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Iron-based chemical looping processes

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Iron-based Chemical Looping Processes

CO2 Summit II: Technologies and Opportunities

April 11th , 2016

Cheng Chung

Graduate Research Assistant

Advisor: Dr. Liang-Shih Fan

Outline

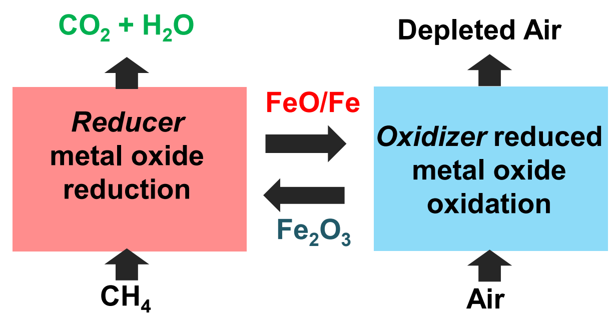
- Applications of chemical looping
- Oxygen carrier design criteria
- Moving-bed reactor design
- OSU chemical looping development
- Concluding remark

Applications of Chemical Looping

Combustion: Complete Fuel Oxidation

Reducer: Fe_2O_3 + CH_4 → **FeO/Fe** + **CO_2 + H_2O**
(oxidized) (reduced)

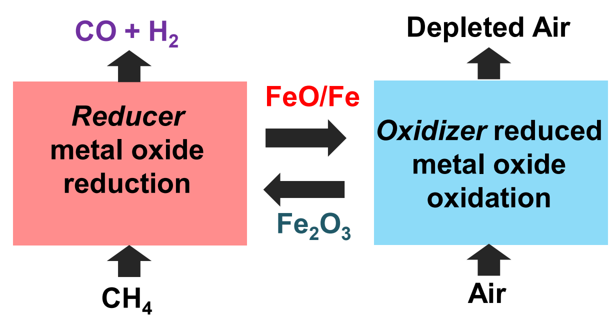
Oxidizer: **FeO/Fe** + Air (O_2) → **Fe_2O_3**



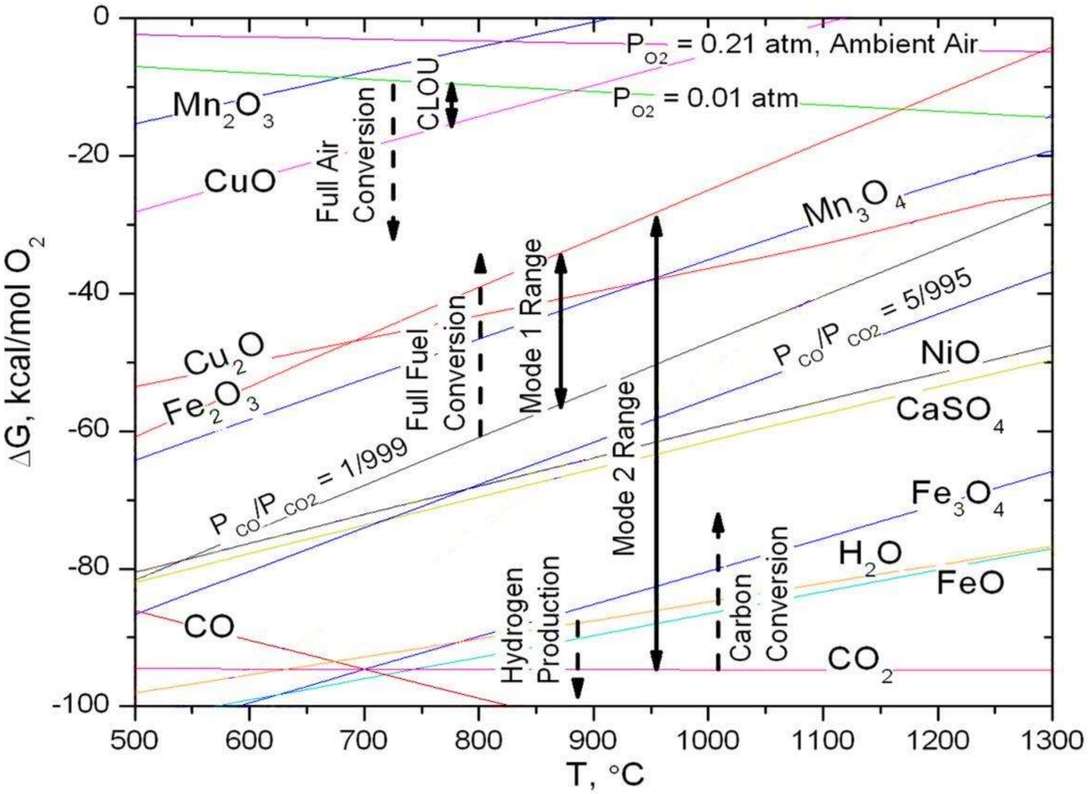
Gasification: Partial Fuel Oxidation

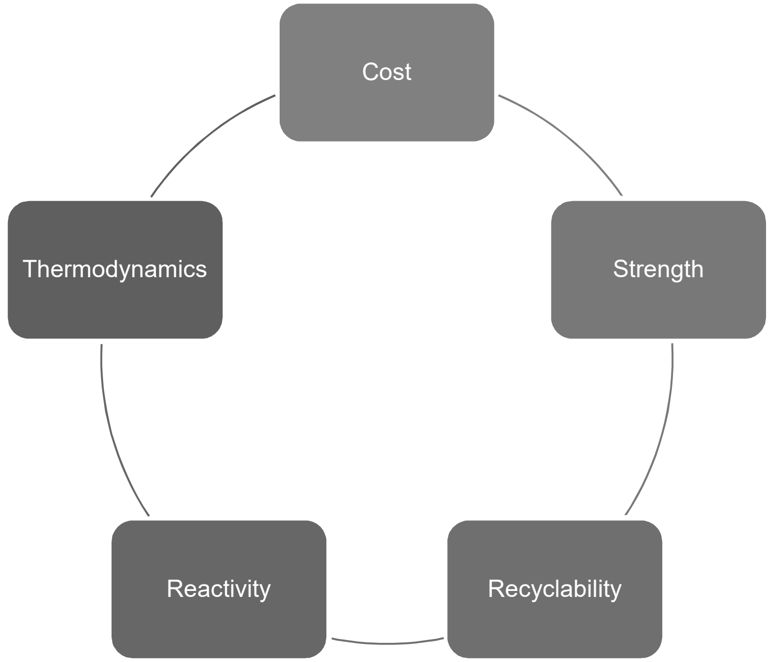
Reducer: Fe_2O_3 + CH_4→ **FeO/Fe** + **CO + H_2**
(oxidized) (reduced)

Oxidizer: **FeO/Fe** + Air (O_2) → **Fe_2O_3**



Oxygen Carrier Design Criteria





Oxygen Carrier Design Criteria

Cost Range ($/kg)

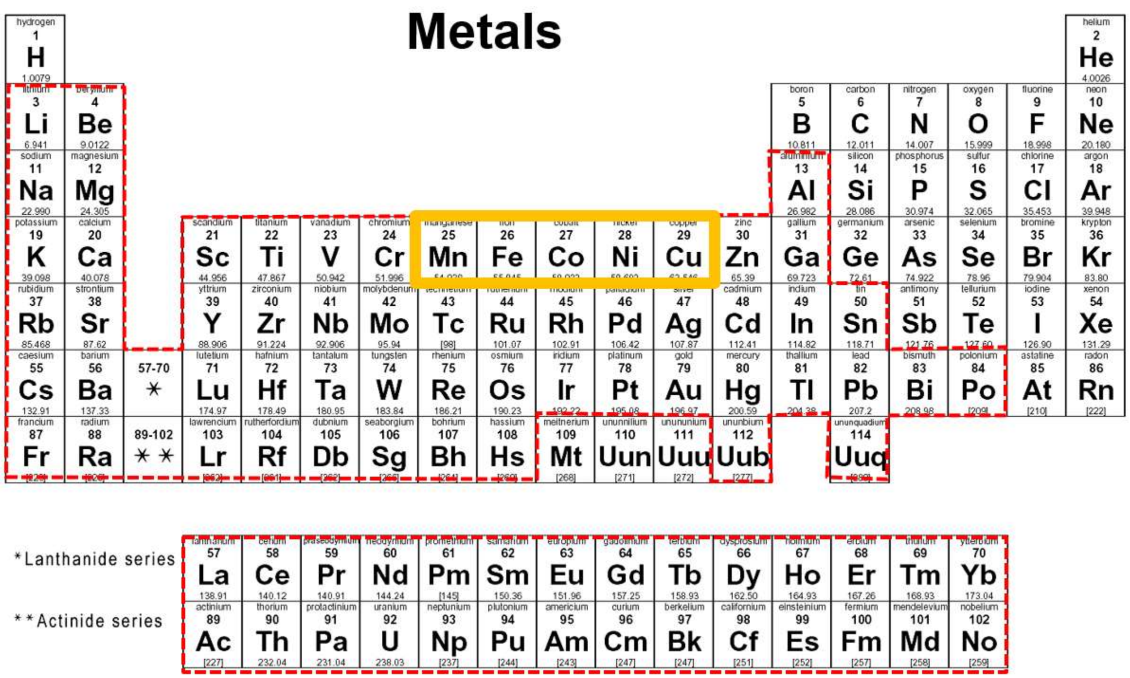
< $1/kg
Fe, K, Ca, Ti, Al, Ba, Na, Sr

$1/kg to $10/kg
Mn, Mg, Cu, Zn, Ce, Cd, Pb, Zr, Cr, La, Rb

$10/kg to $100/kg
Bi, Co, Hg, Sn, Ni, W, V, Li, Y, Nd, Gd

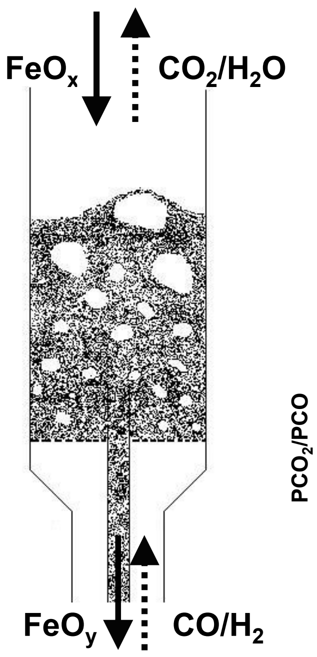
$100/kg to $1000/kg
Ga, In, Ag, Pr, Eu, Er

> $1000/kg
Tl, Dy, Ir, Lu, Ho, Tm, Yt, Ru, Au, Pt, Pd, Rh, Ra, Po, Cs, Sc

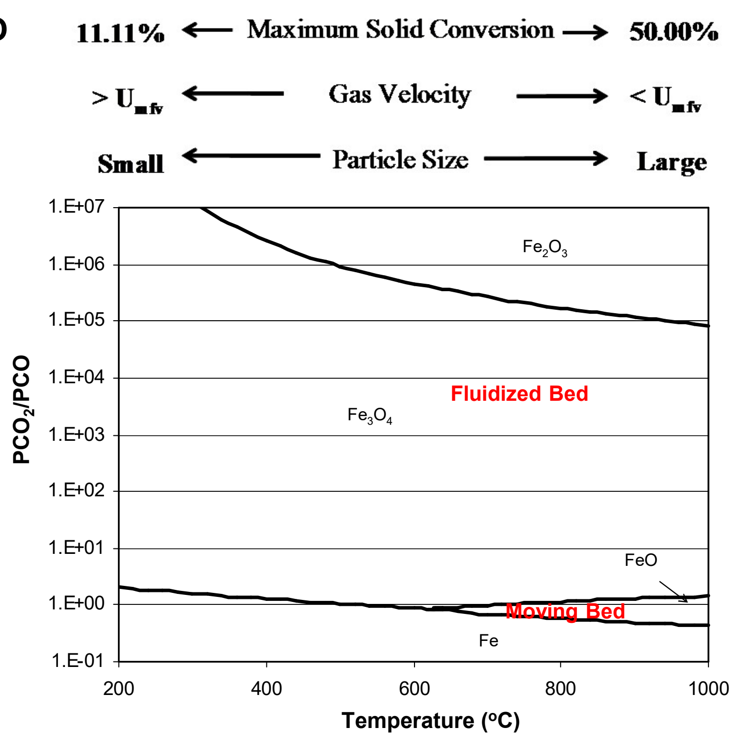


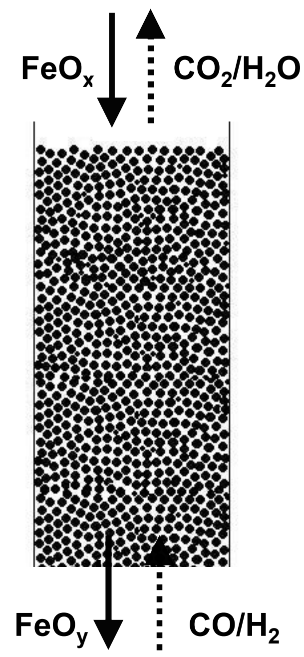
Reducer Design: Fluidized Bed vs Moving Bed

(x>y)



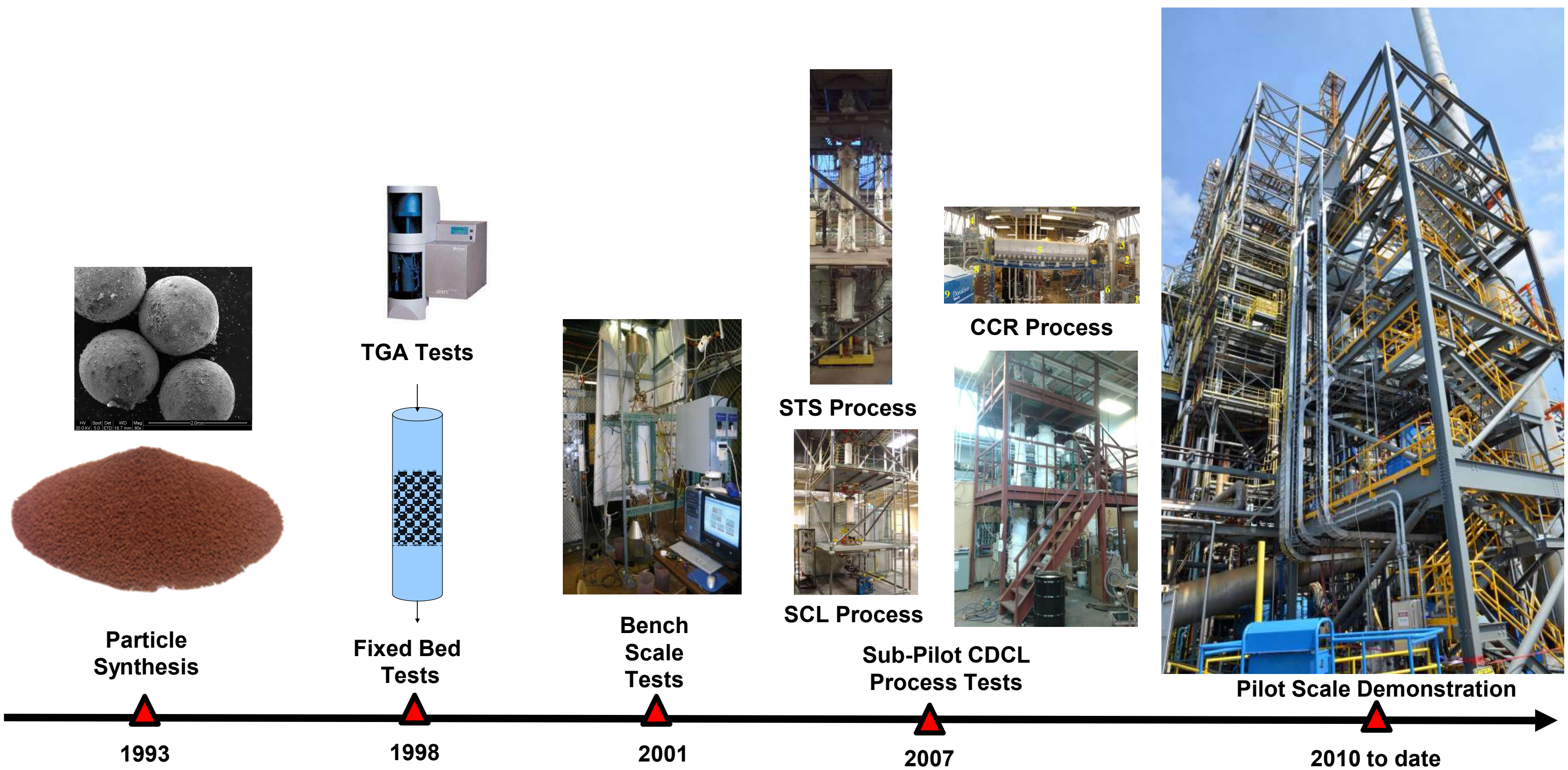
Fluidized Bed





Moving Bed

Evolution of OSU Chemical Looping Technology



OSU Chemical Looping Platform Technology

Feedstock

- Coal
- Natural Gas
- Oil
- Petcoke
- Biomass
- Waste
- Syngas
- F-T light hydrocarbon

Driver

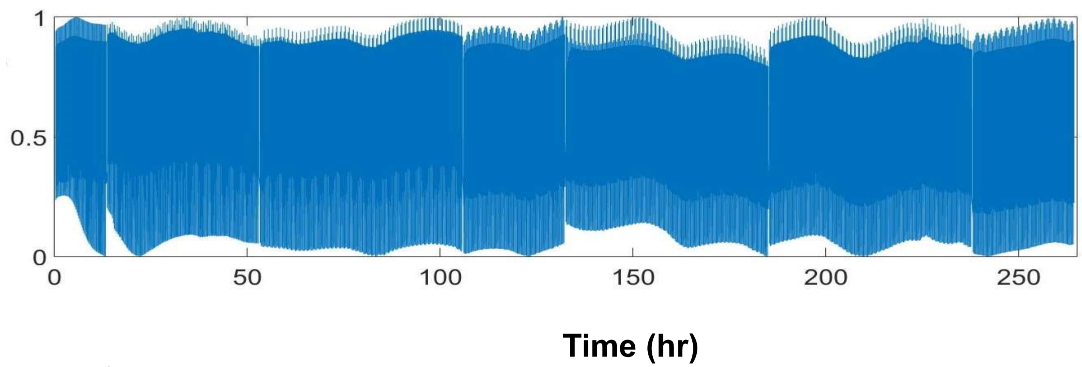
- Chemical Looping Combustion (CLC)
- Chemical Looping Gasification (CLG)
- Carbonation- Calcination Reaction (CCR)
- Calcium Looping Process (CLP)
- Direct Chemical Synthesis (with EcoCatalytic)

Applications and Products

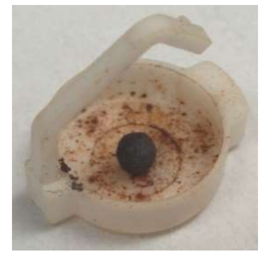
- CO_2 Capture/Emission Control
- Electricity/heat
  - Retrofit to PC
  - New Plant
  - Combined Cycle
  - SOFC
- Hydrogen
- CLG Syngas
- Liquid fuel
  - F-T Synthesis
  - CO_2 Hydrogenation
  - Olefins to Liquid Fuel
- Chemicals
  - Olefins
  - Ammonia

Recyclability of Metal Oxides and Composite Metal Oxides

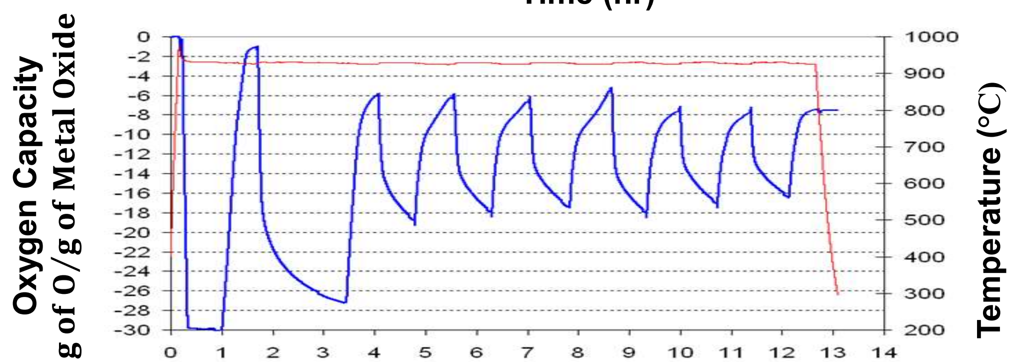
Cyclic Redox of Composite Fe_2O_3



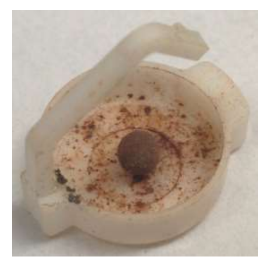
Before



Cyclic Redox of Pure Fe_2O_3

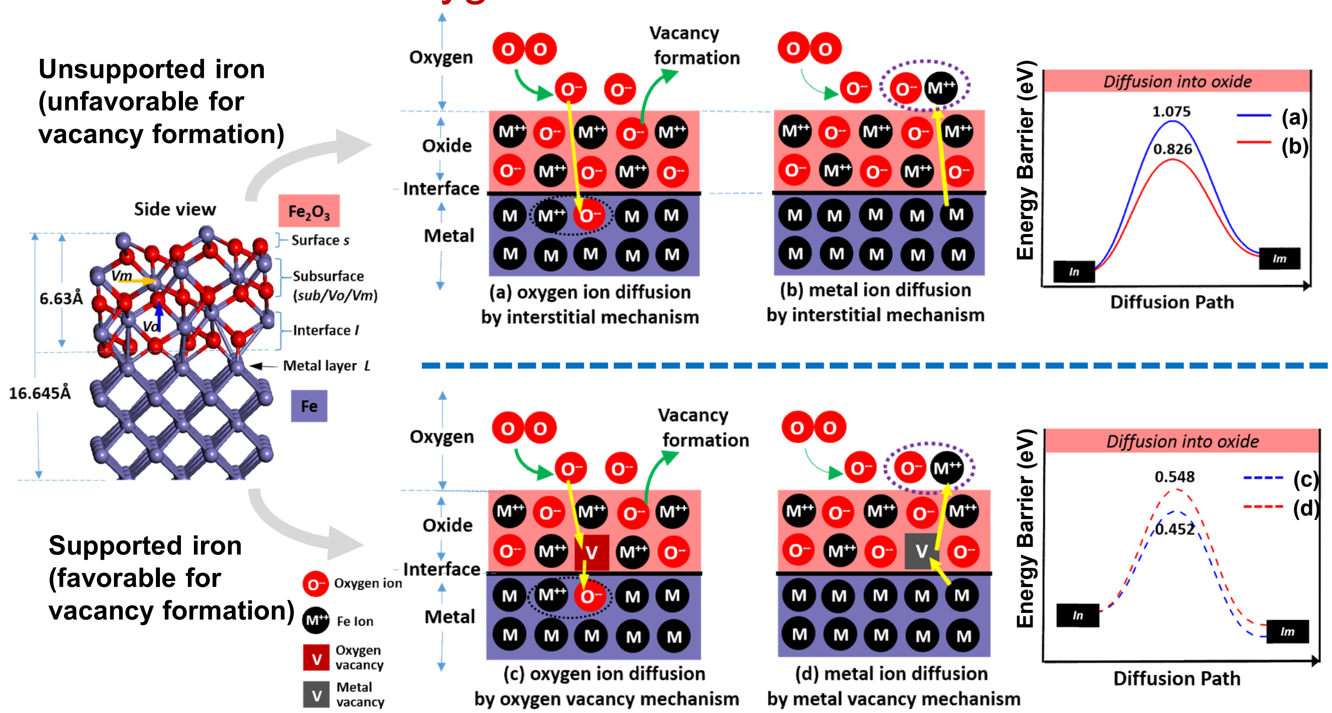


After

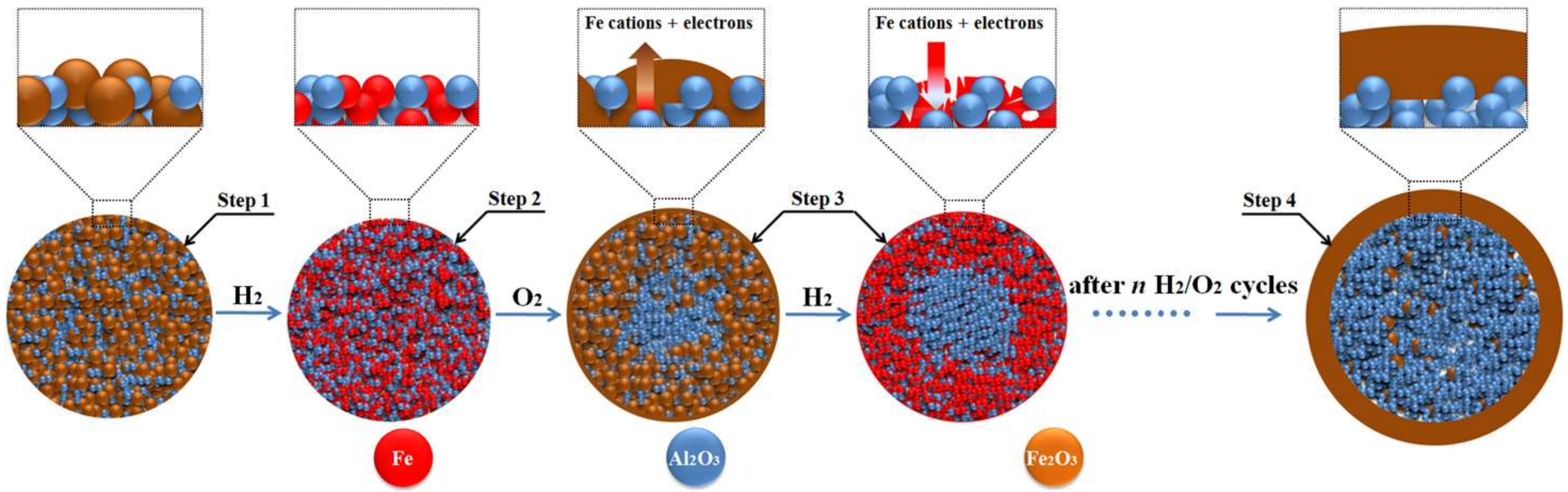


Diffusion Mechanism

Oxygen Anion vs Iron Cation

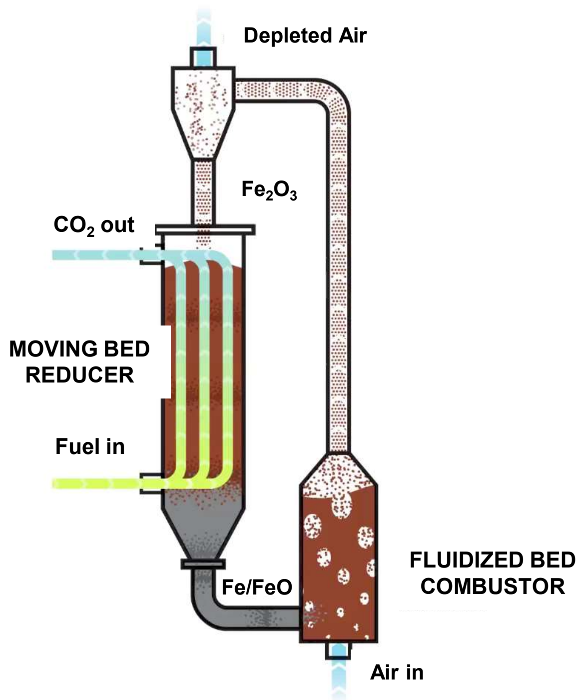


Core-Shell Particle Formation



Chemical looping Combustion vs. Gasification

Counter-current: Full Combustion

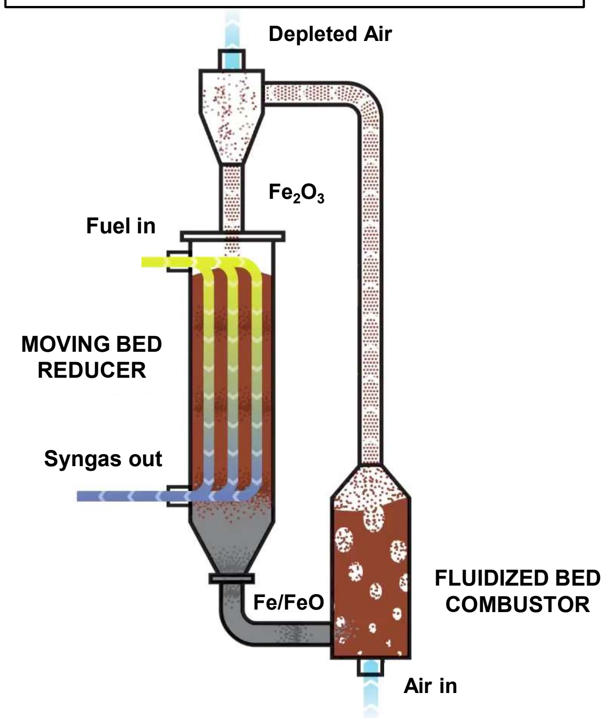


Simplicity:
One Loop

Unique Reducer Configuration:
Moving Bed

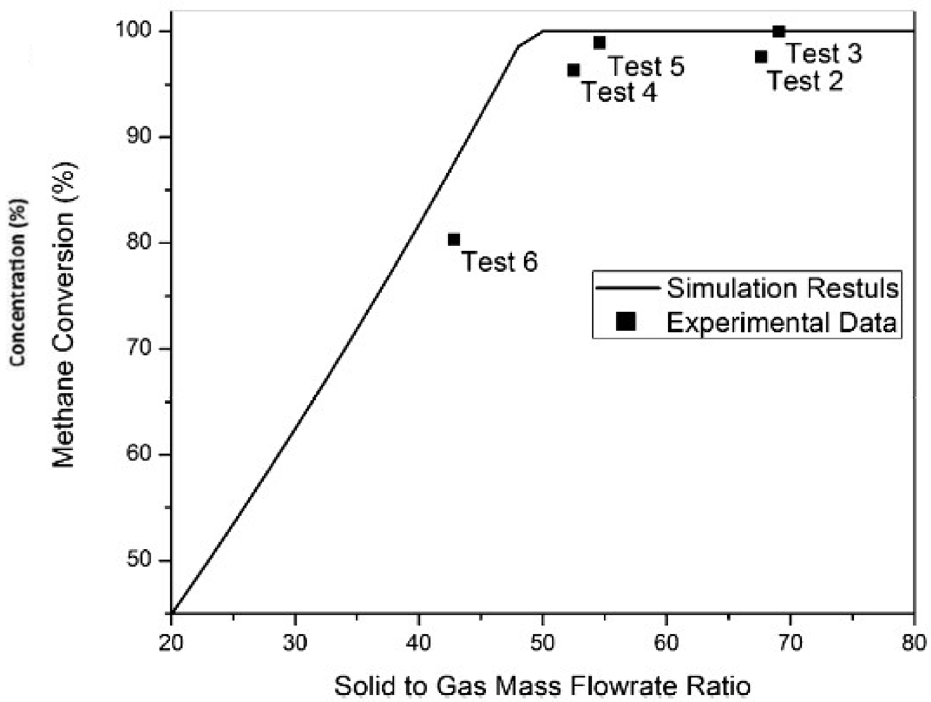
Unique Flow Controller:
Non-Mechanical
L-Valve

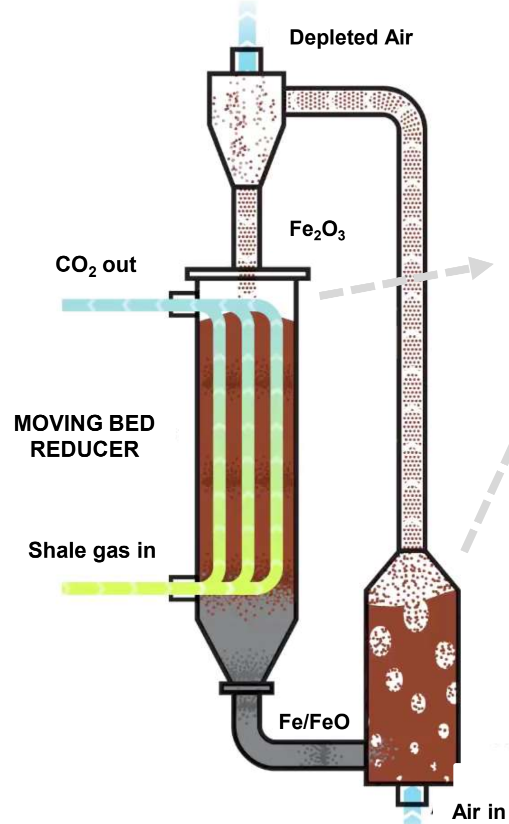
Co-current: Full Gasification



Shale Gas Chemical Looping Combustion

- **>98% Methane Conversion**
- **Data in good agreement with simulation results**





Main Reactions

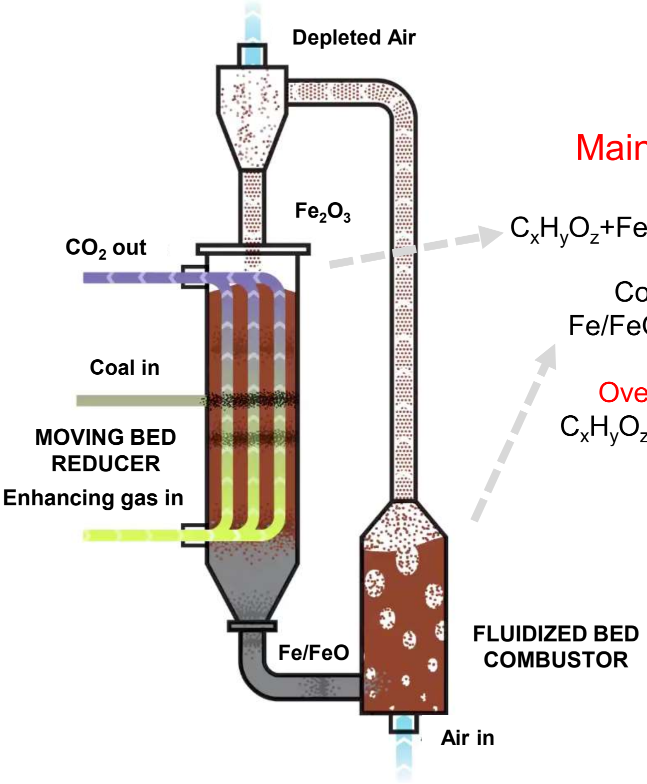
Reducer:
$CH_4+Fe_2O_3 \rightarrow CO_2+H_2O+Fe/FeO$

Combustor
$Fe/FeO+O_2 \rightarrow Fe_2O_3$

Overall Reaction
$CH_4+O_2 \rightarrow CO_2+H_2O$

Coal-direct Chemical Looping Combustion

25 kW_{th} Sub-Pilot Unit



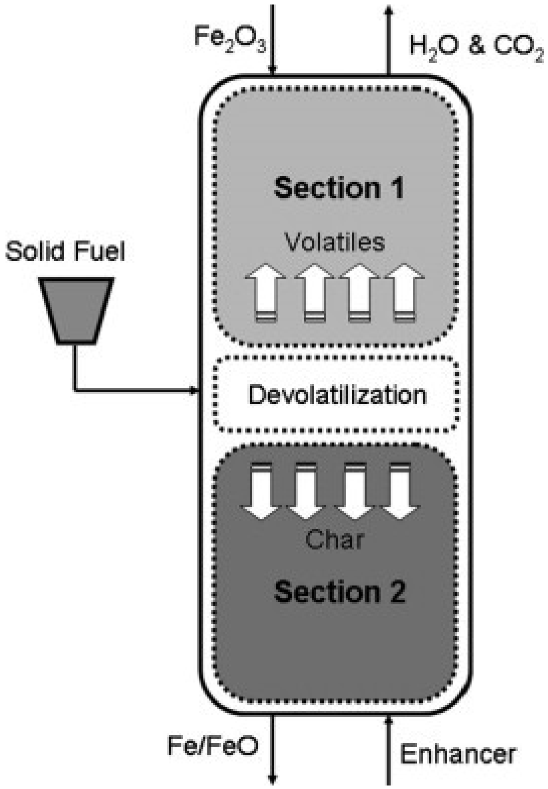
Main Reactions

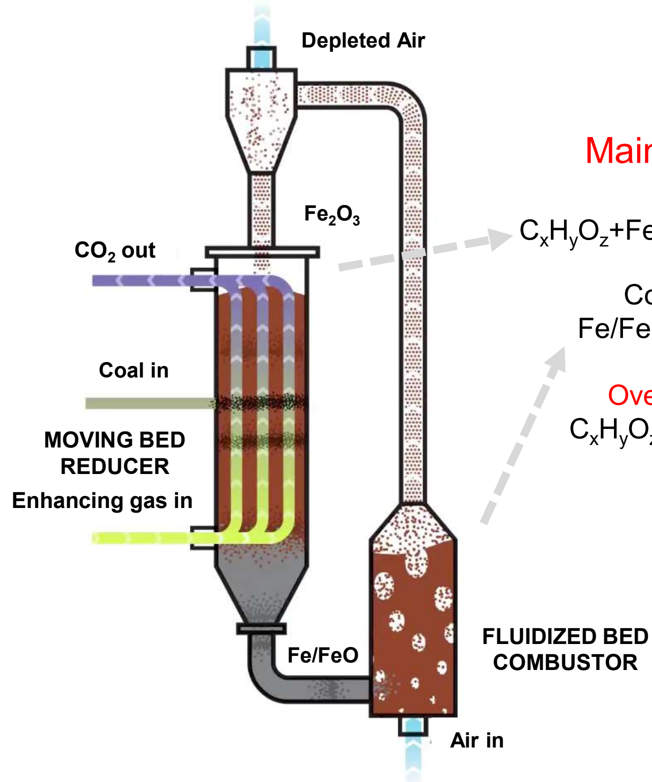
Reducer:
$C_xH_yO_z + Fe_2O_3 \rightarrow CO_2 + H_2O + Fe + FeO$

Combustor:
$Fe/FeO + O_2 \rightarrow Fe_2O_3$

Overall Reaction:
$C_xH_yO_z + O_2 \rightarrow CO_2 + H_2O$

Coal-direct Chemical Looping Combustion





Main Reactions

Reducer:

$C_xH_yO_z+Fe_2O_3 \rightarrow CO_2+H_2O+Fe+FeO$

Combustor:

$Fe/FeO+O_2 \rightarrow Fe_2O_3$

Overall Reaction:

$C_xH_yO_z+O_2 \rightarrow CO_2+H_2O$

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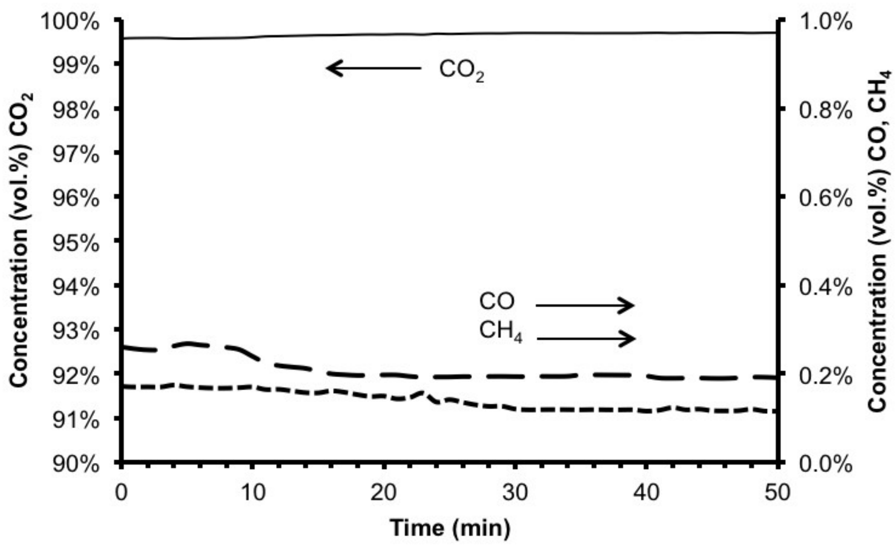
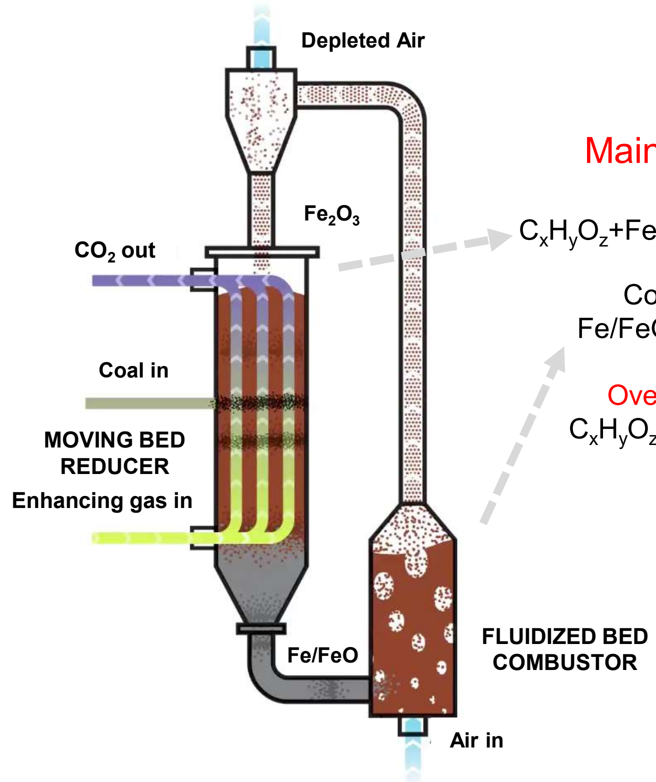
Coal-direct Chemical Looping Combustion





Main Reactions

Reducer:

$C_xH_yO_z+Fe_2O_3 \rightarrow CO_2+H_2O+Fe+FeO$

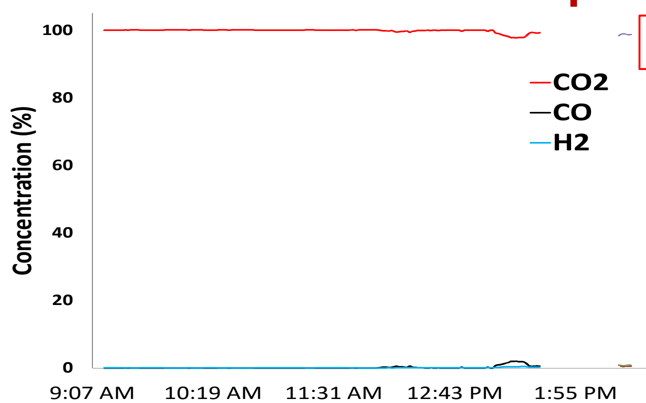
Combustor:

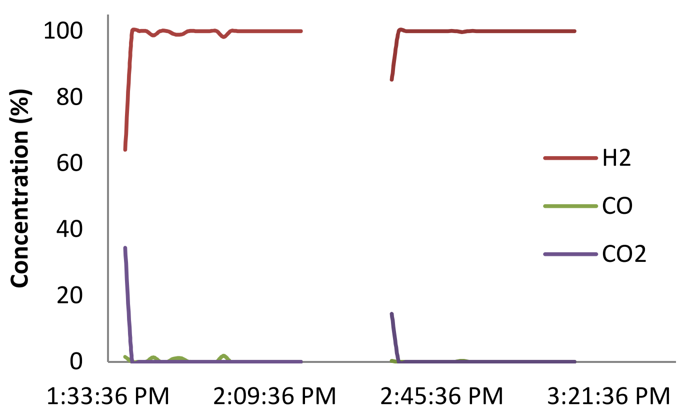
$Fe/FeO+O_2 \rightarrow Fe_2O_3$

Overall Reaction:

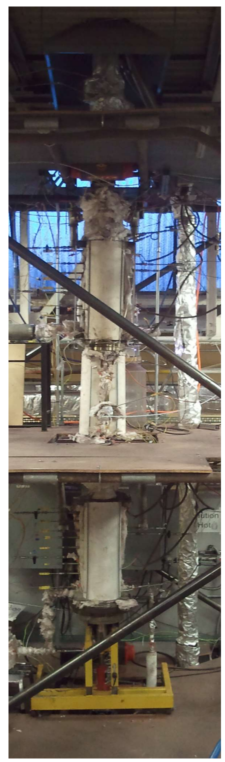
$C_xH_yO_z+O_2 \rightarrow CO_2+H_2O$

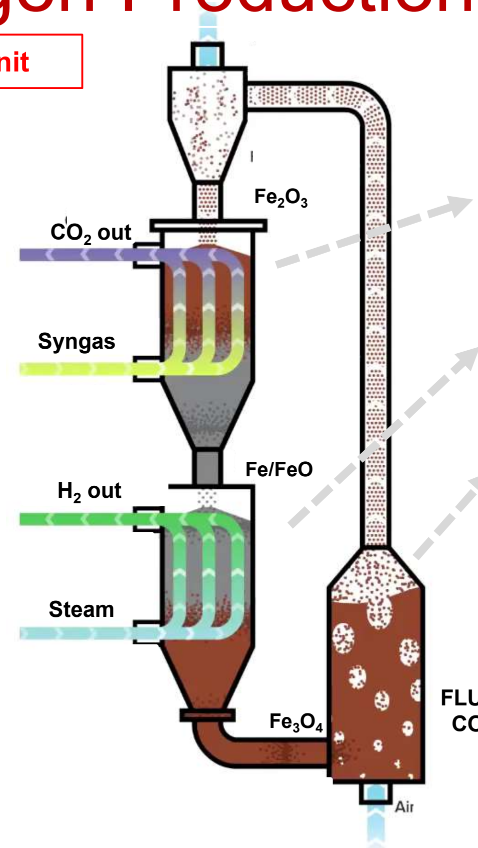
Chemical Looping Hydrogen Production Process





25 kW$_{th}$ Sub-Pilot Unit





Main Reactions

Reducer:
$CO+H_2+Fe_2O_3 \rightarrow CO_2+H_2O+Fe/FeO$

Oxidizer
$Fe/FeO+H_2O \rightarrow Fe_3O_4+H_2$

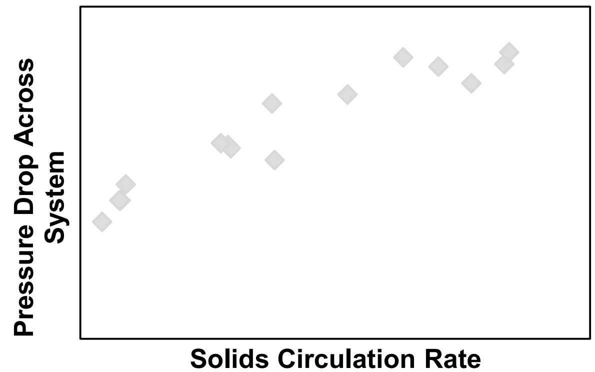
Combustor
$Fe_3O_4+O_2 \rightarrow Fe_2O_3$

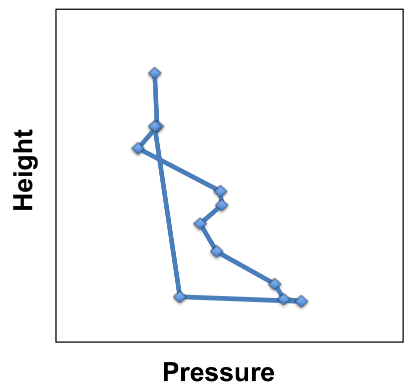
Overall Reaction
$CO+H_2+H_2O+O_2 \rightarrow CO_2+H_2O+H_2$

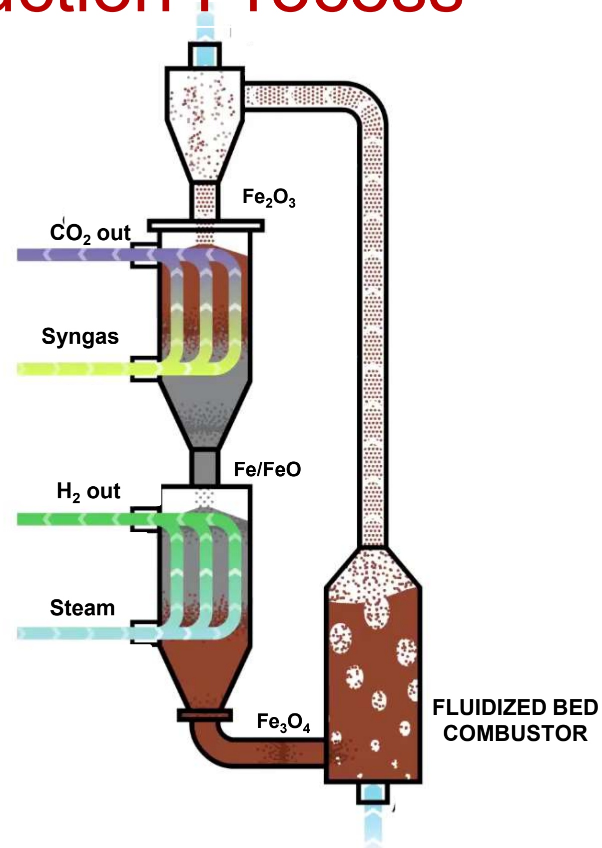
Chemical Looping Hydrogen Production Process

250 kW_{th} - 3 MW_{th} High-Pressure Pilot Unit

1:1 Pilot Unit Cold Model

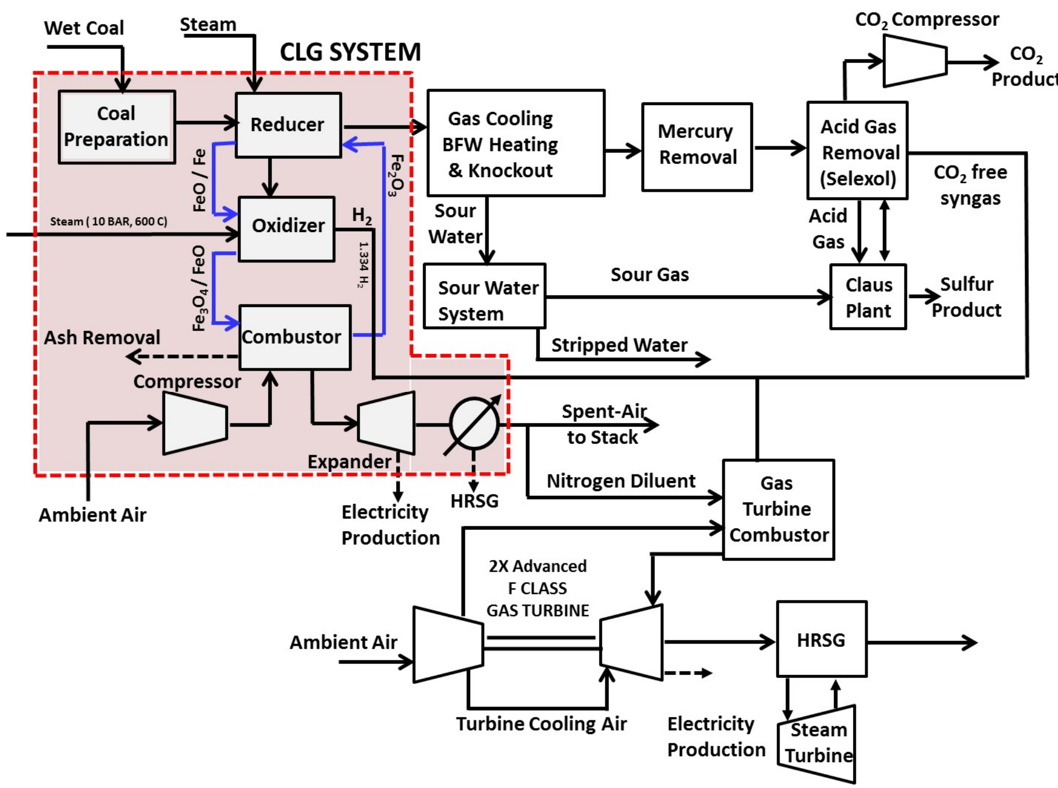




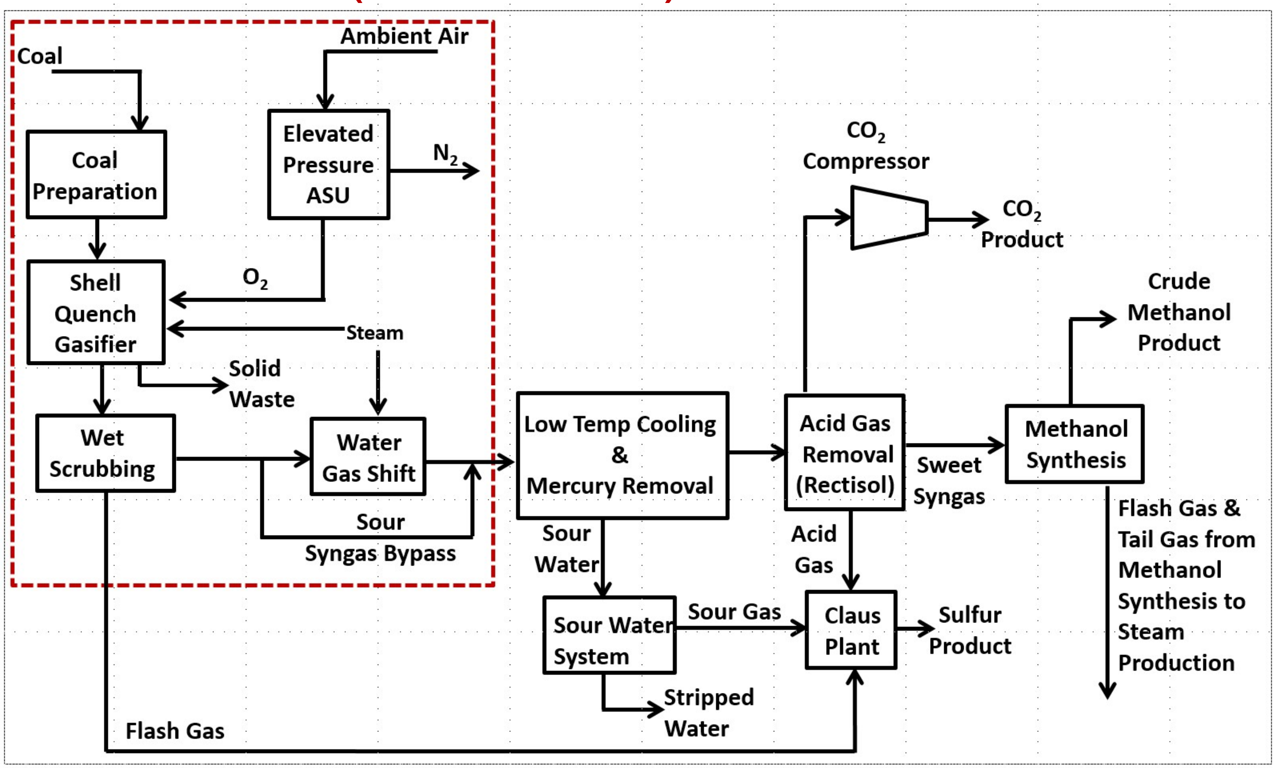


IGCC system with Chemical Looping Gasification

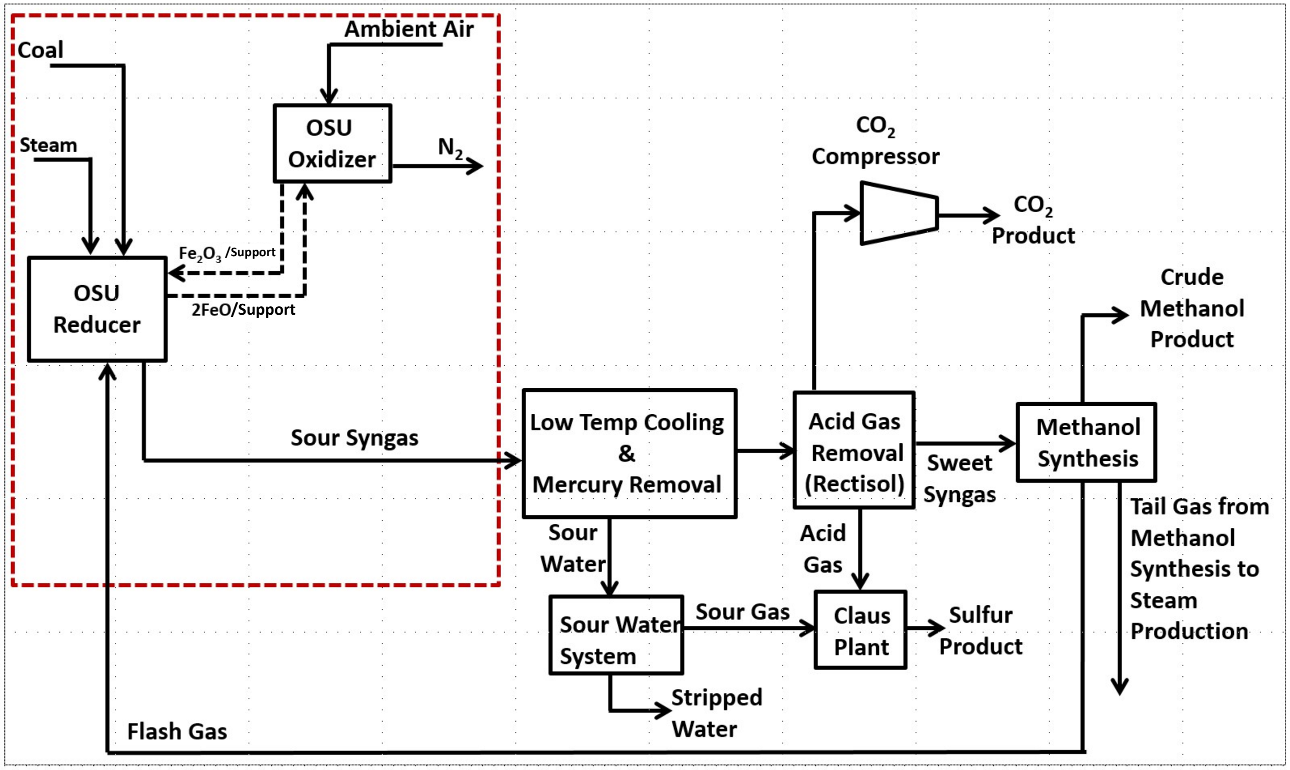
Preliminary economic analysis shows 16-20% decrease in FYCOE when compared with ASU/Gasifier technology with IGCC



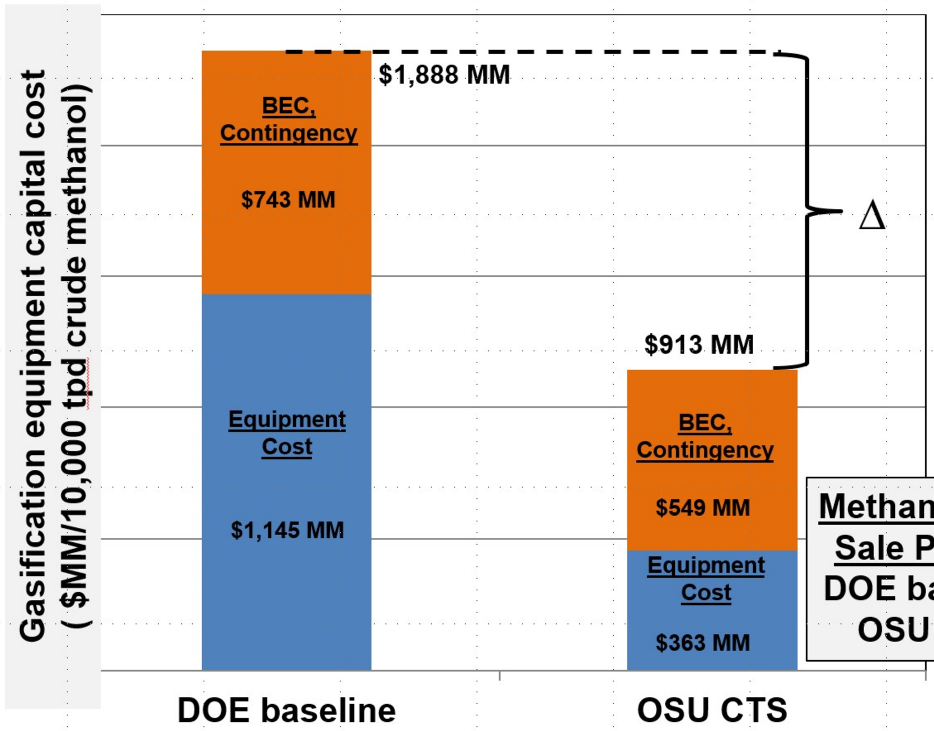
Coal Gasification for Methanol Production: DOE Baseline (Traditional) Process



Coal Gasification for Methanol Production with Chemical Looping



Cost Analysis: Total Plant Capital Cost for 10,000 ton/day Methanol Production from Coal



Methanol Required Sale Price ($/gal):
DOE baseline: 1.78
OSU CTS: 1.41

Concluding Remarks

- The full potential of chemical looping technology is realized with the synergistic effect between oxygen carrier material and suitable reactor configuration
- It is highly tunable, and offers a wide range of opportunities in fossil fuel conversion
- Chemical looping process is compatible with existing technology and can offer significant cost-saving opportunities

Industrial Collaborators

WorleyParsons Group

Babcock & Wilcox Power Generation Group

Particulate Solid Research, Inc.

Test Site Host

National Carbon Capture Center

Sponsors

U.S. Department of Energy (NETL and ARPA-E)

Ohio Development Services Agency

The Ohio State University