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Iron-based chemical looping processes

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THE OHIO STATE UNIVERSITY

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

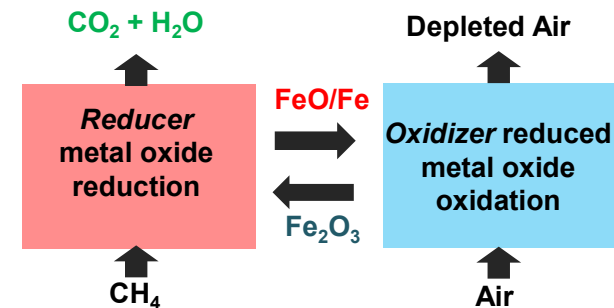
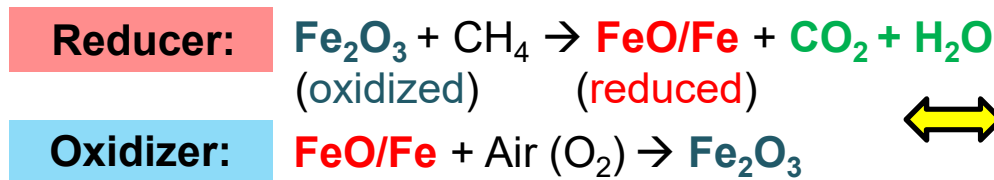
- Applications of chemical looping
- Oxygen carrier design criteria
- Moving-bed reactor design
- OSU chemical looping development
- Concluding remark



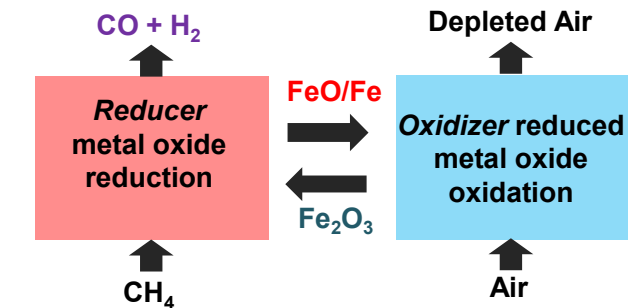
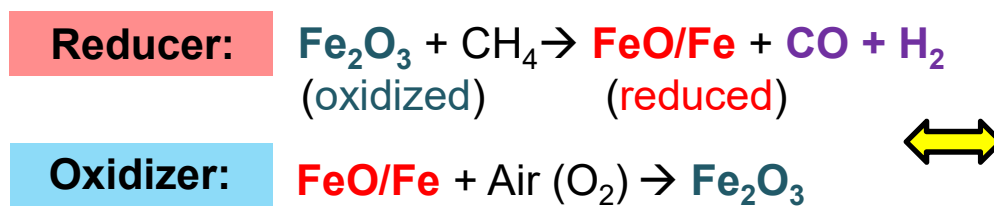


Applications of Chemical Looping

Combustion: Complete Fuel Oxidation

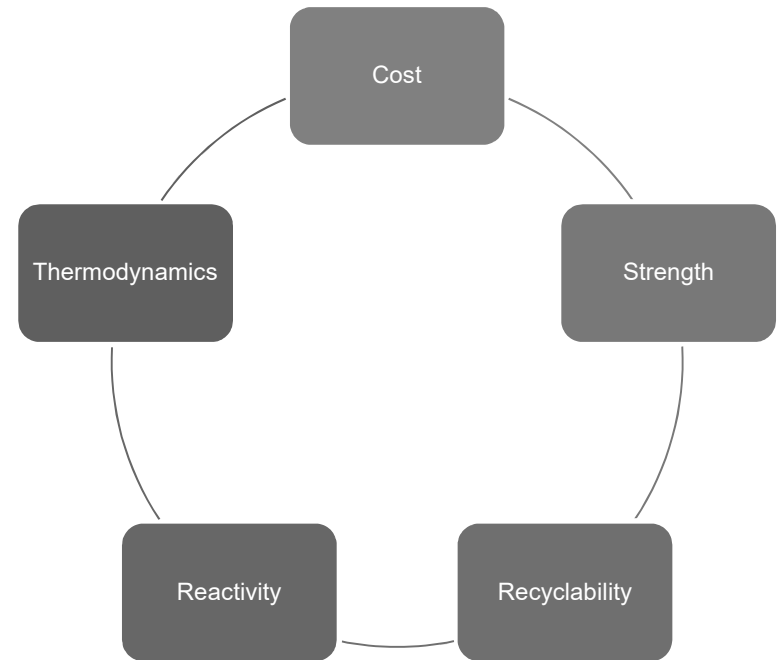
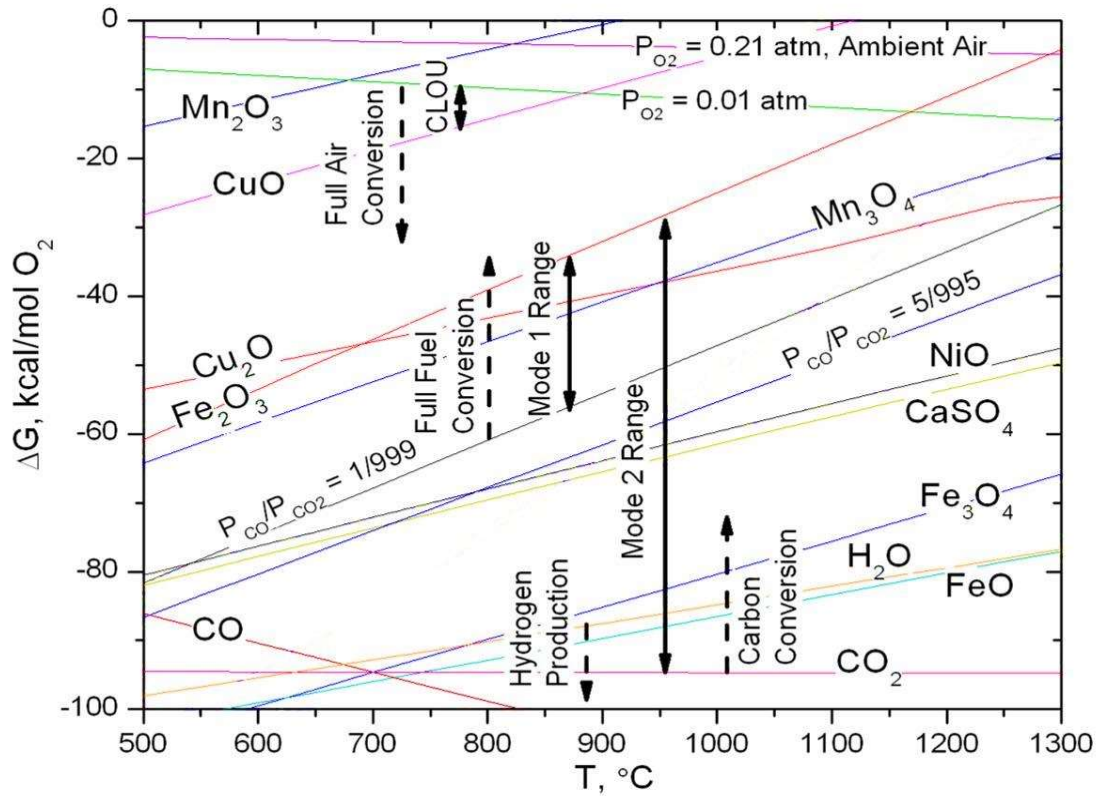


Gasification: Partial Fuel Oxidation





Oxygen Carrier Design Criteria





Oxygen Carrier Design Criteria

Cost Range (\$/kg)

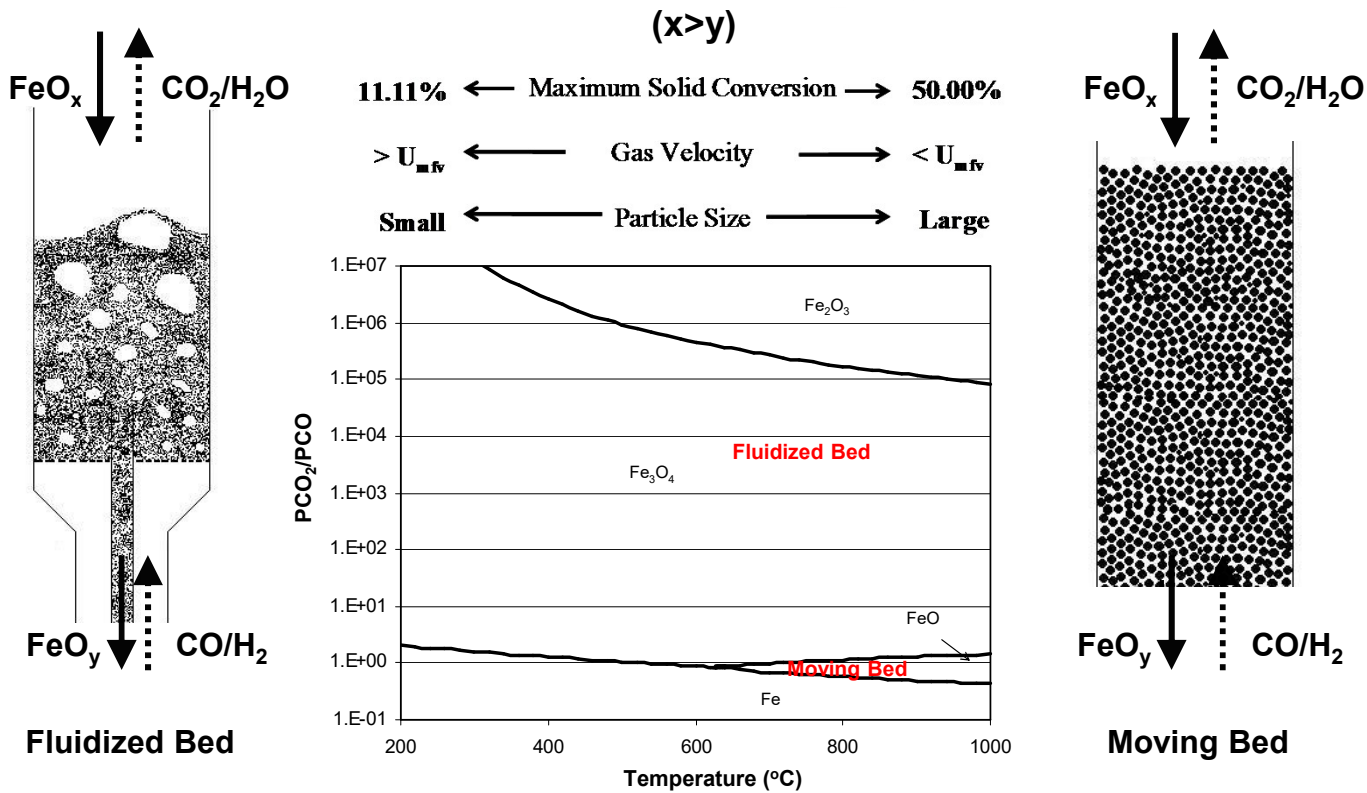
< \$1/kg
Fe, K, Ca, Ti, Al, Ba, Na, Sr
\$1/kg to \$10/kg
Mn, Mg, Cu, Zn, Ce, Cd, Pb, Zr, Cr, La, Rb
\$10/kg to \$100/kg
Bi, Co, Hg, Sn, Ni, W, V, Li, Y, Nd, Gd
\$100/kg to \$1000/kg
Ga, In, Ag, Pr, Eu, Er
> \$1000/kg
Tl, Dy, Ir, Lu, Ho, Tm, Yt, Ru, Au, Pt, Pd, Rh, Ra, Po, Cs, Sc

Metals

hydrogen 1 H 1.0079																	helium 2 He 4.0026				
lithium 3 Li 6.941	beryllium 4 Be 9.0122															boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305															aluminum 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078	scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80				
rubidium 37 Rb 85.468	strontium 38 Sr 87.62	yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	nickel 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29				
cesium 55 Cs 132.91	barium 56 Ba 137.33	lanthanum 57 La 138.91	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]				
francium 87 Fr [223]	radium 88 Ra [226]	actinide series 89-102 Lr [260]	lutetium 71 Lu 174.97	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [263]	bohrium 107 Bh [264]	hassium 108 Hs [265]	meitnerium 109 Mt [266]	unnilium 110 Uun [267]	ununium 111 Uuu [268]	unbibium 112 Uub [269]	ununquadium 114 Uuq [271]								
* Lanthanide series																					
lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04								
** Actinide series																					
actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]								

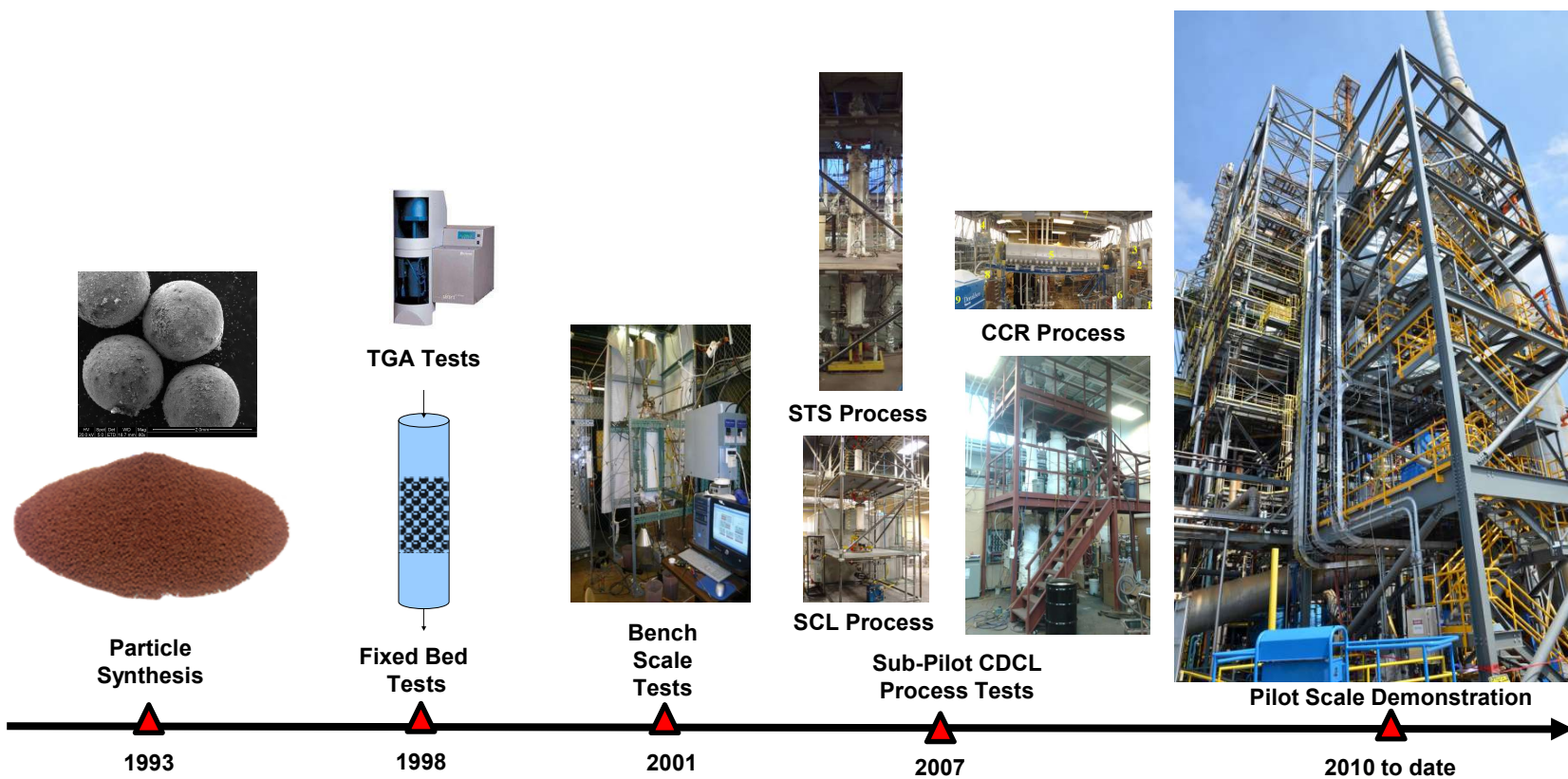


Reducer Design: Fluidized Bed vs Moving Bed



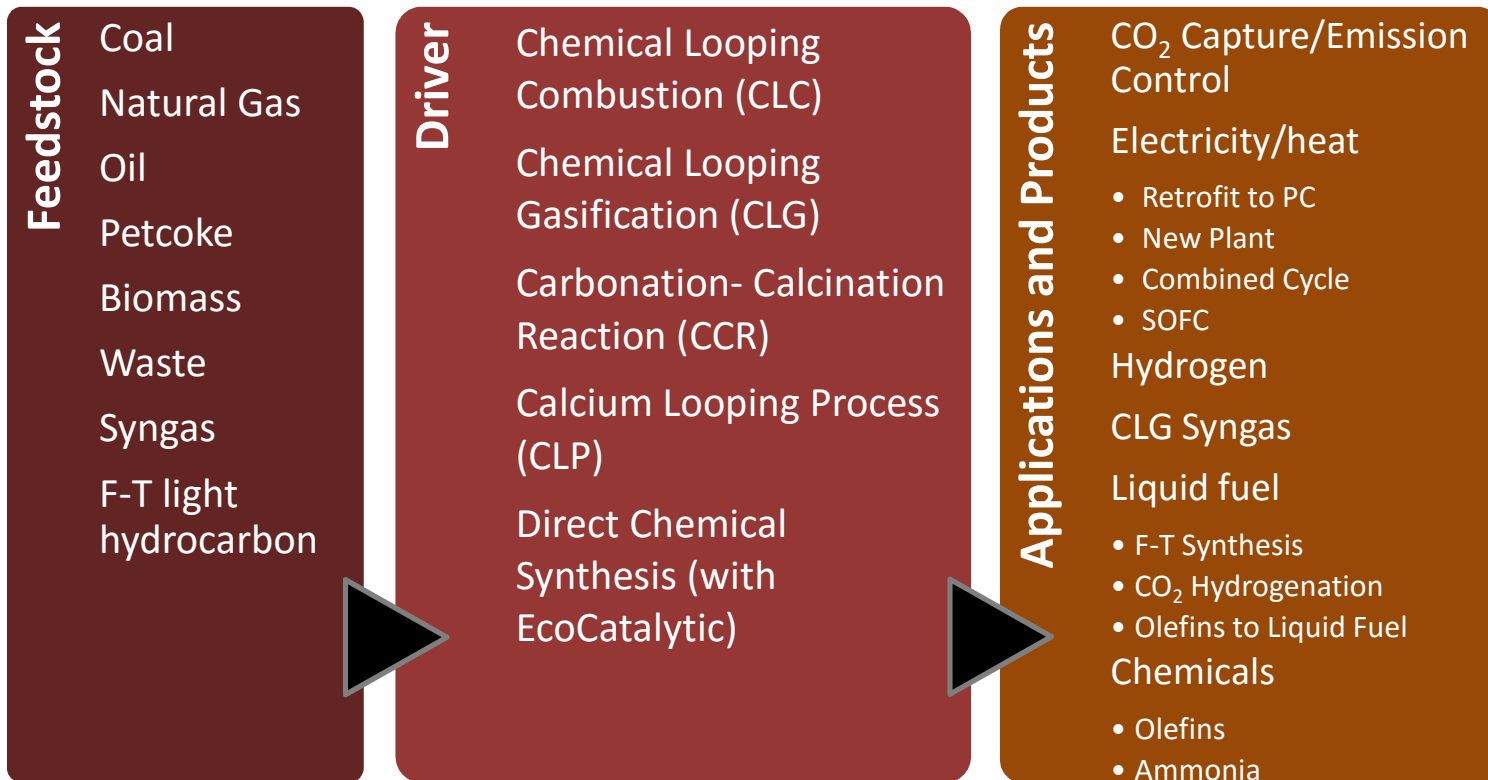


Evolution of OSU Chemical Looping Technology





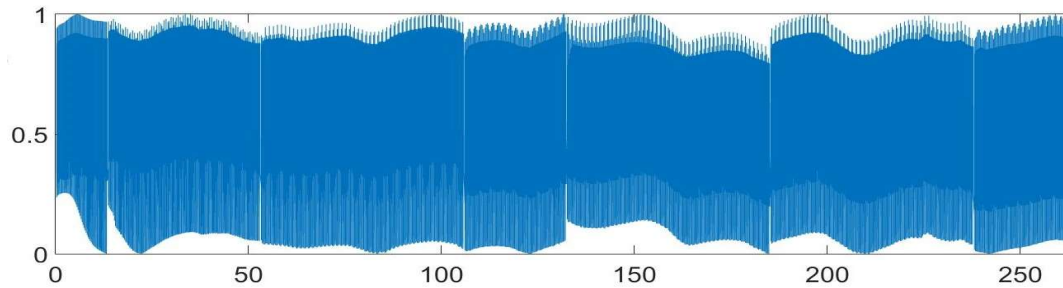
OSU Chemical Looping Platform Technology





Recyclability of Metal Oxides and Composite Metal Oxides

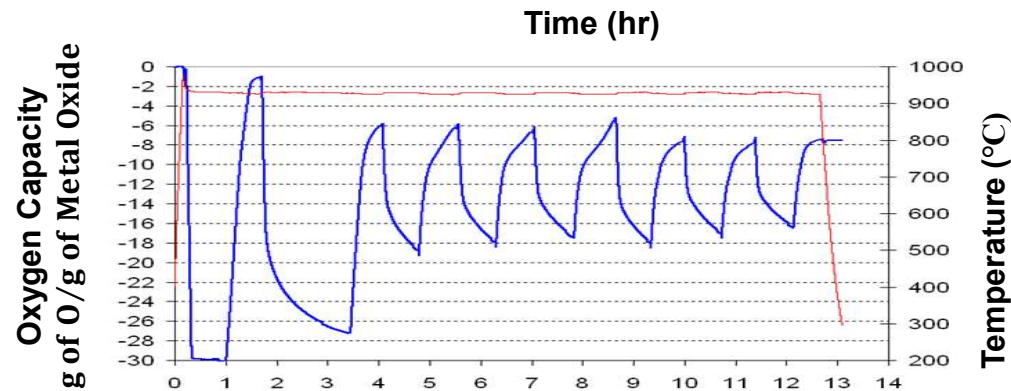
Cyclic Redox of Composite Fe_2O_3



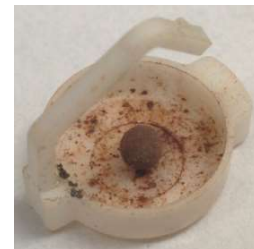
Before



Cyclic Redox of Pure Fe_2O_3



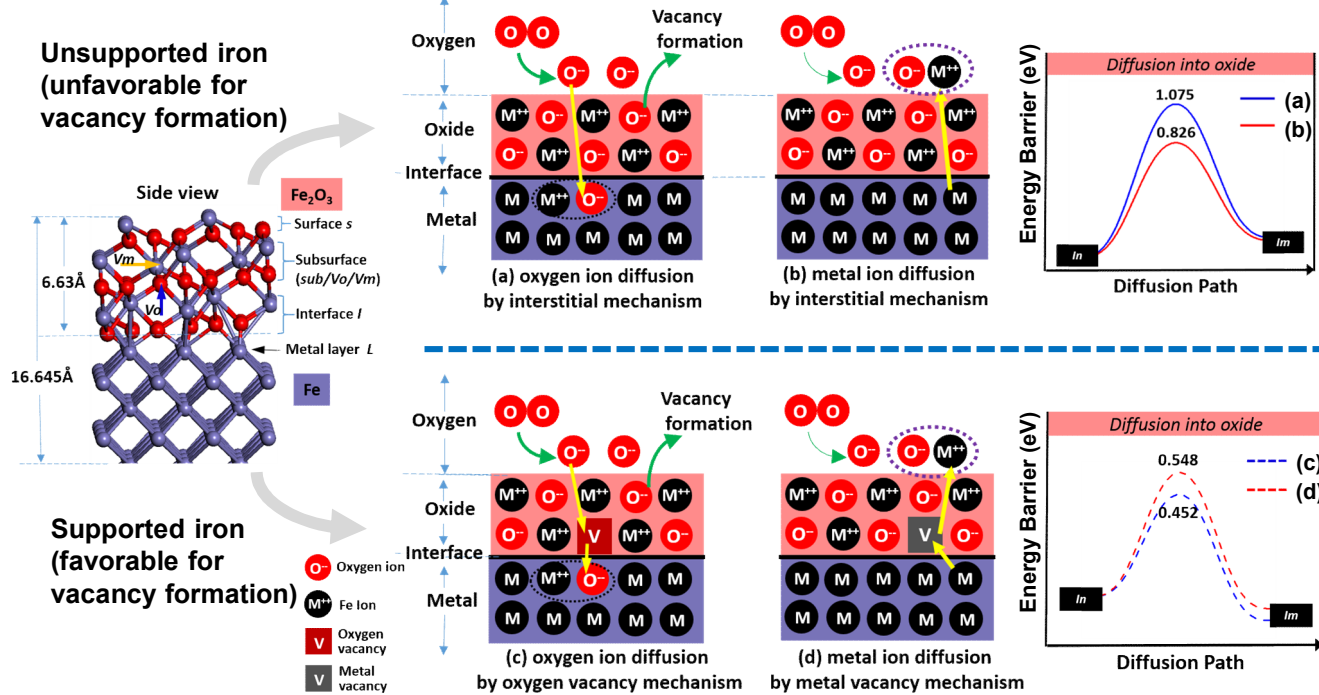
After





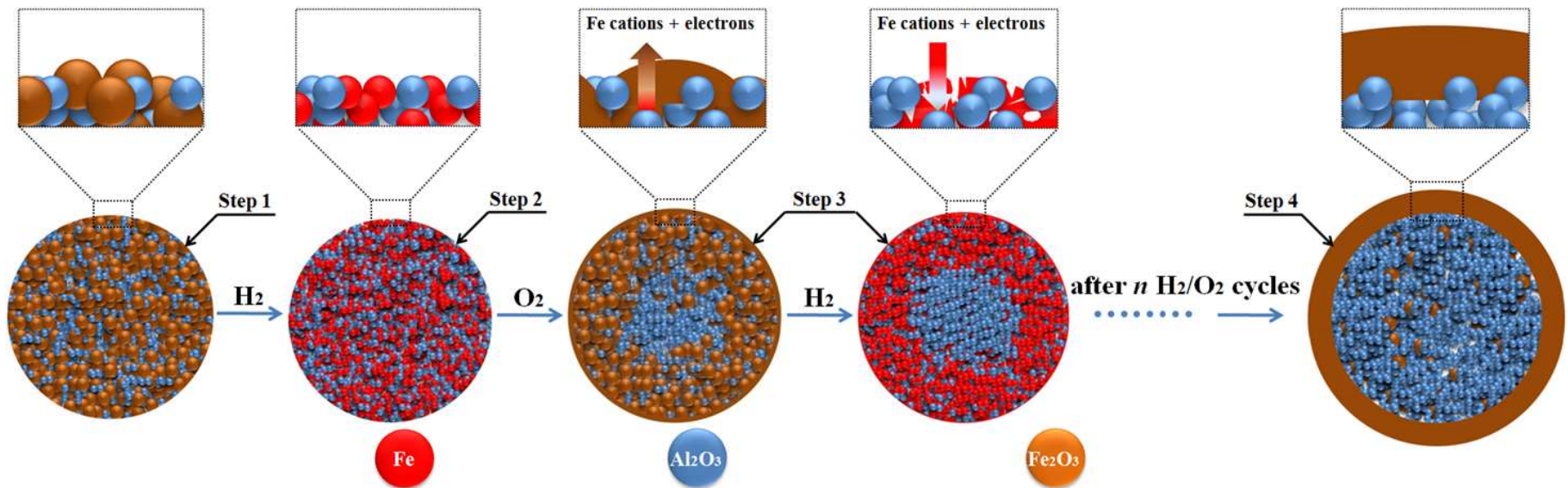
Diffusion Mechanism

Oxygen Anion vs Iron Cation





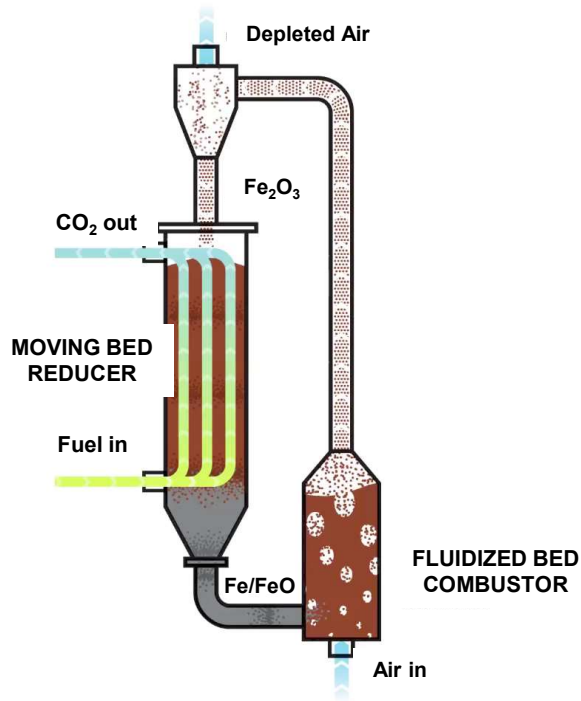
Core-Shell Particle Formation





Chemical looping Combustion vs. Gasification

Counter-current: Full Combustion

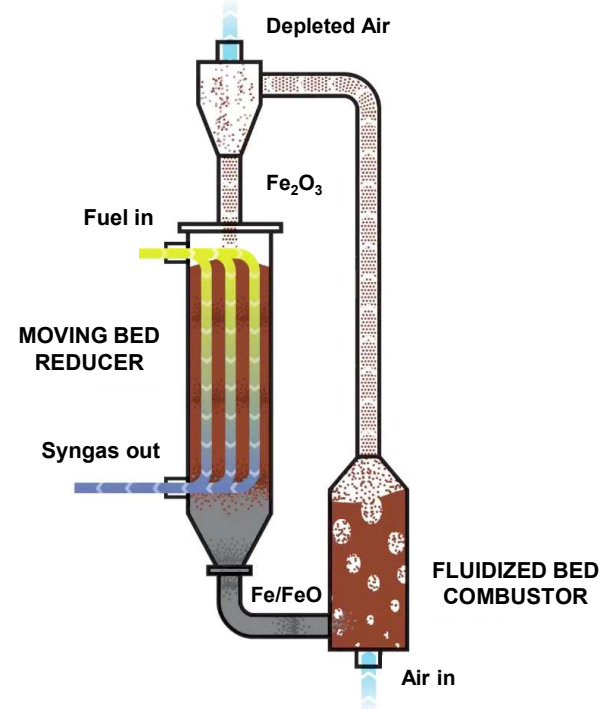


Simplicity:
One Loop

Unique Reducer Configuration:
Moving Bed

Unique Flow Controller:
Non-Mechanical L-Valve

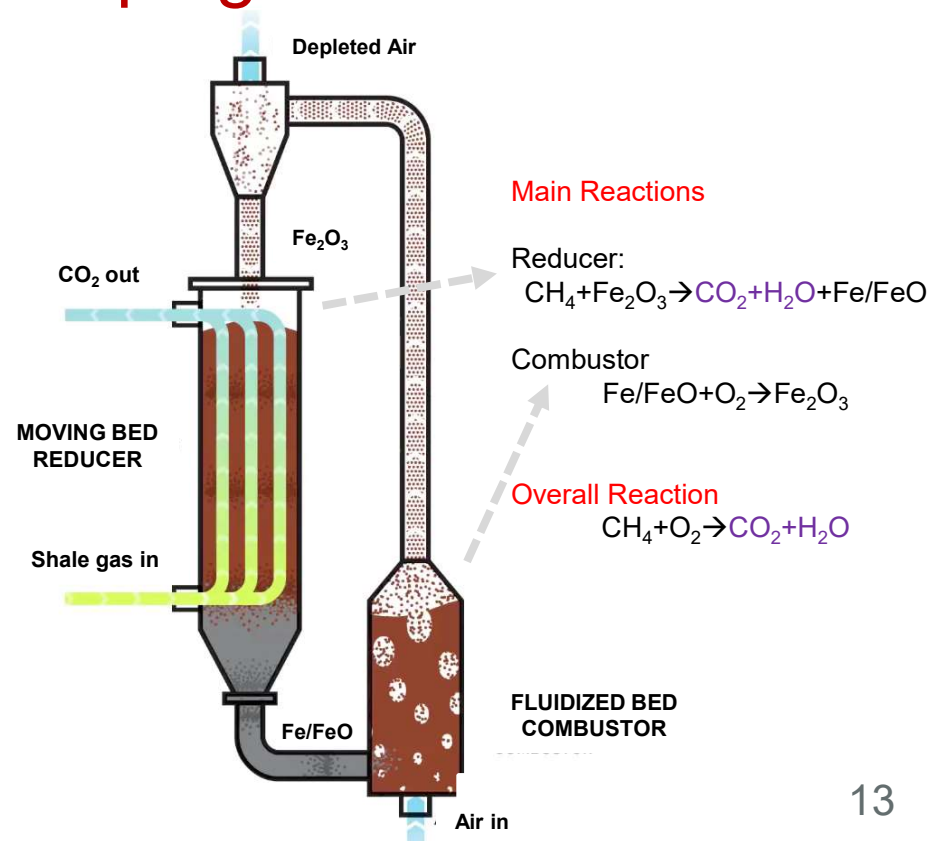
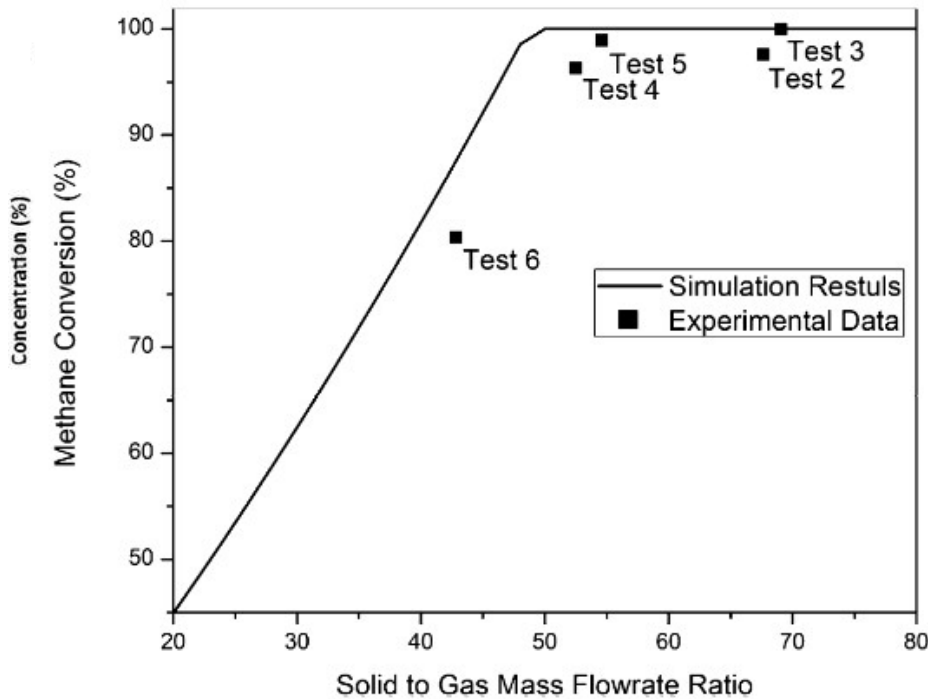
Co-current: Full Gasification





Shale Gas Chemical Looping Combustion

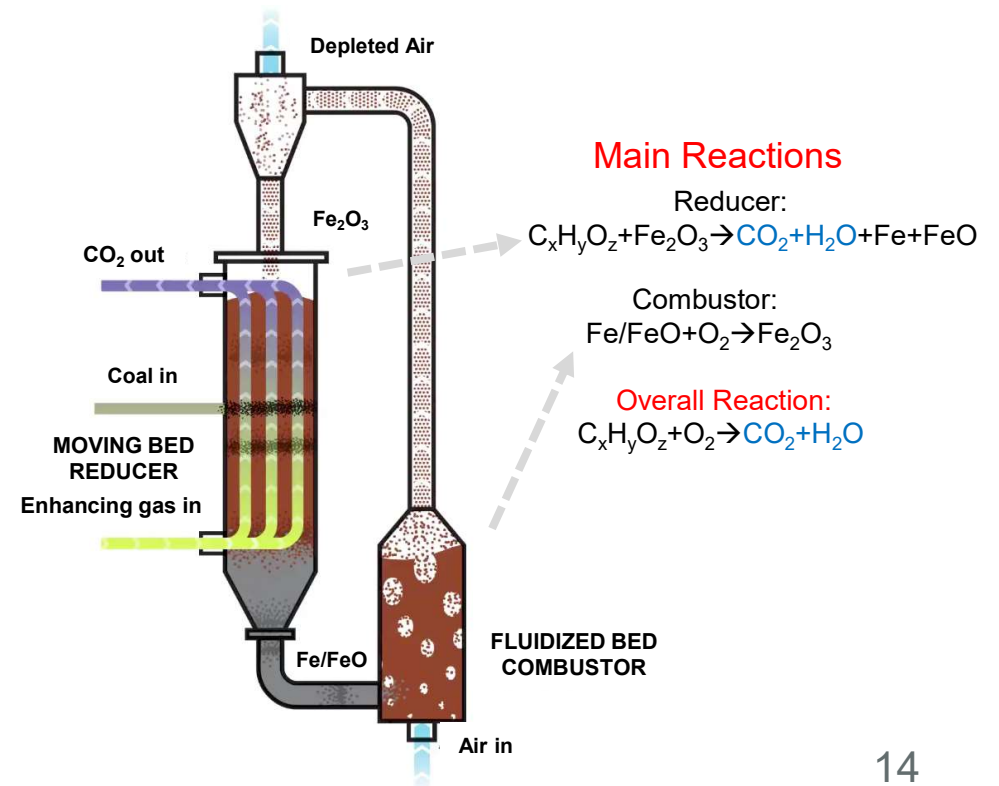
- **>98% Methane Conversion**
- **Data in good agreement with simulation results**





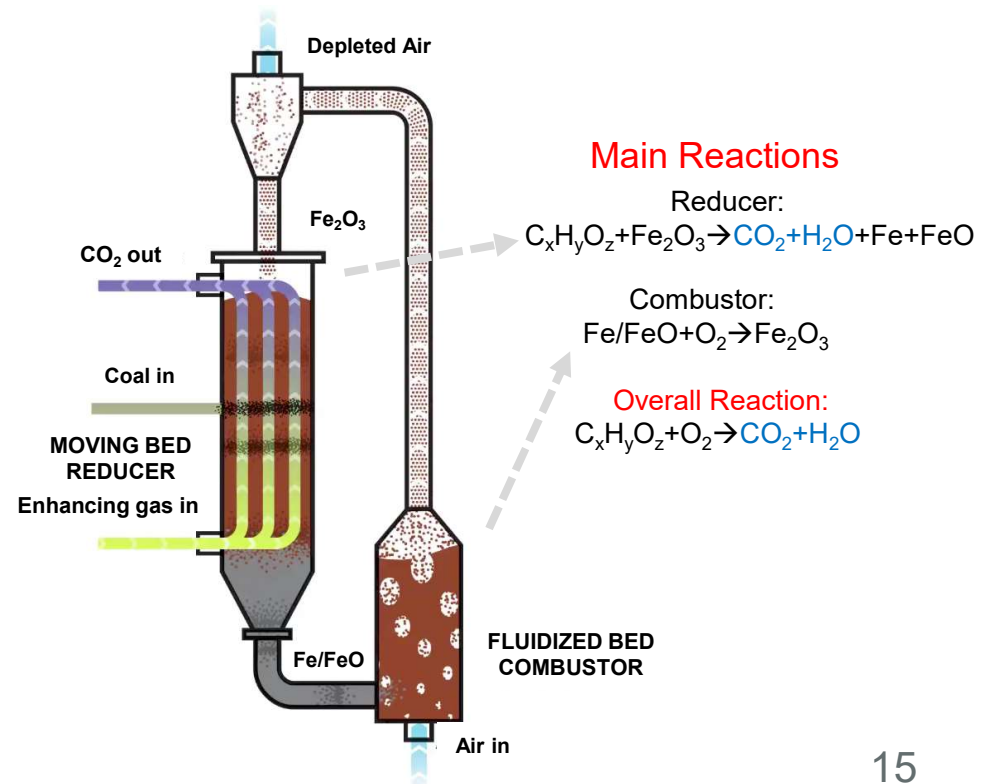
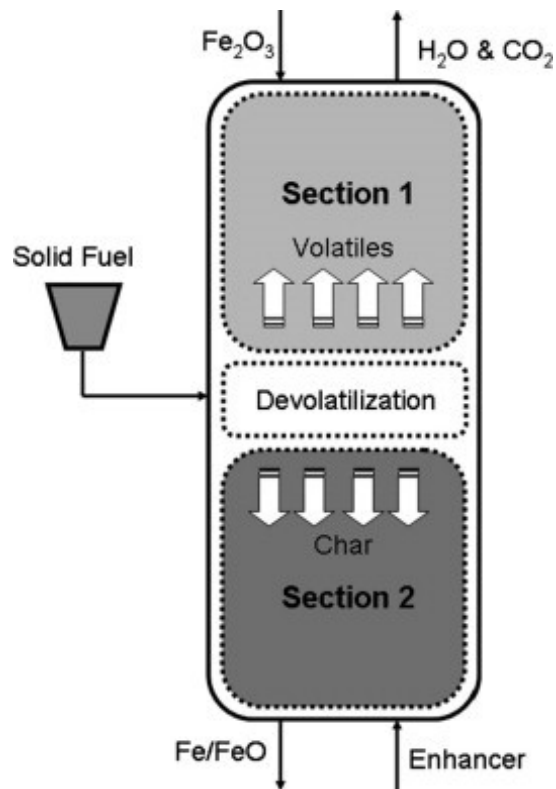
Coal-direct Chemical Looping Combustion

25 kW_{th} Sub-Pilot Unit



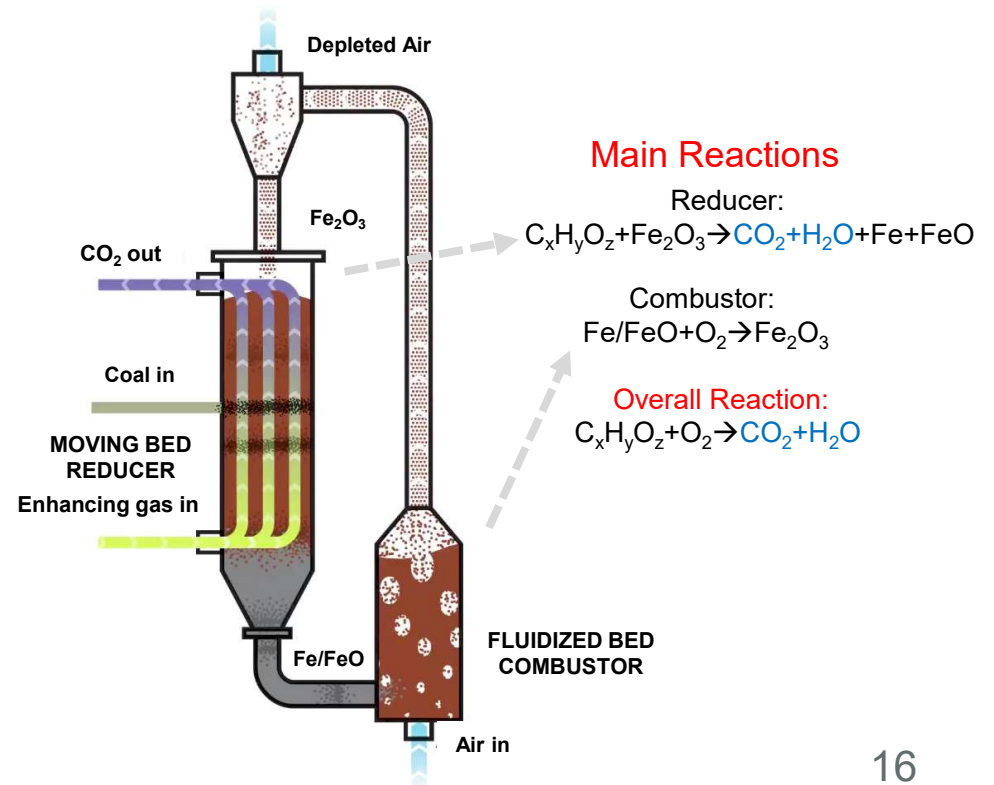
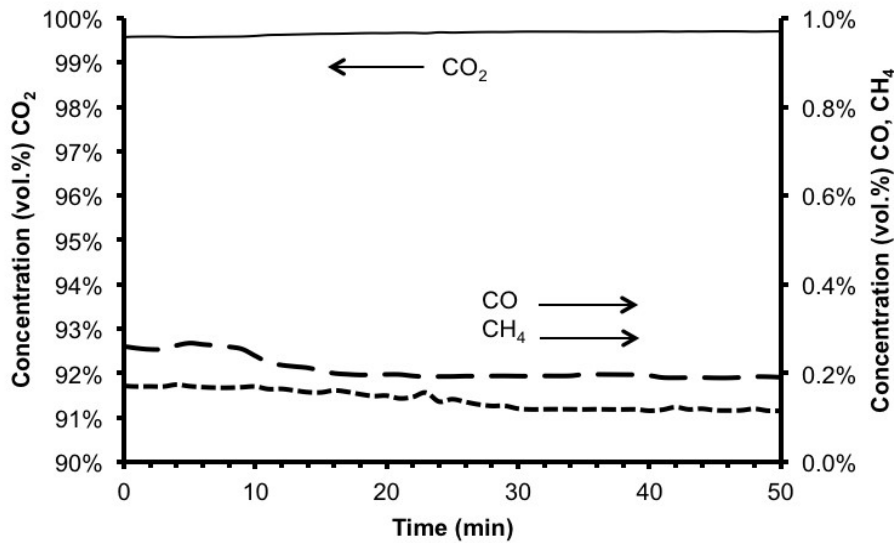


Coal-direct Chemical Looping Combustion





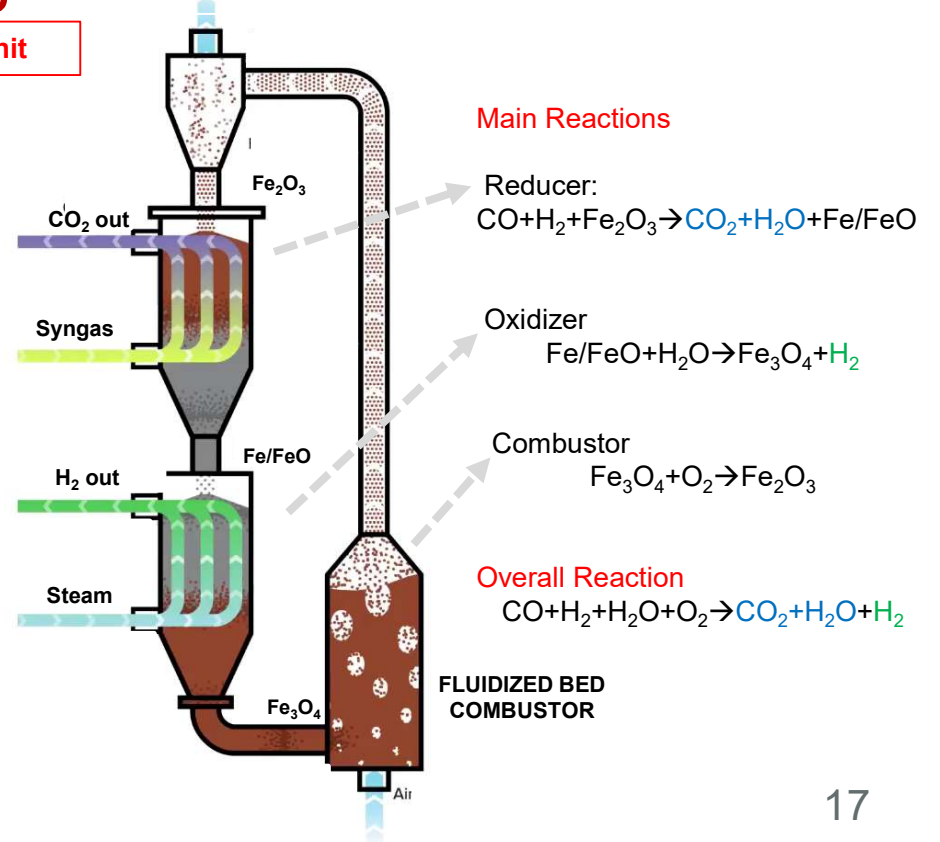
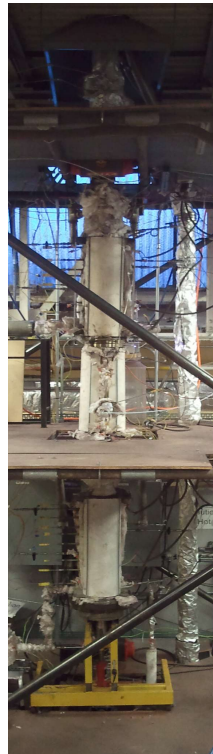
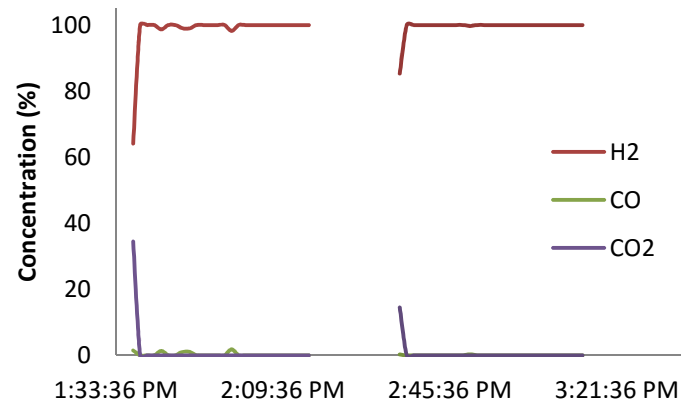
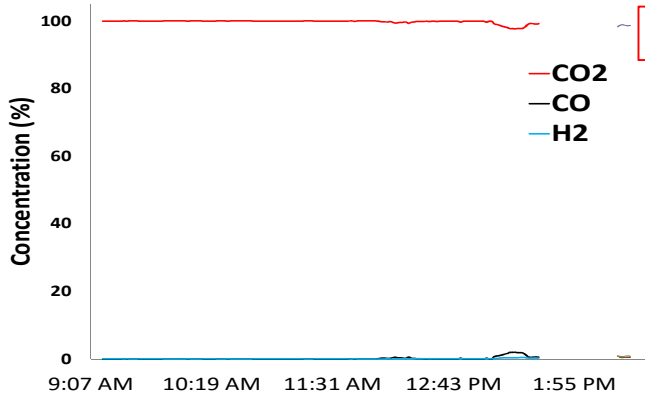
Coal-direct Chemical Looping Combustion





Chemical Looping Hydrogen Production Process

25 kW_{th} Sub-Pilot Unit

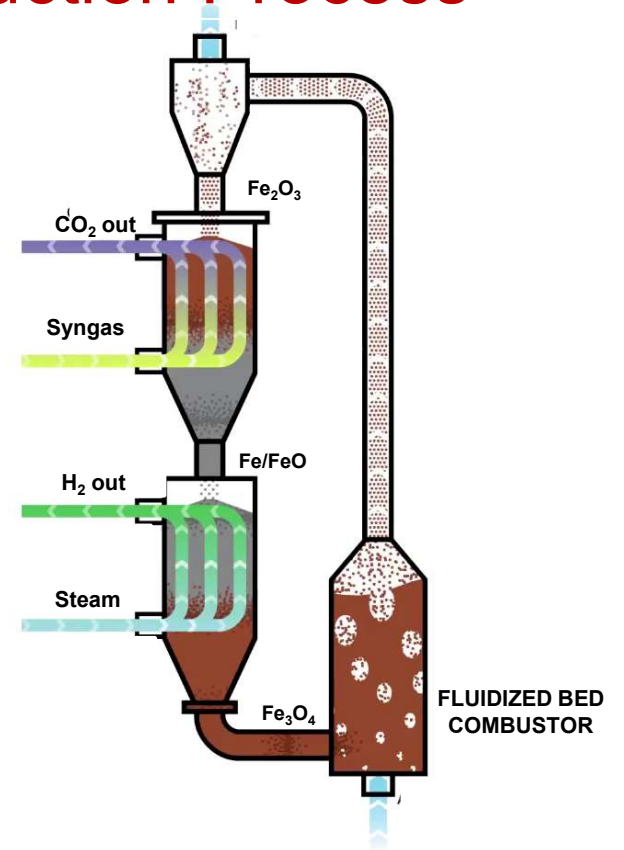
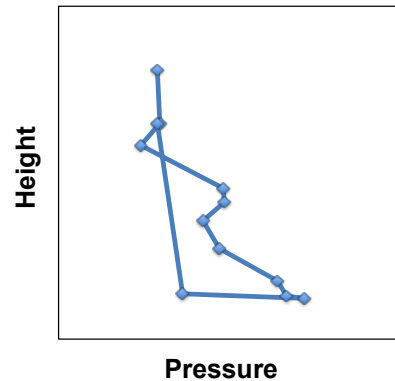
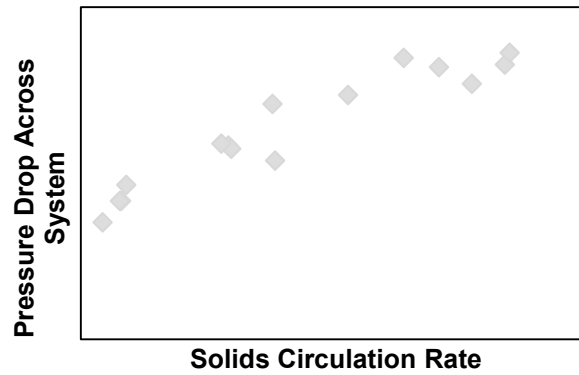
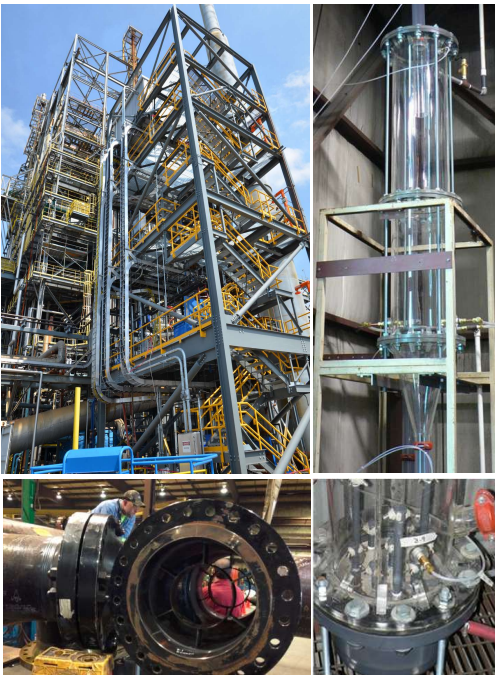




Chemical Looping Hydrogen Production Process

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

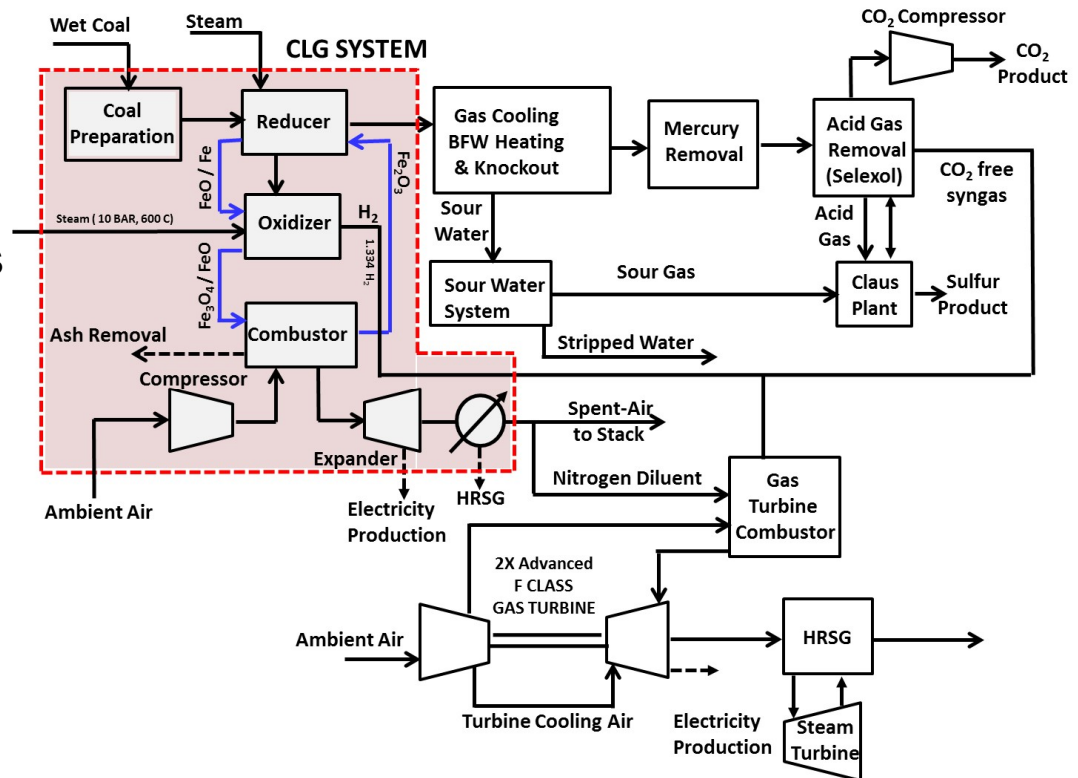
1:1 Pilot
Unit Cold
Model





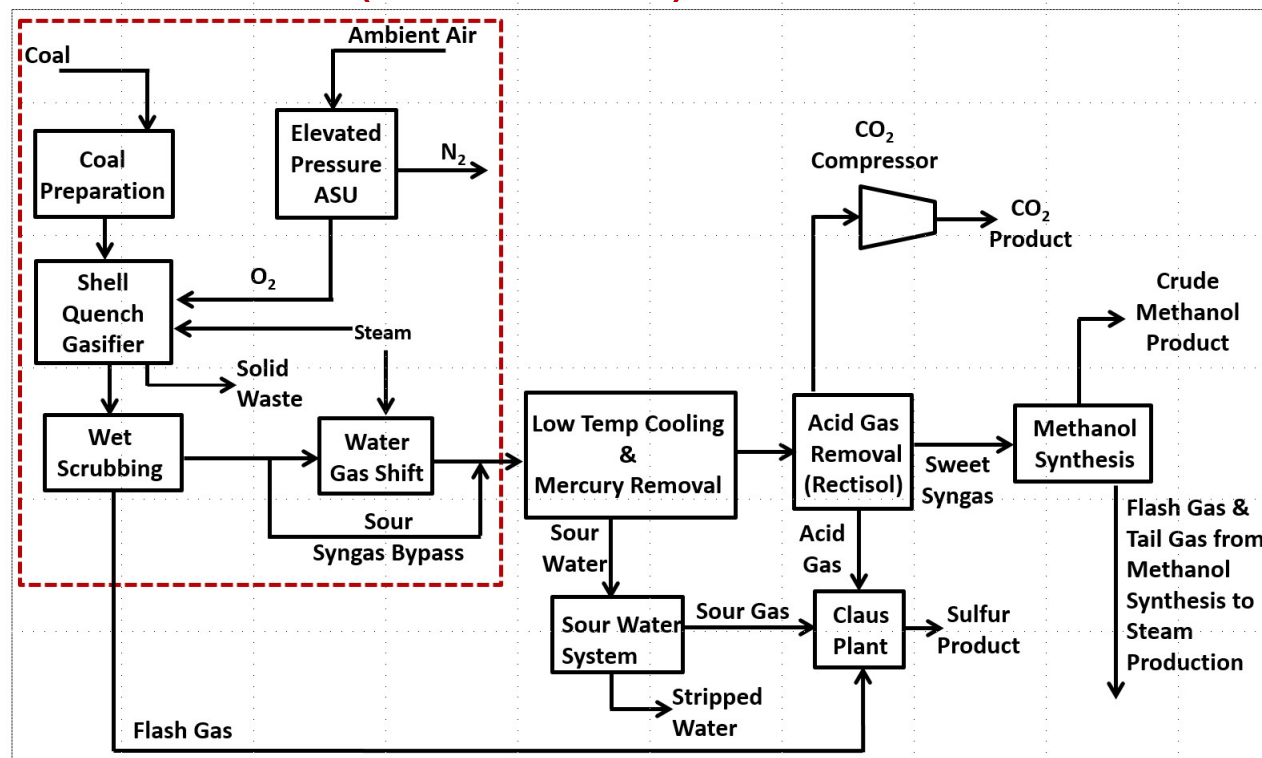
IGCC system with Chemical Looping Gasification

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



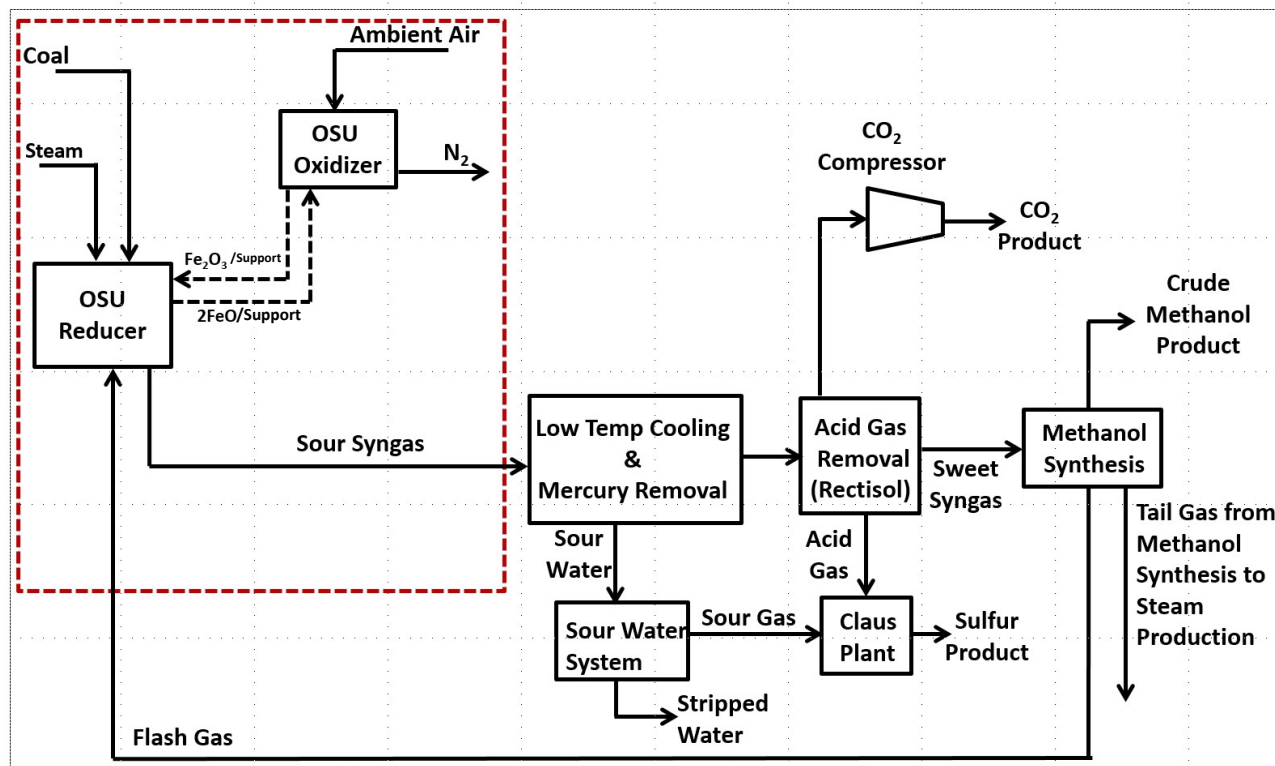


Coal Gasification for Methanol Production: DOE Baseline (Traditional) Process



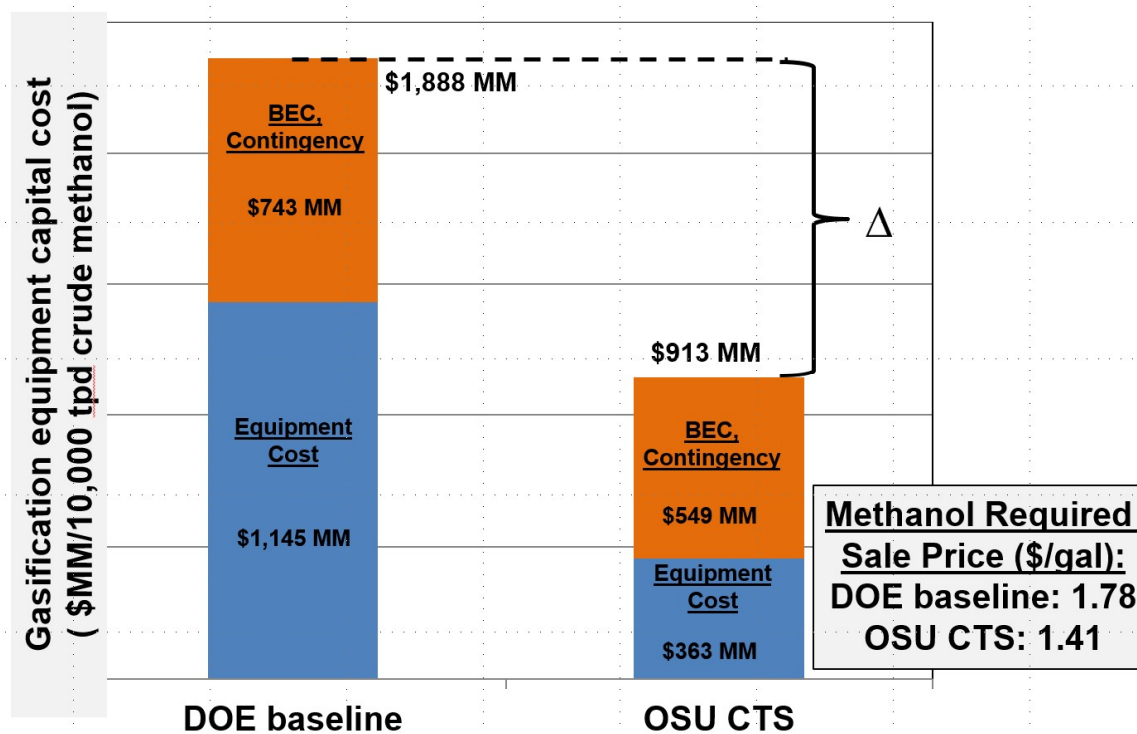


Coal Gasification for Methanol Production with Chemical Looping





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





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



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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)



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