FE0027654: 10MW$_e$ Coal Direct Chemical Looping Large Pilot Plant: Pre-Front End Engineering and Design Study

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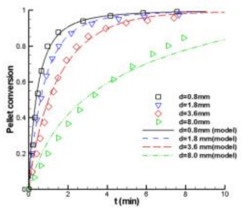
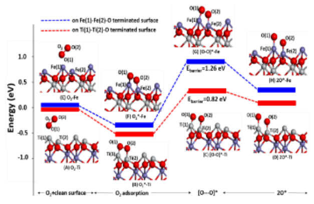
NETL CO_2 Capture Technology Project Review Meeting |25 August 2017

OSU Chemical Looping Evolution

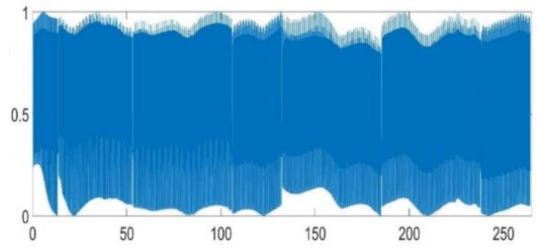
Laboratory Studies

Reduction Kinetics and Mechanism

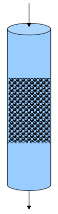




Oxygen Carrier Reactivity (TGA)



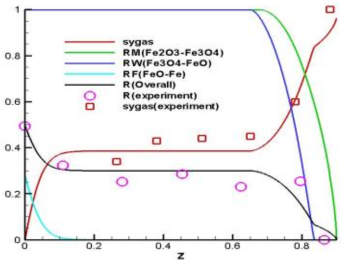
TGA



Fixed Bed

Bench Testing

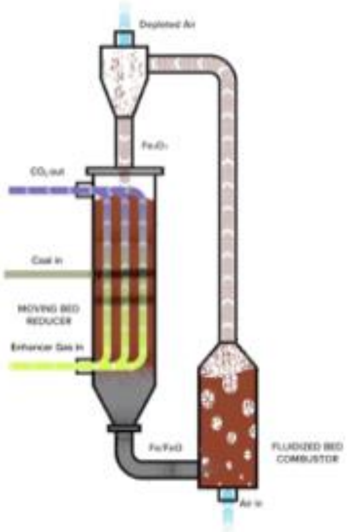
Moving Bed Model and Results



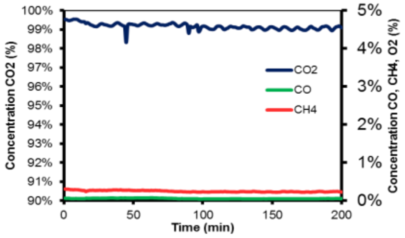
2.5 kW_{th} Reducer

Sub-Pilot Testing

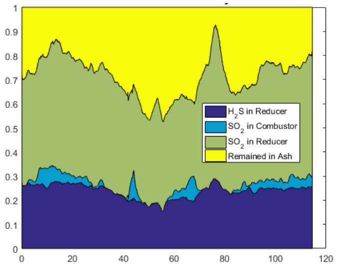
Integrated Design



Reduce Gas Profile

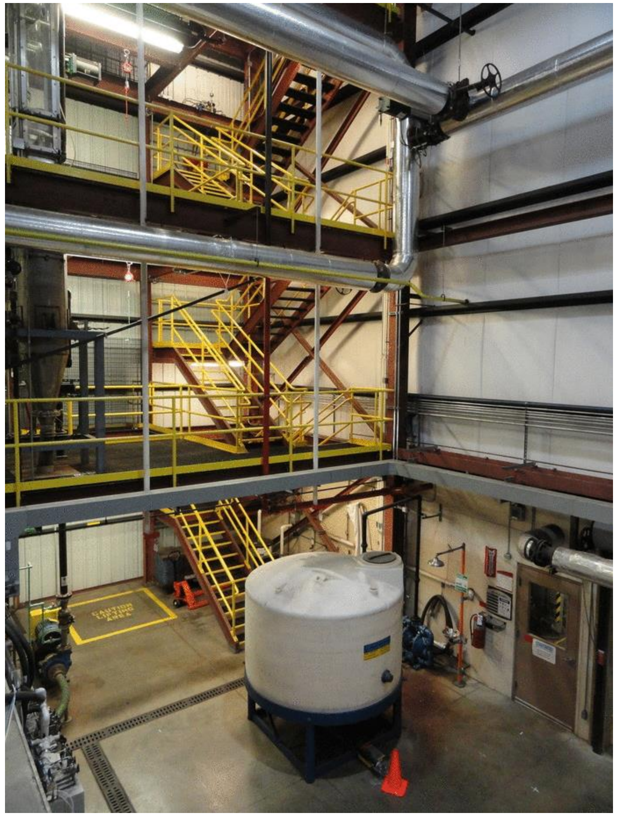


Sulfur Balance



25 kW_{th} CDCL Unit

Pilot Plant Demonstration

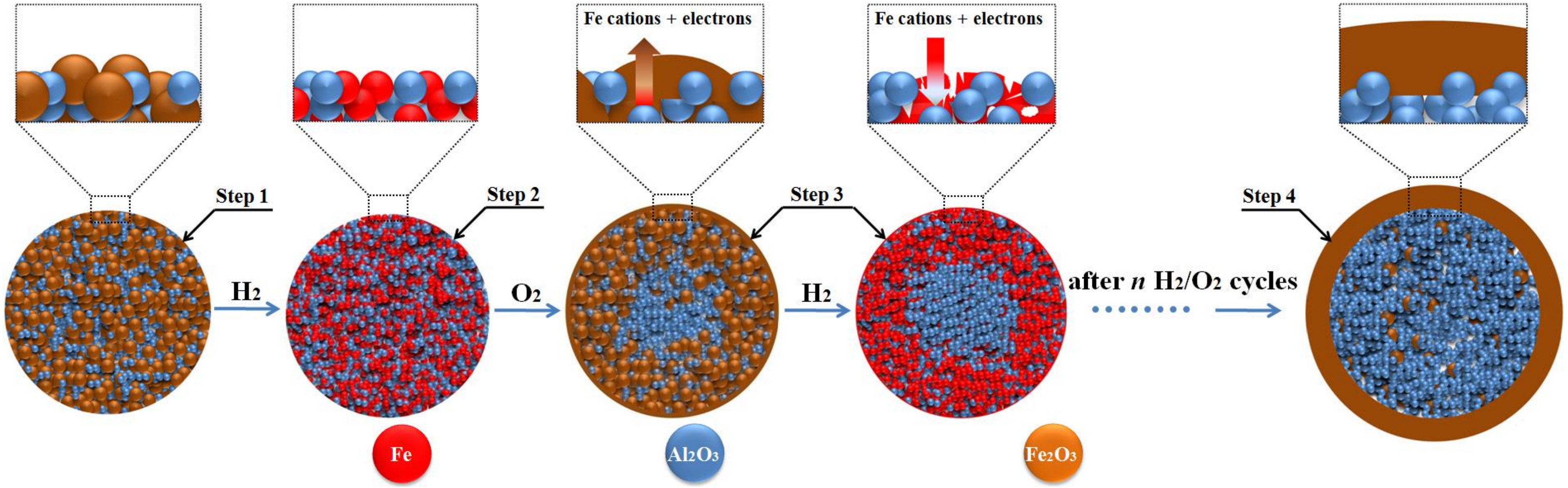


250 kW_{th} CDCL Unit

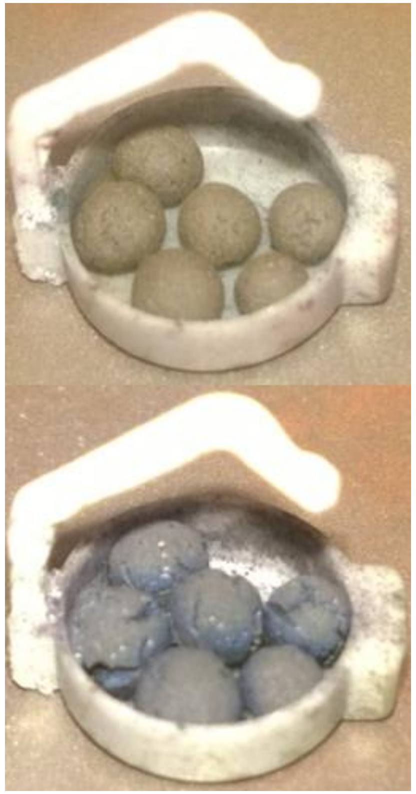
1993

2013 to present

Oxygen Carrier Development



Particle Before and After 100 redox reactions



$$4Fe_{(s)} + 3O_{2\,(g)} \rightarrow 2Fe_2O_{3\,(s)} \quad \text{(a)}$$

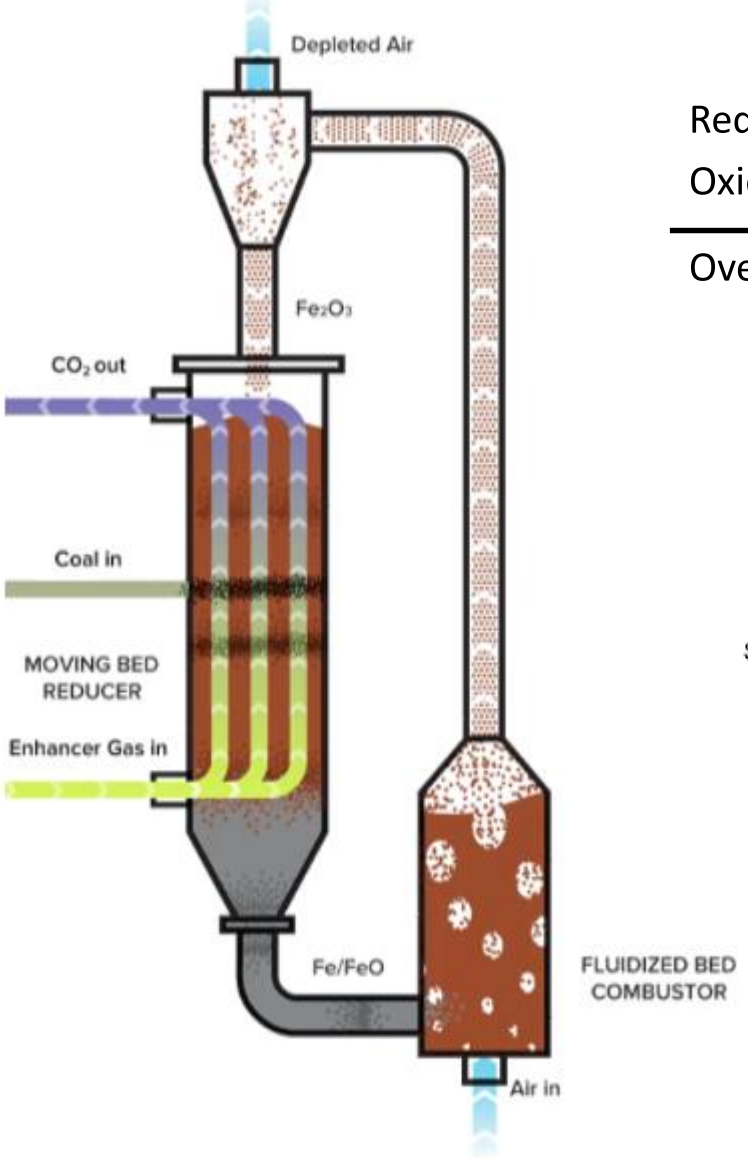
$$Fe_2O_{3\,(s)} + 3H_{2\,(g)} \rightarrow 2Fe_{(s)} + 3H_2O_{(g)} \quad \text{(b)}$$

If the cyclic reactions proceed through Fe cation diffusion, core-shell structure forms, *e.g*. **Fe_2O_3 + Al_2O_3.**

If the cyclic reactions proceed through O anion diffusion, core-shell structure does not forms, *e.g*. **Fe_2O_3 + TiO_2.**

*Al_2O_3 is only a physical support, while TiO_2 alters the solid-phase ionic diffusion mechanism

OSU Coal Direct Chemical Looping Process



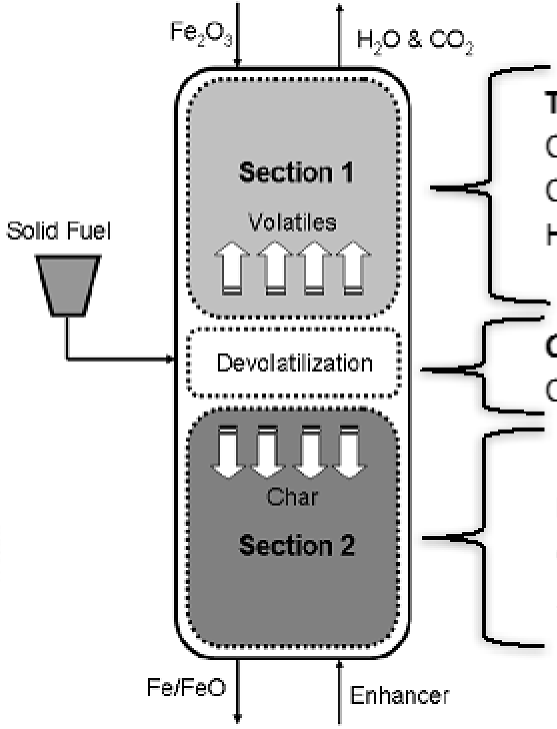
Main reactions:

Reducer: Coal + Fe_2O_3 → Fe/FeO + CO_2 + H_2O

Oxidizer: Air + Fe/FeO → Fe_2O_3 + Spent Air

Overall: Coal + Air → CO_2 + H_2O + Spent Air

Reducer Reactor Design



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 → 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

Fixed solid molar flowrate n_{Fe},

Oxygen content for solid $y = \dfrac{3n_{Fe_2O_3} + 4n_{Fe_3O_4} + n_{FeO}}{n_{Fe}}$

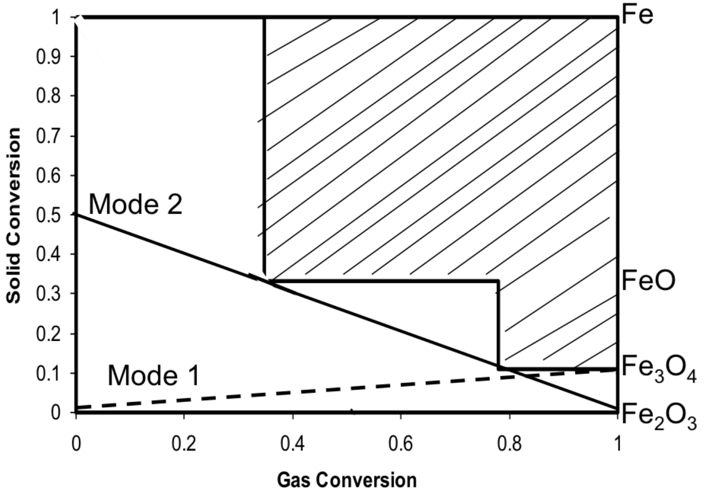
Fixed gas molar flowrate $n_{H2} + n_{H2O}$,

Oxygen content for gas $x = \dfrac{n_{H_2O}}{n_{H_2} + n_{H_2O}}$

Oxygen Balance

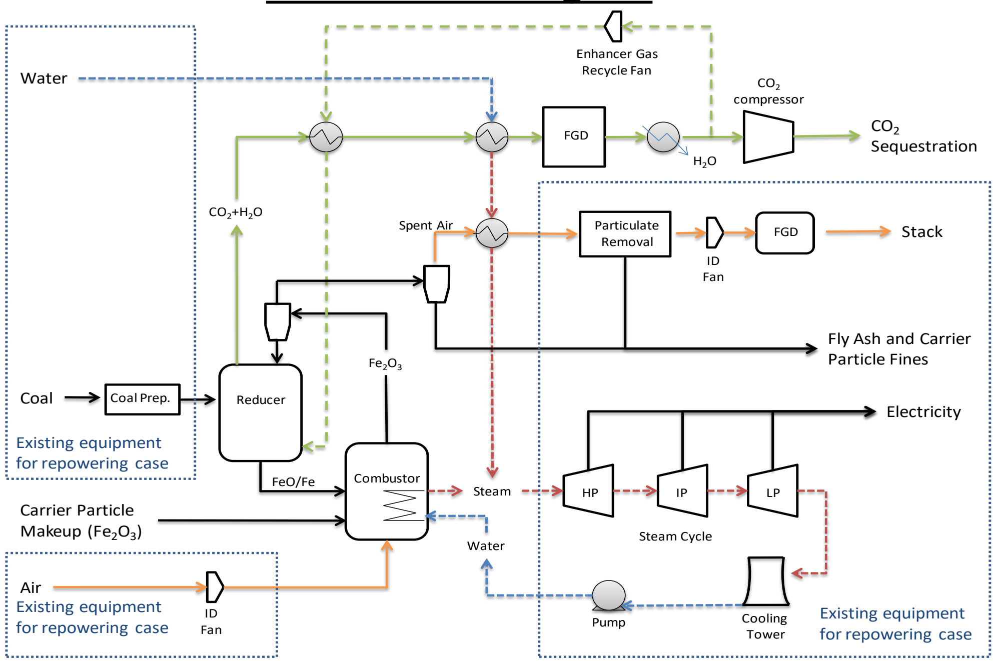
$$n_{Fe}(y_{z+\Delta z} - y_z) = (n_{H_2} + n_{H_2O})(x_{z+\Delta z} - x_z)$$

$$\Delta z \rightarrow 0 \Rightarrow dy/dx = (n_{H_2} + n_{H_2O})/n_{Fe}$$

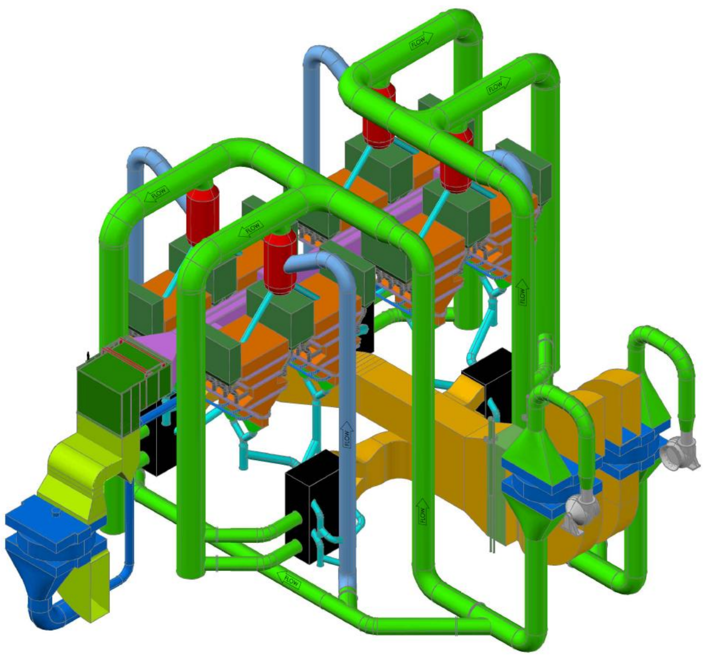


CDCL Process Analysis

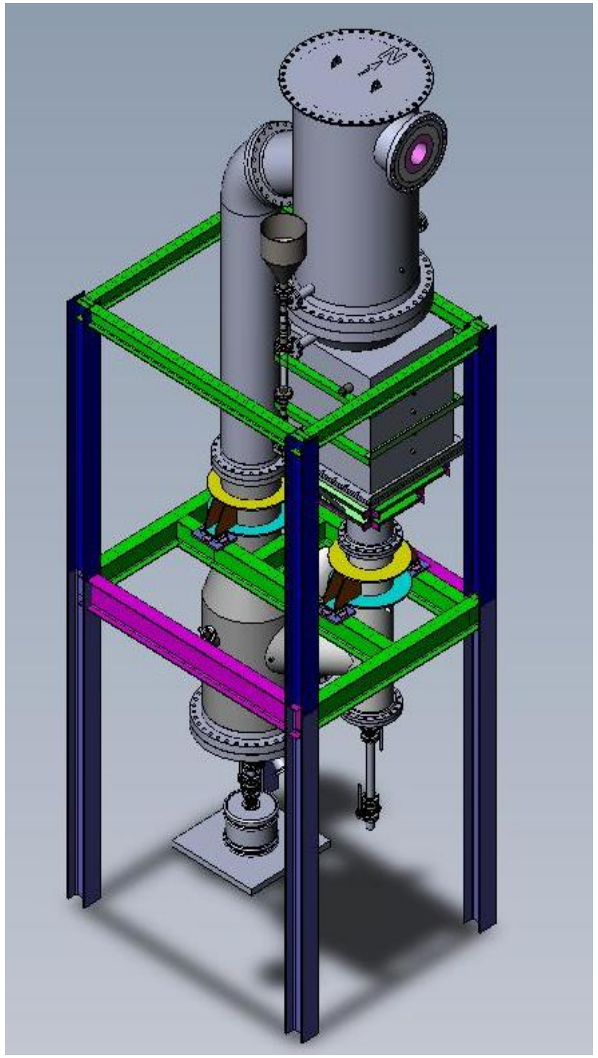
Process Flow Diagram



550 MW$_e$ CDCL Plant Conceptual Design



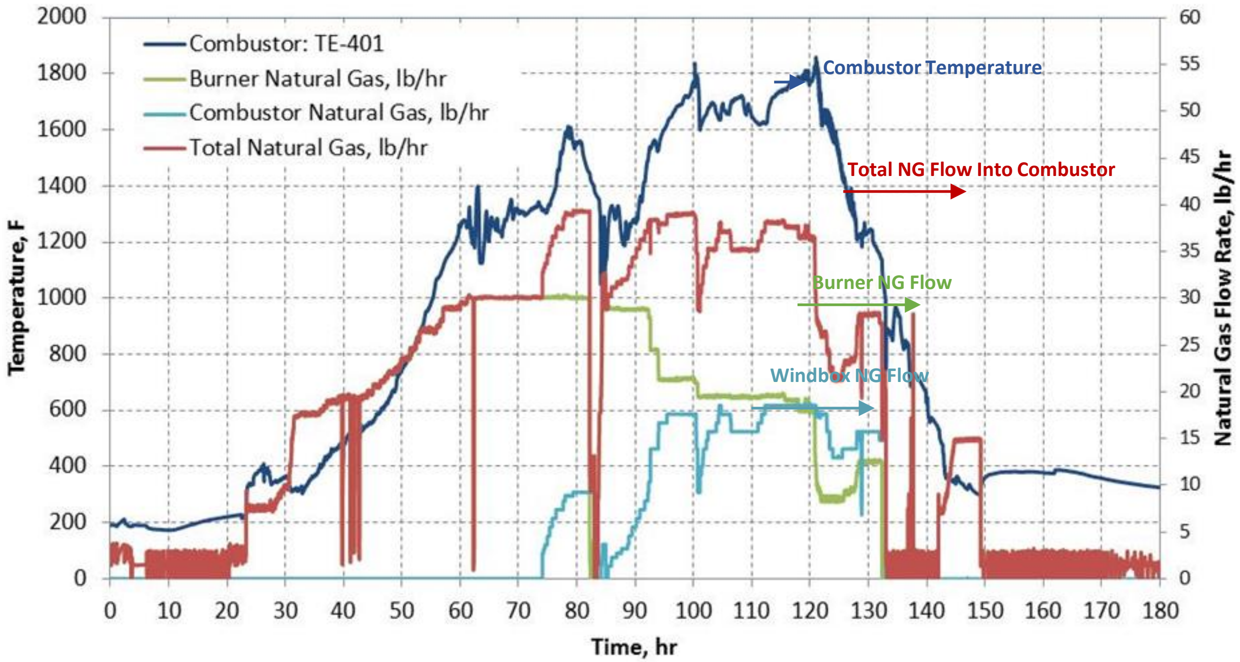
Constructed 250 kW$_{th}$ Test Unit



	Base Plant	MEA Plant	CDCL Plant
Coal Feed, kg/h	185,759	256,652	205,358
CO_2 Capture Efficiency, %	0	90	96.5
Net Power Output, MW$_e$	550	550	550
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**

250 kW$_{th}$ CDCL Pilot Test Unit

Combustor Temperature with Natural Gas Heating



Project Objective

- Perform the (pre-) Front end Engineering Design (FEED) of a modular 10 MW_e coal-direct chemical looping (CDCL) large pilot plant.
- Provide Functional specifications for integration with host site.
- Provide risk assessment, schedule and cost estimate for fabrication, construction and testing.
- Update design and commercial 550 MW_e CDCL plant economic analysis

Project Objective and Schedule

- Objective: Completed a site specific design of a 10 MW_e large pilot CDCL test unit with >90% CO_2 capture
- 3 Major task to complete project
  - Task 2: Continued operation of 250 kW_{th} pilot test unit and 10 MW_e cold flow model studies
    - Coal/Fe ratio optimization, site specific coal studies, etc.
    - CFM studies on coal/reducing gas distribution and combustor fluidization performance
  - Task 3: 10 MW_e Unit Design and Costing
    - Host site selected
    - Oxygen carrier synthesis process costing
    - Detailed reactor sizing, HMB, HAZOP review, etc.
  - Task 4: Refine TEA models base on project results

10 MWe CDCL FEED STUDY

2016 | 2017 | 2018

Budget Period 1: 10/1/16 - 9/30/17 | Budget Period 2: 10/1/17 - 9/30/18

	Start Date	End Date	COST
Task 1. Project Management and Planning			**$502,226**
Subtask 1.1. Project Management	10/1/2016	9/30/2018	
Milestones			
Project Kick-Off Meeting	10/1/2016	10/31/2016	
NETL's CO2 Capture Meeting	7/1/2017	7/31/2017	
NETL's CO2 Capture Meeting	7/1/2018	7/31/2018	
NETL's Peer Review Meeting	4/1/2017	4/30/2017	
NETL's Peer Review Meeting	4/1/2018	4/30/2018	
Quarterly Reports	10/1/2016	9/30/2018	
Updated Phase II Management Plan	10/1/2016	11/30/2016	
IRC Meeting	10/1/2016	9/30/2018	
Travel for Phase II Closeout Meeting	9/1/2018	9/30/2018	
Task 2. 250 kW_t Small Pilot and Modular 10 MW_e Cold Flow Model Testing			**$841,106**
Subtask 2.1. 250 KW_t Pilot Testing	10/1/2016	3/31/2017	
Milestone: 250 kW_t Pilot Testing Report	3/1/2017	3/31/2017	
Subtask 2.2. Design, Construction and Testing of Modular Cold Flow Model	10/1/2016	5/31/2018	
Milestone: Cold Flow Model Testing Report	6/1/2018	6/30/2018	
Task 3. 10 MW_e CDCL Large Pilot Facility Design and Costing			**$3,243,781**
Subtask 3.1. Host Site Selection and Agreement	10/1/2016	12/31/2016	
Subtask 3.2. Modular CDCL Reactor System Integration Design	11/1/2016	1/31/2017	
Subtask 3.3. Technology Engineering Design Specifications	1/1/2017	3/31/2017	
Milestone: Design Basis Report	4/1/2017	4/30/2017	
Subtask 3.4. Data Management Plan	10/1/2016	12/31/2016	
Subtask 3.5. Technology Readiness and Risk Assesment	1/1/2017	3/31/2017	
Subtask 3.6. Oxygen Carrier Commercial Manufacturing Development	11/1/2016	11/30/2017	
Milestone: Oxygen Carrier Commercial Manufacturing Report	12/1/2017	12/31/2017	
Subtask 3.7. CDCL Large Pilot Facility Design			
Subtask 3.7.1 Detail Heat and Material Balances	12/1/2016	1/31/2017	
Subtask 3.7.2. Equipment Performance Analysis and Performance Testing Plan	1/1/2017	4/30/2017	
Subtask 3.7.3. Integration of Pilot Facility with Existing Equipment and Piping Design	4/1/2017	7/31/2017	
Subtask 3.7.4. Piping & Instrumentation Diagrams (P&IDs) Drawings	6/1/2017	8/31/2017	
Subtask 3.7.5. Mechanical, Electrical and Equipment Specifications and Drawings	8/1/2017	10/31/2017	
Subtask 3.7.6. System Control Specifications	10/1/2017	12/1/2017	
Milestone: Design Functional Specifications	1/1/2018	1/31/2018	
Subtask 3.7.7. Hazard Design and Harzard Operation (HAZOP) Analysis	9/1/2017	11/30/2017	
Subtask 3.7.8. General Arrangement Drawings	12/1/2017	6/30/2018	
Subtask 3.7.9. Foundations and Steel Structural Support	4/1/2018	7/31/2018	
Subtask 3.8. Building and Utilities			
Subtask 3.8.1. Balance of Plant Specifications and Modifications	7/1/2017	10/31/2017	
Subtask 3.8.2. Environmental Control Equipment and CO_2 Capture	11/1/2017	1/31/2018	
Subtask 3.8.3. Waste Treatment and Disposal	2/1/2018	4/30/2018	
Milestone: Emissions Performance and Environmental Control Report	6/1/2018	6/30/2018	
Subtask 3.9. Construction and Operation Cost Estimate			
Subtask 3.9.1. Equipment Cost Estimate	4/1/2018	6/30/2018	
Subtask 3.9.2. Construction and Operation Schedule	6/1/2018	7/31/2018	
Task 4. Refine Commercial Plant Design and Economic Evaluation			**$596,925**
Subtask 4.1. Update Commercial Plant Design and Evaluation of the TRL	3/1/2018	5/31/2018	
Subtask 4.2. Update Commercial Cost Analysis and Comparison	4/1/2018	6/30/2018	
Subtask 4.3. CDCL Commercialization Roadmap and Risk Assessment	5/1/2018	7/31/2018	
Task 5. Final Report and Close Out Documents			**$152,603**
Subtask 5.1. Phase II Final Report and Close Out Documents	7/1/2018	9/30/2018	
Milestones			
Pilot Demonstration Decision Point Go/No-Go	9/1/2018	9/30/2018	
Phase II Final Report and Close Out Documents	7/1/2018	9/30/2018	
TOTAL COST			**$5,336,640**

Project Team

OSU/B&W	**Lead and manage overall project activities Task 1 and conduct research, design and Engineering studies in Task 2, 3 and 4**
Clear Skies Consulting	Task 3 & 4: Coordinate IRC meetings
EPRI	Task 4: TEA review and Balance of Plant Support
Johnson Matthey	Task 3: Develop OC manufacturing techniques
PSRI	Task 2: Perform cold flow model experiment
Dover	Task 3: Test site selection
Nexant	Task 4: TEA review

Dover Test Site

Task 3.6: Oxygen Carrier Commercial Manufacturing Development

Phase I

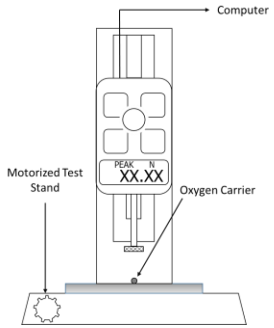
- Verification of reactivity with TGA
- Strength and attrition analysis with Jet-Cup

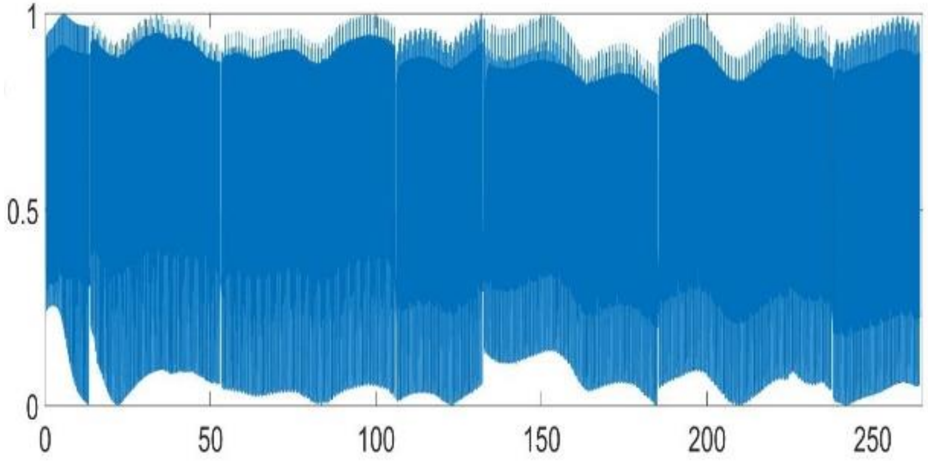
Phase II

- Incorporation of natural ilmenite
- Raw material size optimization
- Shape factor optimization

Phase III

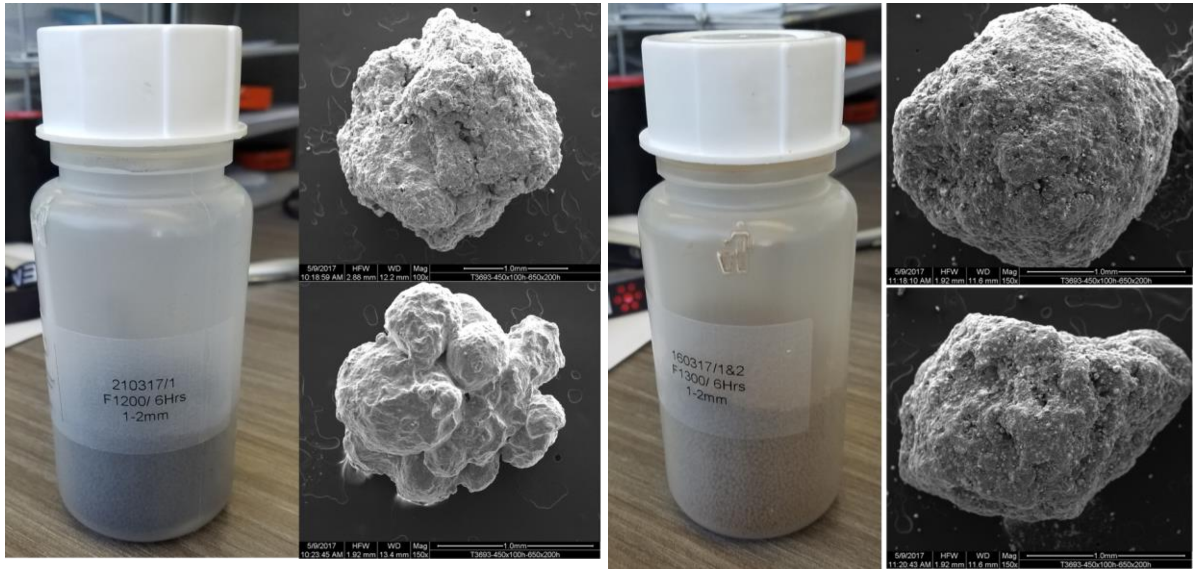
- JM cost-model analysis
- First estimate of ITCMO production cost

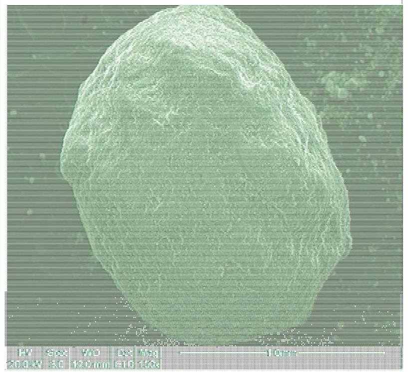




JM Johnson Matthey

Task 3.6: Oxygen Carrier Commercial Manufacturing Development





Johnson Matthey

- First round of samples have been received and characterized
- One sample achieved target conversion (33%) with stable strength after 200 cycles (64 MPa)
- Next steps:
    - Optimize sphericity of oxygen carrier
    - Use of natural ore ilmenite as raw material
    - Attrition resistance measurement with Jet-cup

Sample #160317/1&2	
Density	2871 kg/m^3
Average Diameter	1.58 mm
Crushing Strength after 200 redox cycles	64 MPa
Conversion (%)	33%

Concluding Remarks

- CDCL process represents an advanced, next generation oxy-combustion technology capable of high process efficiency for electricity production with >95% carbon capture
- Project objective is to complete a Preliminary FEED study of the CDCL $10MW_e$ large-pilot facility incorporating a modular reactor design
- Small pilot scale testing ongoing with promising initial results
- Oxygen carrier synthesis assessment initiated with initial sample production from Johnson Matthey showing good performance. OSU sample characterization studies ongoing.

Acknowledgements

Government Agency

- DOE/NETL: John Rockey
- Ohio Development Services Agency: Greg Payne

Fan Research Group Members

Project Participants

- Electric Power Research Institute
- Particle Solids Research Incorporated
- Dover Light & Power
- Johnson Matthey
- Clear Skies Consulting
- Nexant
- Industrial Review Committee
    - AEP
    - First Energy
    - Dayton Power & Light
    - Ohio EPA
    - CONSOL Energy
    - Public Utility Commission of Ohio