B&W

power generation group

Atmospheric Iron-Based Coal Direct Chemical Looping Process for Power Production

Pittsburgh, PA. Jun 26. 2015

Project Objectives

Phase I Project objectives: 2012 -2013

- Evaluate commercial viability of OSU's coal-direct chemical looping process for power production with CO_2 capture.
- Perform a techno-economic evaluation of the commercial design.

Phase II Project Objectives:2013-2016

- Reduce technology gaps identified in Phase I by conducting laboratory testing and small pilot-scale testing.
- Update design and cost performance of the commercial 550 MWe CDCL power plant
- Re-evaluate the CDCL technology and identify development pathway for commercialization in year 2025.

Project Participants

Federal Agencies:

- DOE/NETL

Project participants:

- The Babcock & Wilcox, PGG
- The Ohio State University
- Clear Skies Consulting

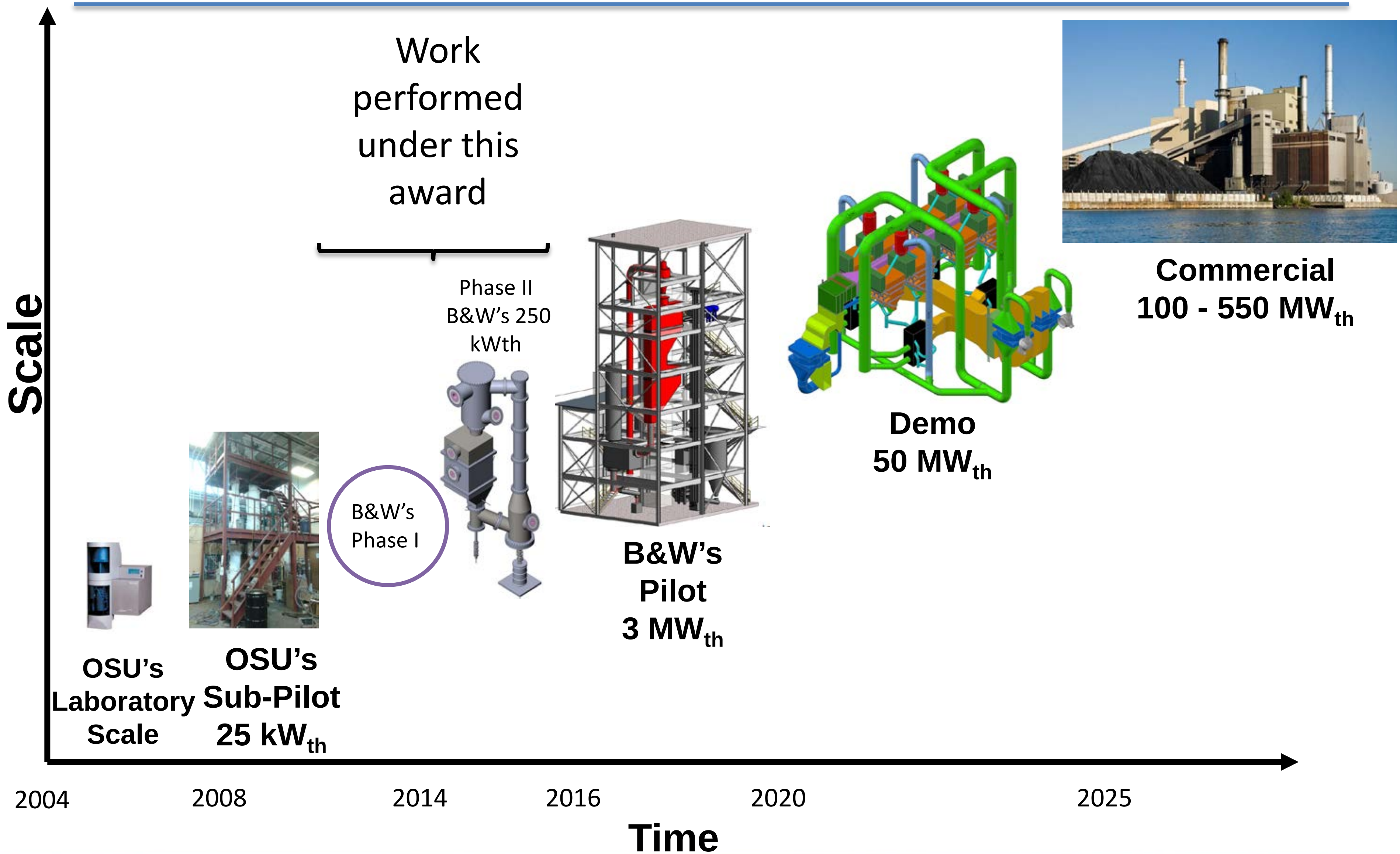
Industrial Review Committee:

- American Electric Power
- Consol Energy
- Dayton Power & Light
- Duke Energy
- First Energy
- Ohio Development Service Agency

Outline

- **Commercialization Path**
- **Phase I: CDCL Concept and Techno-Economic Analysis**
- **Phase I: Technology Gaps**
- **Phase II: Pilot Design**
- **Phase II: Laboratory Testing and Studies**
- **Project Schedule**
- **Conclusions and Acknowledgments**

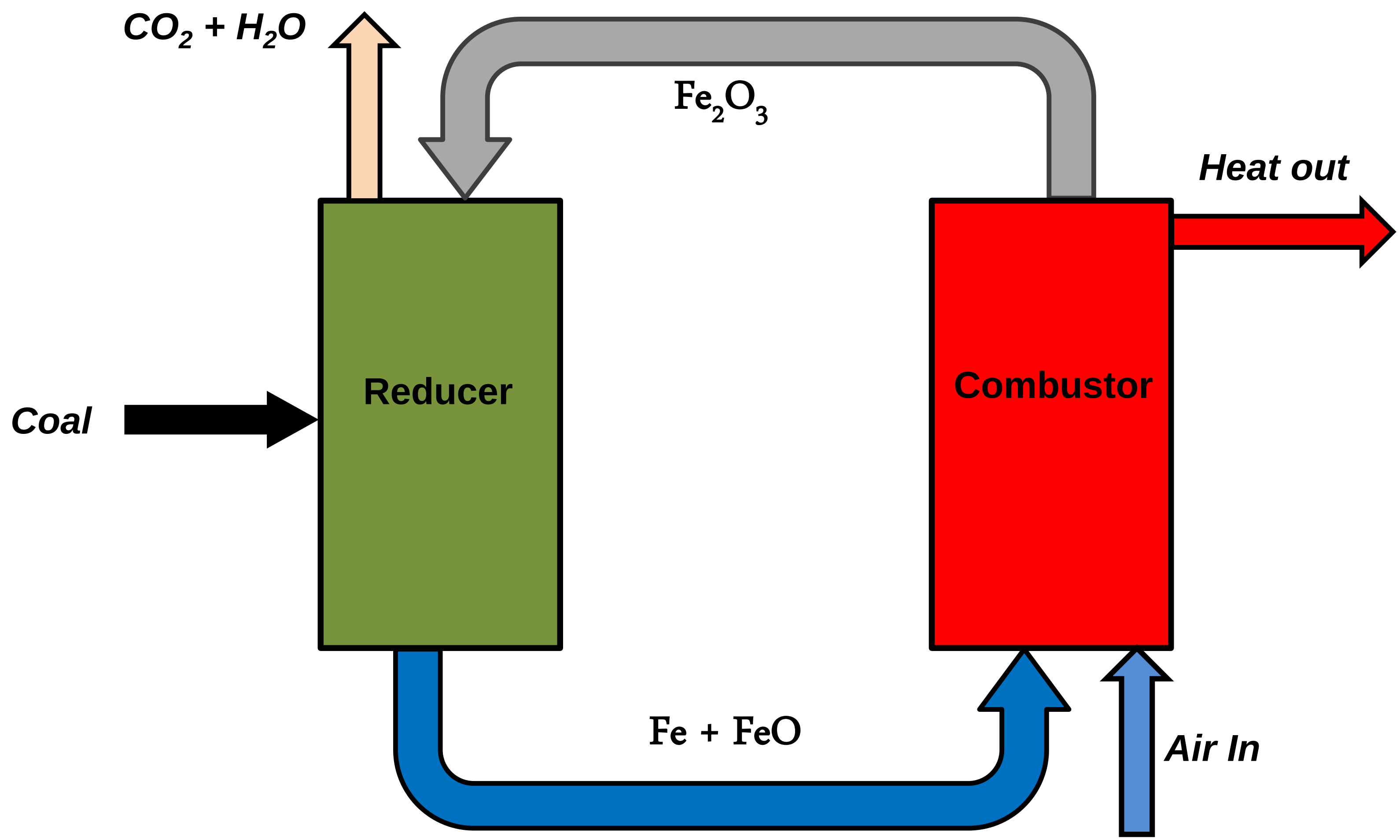
Commercialization Path



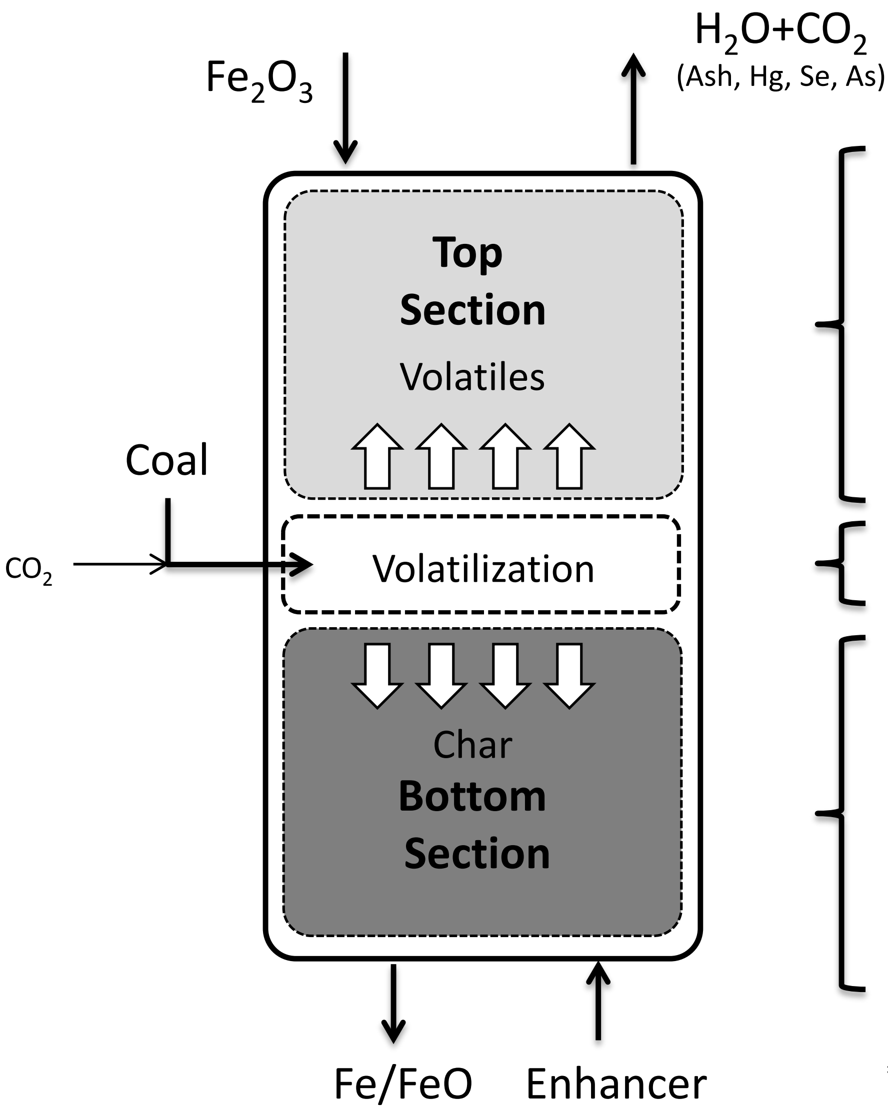
Outline

- Commercialization Path
- Phase I: CDCL Concept and Techno-Economic Analysis
- Phase I: Technology Gaps
- Phase II: Pilot Design
- Phase II: Laboratory Testing and Studies
- Project Schedule
- Conclusions and Acknowledgments

Chemical Looping Concept



CDCL Moving Bed Reactor Concept



Top Section*

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

$CO + Fe_2O_3 \rightarrow Fe + FeO + CO_2$

$H_2 + Fe_2O_3 \rightarrow Fe + FeO + H_2O$

Coal Volatilization*

Coal $\rightarrow C + C_xH_y$ (Volatiles)

Bottom Section*

$C + CO_2 \rightarrow 2\ CO$

$2\ CO + Fe_2O_3 \rightarrow Fe + FeO + 2\ CO_2$

* Reactions not balanced

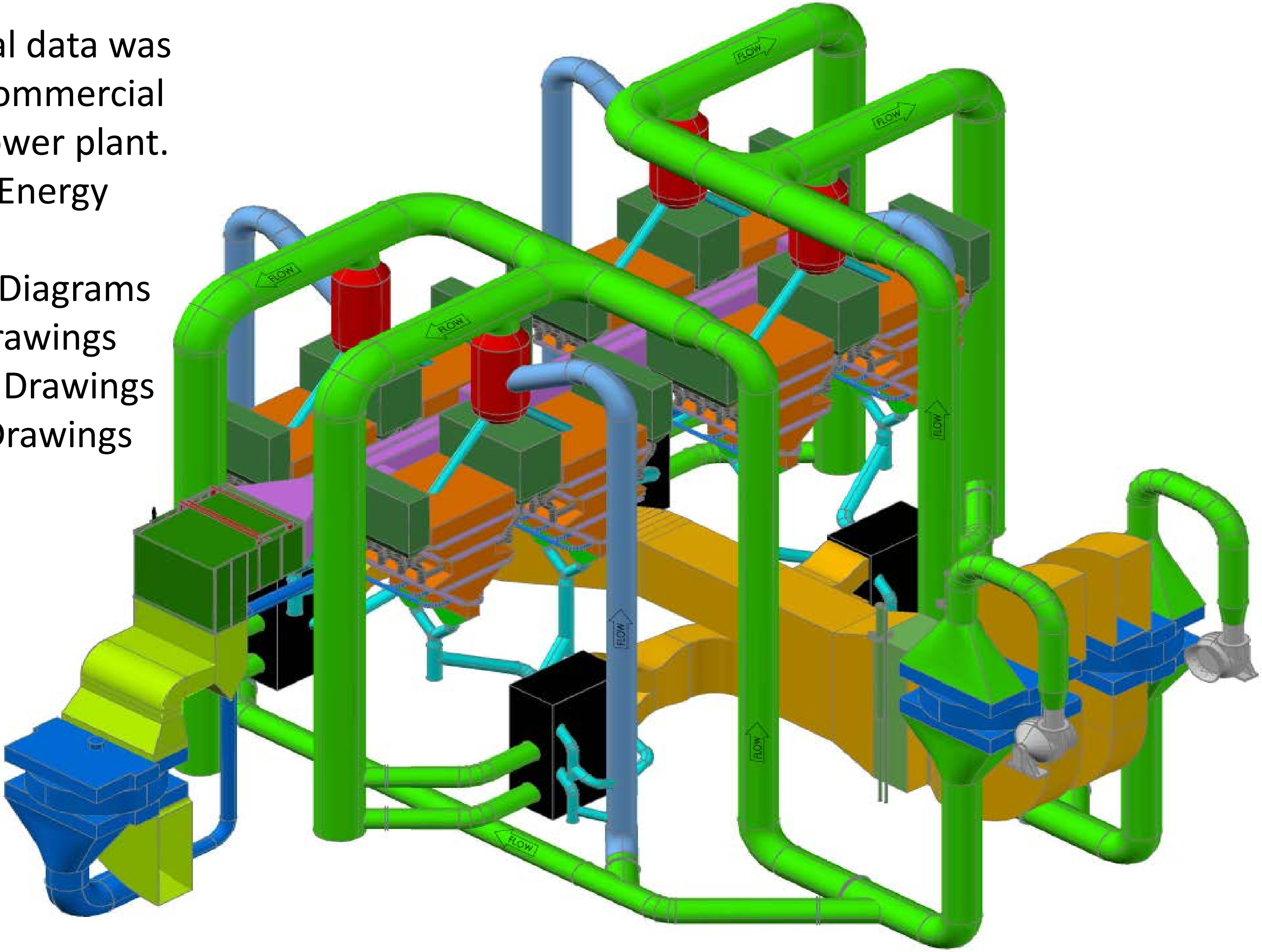
Outline

- Commercialization Path
- Phase I: CDCL Concept and Techno-Economic Analysis
- Phase I: Technology Gaps
- Phase II: Pilot Design
- Phase II: Laboratory Testing and Studies
- Project Schedule
- Conclusions and Acknowledgments

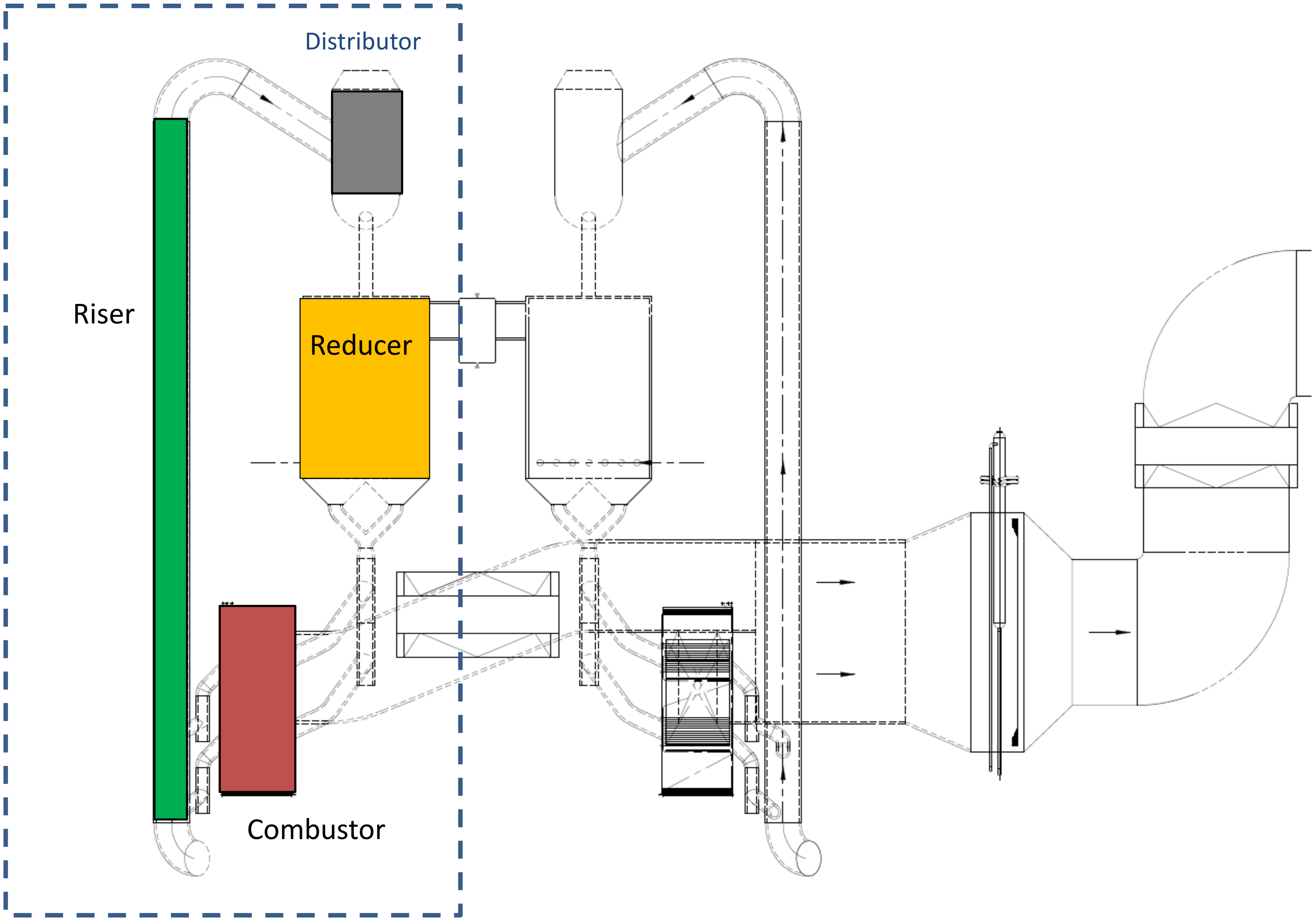
CDCL Commercial Plant Design and Engineering

OSU's experimental data was converted into a commercial 550 MWe CDCL power plant.

- Material and Energy Balance
- Process Flow Diagrams
- Equipment Drawings
- Arrangement Drawings
- Plant layout Drawings
- 3-D Models



Modular Loop Design



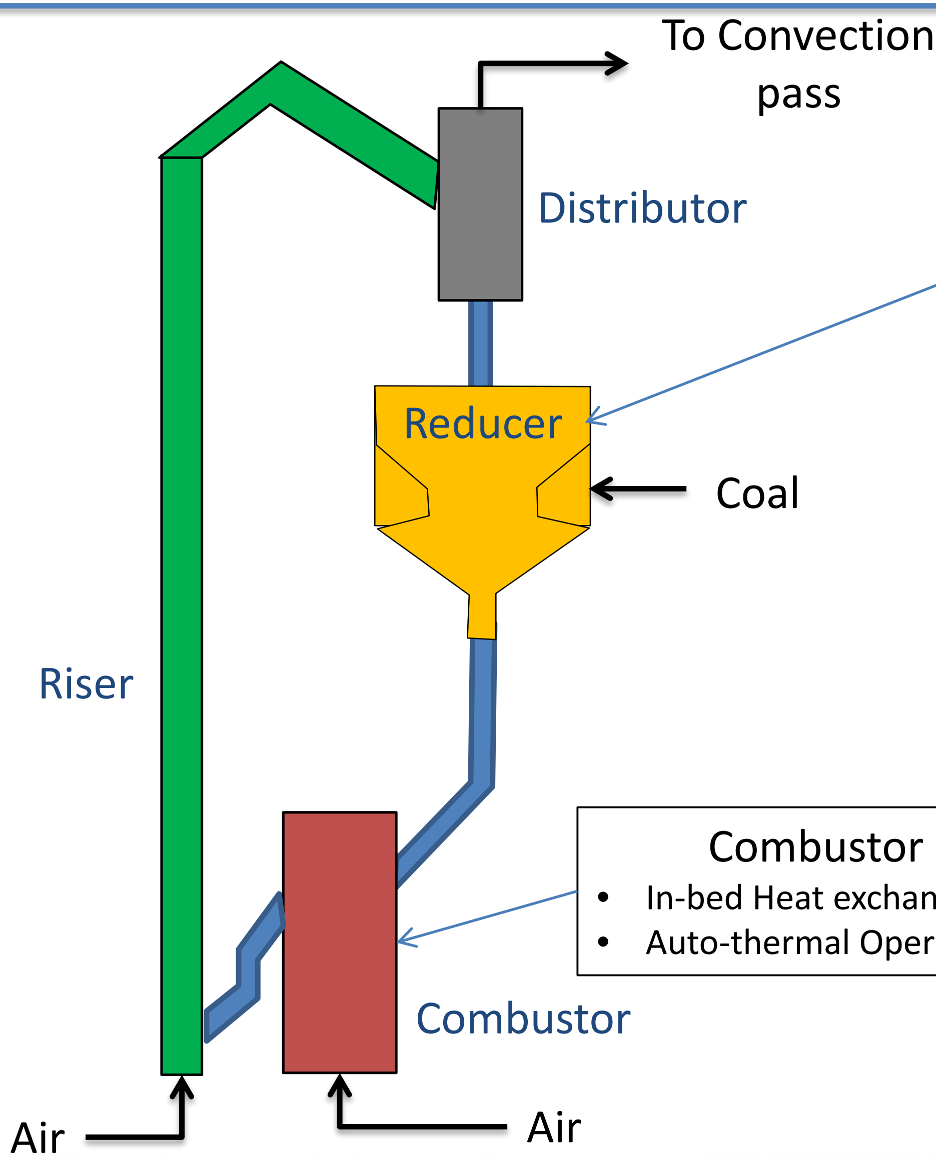
CDCL Technology Comparison

	Base Plant	MEA Plant	CDCL Plant
Coal Feed, kg/h	185,759	256,652	205,358
CO_2 Emissions, kg/MWh$_{net}$	801	111	31
CO_2 Capture Efficiency, %	0	90	96.5
Net Power Output, MW$_e$	550	550	550
Net Plant HHV Heat Rate, kJ/kWh (Btu/kWh)	9,165 (8,687)	12,663 (12,002)	10,084 (9,558)
Net Plant HHV Efficiency, %	39.3	28.5	35.6
Cost of Electricity, $/MWh	80.96	132.56	102.67
Increase in Cost of Electricity, %	-	63.7	26.8

Outline

- Commercialization Path
- Phase I: CDCL Concept and Techno-Economic Analysis
- Phase I: Technology Gaps
- Phase II: Pilot Design
- Phase II: Laboratory Testing and Studies
- Project Schedule
- Conclusions and Discussion

Technology Gap Analysis



Reducer

- Coal Injection and distribution
- Char residence time
- Ash Separation/ Enhancer Gas
- Fate of alkali
- Fate of S, Hg, and N

Combustor

- In-bed Heat exchanger
- Auto-thermal Operation

Particles

- Max. op. temp.
- Attrition
- Reactivity
- Deactivation

Operation

- Start up
- Shut down
- Turn down – Idle
- Hazardous Op

CDCL Technolgy Gaps

Design/Technology Issues	Ongoing/Past Mitigation	Planned Mitigation	Future Mitigation
Particles			
Manufacturing Cost	Under OSU's SOW	Particle Manufacturer	
Attrition	NCCC	Lab 2" BFB / Envergex	
High Temperature Resistance	TGA	TGA	
Reducer Design			
Coal Injection & Distribution	OSU's Sub-Pilot	Small-pilot Unit	3 MWth-Pilot
Char Residence Time	OSU's Sub-Pilot	TGA, Small-pilot Unit	
Ash Separation / Enhancer Gas	OSU's Sub-Pilot	Small-pilot Unit	
Pressure Drop	Phase I (Calculation)	Small-pilot Unit	
CO_2 Purity	Phase I (Calculation)	Small-pilot Unit	
Sulfur, NOx, Hg Emissions	OSU's Sub-Pilot	Small-pilot Unit	3 MWth-Pilot
Alkaline Management	2" BFB (Preliminary)	2" BFB	3 MWth-Pilot
Combustor Design			
Heat Exchanger surface	B&W's CFB Technology		3 MWth-Pilot
Auto-thermal Operation	Phase I (Calculation)	Small-pilot Unit	3 MWth-Pilot
System			
Operation	NCCC	Small-pilot Unit	3 MWth-Pilot
Start up/Shut down	NCCC	Small-pilot Unit	3 MWth-Piot
Safety	NCCC	Small-pilot Unit	3 MWth-Pilot

Outline

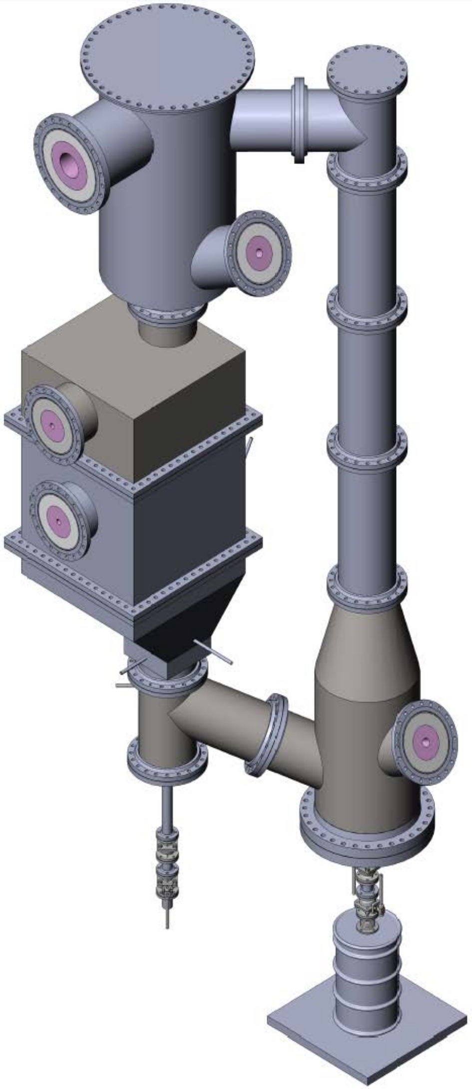
- Commercialization Path
- Phase I: CDCL Concept and Techno-Economic Analysis
- Phase I: Technology Gaps
- **Phase II: Pilot Design**
- Phase II: Laboratory Testing and Studies
- Project Schedule
- Conclusions and Acknowledgments

Pilot Unit Design

Physical Specifications
•Materials: Refractory lined Carbon Steel
•Overall Height: 32 ft
•Footprint = 20’ x 20’

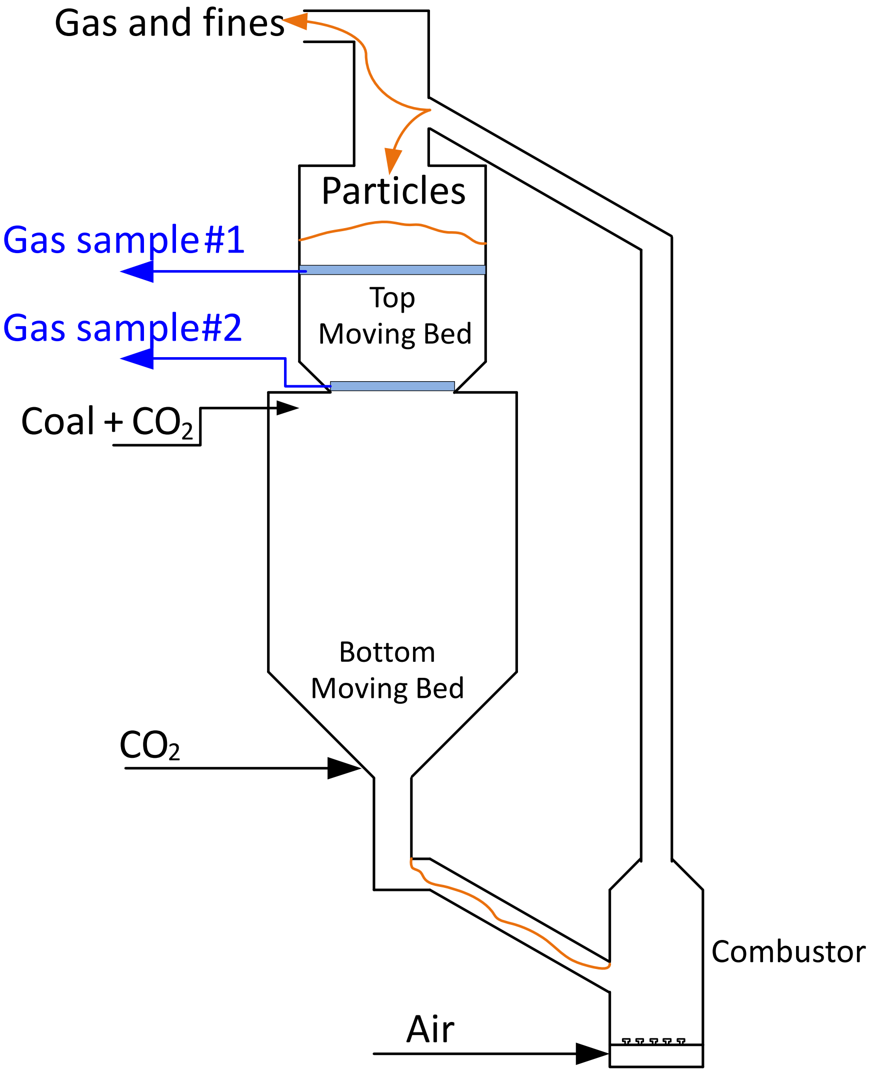
Process Specifications
•Thermal rating: 250 kWth
•Coal Feed Rate: 70 lb/hr
•Coal size: Pulverized coal
•Max Operating Temperature: 2012 ^{o}F
•Oxygen Carrier: Iron based
•Reducer : Counter-current moving bed
•Combustor : Bubbling bed
•Particle tranport: Pneumatic

Oxygen Carrier Specifications
•Active metal: Iron based
•Size: 1.5 mm



CDCL 250 kW_{th} Pilot

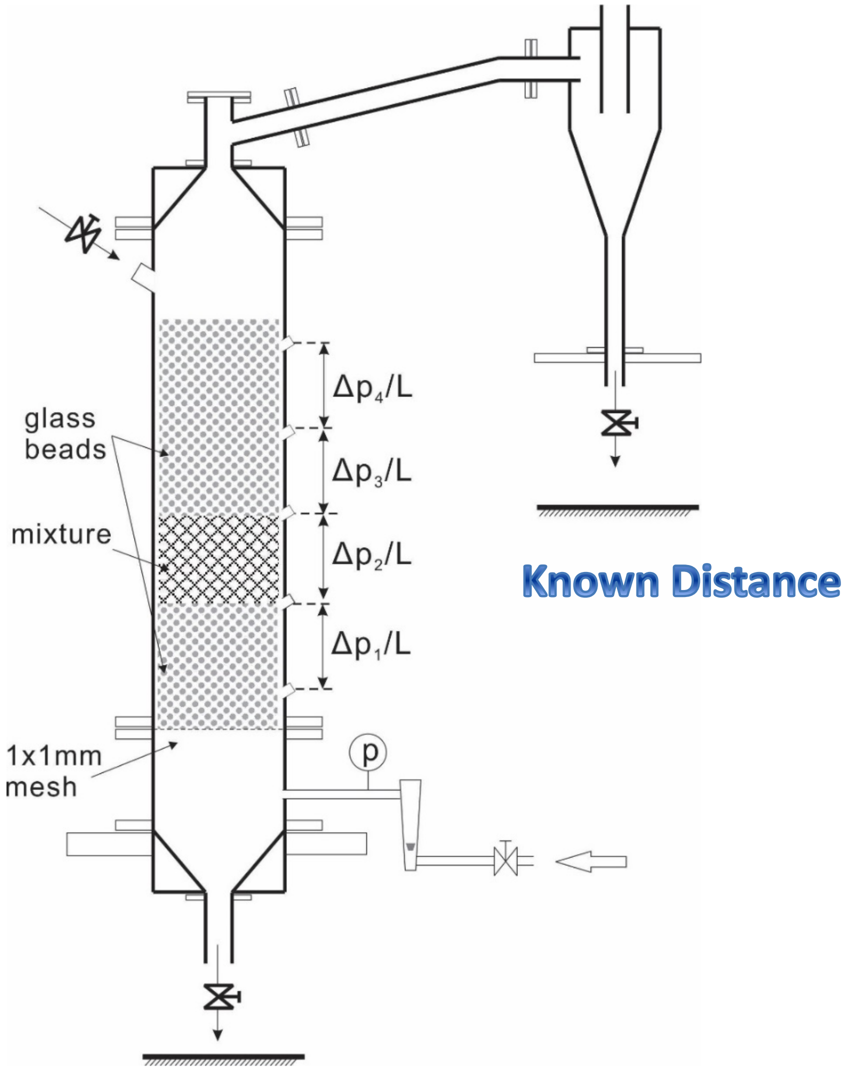
- **Coal residence time**
  Controling coal and particle flow rate
- **Ash separation**
  Controling enhancer gas flow rate; Material (ash) balance.
- **Pressure drop**
  Pressure balance on the system
- **CO_2 Purity; Sulfur, NOx emissions**
  Gas analysis through out the reactor
- **Autothermal operation**
  Steady-state operation without primary burner
- **System Operation**
  Start up and shutdown,
  HazOp, JSA and other operation protocols



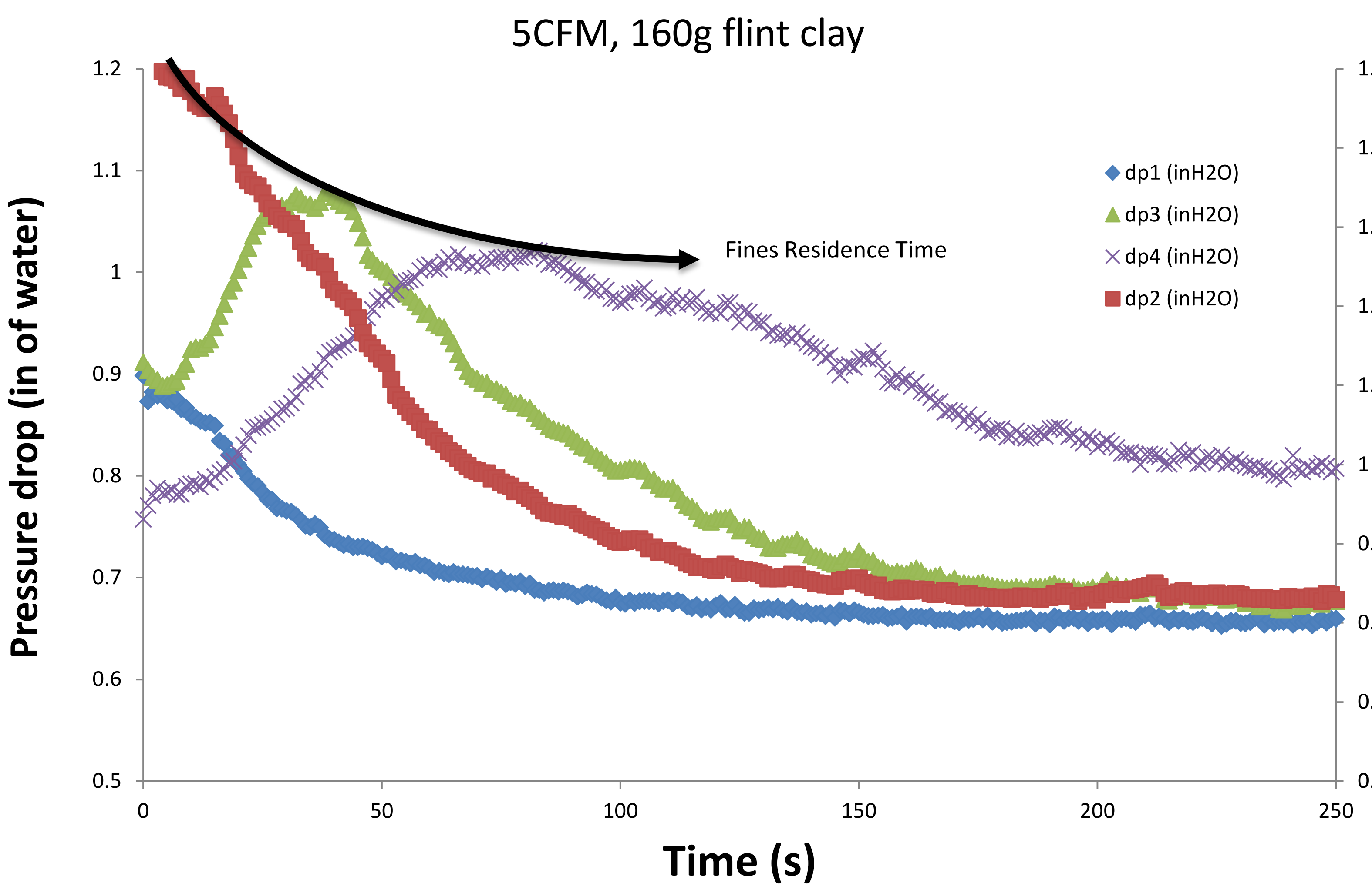
Outline

- Commercialization Path
- Phase I: CDCL Concept and Techno-Economic Analysis
- Phase I: Technology Gaps
- Phase II: Pilot Design
- Phase II: Laboratory Testing and Studies
- Project Schedule
- Conclusions and Acknowledgments

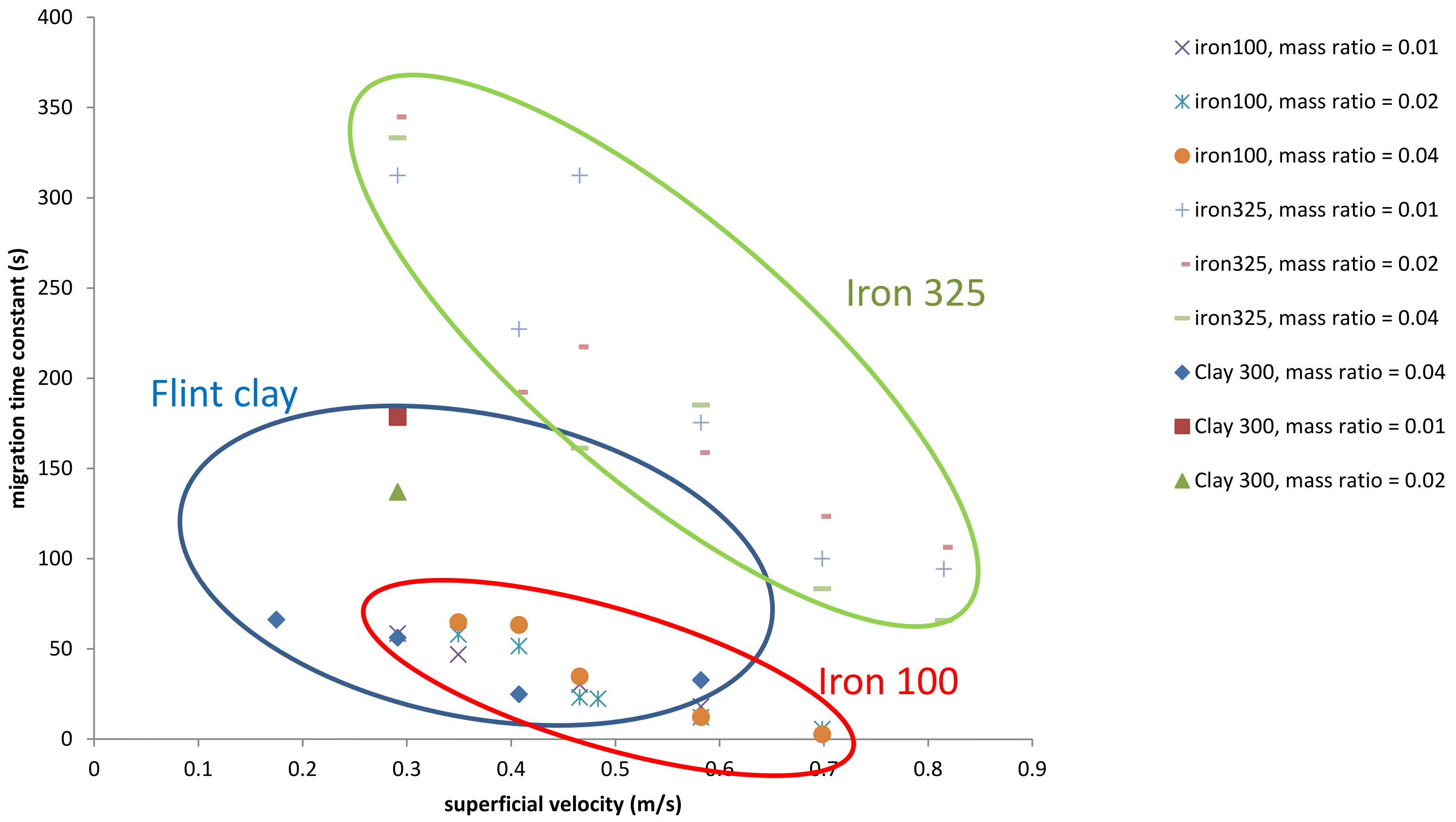
Coal Flow Model Tests: Fines entrainment



Fines Residence Time in Moving Bed



Ash and Fines residence time (τ_r)

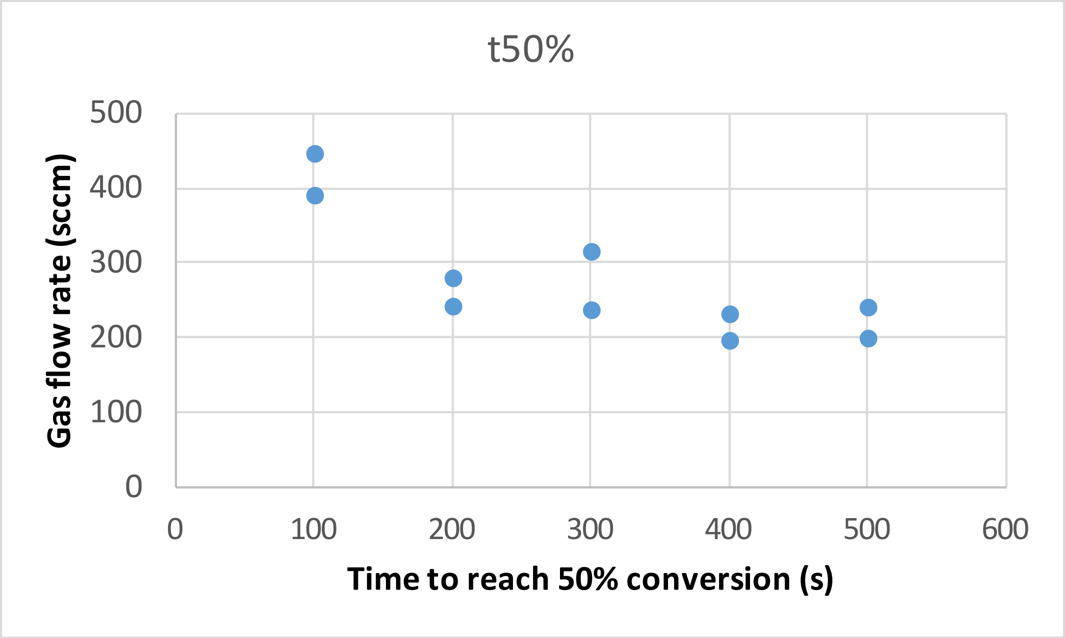


Particle Characterization

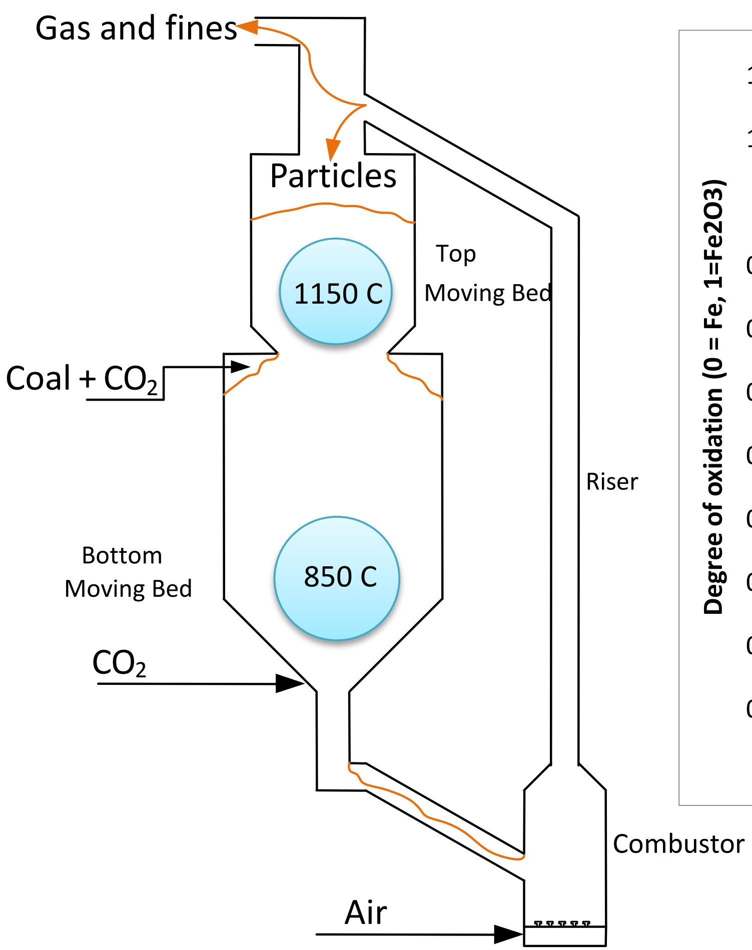
Photograph of TGA Analyzer

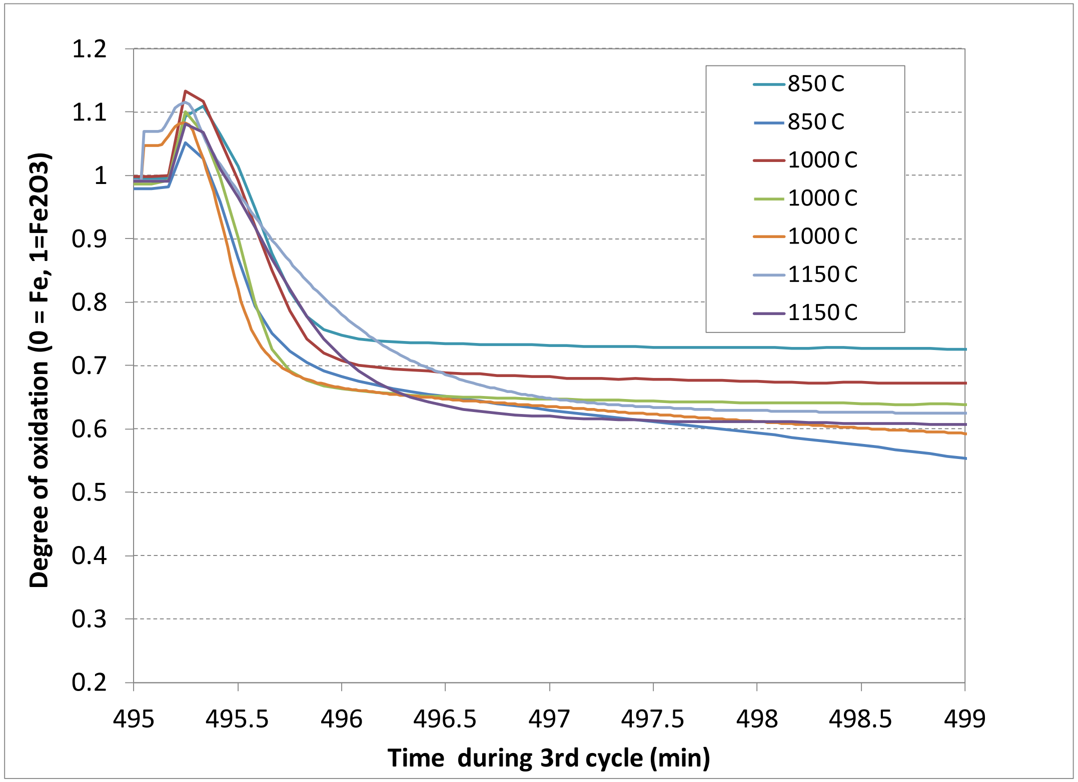
Gas Delivery System

Time to reach 50% conversion as a function of gas flow rate

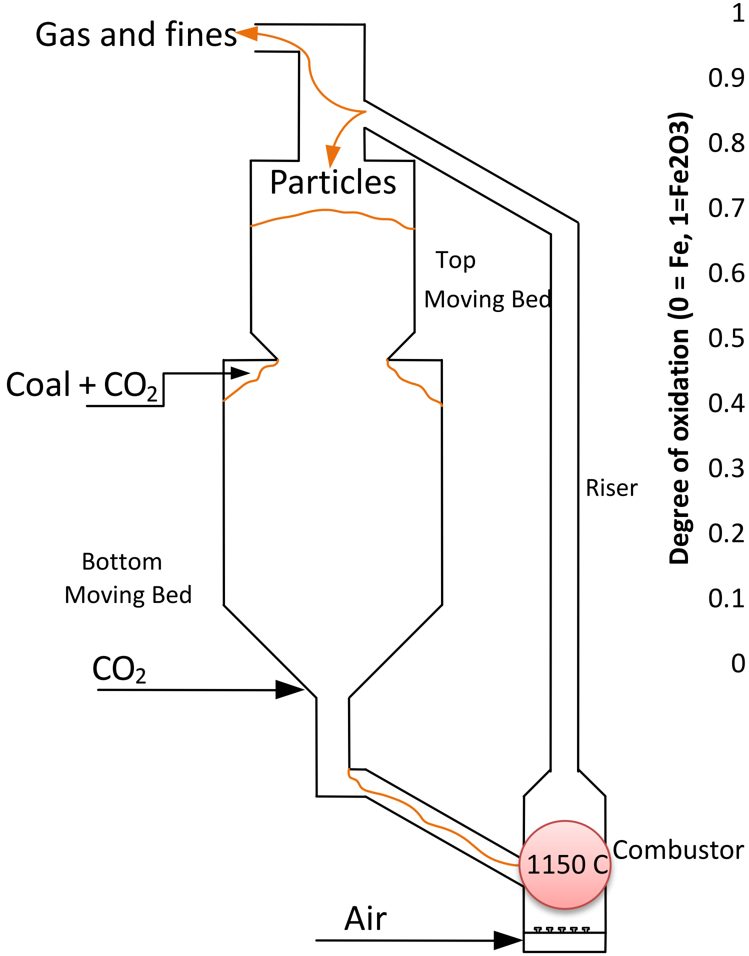


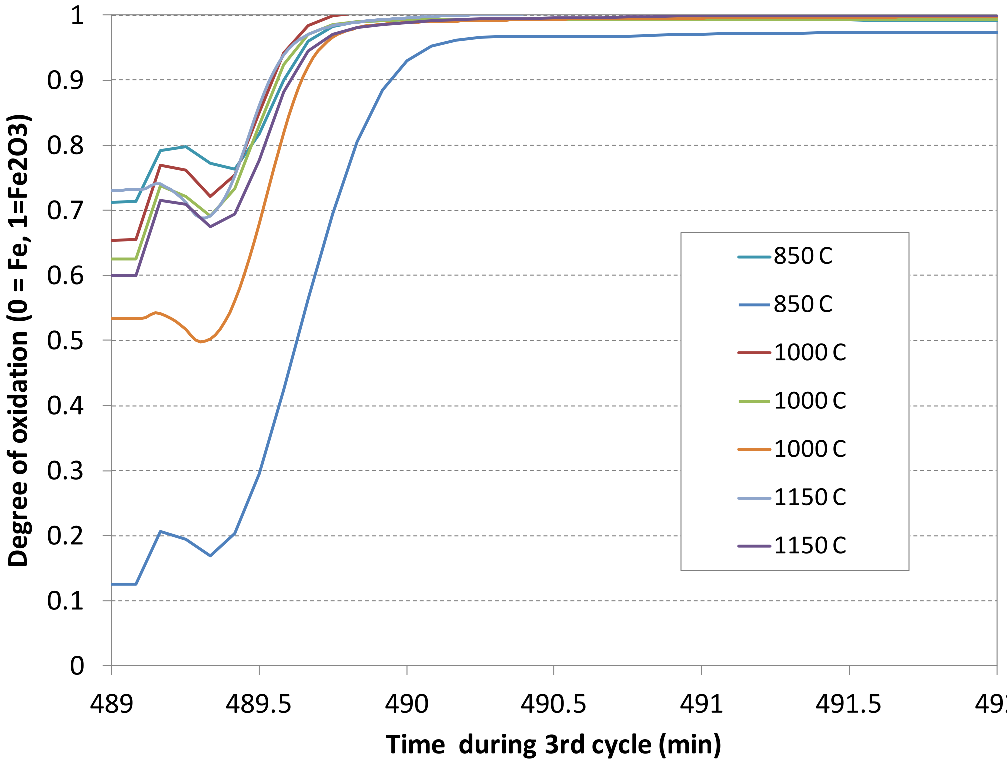
Particle Reduction Studies



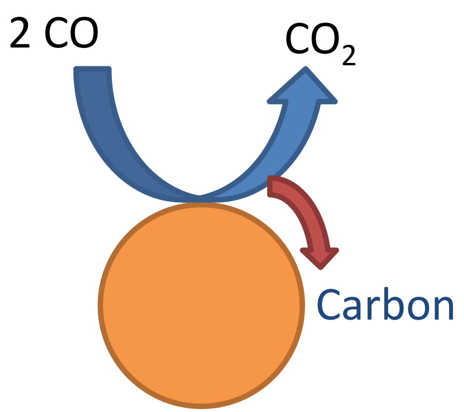


Particle Oxidation Studies



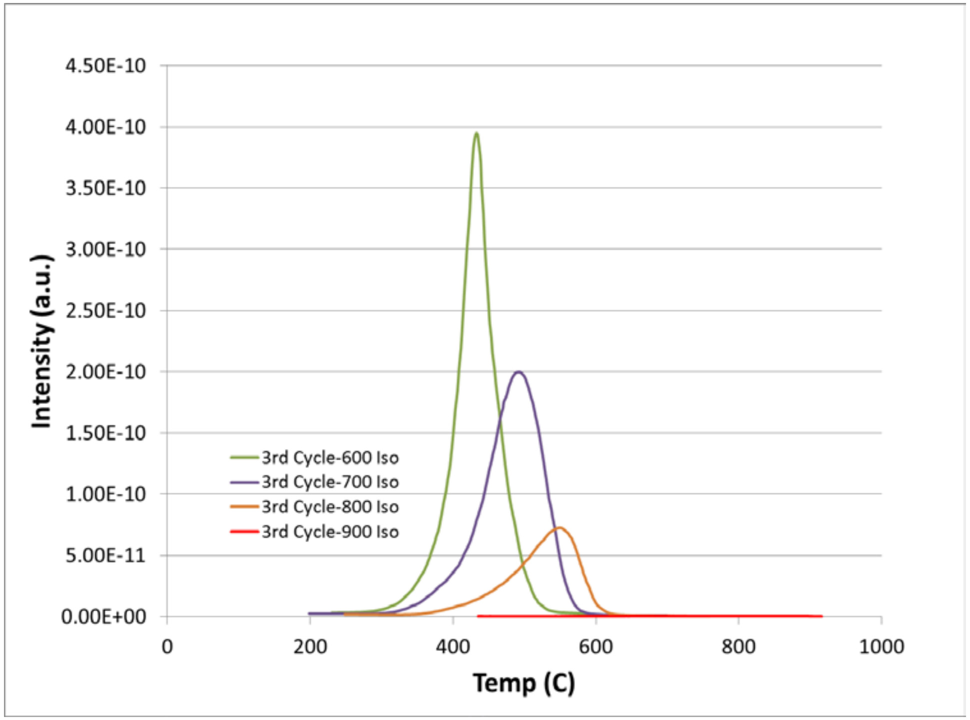


Particle Integrity Studies: Carbon formation



Iron-based Oxygen Carrier

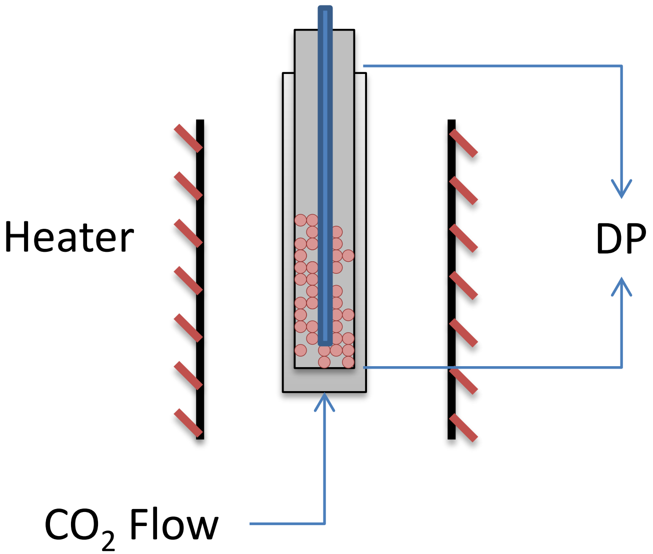
CO_2 Evalution after carbon formation on oxygen carrier particles

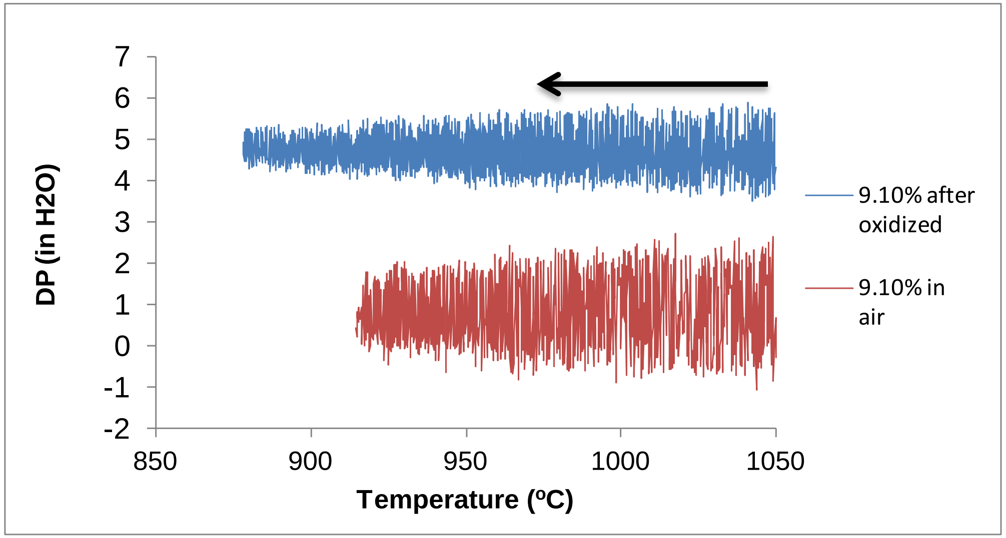


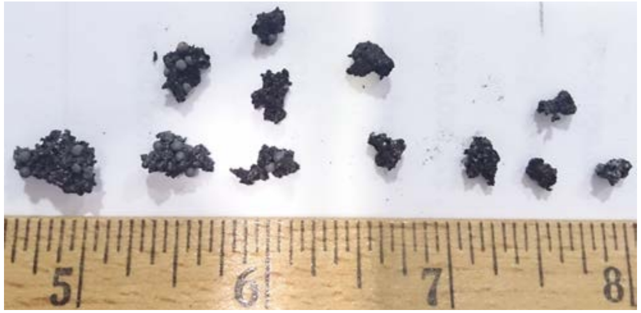
Above 900 ^{o}C there is no carbon formation

Alkaline Agglomeration Test

Alkaline injection test inn BFB

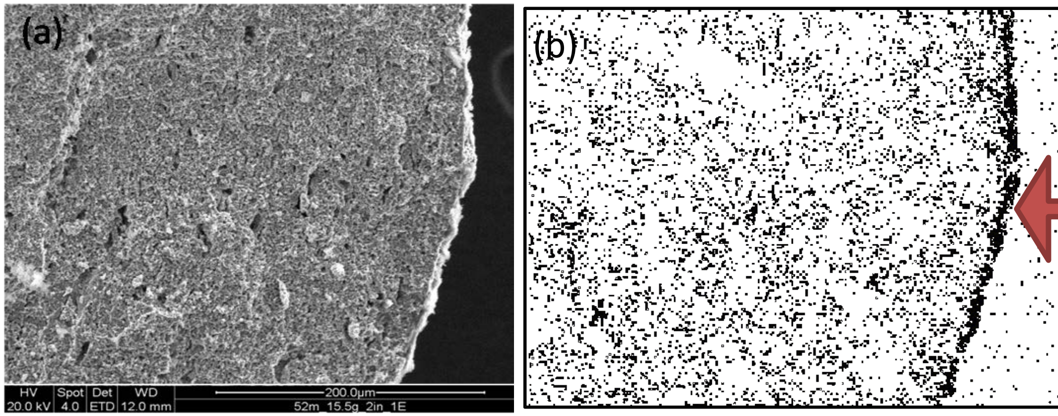




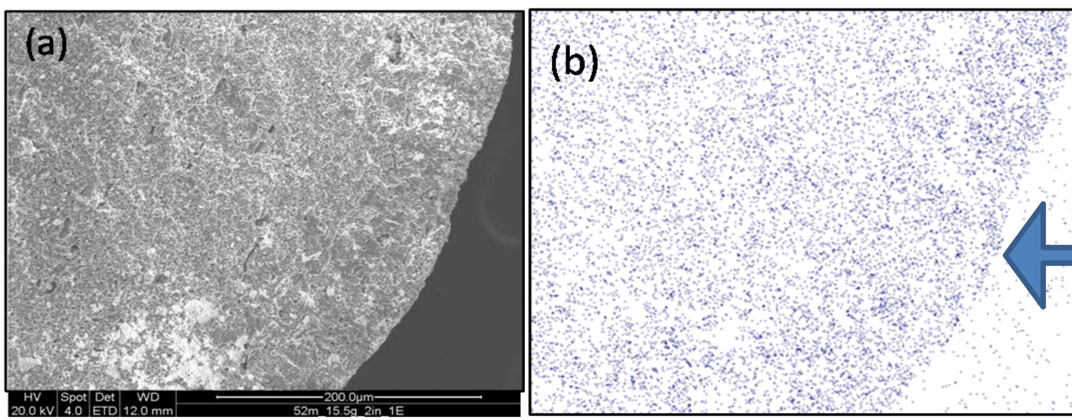


Particles aglomerate at very high alkaline content : ~9.1wt.%

Particle Regeneration



Agglomerated particles



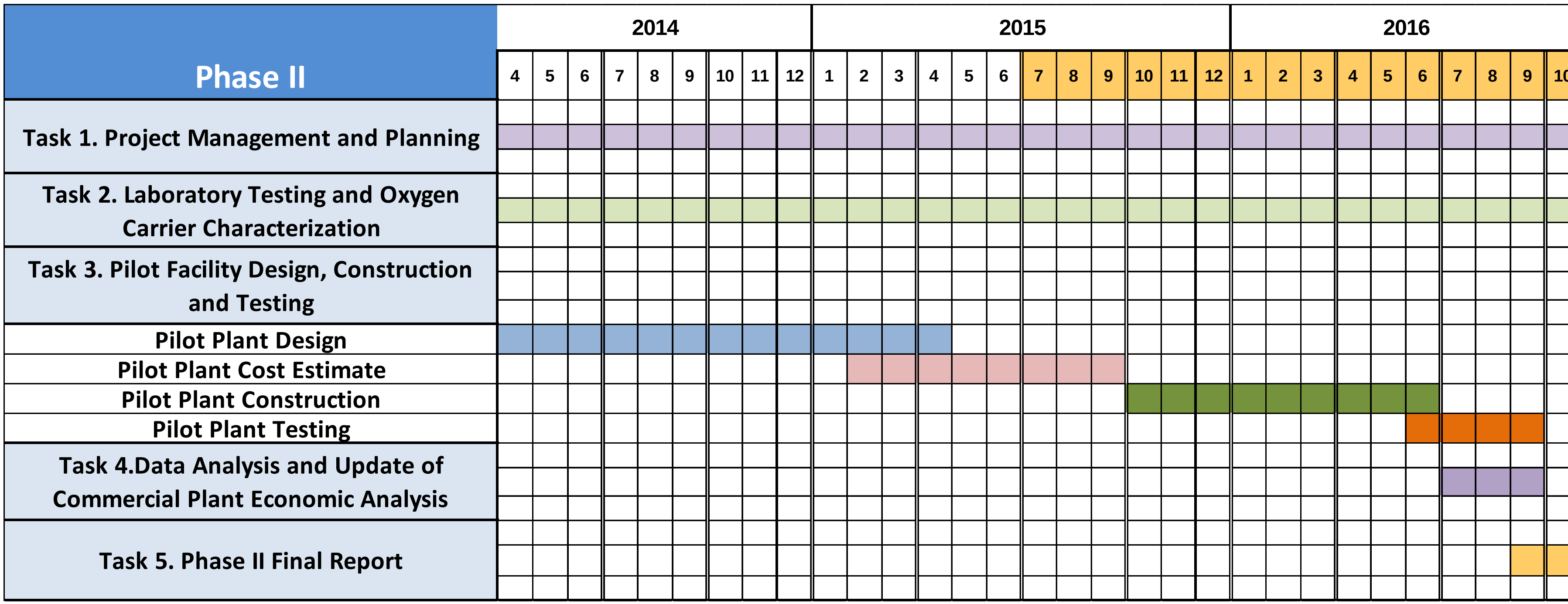
Regenerated particles

Agglomerated particle caused by alkaline can be regenerated in the combustor.

Outline

- Commercialization Path
- Phase I: CDCL Concept and Techno-Economic Analysis
- Phase I: Technology Gaps
- Phase II: Pilot Design
- Phase II: Laboratory Testing and Studies
- **Project Schedule**
- Conclusions and Acknowledgments

Project Schedule



Outline

- Commercialization Path
- Phase I: CDCL Concept and Techno-Economic Analysis
- Phase I: Technology Gaps
- Phase II: Pilot Design
- Phase II: Laboratory Testing and Studies
- Project Schedule
- **Conclusions and Acknowledgments**

Conclusions

- CDCL offers a cost-effective alternative for coal-based power generation with carbon capture

- The commercial CDCL modular design is ideal for commercial deployment of the technology

- Cold flow model and laboratory testing is confirming assumptions and design features of the 250 kWth pilot unit and the commercial design

- The design of 250 kWth pilot plant has been completed and we are moving soon towards the construction and testing

Acknowledgments

This material is based upon work supported by the Department of Energy under Award Number DE-FE0009761