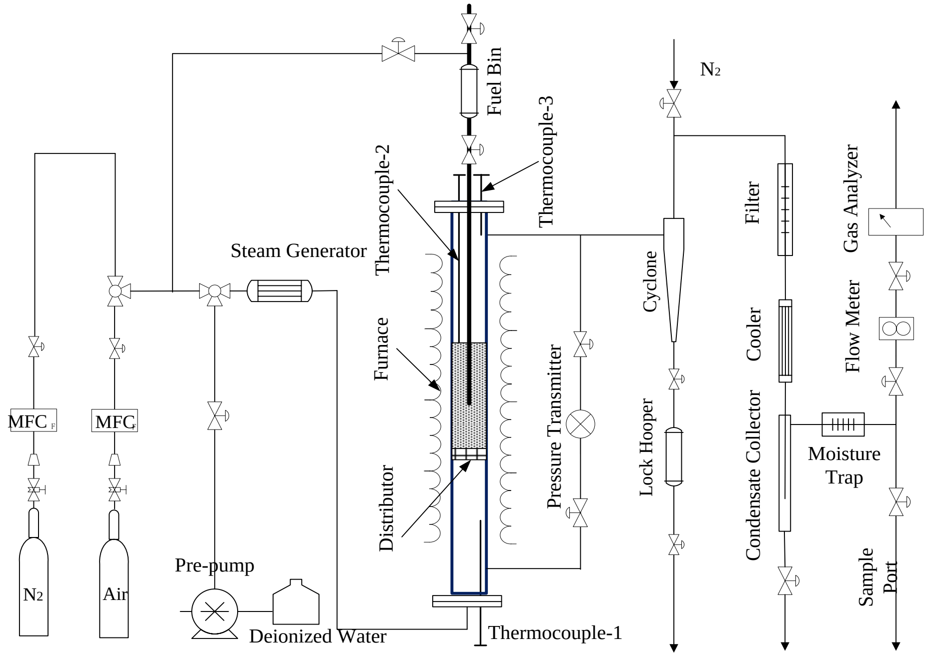

Baking under 1100 for 1000 h


Baking under 1100 for 1500 h


Baking under 1100 for 2000 h


Baking under 1100 for 2500 h

Experiments in Fluidized Bed Reactor



Oxygen carriers:

- Ilmenite
- S Red mud OC (FG1150 C/6h)
- A Red mud OC (FG1150 C/6h)
- Particle size: 125-350 um

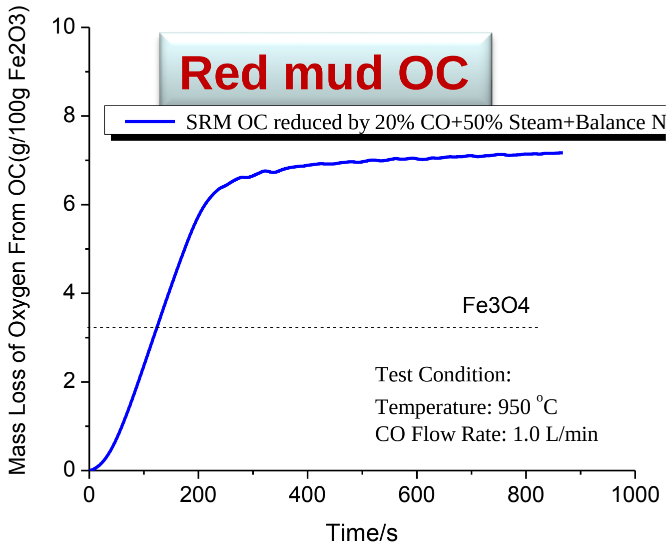
Operation condition:

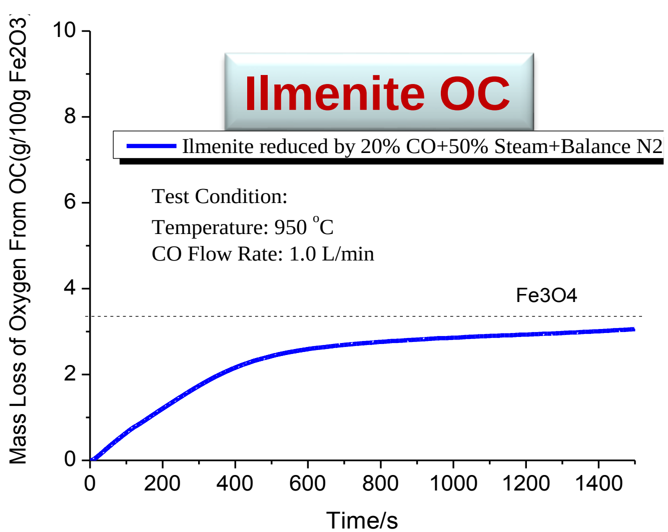
- Gasification agent: 50% steam balanced by N_2
- OC/Fuel ratio: 150: 1

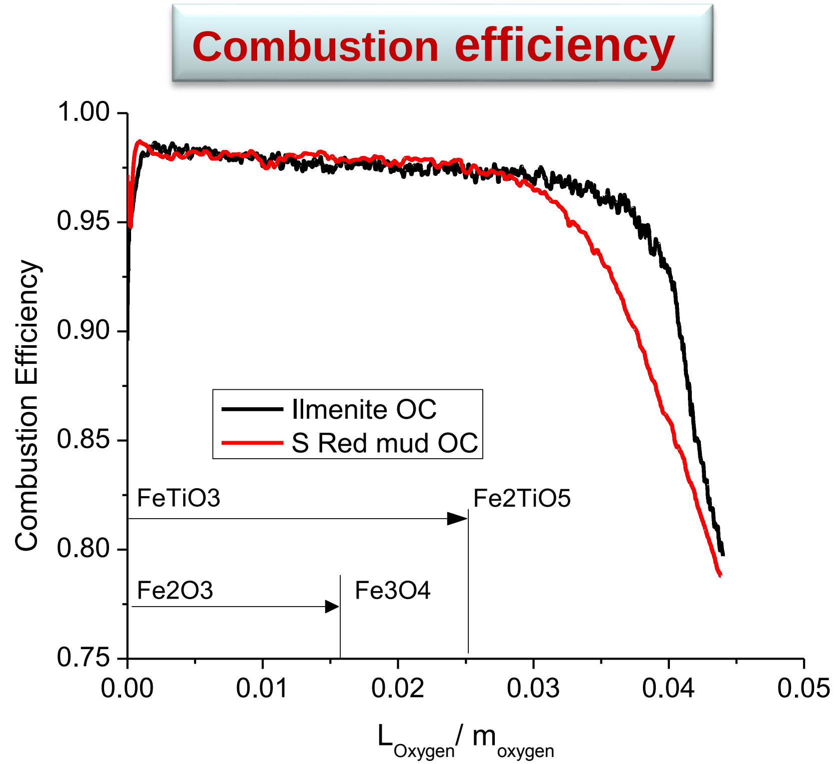
Fuels:

- EKy coal char (pretreated at 700 C)
- WKy coal char (pretreated at 700 C)
- PBR coal char (pretreated at 800 C)
- Particle size: 180-350 um

OC Reduction with Simulated Syngas







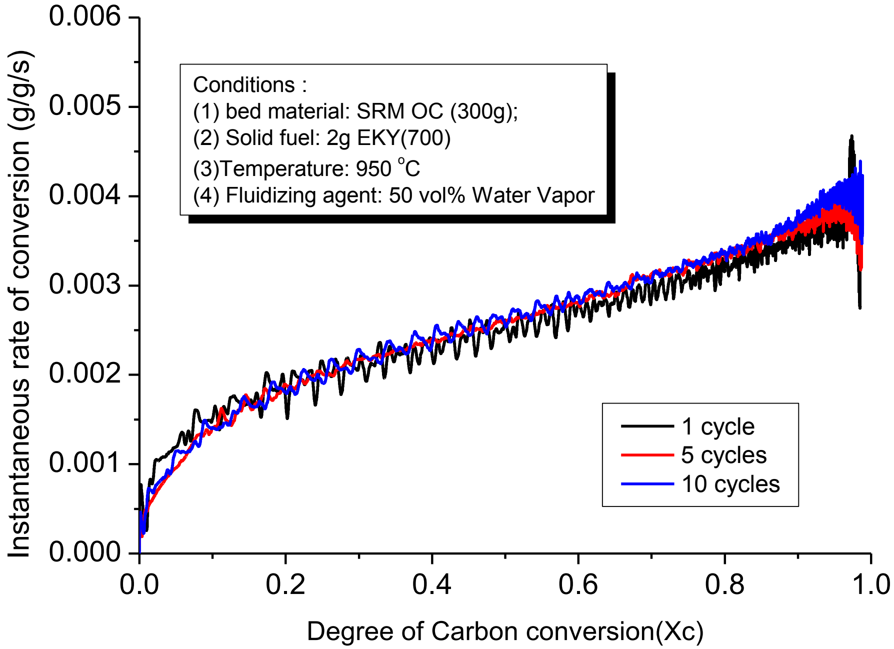
Fixed bed reactor:

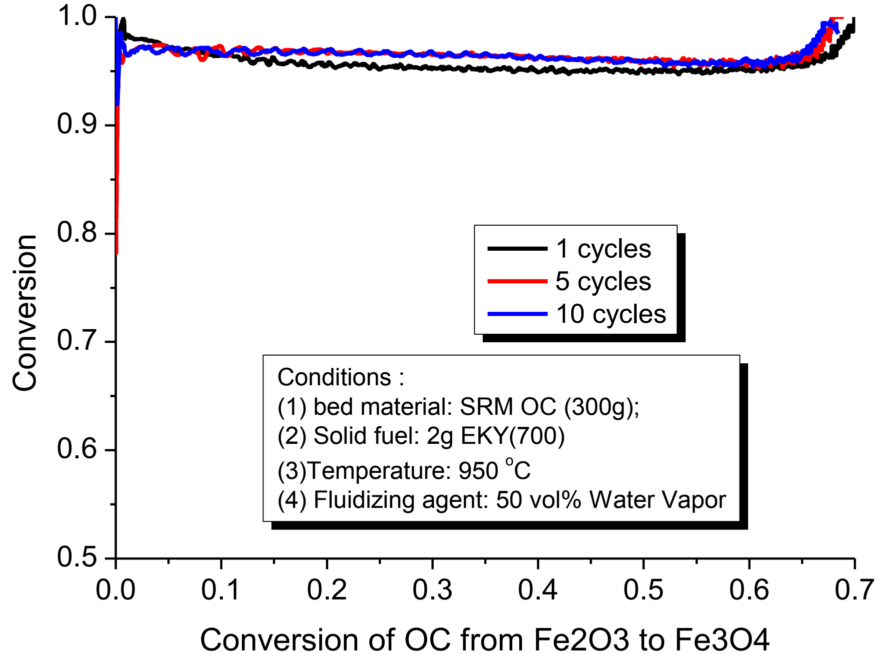
(1) Bed material: 600 g ilmenite OC

(2) Fuel: 1.5 L/min CO +1.1 g/min water +1.5 L/min N2

(3) Temperature: 950 °C

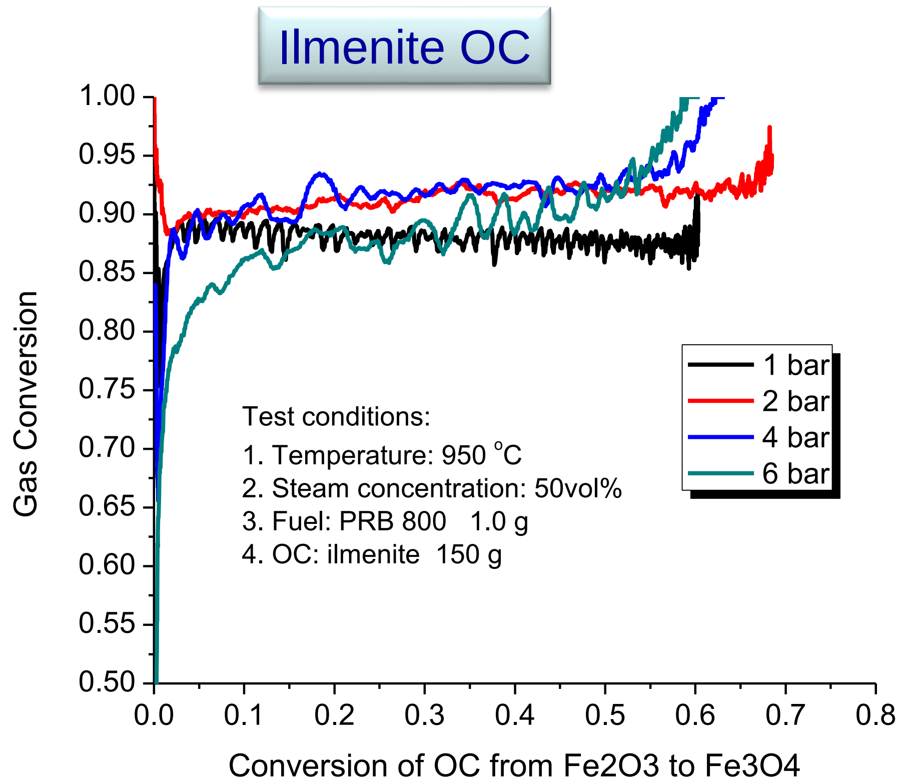
The Effectiveness of Red Mud with Solid Fuel-2

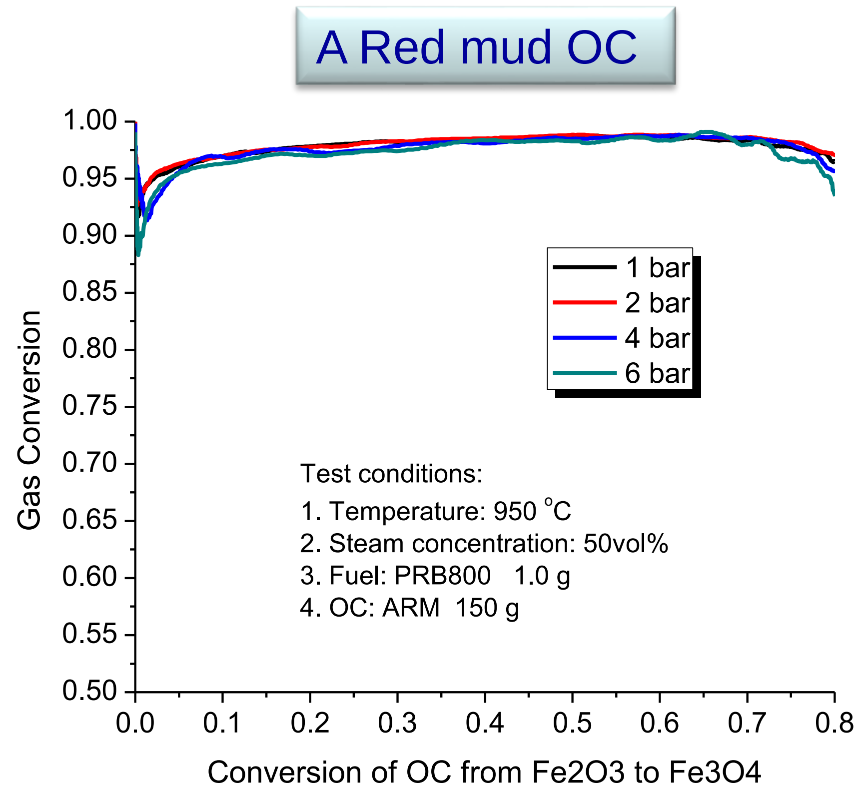




High Stability in Fuel Conversion

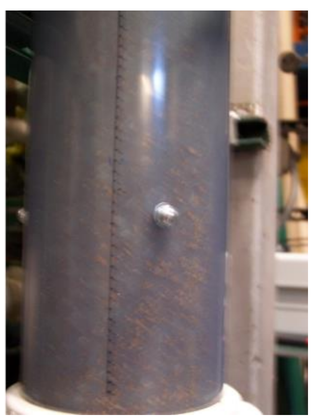
Combustion efficiency of PCLC process

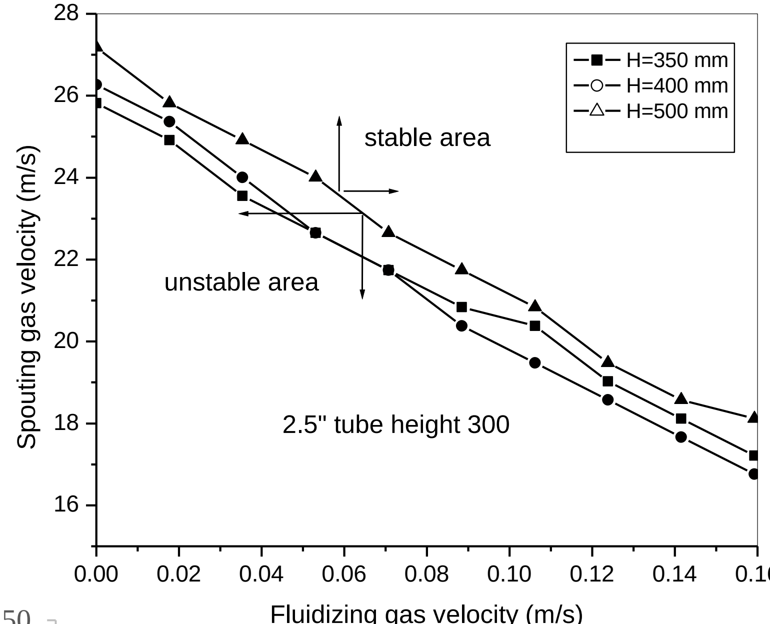


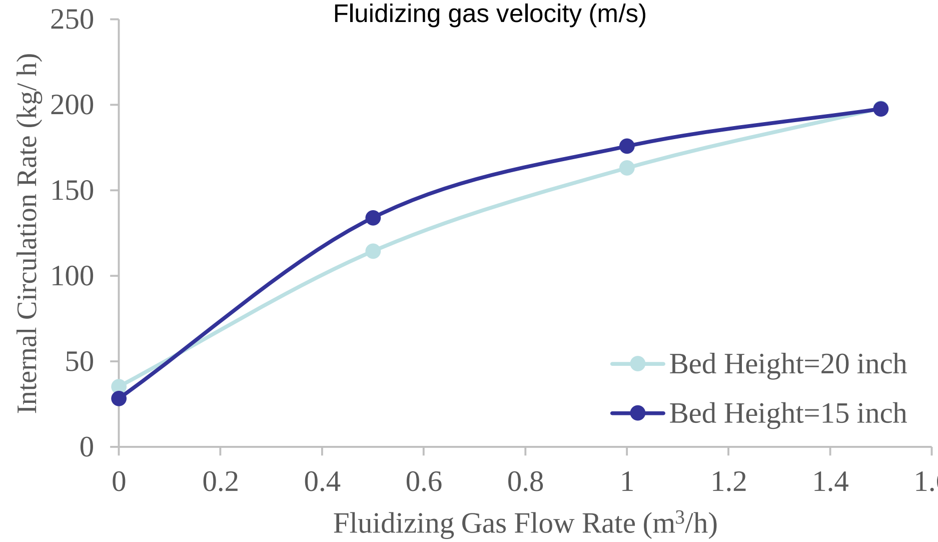


- *Combustion efficiencies are independent of operation pressure and the type of fuels*

Hydrodynamics in Spouted Bed







Discussion

- Question/clarification
- Path forward
- Task modification
- Expected deliverables