Application of Chemical Looping with Spouting Fluidized Bed for Hydrogen-Rich Syngas Production from Catalytic Coal Gasification

Award Number
DE-FE0024000

Kunlei Liu
Liangyong Chen, Zhen Fan, and Fang Liu
Center for Applied Energy Research
University of Kentucky
2540 Research Park Drive
Lexington, KY 40511-8410

Traditional Coal Gasification

Limitations

- ❖ ASU & external water gas shift reaction
- ❖ Narrowed temperature range, and limited availability of sensible heat
- ❖ Extensive CH_4 and tar formation for low temperature gasification
- ❖ Low H_2 / CO ratio, and complicated process for slag discharge and waste water treatment

Characteristics of different gasification process

Process	Outlet Gas Temperature (°C)	Oxidant Demand	Steam Demand	Carbon Conversion	CH_4 concentration/ tar	H_2/CO (mol/mol)
Moving/fixed bed	425-650	low	high	low	>4%/ high	2
Fluidized bed	900-1050	moderate	moderate	moderate	>2%/ low	0.6~0.7
Entrained flow	1250-1600	high	low	High>95%	<1000ppm/No	0.7

Project Objectives

❖ **Develop a transformative catalytic coal gasification technology**

- Avoidance of ASU and external WGS
- High temperature gasification to improve cold gas efficiency
- Improve H_2/CO ratio and eliminate CH_4 formation

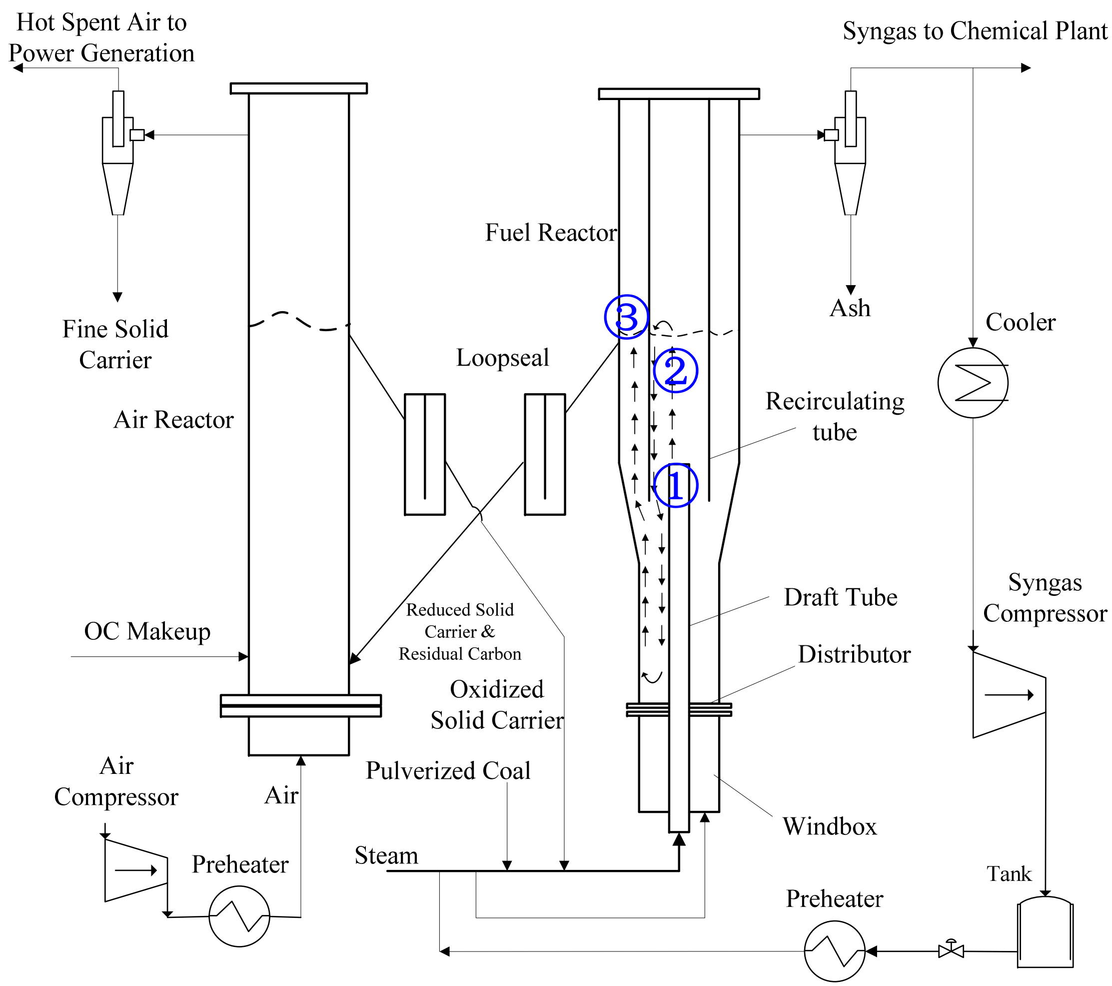
❖ **Multi-function oxygen carrier development**

- Oxygen & heat carrier
- Catalyst to improve gasification and WGS reaction

❖ **Demonstration of novel spouted bed reactor**

- Combination of gasification and WGS reaction
- Avoidance of ash melting
- Ash separation

Diagram of Proposed CLG Process



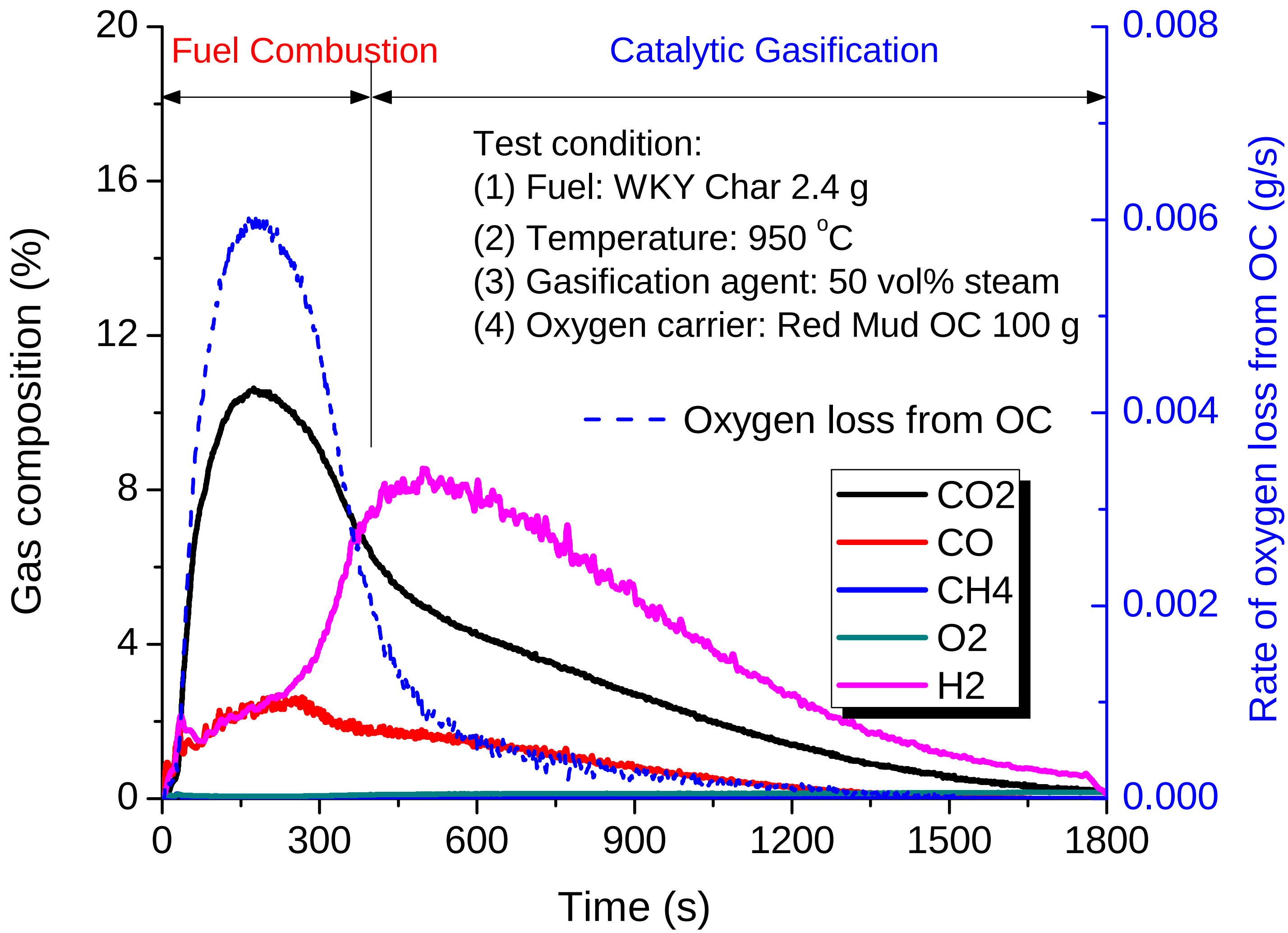
1. Temp = 950-1000 ^oC
2. Temp = 800-950^oC
3. Temp = 600-800^oC

Avoiding the external ASU and WGS and their auxiliary power through cost effective chemical looping.

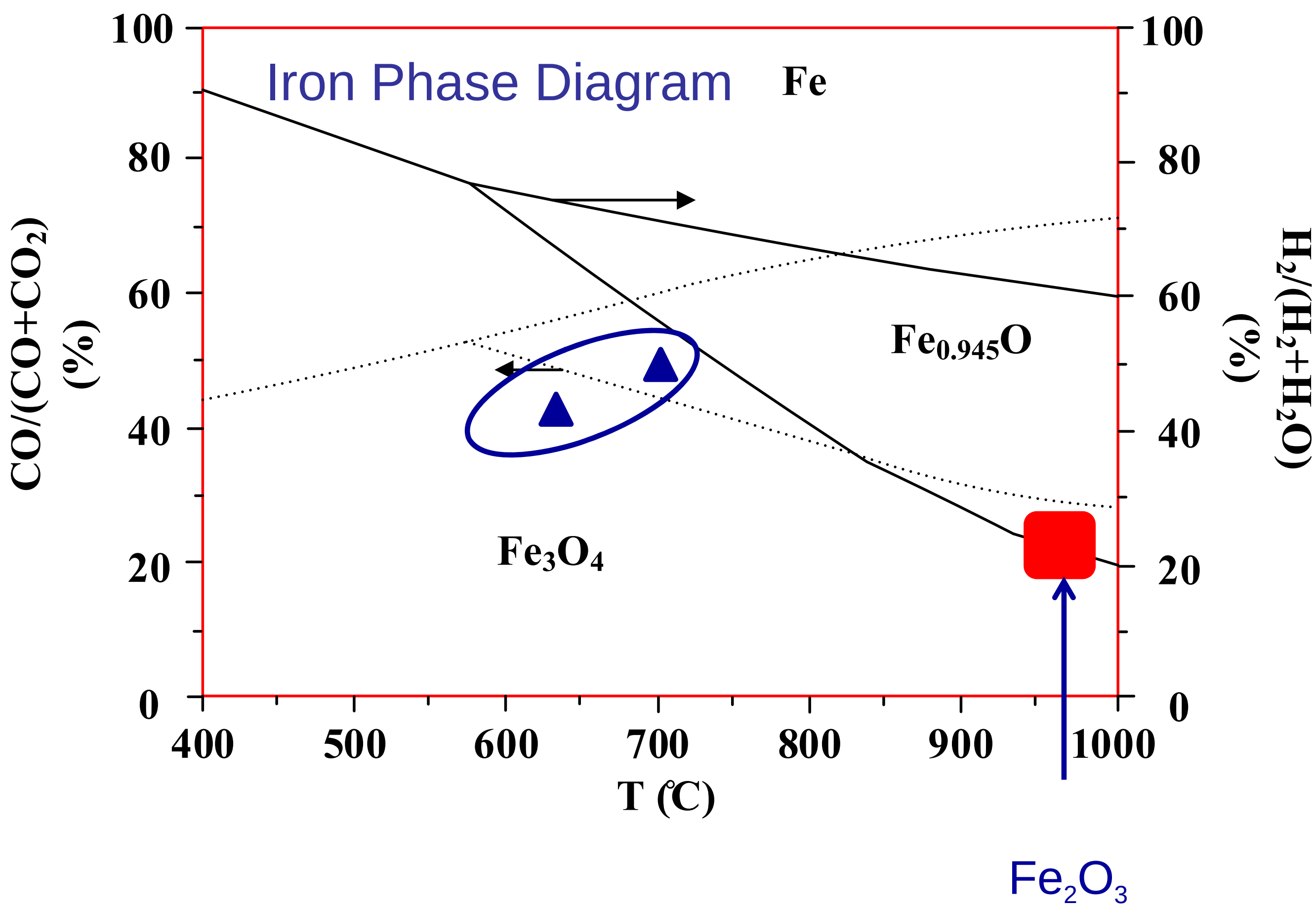
Challenges

- Catalyst-Oxygen Carrier: reactivity, cost, sintering or attrition
- Heat balance
- Fuel reactor configuration

CLG in Bench Scale Fluidized Bed



Feasibility and Iron State of Red Mud Catalyst-OC During Reaction



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

Chemical Composition(Dry)

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

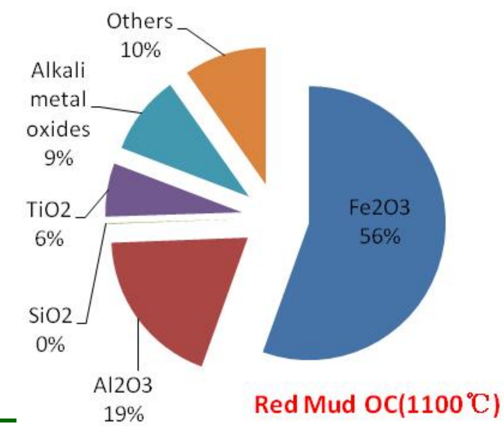
- Al_2O_3:10%-20%
- SiO_2: 3%-50%
- TiO_2: 2%-25%

→ **Support**

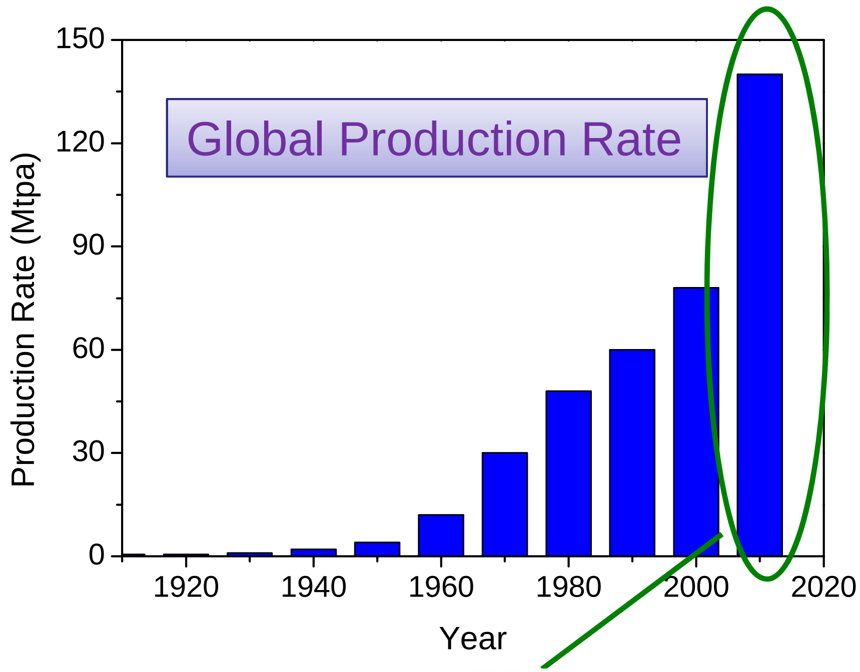
- Na_2O: 2%-10%
- CaO: 2%-8%

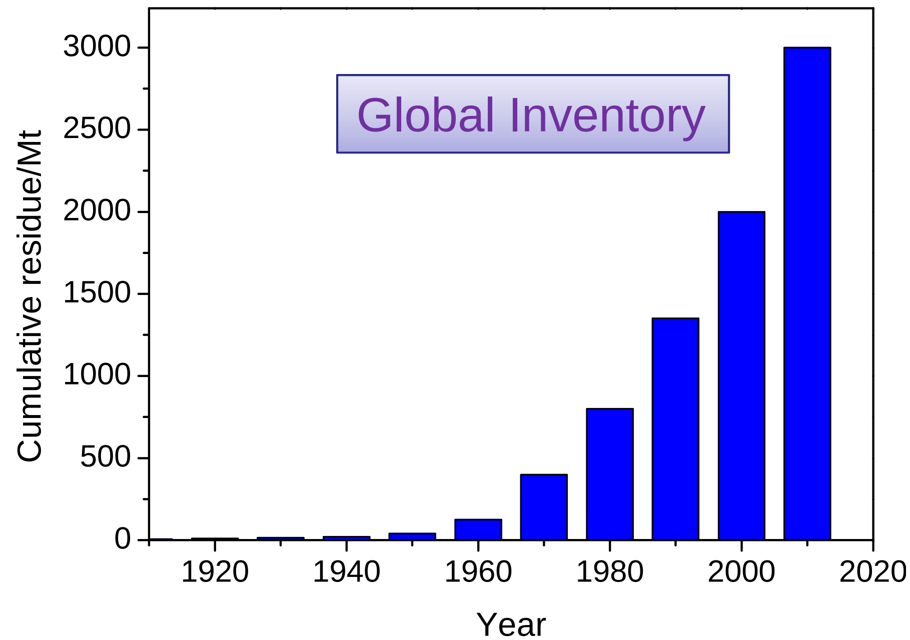
→ **Bonding**

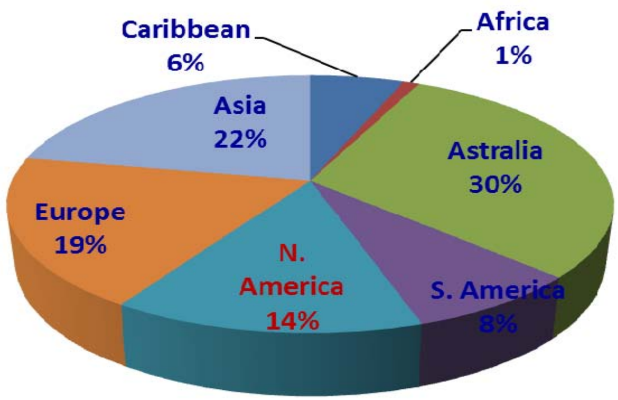
No additive needed



Why Red Mud – Abundant







Availability

50%

OC/8Mt

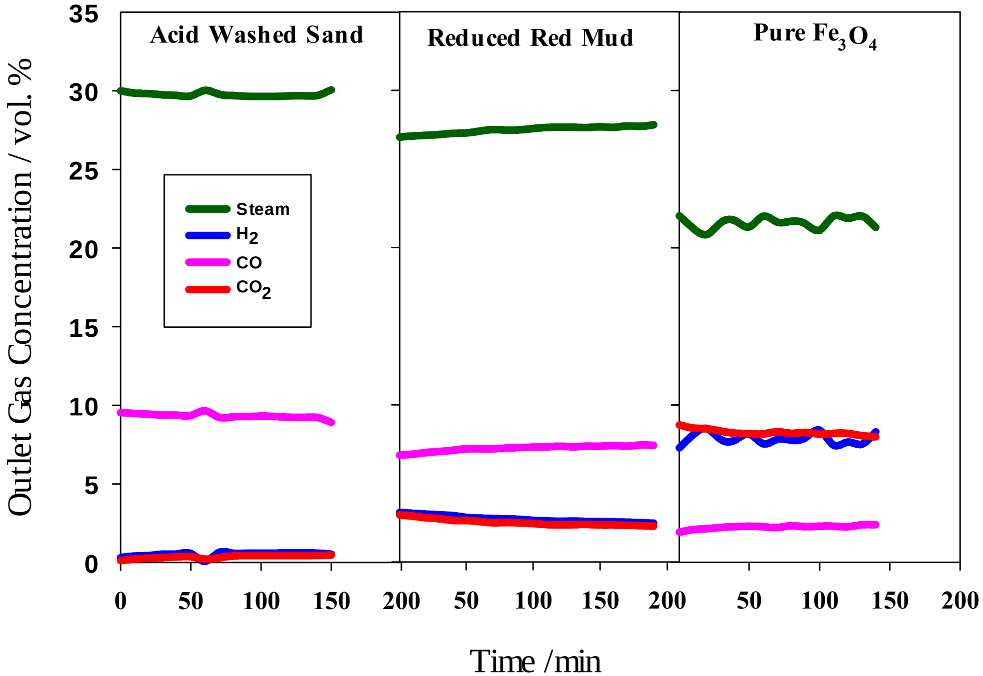
Lifetime

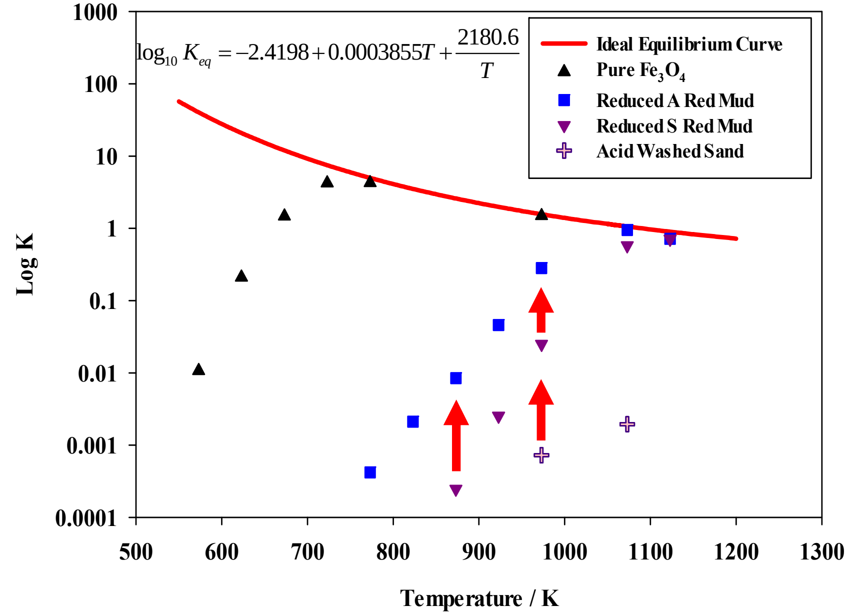
4,000~5,000h

Capture
> 2Gt CO_2

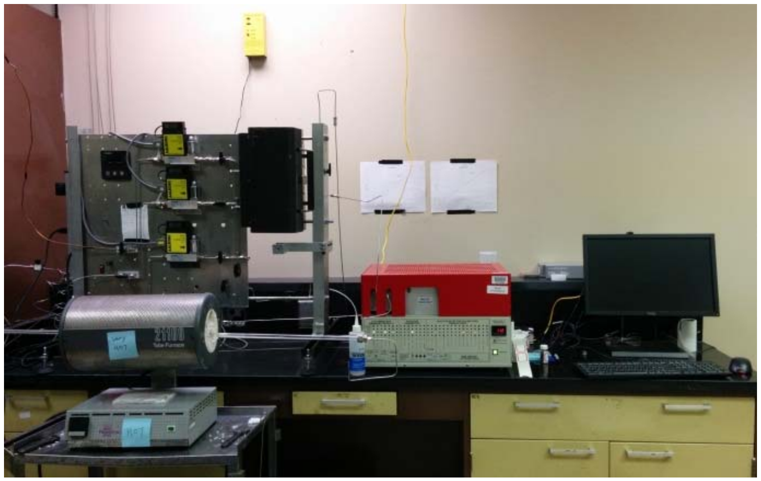
>30% of total CO_2 emission of USA

Catalytic Function for *WGS* Reaction



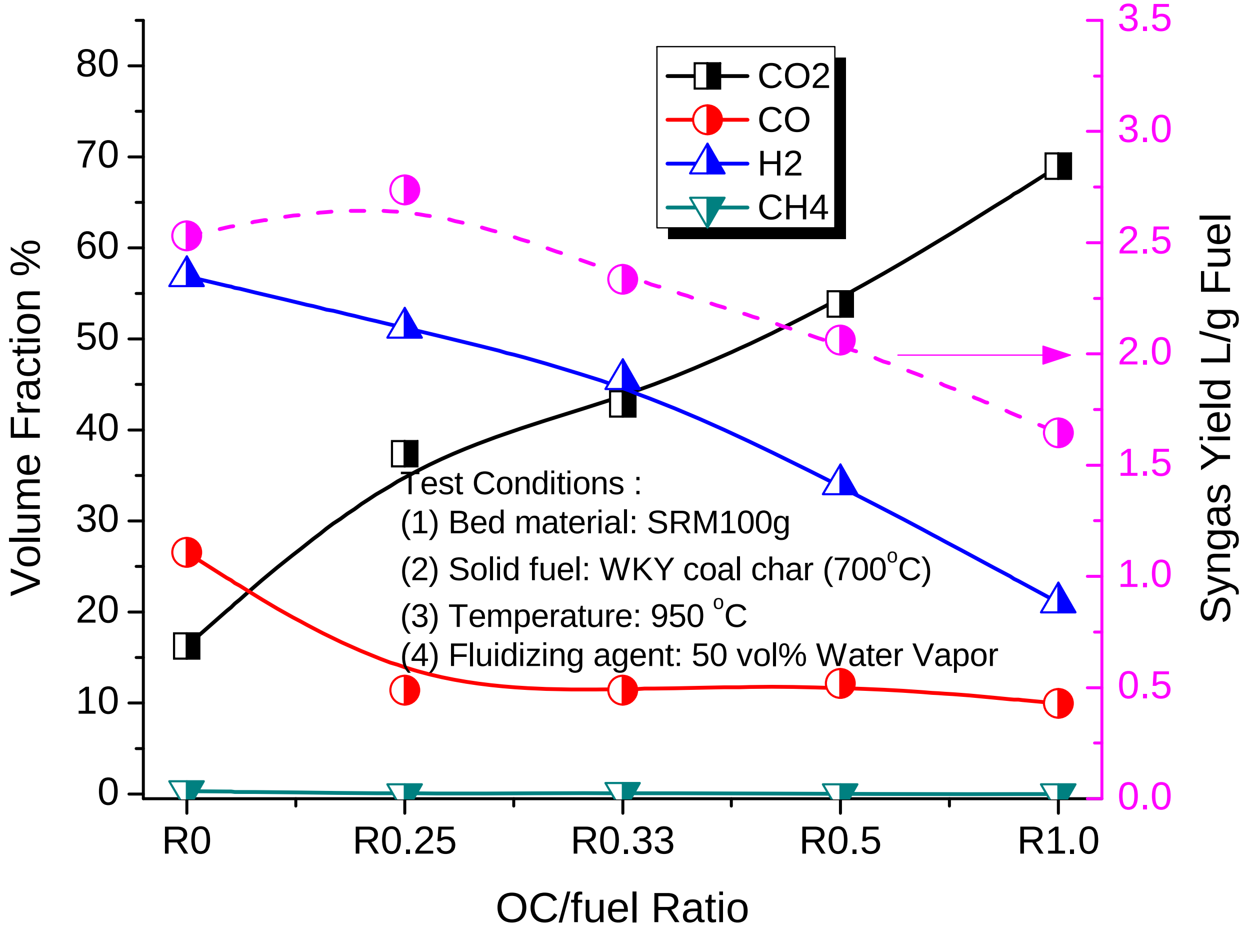


T = 973 K
Identical gas space velocity:
-residence time=6s
Inlet gas composition:
- 10% CO + 30% Steam+60% N_2

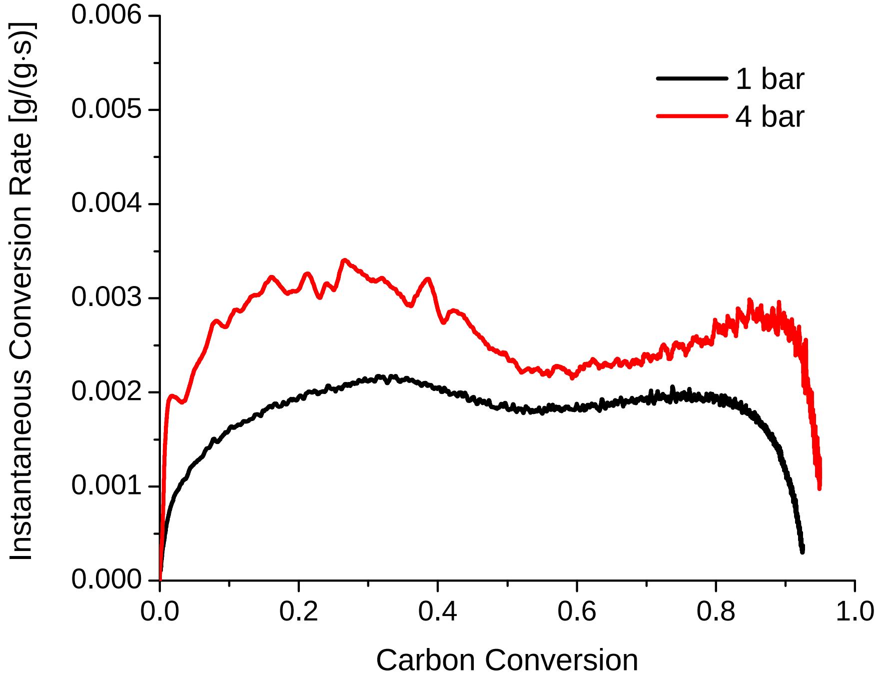


Gas Composition of CLG

-At different oxygen carrier/fuel ratios



Predicting Real Application



Promotion of gasification rate at elevated pressure

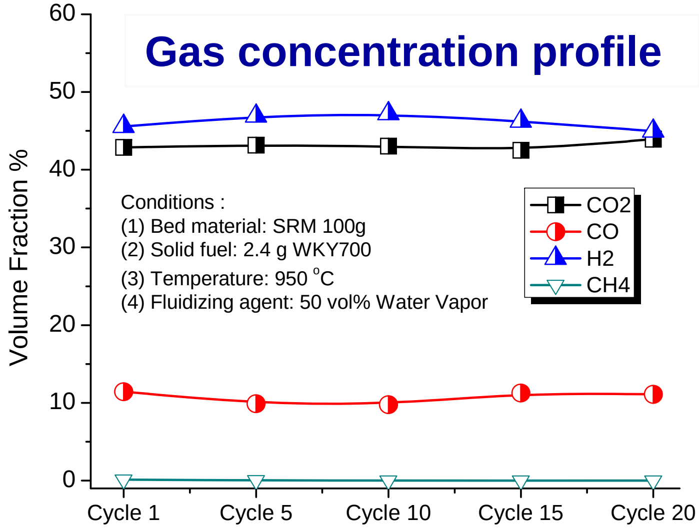
Test condition:
(1) Fuel: Char 2.4 g
(2) Temperature: 950 ^{o}C
(3) Gasification agent: 50 vol% steam
(4) Red Mud OC 100 g

Syngas product

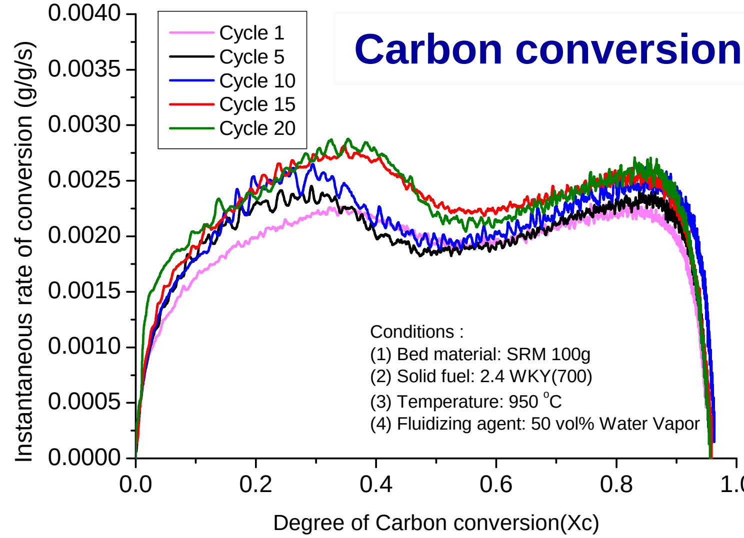
	1 bar	4 bar
CO_2	*42.9*	*43.0*
CO	*11.4*	*8.3*
H_2	*45.6*	*48.7*
CH_4	*0.14*	*0*

Cyclic Performance Evaluation

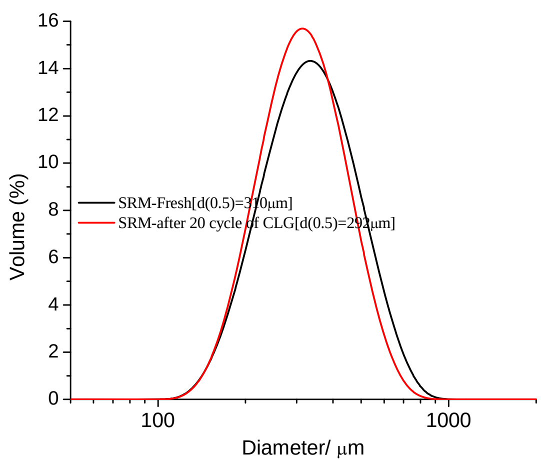
Gas concentration profile

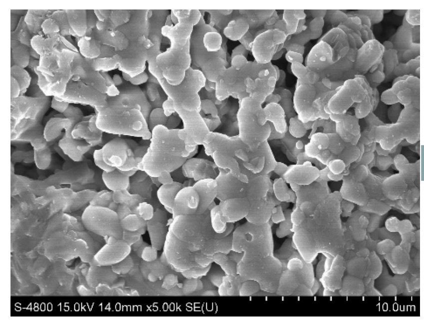


Carbon conversion rate

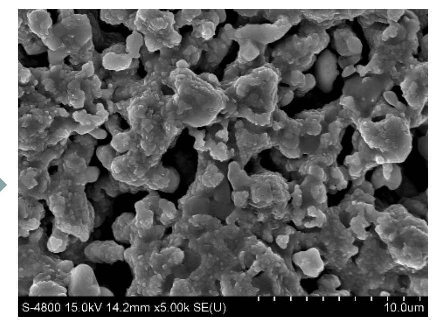


Particle size distribution





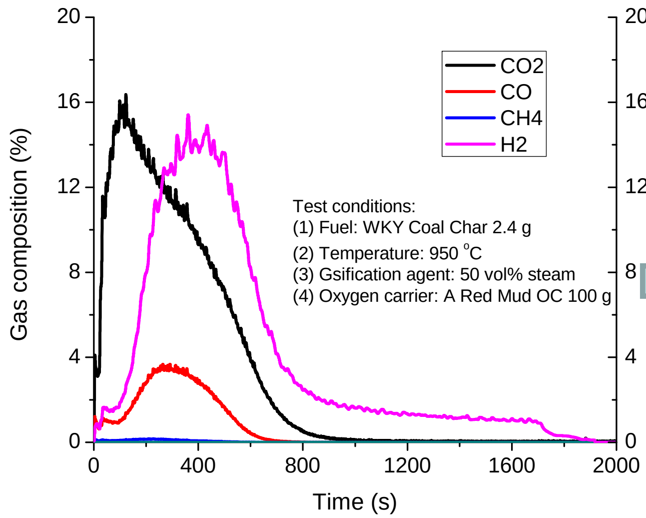
Fresh OC



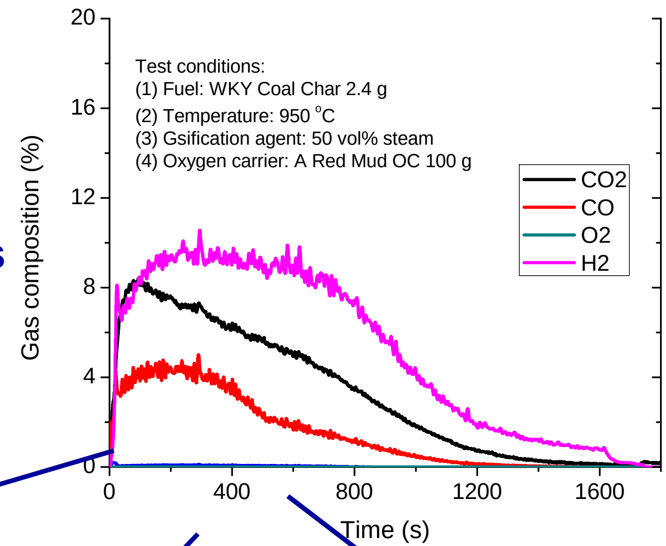
After 20 cycles

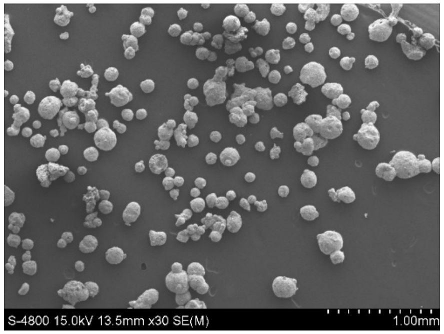
Strategy to Avoid Agglomeration (1)

Regeneration at high excess temperature: >35 ^oC

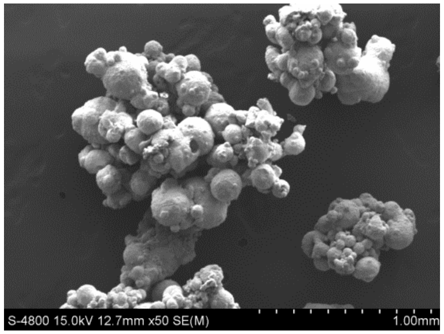


After 15 cycles

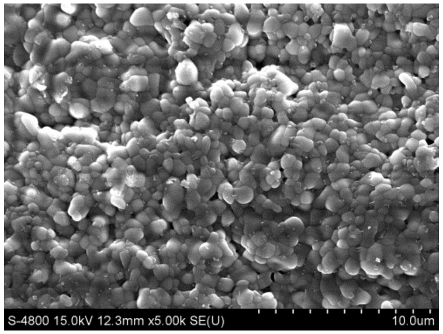




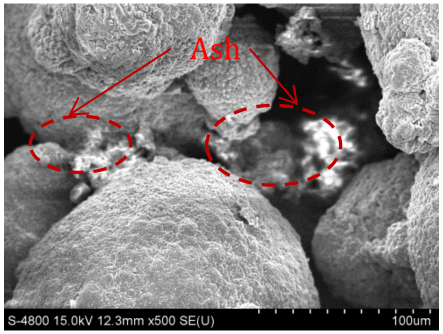
Fresh OC



Agglomerate



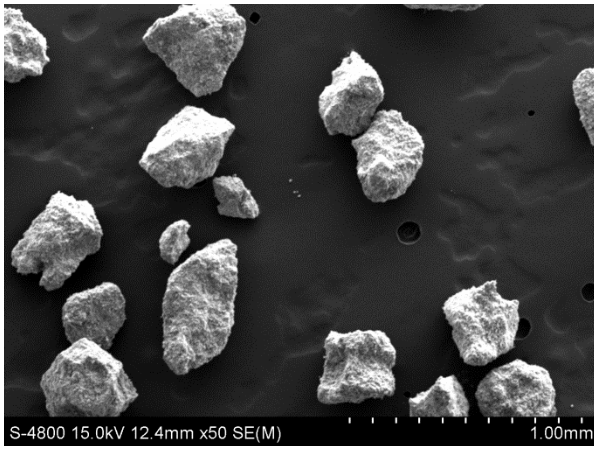
Sintering Surface



Ash-induced Agglomerate

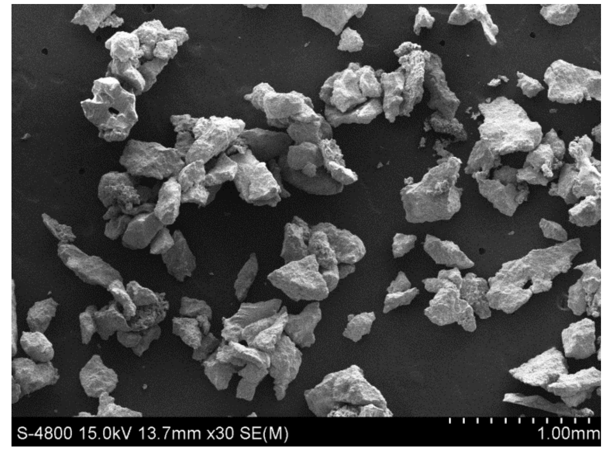
Strategy to Avoid Agglomeration (2)

Low steam concentration < 30%

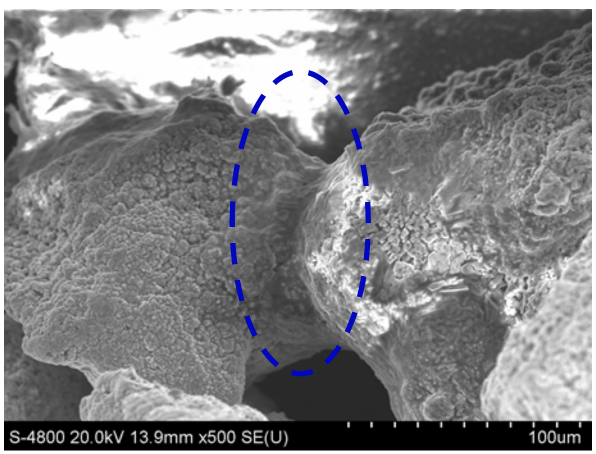


Fresh OC

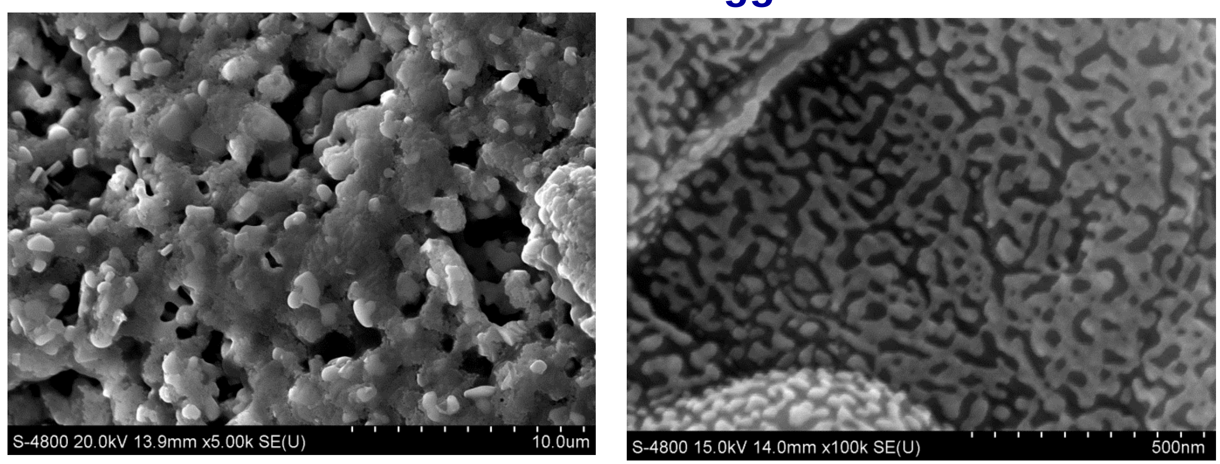
After 10 cycles



Soft Agglomeration



Sintering bridge



Molten surface (×5 k & ×100 k)

Future Plans

- Cyclic performance of catalyst-OC with CuO additives
  - ✓ Better heat balance between two reactors
- Modification of existing spouted bed facility
  - ✓ On going
- Demonstration of spouted bed reactor and performance evaluation of gasifier
- Process modeling and performance evaluation
  - ✓ Sensitivity study (operation pressure, OC/fuel/steam ratio and catalyst-OC type)

Available Instruments & Equipment



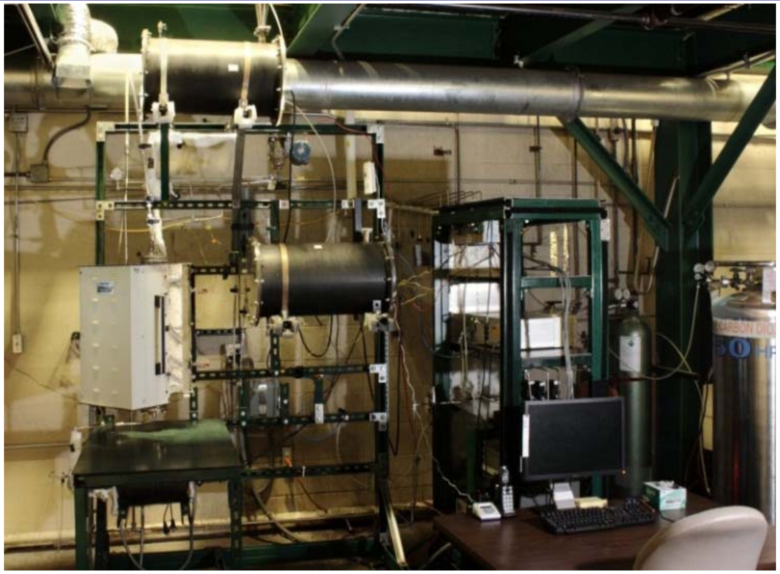


TGA/DSC/DTA/MS with WV Furnace

Hitachi S-4800

Philips X’pert

Available Facilities



Bench Scale Fluidized Bed Facility

Spouted Bed Reactor

Acknowledgement

- DOE/NETL
  - Briggs White, Heather Quedenfeld and Jenny Tennant
- CAER
  - Lisa Richburg, Jinhua Bao, and Heather Nikolic