Solid Fuels Conversion Using the Iron-Based Chemical Looping Process

The Ohio State University
Chemical and Biomolecular Engineering

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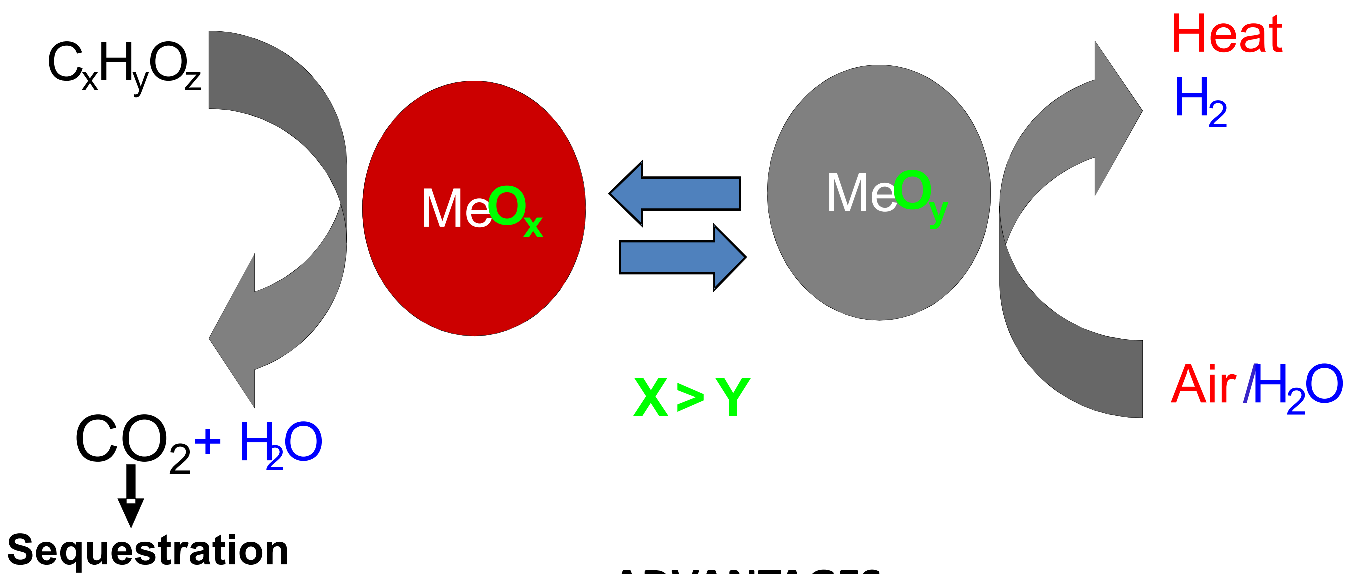
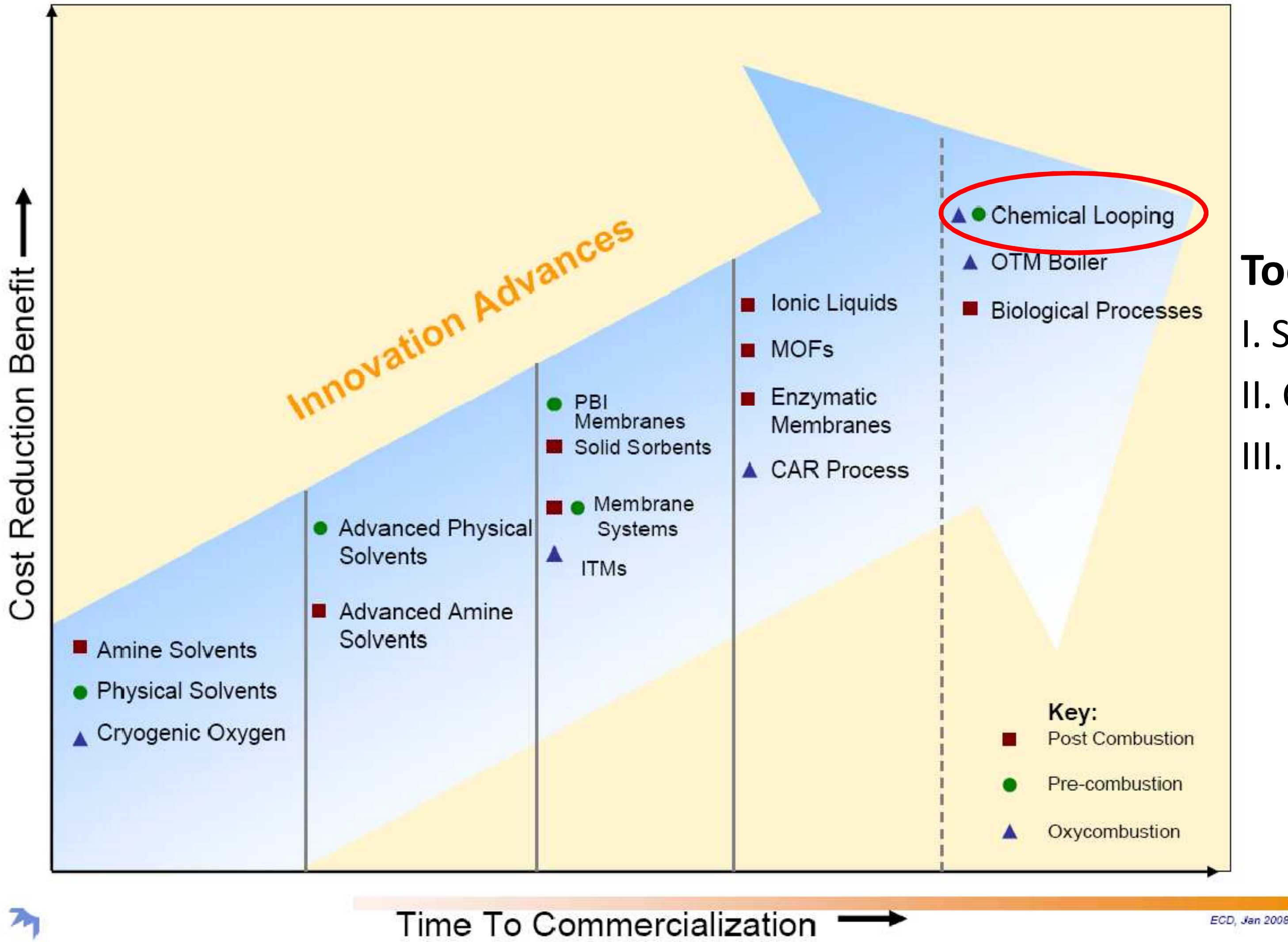
Chemical Looping Combustion/Gasification Processes



ADVANTAGES

- Indirect Oxidation of the Fuel – separate the Air and the Fuel
- No CO_2 separation cost – prevent dilution of CO_2 with N_2 in Air
- Fuel Flexibility – concept can be applied to any carbonaceous fuel
- Product Flexibility – co-generate H_2 and electricity, and also Liquid Fuels
- Variety of metal oxide – Fe, Ni, Mn, Cu

Chemical Looping Process



Today's Presentation

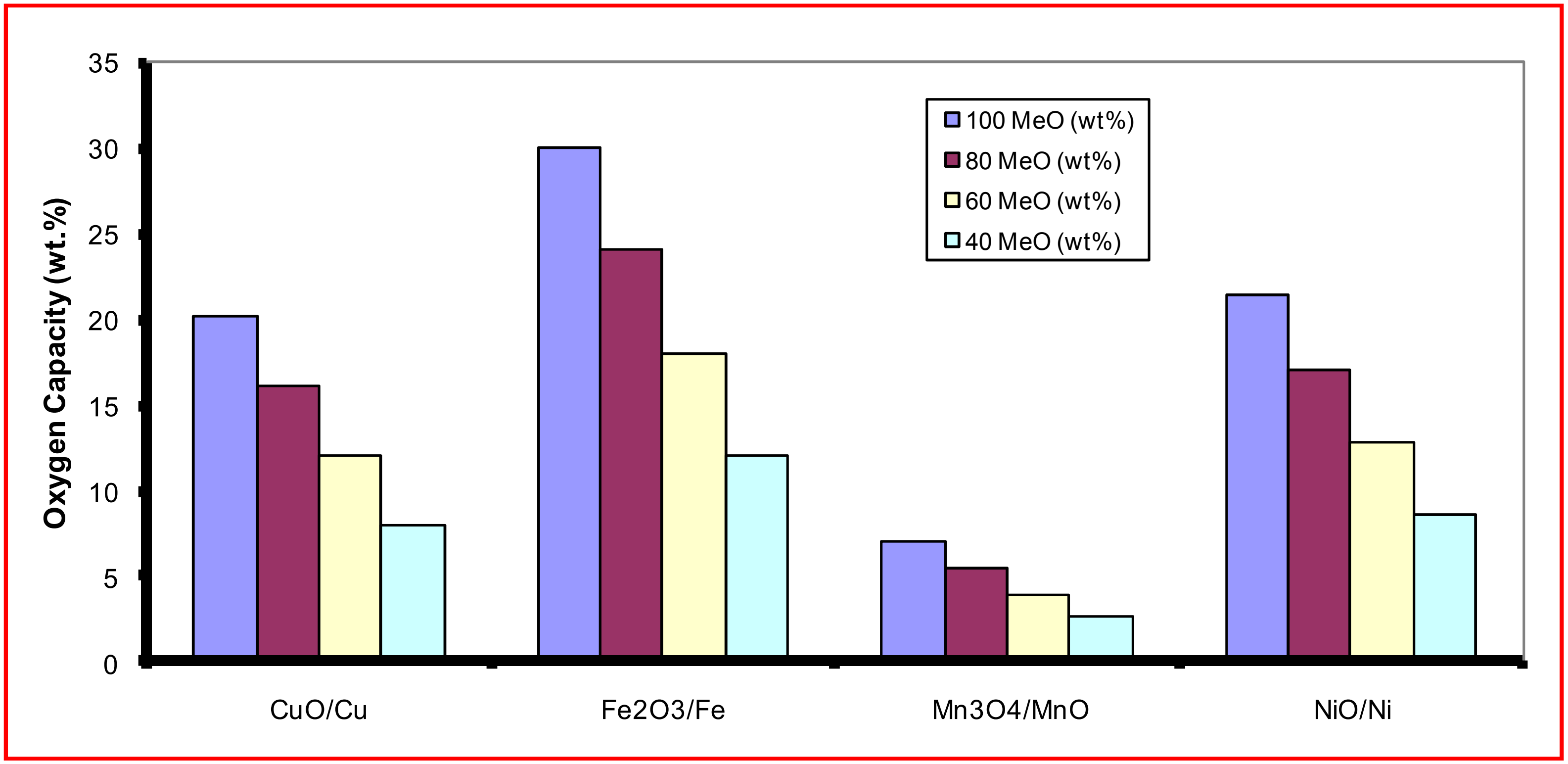
I. SCL

II. CL in CTL

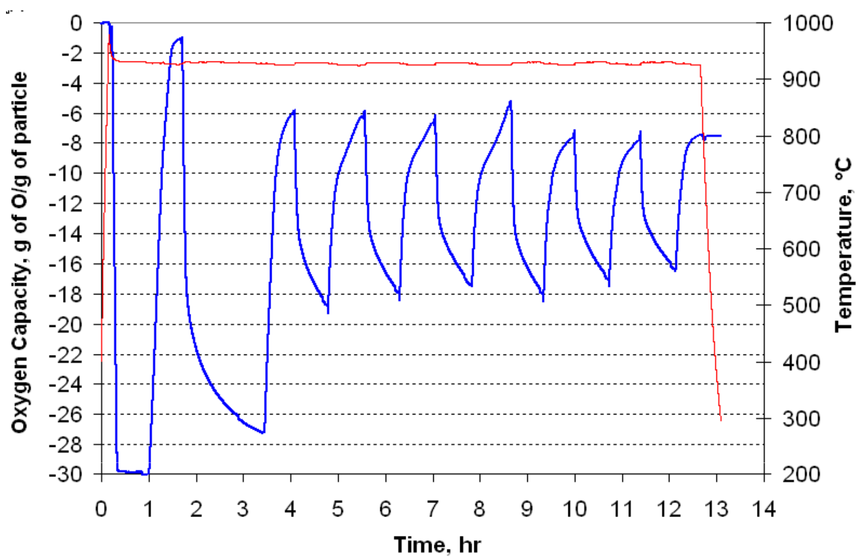
III. CDCL

Technical Merit - Particle Performance

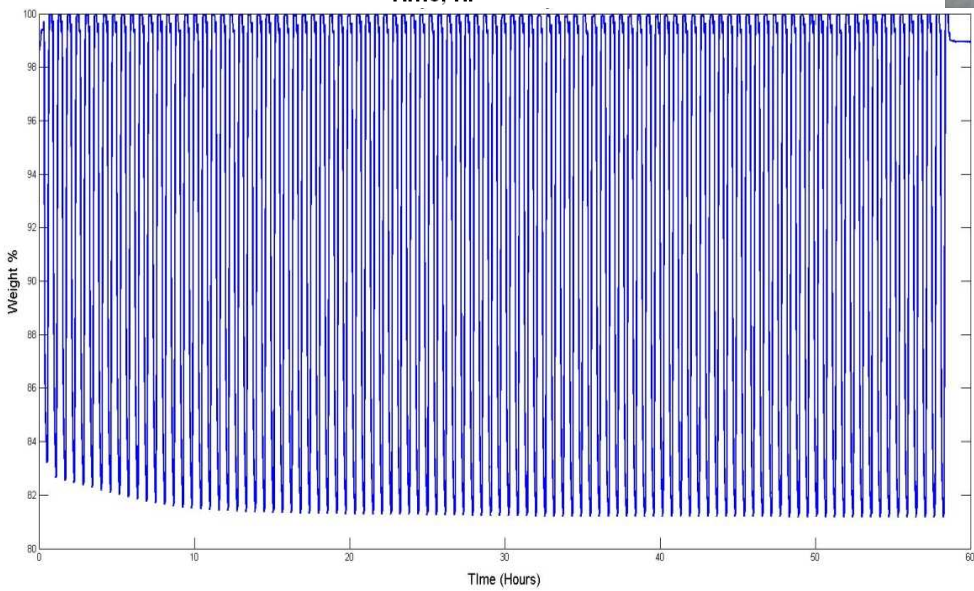
- Iron Based Composite Particle
  - **Low Cost**
    - Much less than NiO & CuO
  - **Strong Physical Strength**
    - 120 MPa
  - **High Oxygen Capacity**
    - Higher conversion/Low Solid Handling
    - Efficient combustion
  - **Reactivity & Recyclability**
    - Higher conversion
    - Low make-up cost



OSU Particle vs. Commercial Fe_2O_3



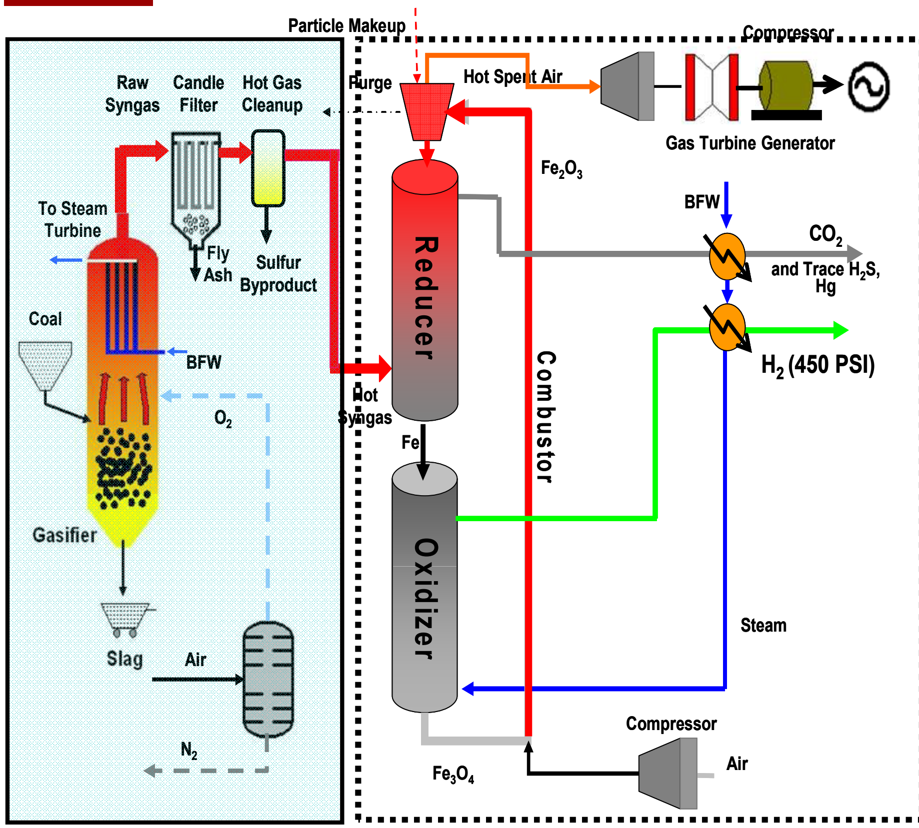
- Not Recyclable
- Non-Uniform Reactivity
- Separation Issue



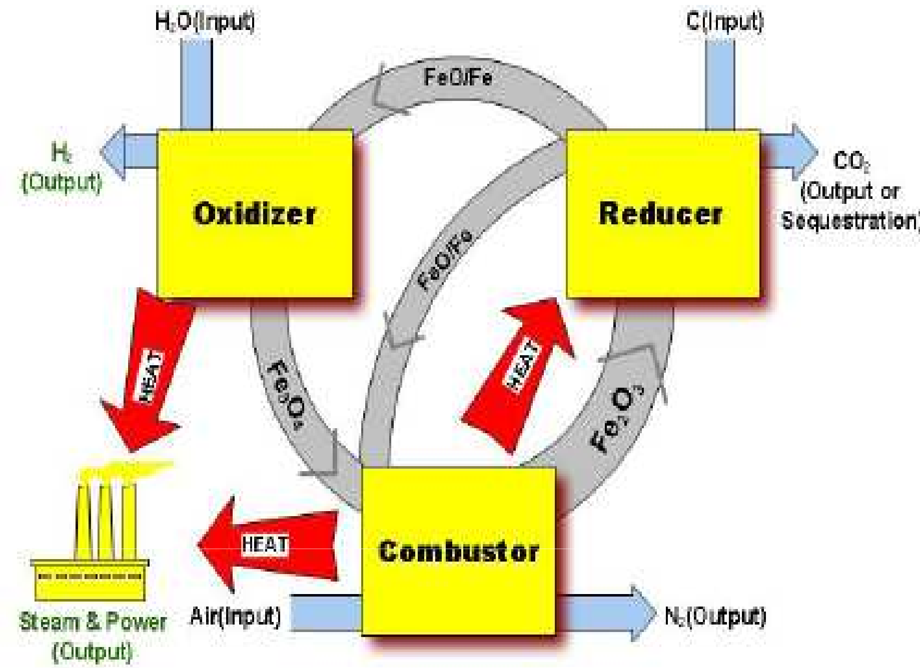
- Processed and Pelletized
- More Than 100 Cycles of Reduction and Oxidation
- More Than 75 Hours of Reactions
- Low Particle Make-up

Process Configuration I

Syngas Chemical Looping - Process Flow



State-of-the-art Developed at OSU

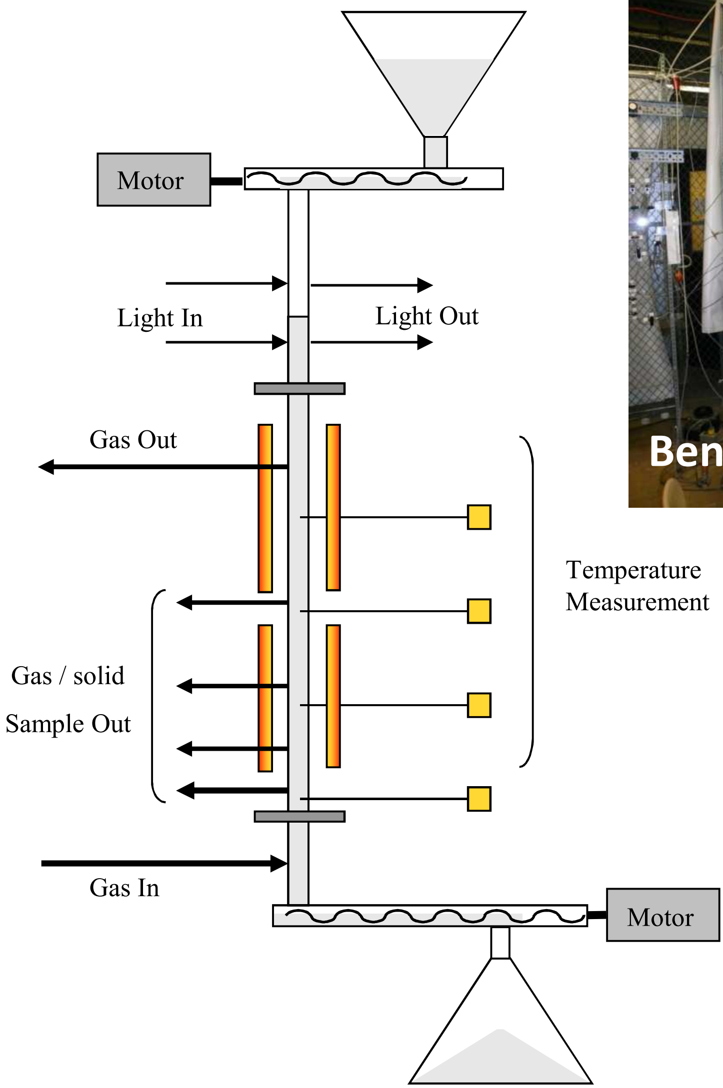


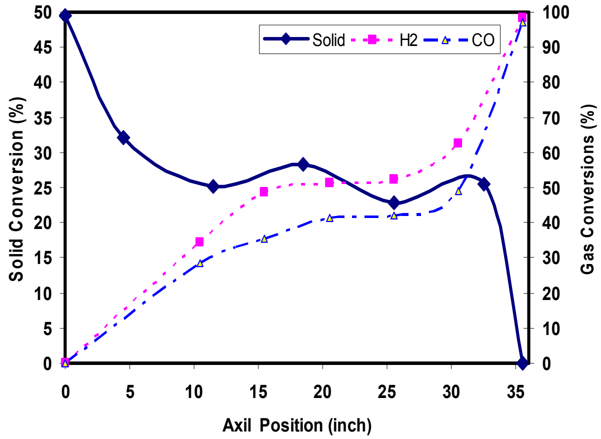
	IGCC Process	SCL Process Electricity	Conventional Coal to Hydrogen Process	SCL Process
Coal feed(ton/hr)	132.9	132.9	132.9	132.9
Carbon Capture(%)	90	100	90	100
Hydrogen(ton/hr)	0	0	14.4	15.6
Net Power(MW)	348.1	422.0	57.6	57.4
Efficiency(%HHV)	34.8	42.2	62.7	66.5

- Can co-generate any ratio of H_2 and Electricity from gaseous fuels

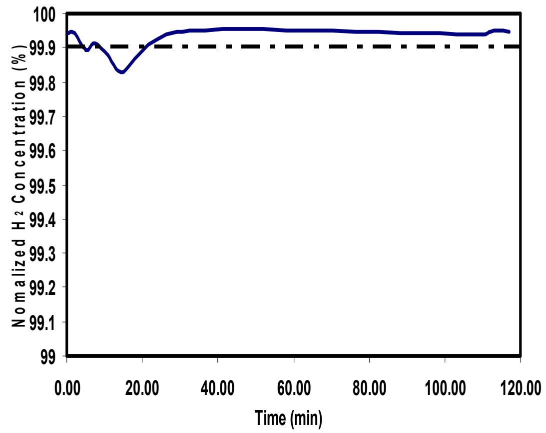
- Improved efficiency for H_2 or electricity generation compared to conventional state-of-the-art processes using Coal

Syngas Chemical Looping - Key Performance Results





~100% conversion of syngas



Avg. H_2 purity > 99.99%z

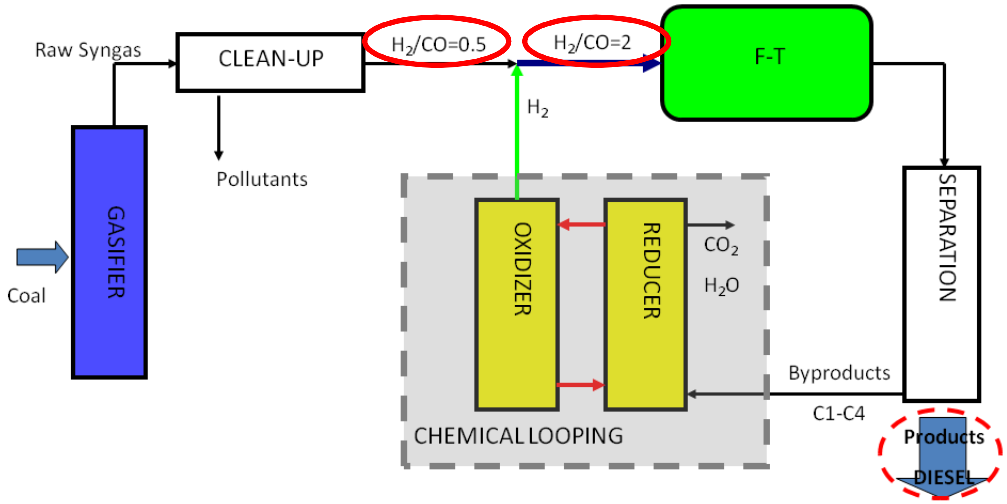
Syngas can be fully converted to CO_2 and H_2O in the Reducer. High purity H_2 generated with solids fully regenerated to Fe_2O_3 in Combustor

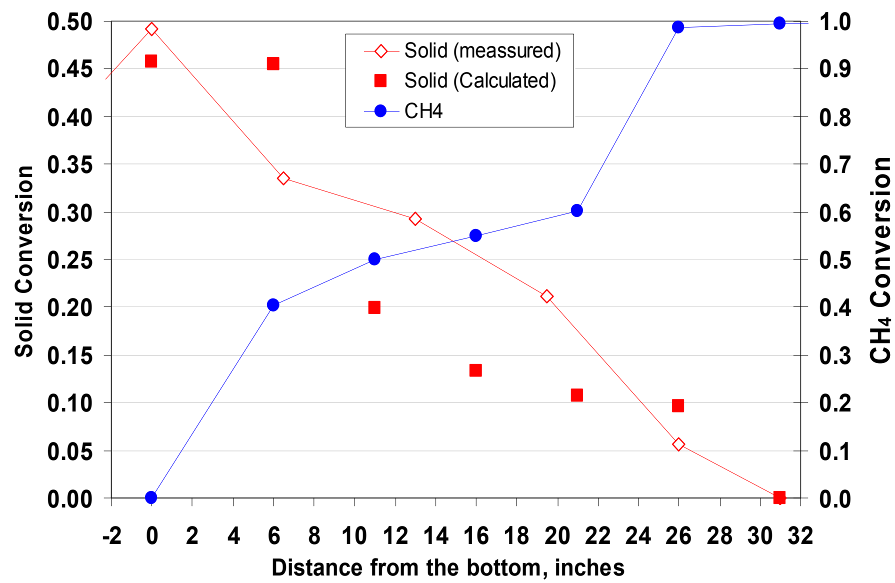
Accomplishments of the SCL Demonstrations

- **2.5 kW_{th}** Demonstration Completed, > 99.5% Pure CO_2 and >99.95% Pure Hydrogen Obtained
- **H_2 Production:** SCL is 7 – 10% More Efficient Than Conventional Process (Analyzed by SAIC)
- **Electricity Generation:** SCL is 4.5 – 7% More Efficient Than IGCC with 100% CO_2 Capture (Analyzed by Noblis)
- **A 25 kW_{th} Sub-Pilot** unit constructed and successfully operated, >90% in both syngas conversion and H_2 purity obtained
- DOE/ARPA-E grant awarded, a **250 kW_{th}** plant is being designed and will be constructed at NCCC (National Carbon Capture Center) in Alabama.

Process Configuration II

Chemical Looping in CTL



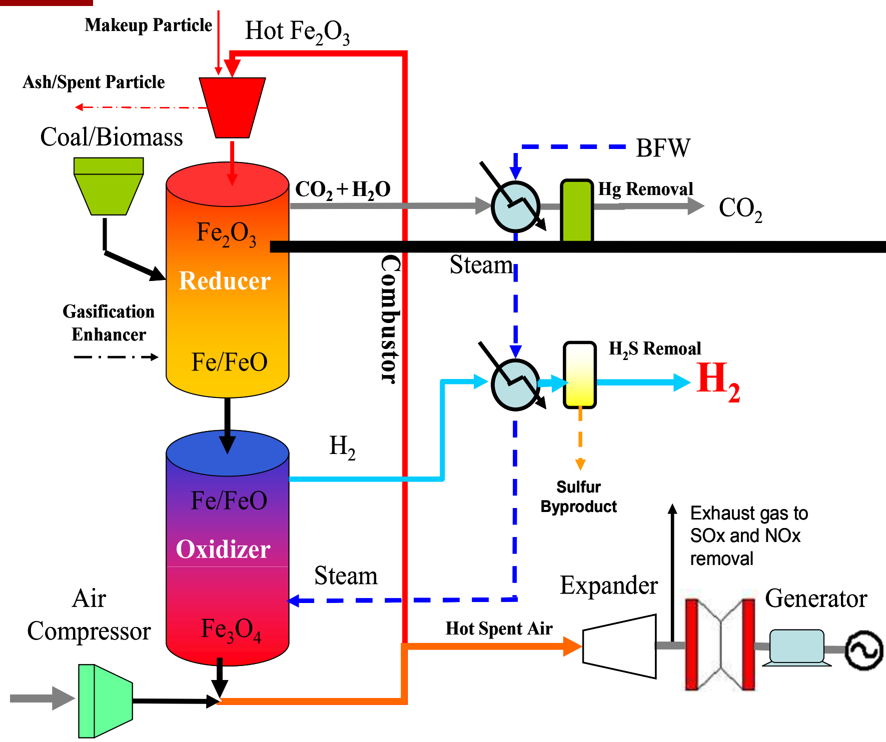


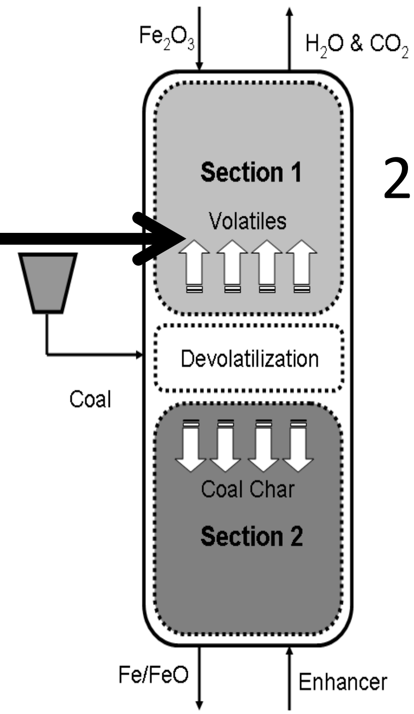
- No Water-Gas Shift Reactor for H_2 Make-Up
- Recycle Stream (Low Hydroarbon By-Products) from FT utilized to achieve 2:1 = H_2:CO by Chemical Looping
- Bench Scale Demonstration for CH_4 (Most Stable Hydrocarbon) Conversion
  - Nearly 100% CH_4 Conversion in Moving Bed

When Integrated CTL, SCL can Increase the Liquid Fuel Yield by 10% with 19% Reduction in CO_2 Emission (Analyzed by Noblis)

Process Configuration III

Coal Direct Chemical Looping – Process Flow





2-Stage Moving Bed

Counter-current flows
Gaseous volatiles
Coal char

More challenging reducer operation less developed compared to SCL due to handling of solids at different sizes : Pulverized coal (~μm) vs. OC (2-5mm)

- **No need for Capital/Energy Intensive Gasifier and Air Separation Unit**
- **Great Scheme for the Retrofit to PC**

Reaction Enhancer

- Initiates the solid-solid reaction
- Direct enhancer : CO_2, H_2O, O_2
  - $CO_2 + C \rightarrow 2CO$
  - $H_2O + C \rightarrow H_2 + CO$
- Indirect enhancer : H_2
  - $3H_2 + Fe_2O_3 \rightarrow 2Fe + 3H_2O$

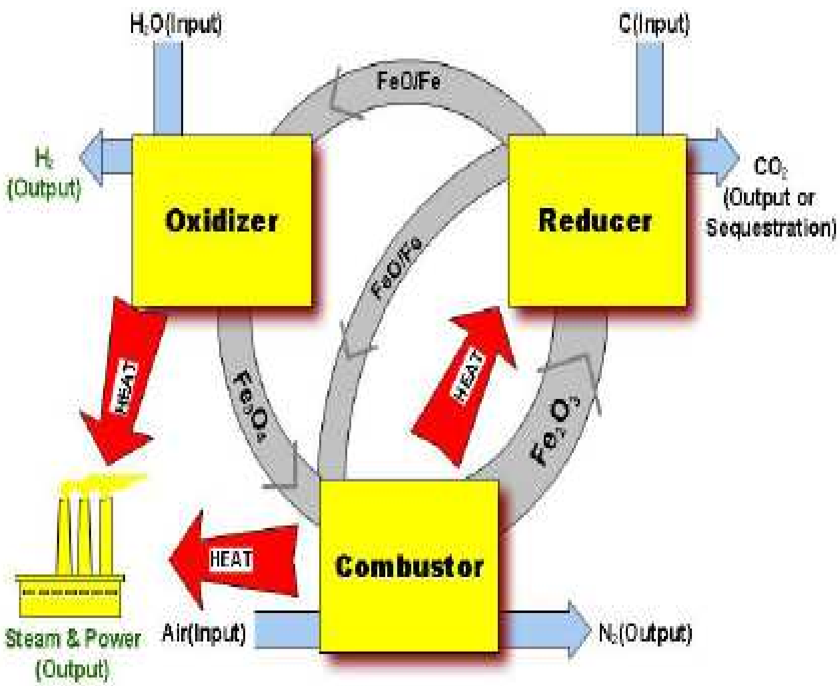
Coal Direct Chemical Looping – ASPEN simulation results

Mass Balance of the CDCL process for H_2 production

Stream	Input			Recycled Solids	Output				
	Coal	Water	Air		Off Gas	CO_2	H_2	Ash	Other
Temperature (°C)	25			1,250	120	40	40	800	25
Pressure (atm)	1			30	16	135	60	30	1
Mass Flow (t/hr)	132.9	178	477.7	2,312.2	373.4	311.8	19.9	12.9	70.6

Energy Balance of the CDCL process for H_2 production

	Coal Feedstock	Air Compressor (Electricity Consumption)	Steam Turbine (Electricity Generation)	H_2 Product	Waste Heat
Energy (MW)	1000	67.3	–67.5	–782.9	–216.9



- Hydrogen Production: CDCL can produce hydrogen with **~80% efficiency** (Obtained through ASPEN Plus® Simulations)
- Electricity Generation: CDCL has the potential to achieve **~50% Efficiency with 100% CO_2 Capture**

Team Work is Key

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Ray Kim
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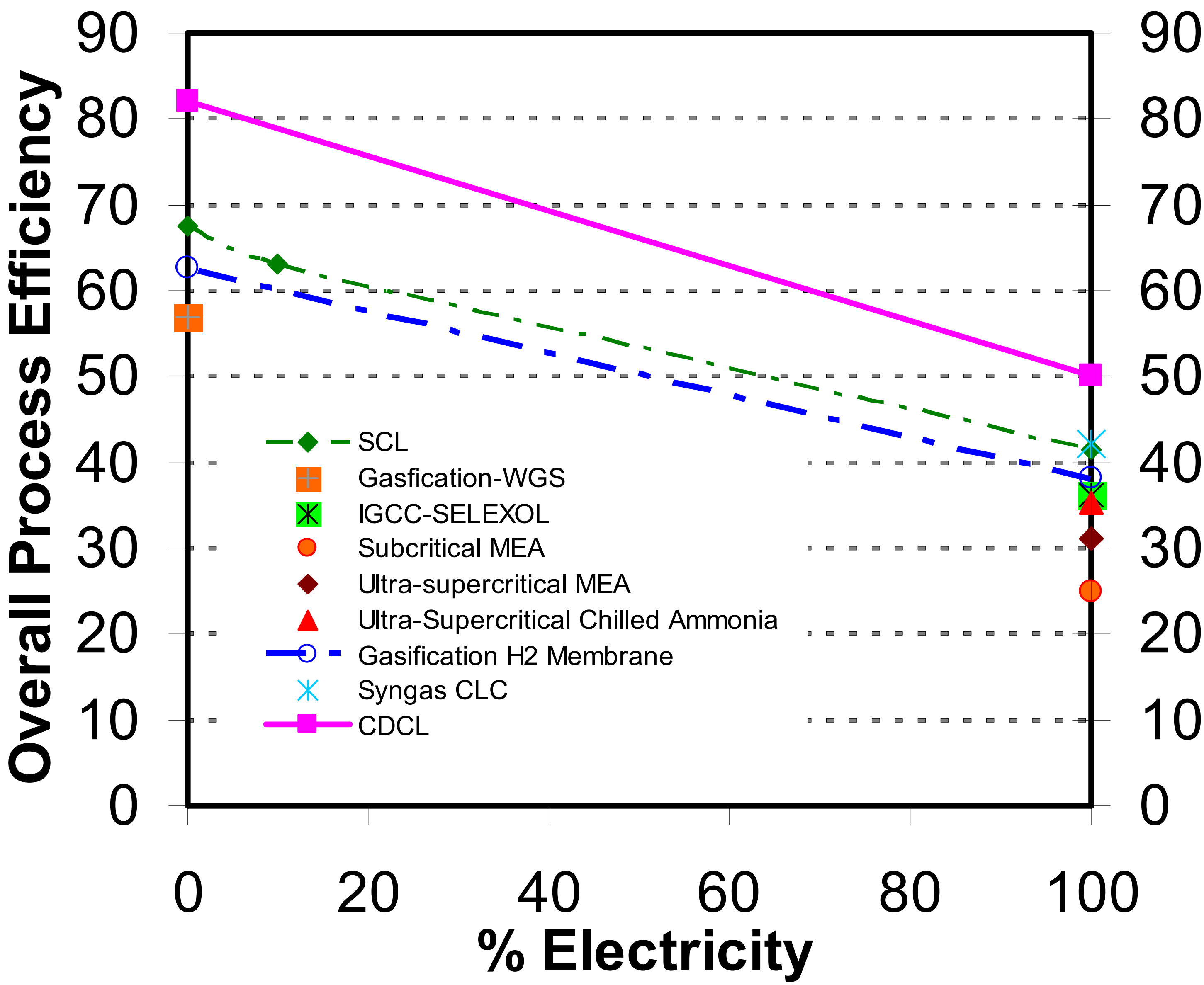
Fei Wang
Liang Zeng
Zhenchao Sun
Siwei Luo

Industrial Partnership

- Shell/CRI
- Babcock and Wilcox Company
- Southern Company
- Air Product and Chemicals Inc.
- CONSOL Energy R&D Center

Comparison Among SCL, CDCL and Traditional Coal to Hydrogen/Electricity Processes



Acknowledgements

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Thank You