THE OHIO STATE UNIVERSITY

DE-FE-0029093: Heat Integration Optimization and Dynamic Modeling Investigation for Advancing the Coal Direct Chemical Looping Process

Dikai Xu

Andrew Tong (PI), L.-S. Fan (Co-PI)

Department of Chemical and Biomolecular Engineering

THE OHIO STATE UNIVERSITY

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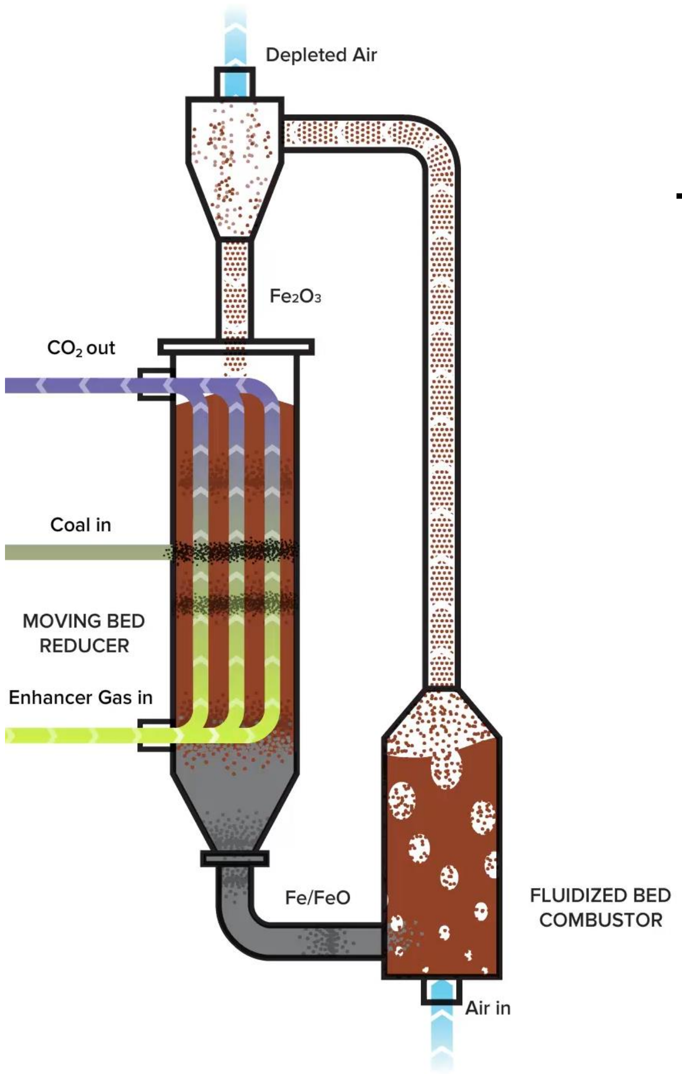
OSU Coal Direct Chemical Looping Process

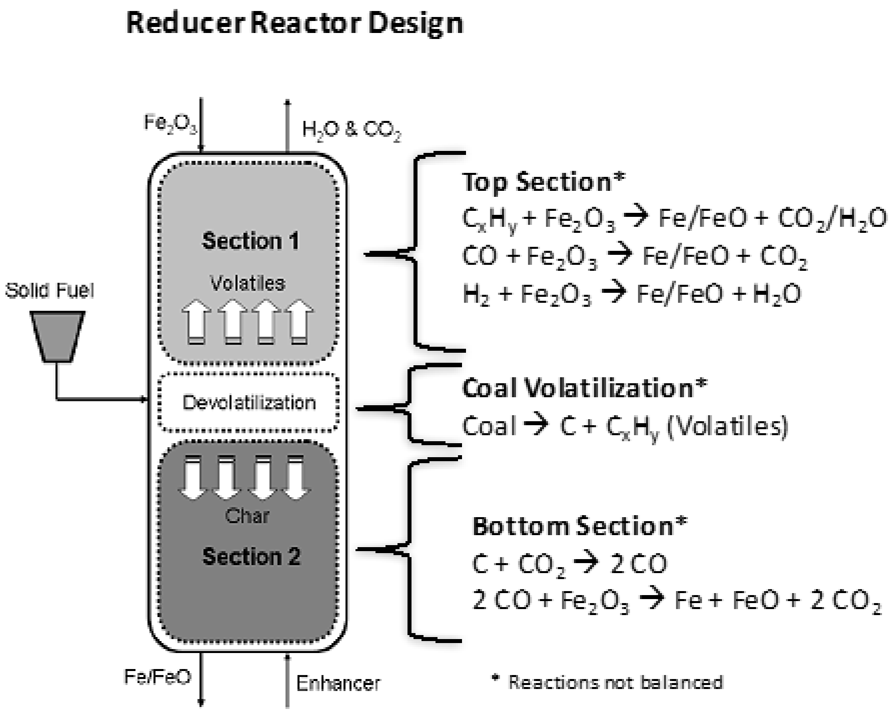


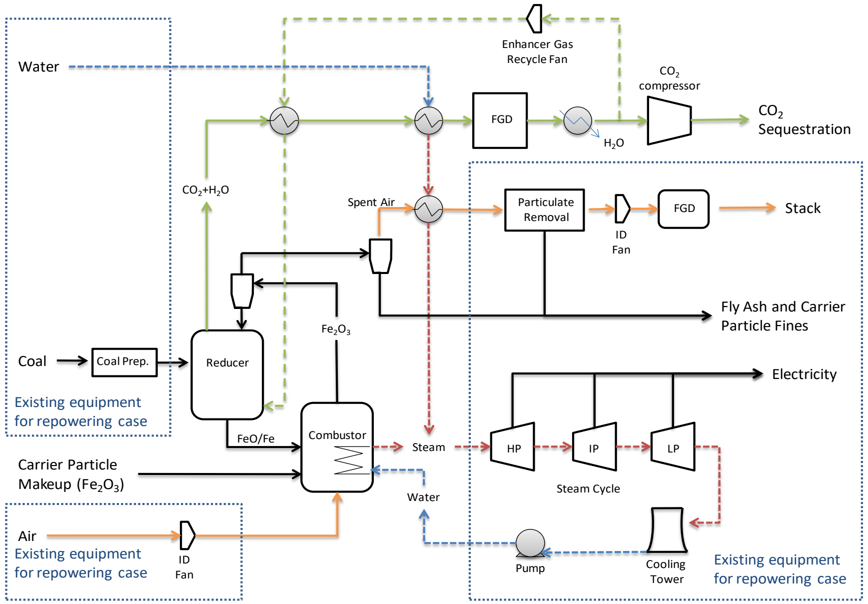
Main reactions:

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



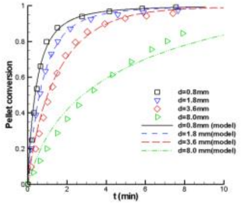


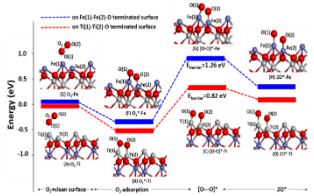
	CDCL Plant
Coal Feed, kg/h	205,358
CO_2 Capture Efficiency, %	96.5
Net Power Output, MW_e	550
Net Plant HHV Efficiency, %	35.6
Cost of Electricity, $/MWh	102.67
Increase in Cost of Electricity, %	**26.8**

OSU Chemical Looping Evolution

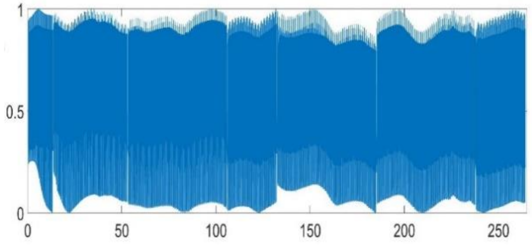
Laboratory Studies

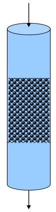
Reduction Kinetics and Mechanism





Oxygen Carrier Reactivity (TGA)



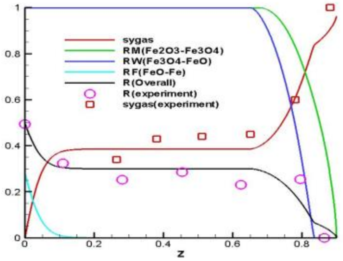


TGA

Fixed Bed

Bench Testing

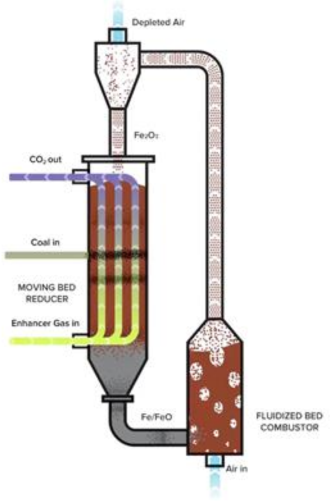
Moving Bed Model and Results



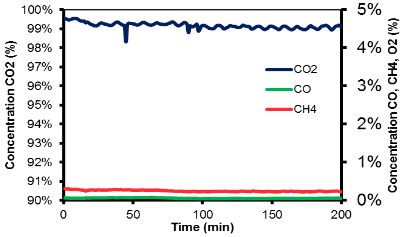
2.5 kW_{th} Reducer

Sub-Pilot Testing

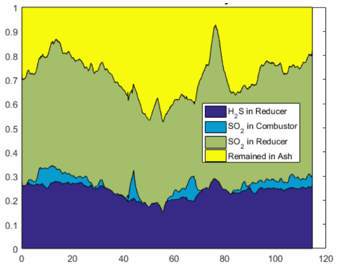
Integrated Design



Reduce Gas Profile



Sulfur Balance



25 kW_{th} CDCL Unit

Pilot Plant Demonstration

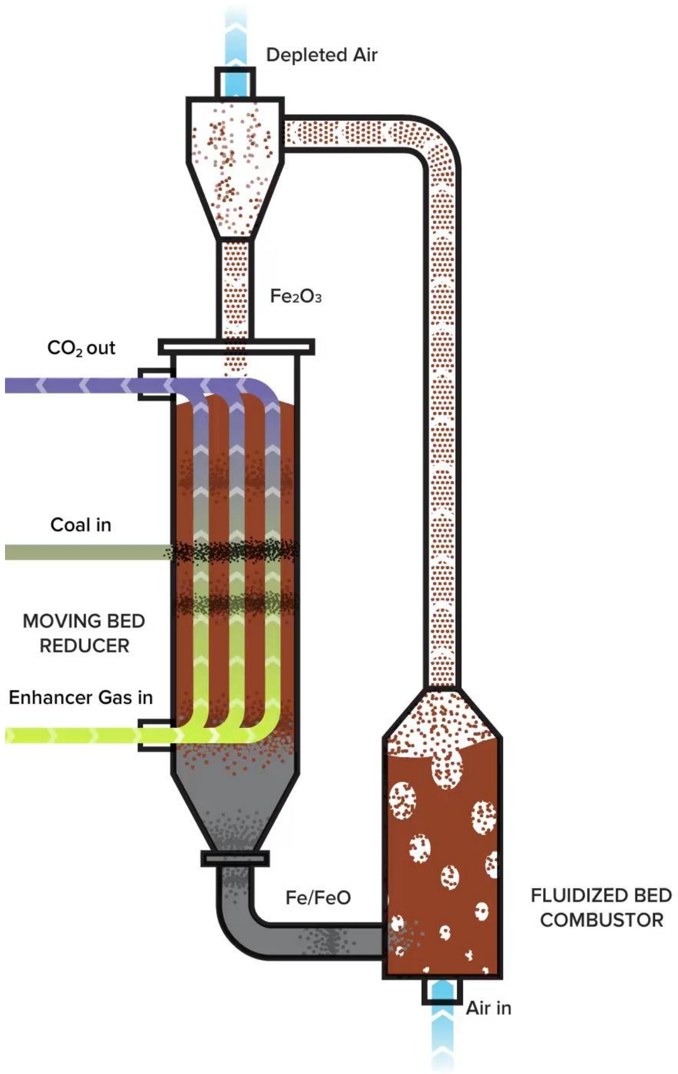
250 kW_{th} CDCL Unit

1993

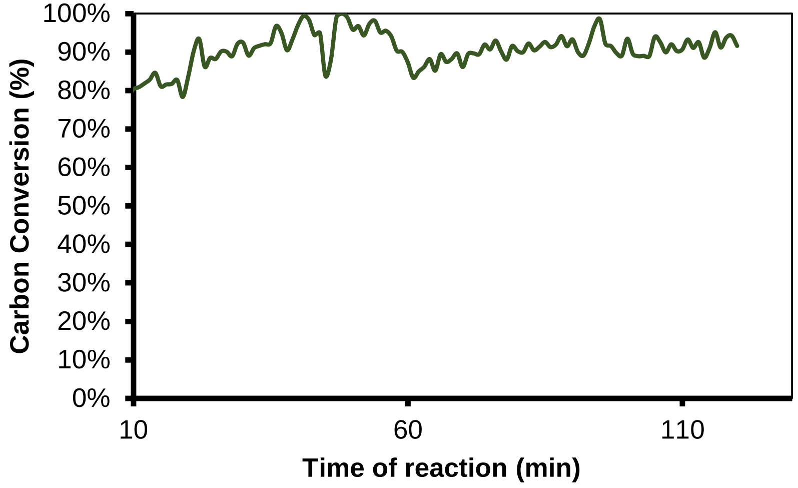
2013 to present

OSU Coal Direct Chemical Looping Process

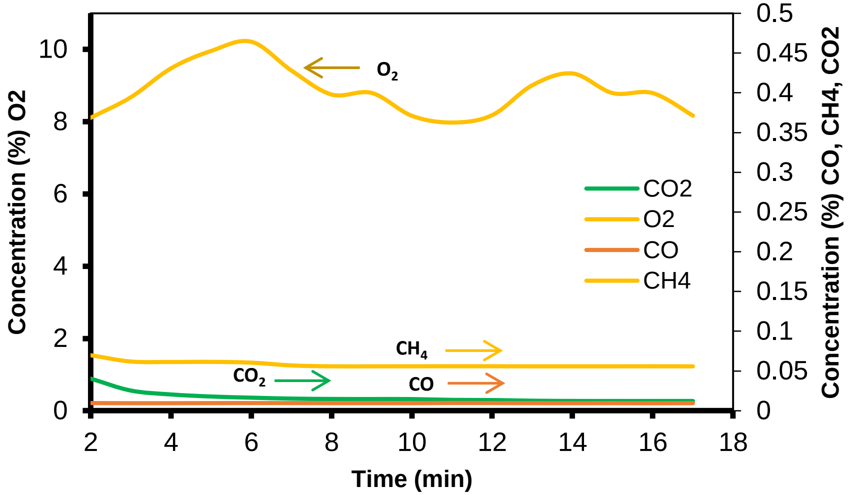
200-Hour Continuous Operation at 25kW$_{th}$ Sub-pilot Scale



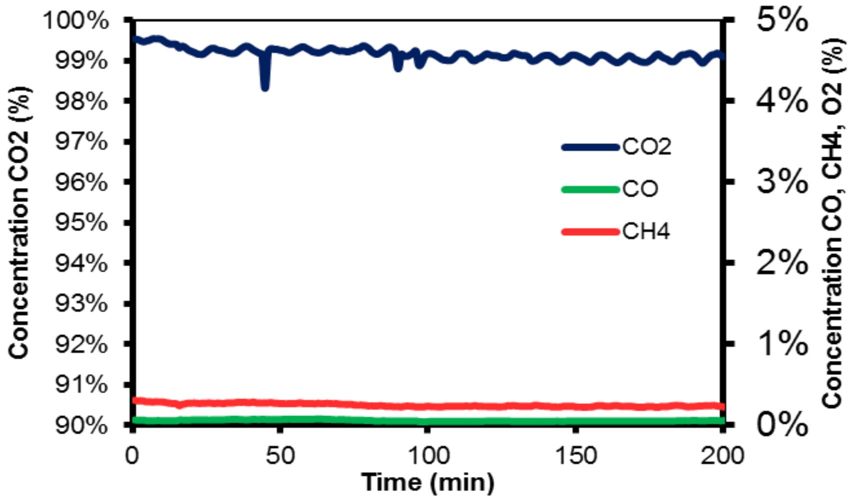
Reducer Carbon Conversion Profile



Combustor Gas Concentration Profile



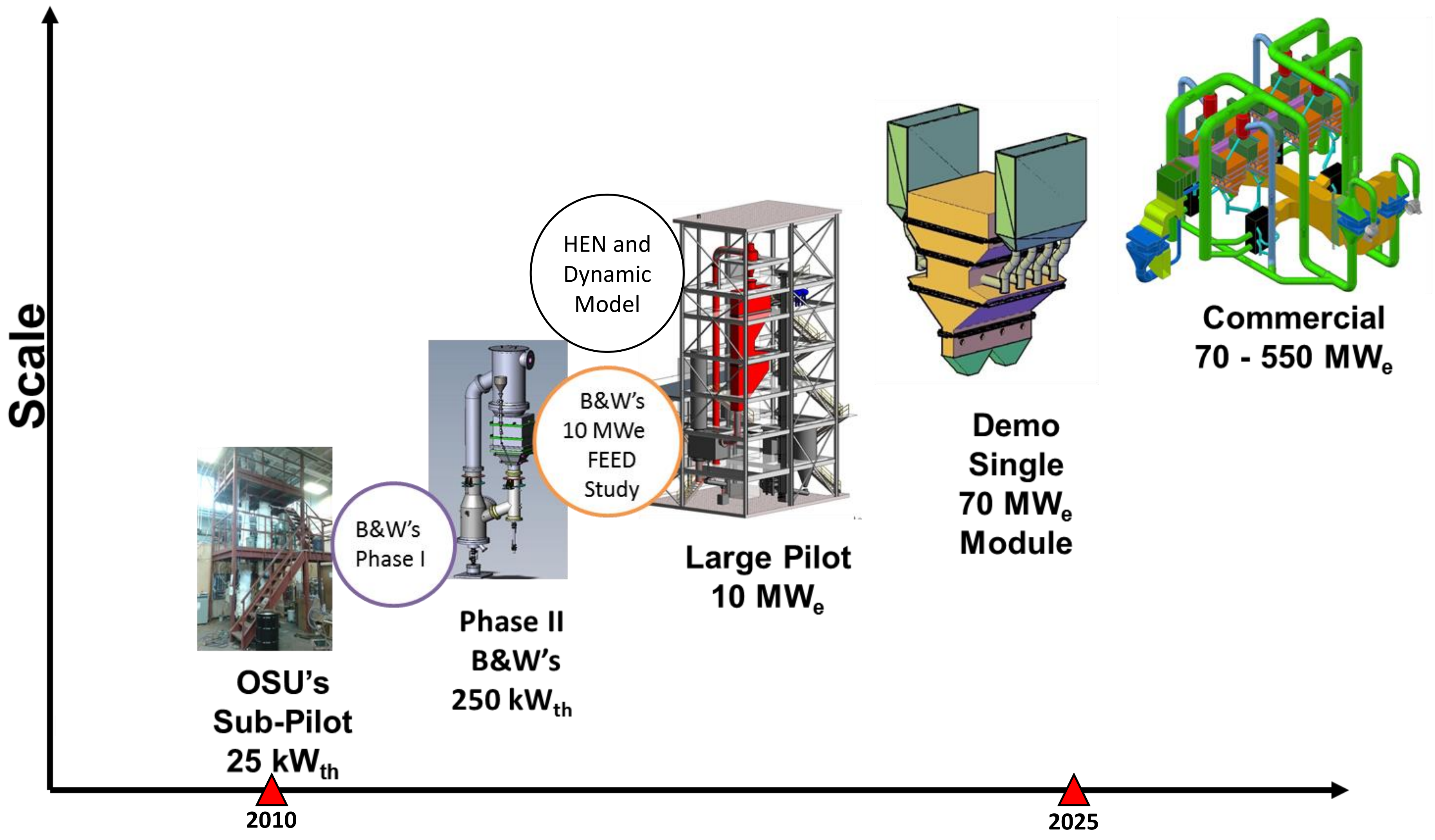
Reducer Gas Concentration Profile



Sample Data: PRB Process Performance

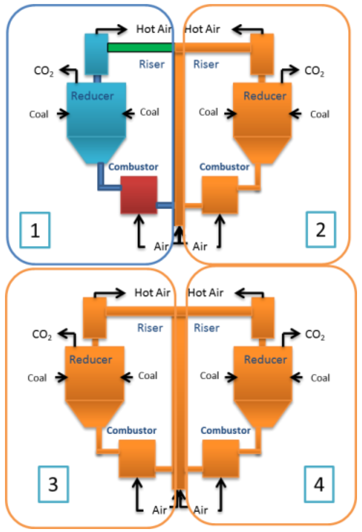
- Continuous steady carbon conversion from reducer throughout all solid fuel loading (5-25kW$_{th}$)
- <0.25% CO and CH_4 in reducer outlet = full fuel conversion to CO_2/H_2O
- <0.1% CO, CO_2, and CH_4 in combustor = negligible carbon carry over, nearly 100% carbon capture

CDCL Development Pathway



Scale Up Plan

Modular Reactor Design



- Chemical looping inherent low capital cost technology
- Reduce risks for large scale-up

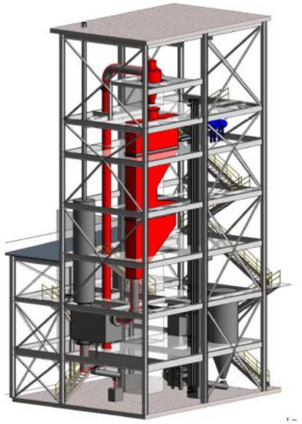
High Risk

100x

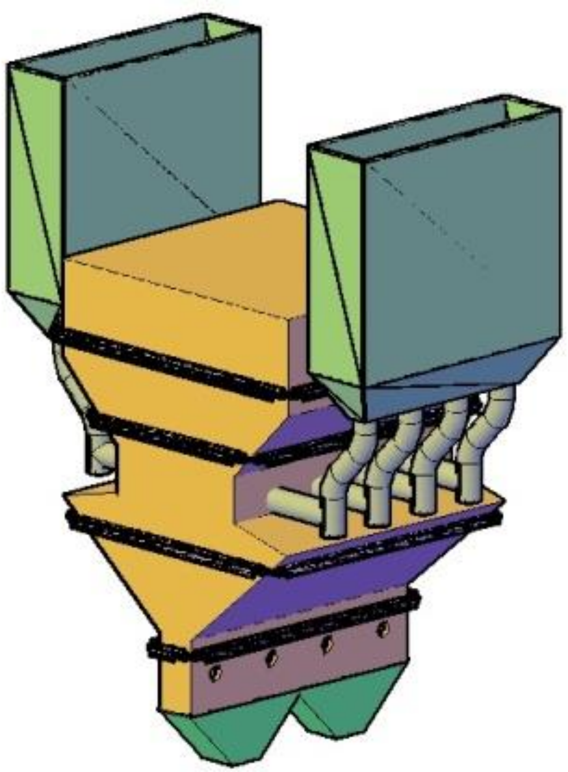
Lab Testing

Bench ($25\ kW_{th}$)

Small Pilot (250_{th})



Large Pilot ($10\ MW_e$)

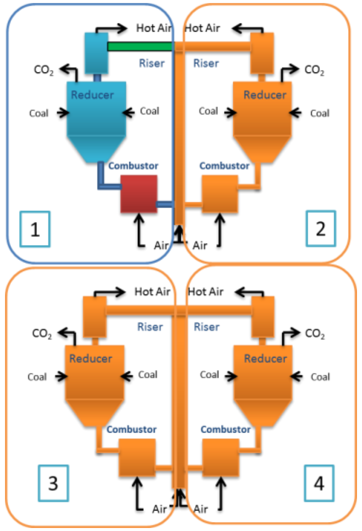


Commercial Offering

Time

Scale Up Plan

Modular Reactor Design



Challenge: Integrating with Dover Site

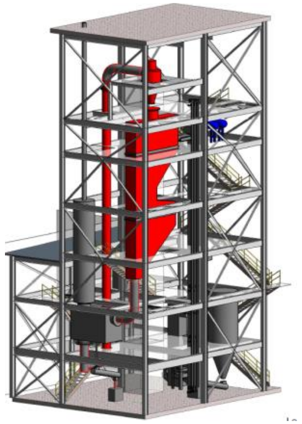
Lab Testing

Bench (25 kW_{th})

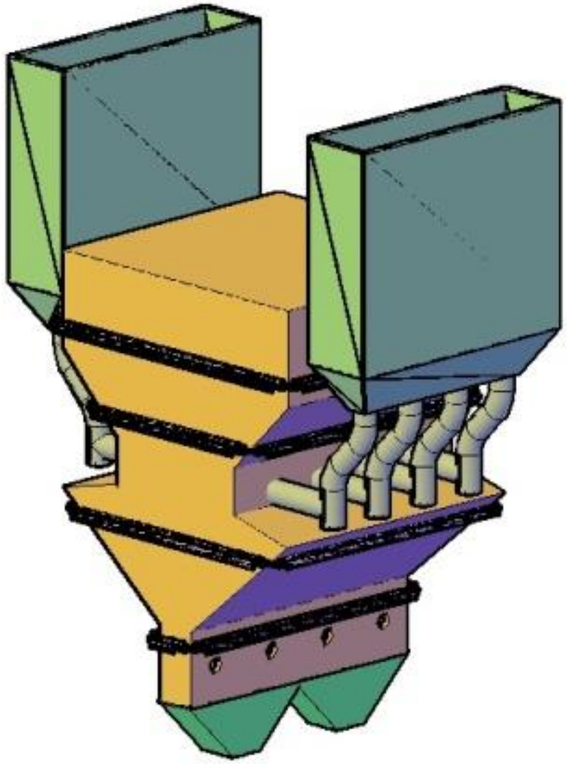
Small Pilot (250_{th})

High Risk

100x



Large Pilot (10 MW_e)



Commercial Offering

Time

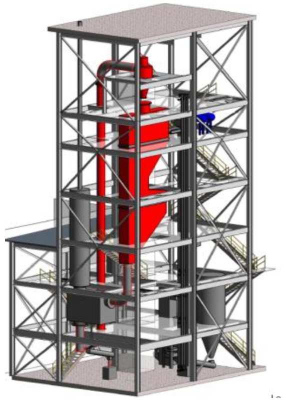
Project Objective

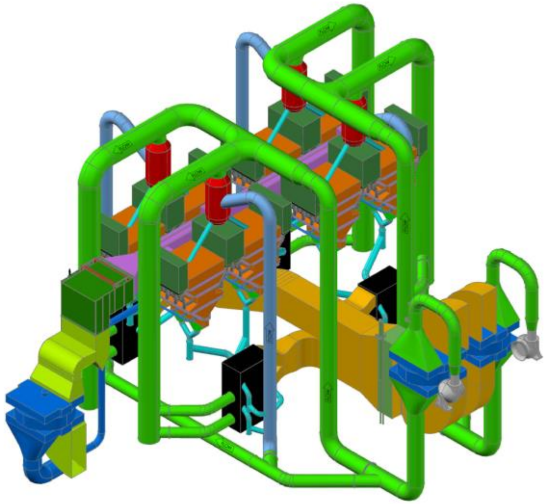
Reduce risks in the CDCL technology development to enable scale-up and eventual commercialization

	Tasks/Milestones	BP1				BP2				BP3			
		1	2	3	4	1	2	3	4	1	2	3	4
1	**Project Management and Planning**												
	Quarterly Reports												
	Final Report Preparation												
2	**Chemical Looping Combustor Simulation**												
2.1	Bench Unit Combustor Apparatus Setup												
2.2	Oxygen Kinetic Model Development and Verification												
2.3	Modeling Scheme Including Coupling of Hydrodynamics, Heat Transfer and Reaction												
2.4	Pilot and Commercial Scale Combustor Analysis												
	Milestone 2.1: Combustor Apparatus Ready for Operation		◆										
	Milestone 2.2: Oxygen Carrier Kinetic Model Developed				◆								
	Milestone 2.3: Modeling Scheme Coupling of Hydrodynamics, Heat Transfer and Reaction Developed								◆				
3	**Heat Exchanger Network Integration and Optimization**												
3.1	CDCL Static Model Development												
3.2	HEN Design with Steam Cycle												
3.3	HEN Optimization												
3.4	Heat Exchanger Sizing and CDCL 550 MWe Cost Analysis Update												
	Decision Point 1: Integrated CDCL Systems Analysis Model Developed					◆							
	Milestone 3.2: HEN Design Developed for Cost Analysis										◆		
4	**Dynamic Modeling of Integrated CDCL-Steam Cycle System**												
4.1	CDCL Process Model Development												
4.2	Steam Cycle Model Development												
4.3	Integrated System Model Development												
4.4	System Operation Simulation												
	Milestone 4.1: Dynamic Model for 10 MWe CDCL Reactor Developed			◆									
	Milestone 4.2: Dynamic Model for 10 MWe Steam Cycle Developed							◆					
	Decision Point 2: Integrated Dynamic Model for 10 MWe CDCL Process DevelopedDecision Point 2: Integrated Dynamic Model for 10 MWe CDCL P											◆	

1. Enable Commercialization

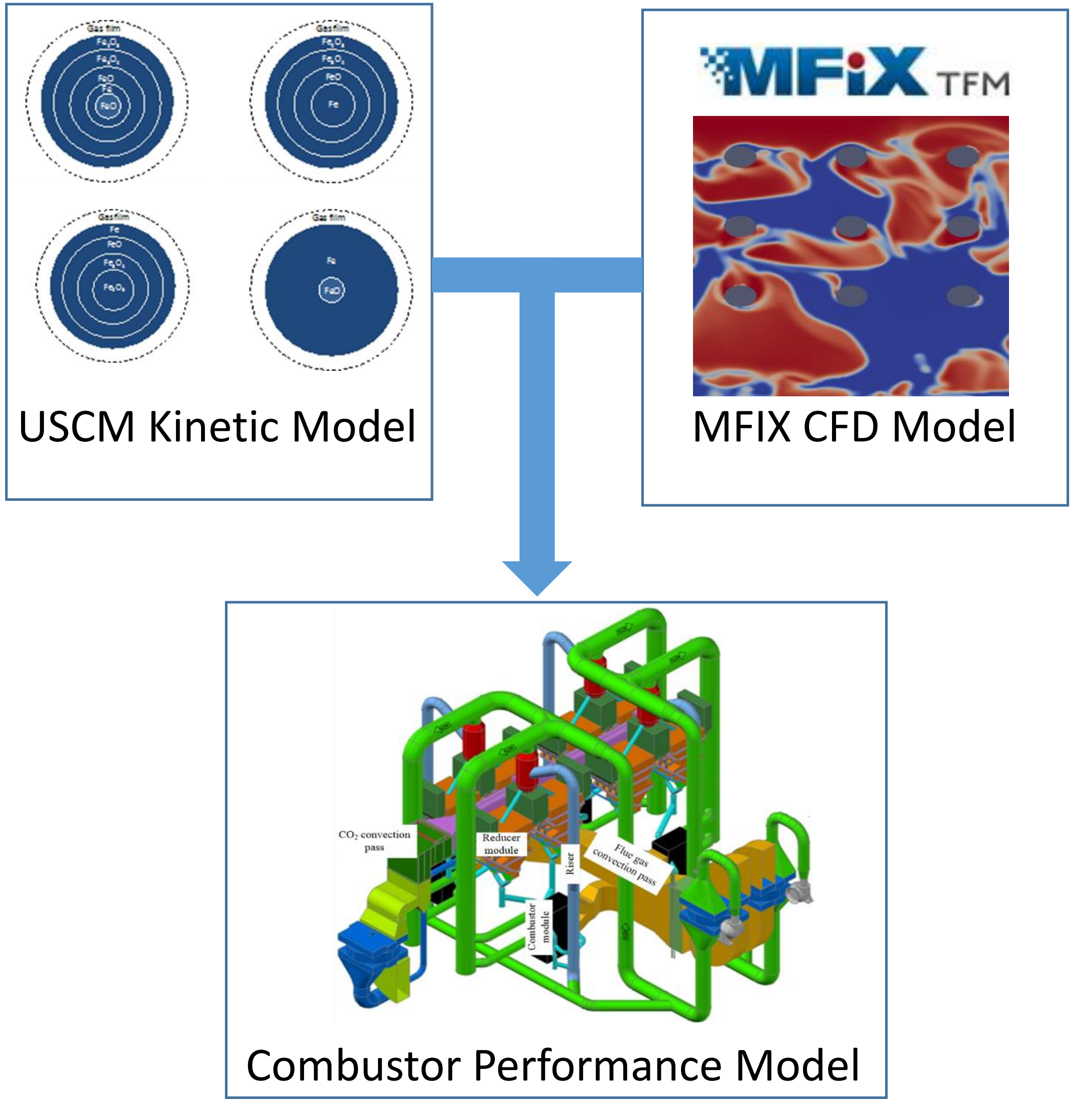
2. Enable Scale-Up





Task 2: Combustor Simulation

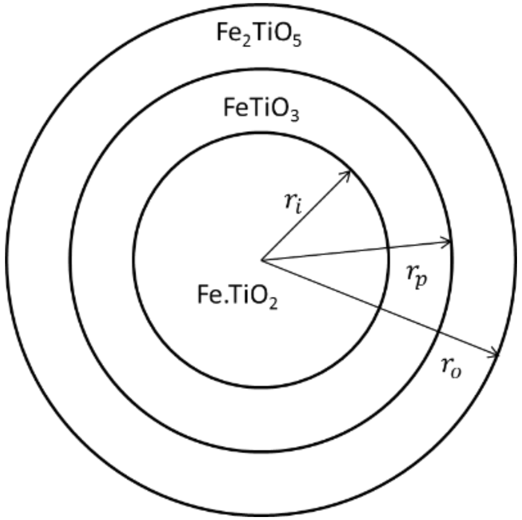
- CDCL Combustor Model
  - USCM Kinetic Model
  - MFiX CFD Model
- Design and Analysis of 10MW$_e$ Pilot and 550MW$_e$ Commercial Plant
  - Lateral Transport & Mixing
  - Oxygen Carrier Conversion
  - Heat Transfer



Task 2: Combustor Simulation

- USCM Kinetic Model
  - Extended model to consider partially-reduced particle
  - Used TGA experiments to determine rate constants
  - Model tested at different temperature and O_2 concentration

URSM for Fully-reduced Particle



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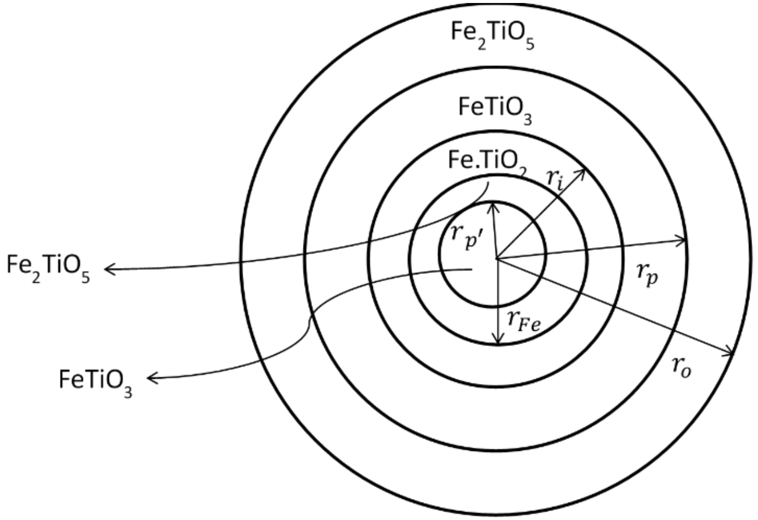

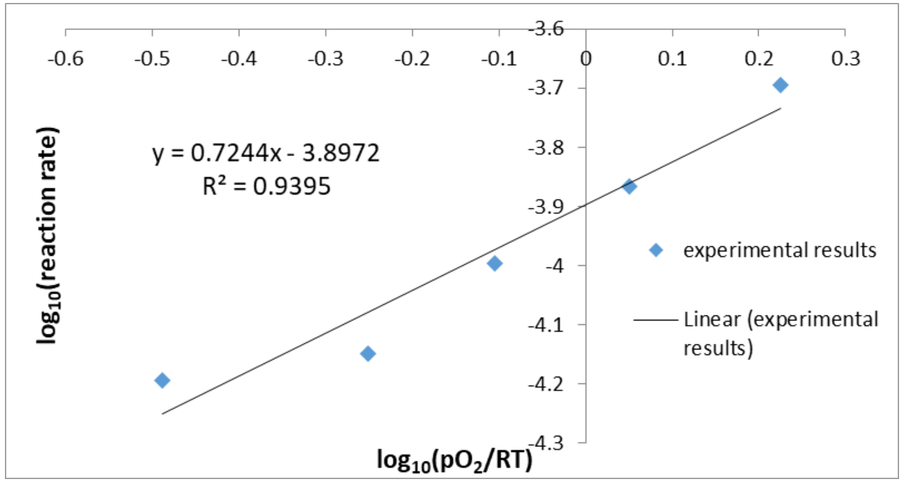

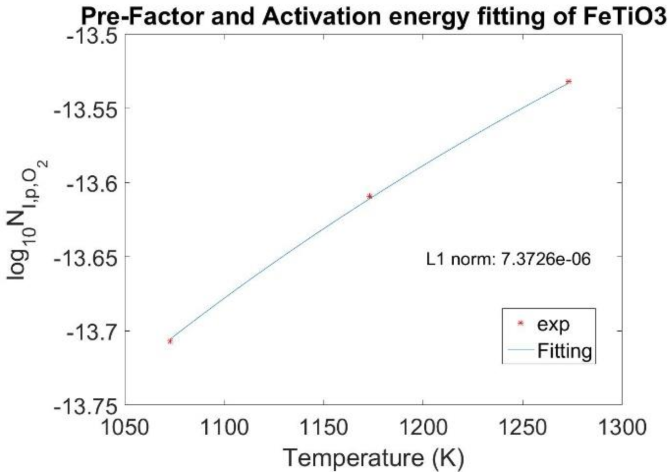

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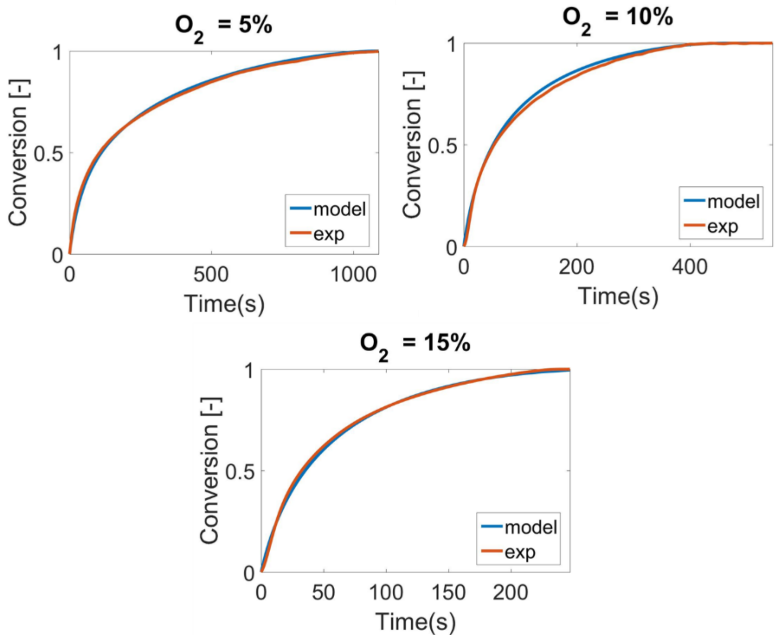
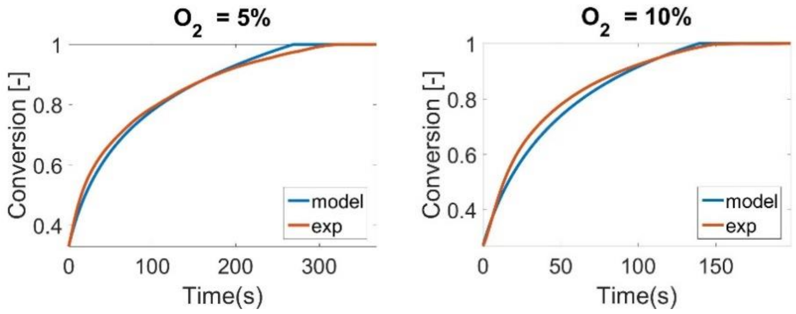
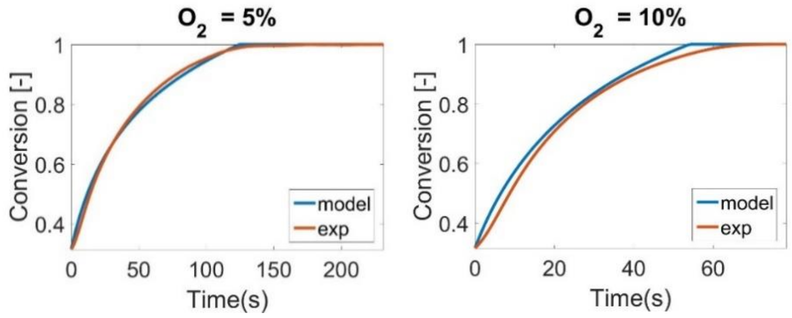
800°C, Fully-reduced Particle



800°C, Partially-reduced Particle

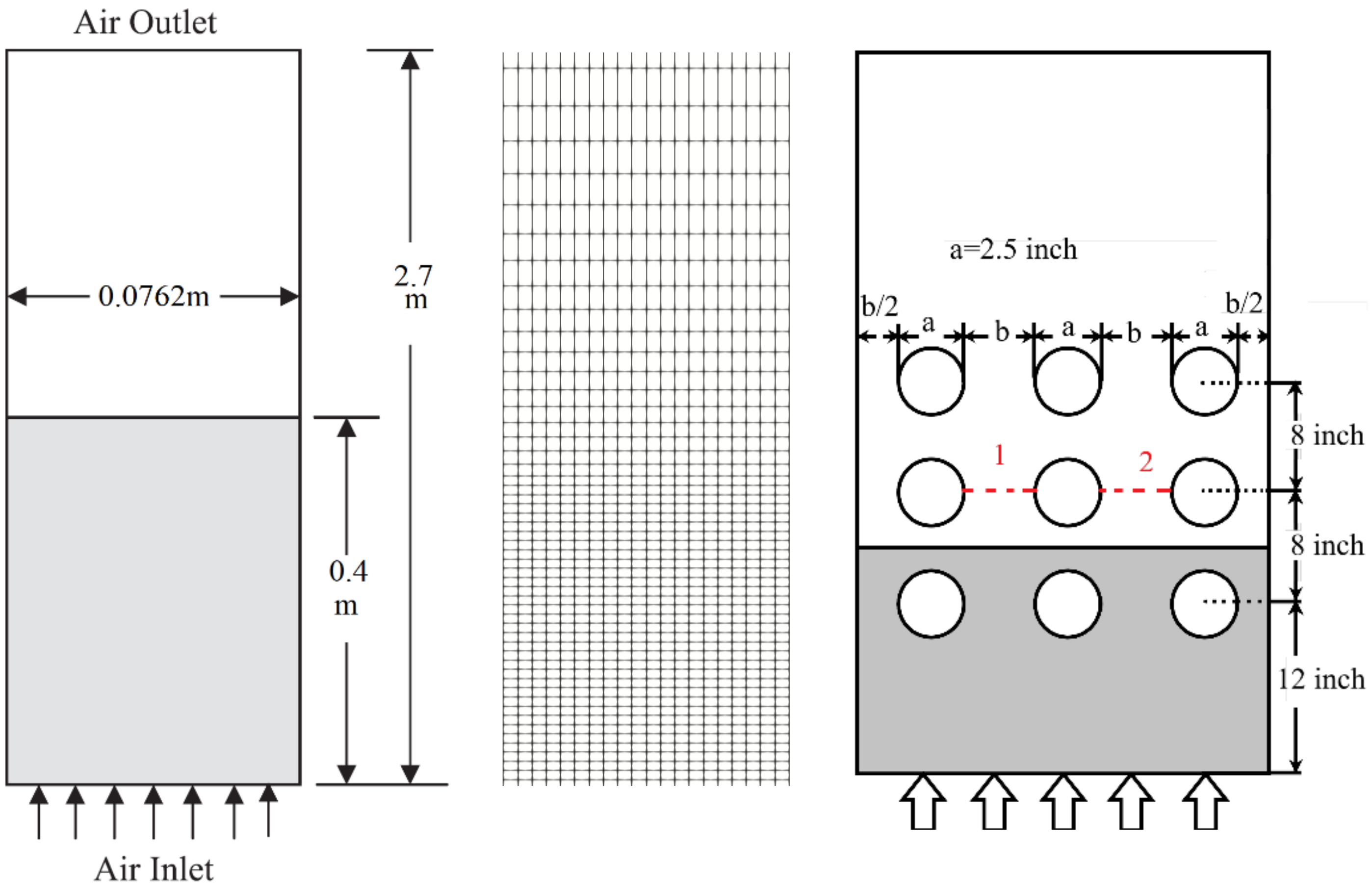


1000°C, Partially-reduced Particle



Task 2 Hydrodynamic Modeling

- MFiX CFD Model of Combustor
  - Based on MFiX Two Fluid Model
  - Study the effect of reactor geometry and in-bed heat exchanger on combustor performance
  - Validation by cold flow model with heat exchanger tubes



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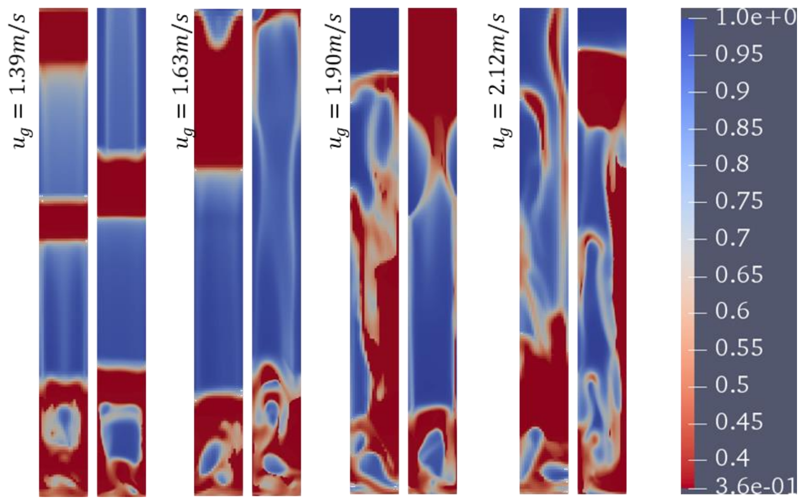

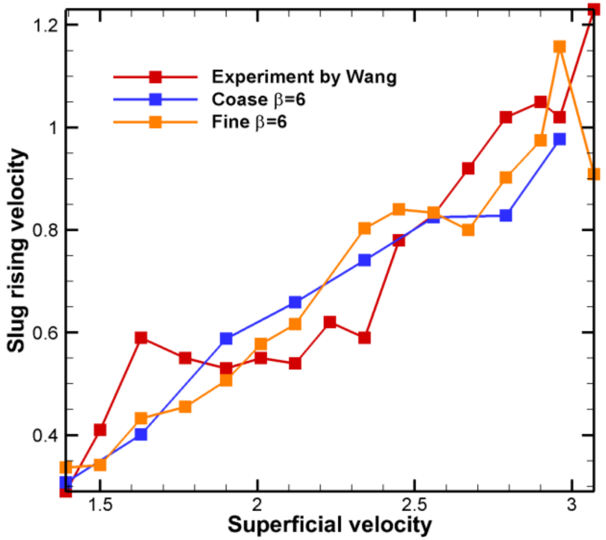

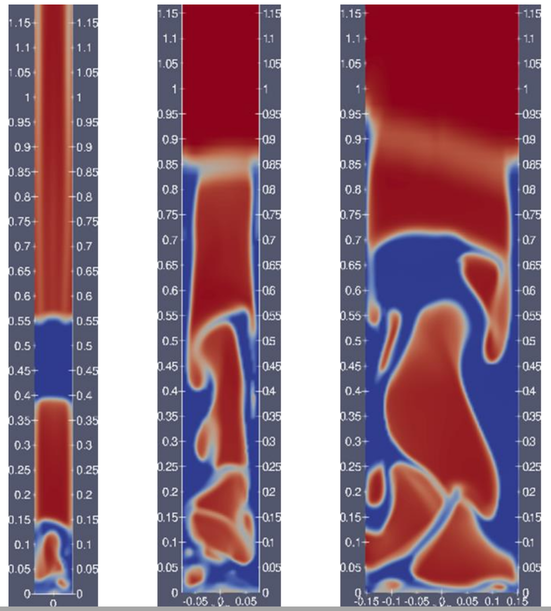

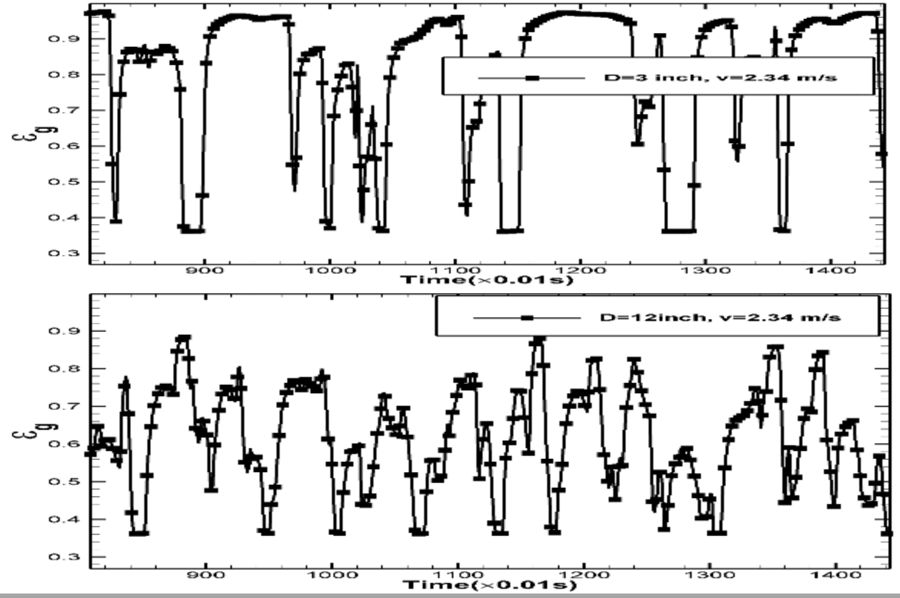

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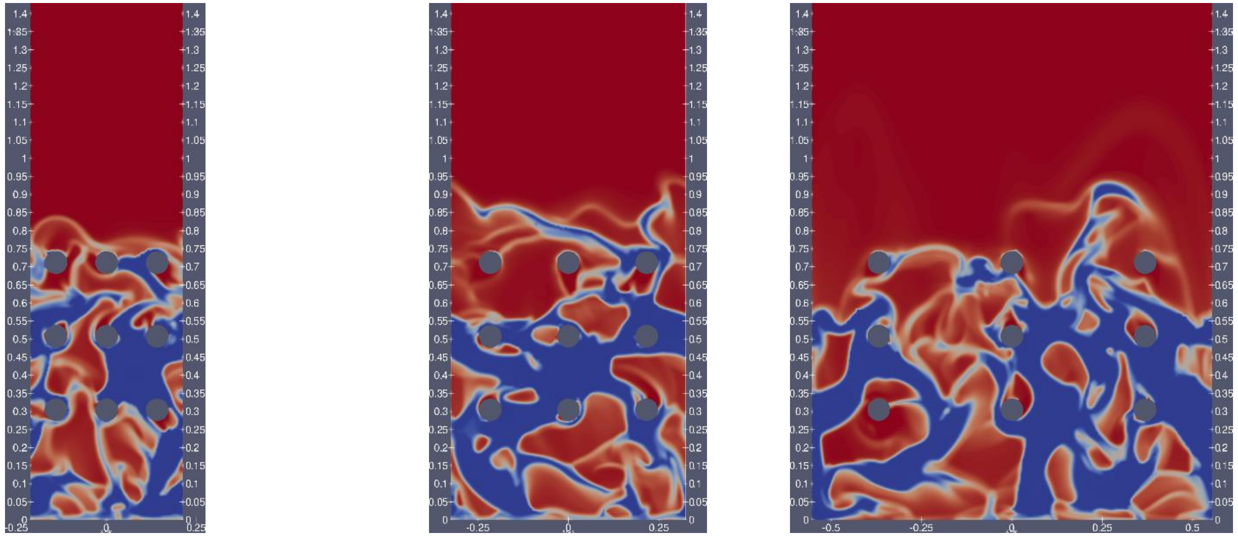
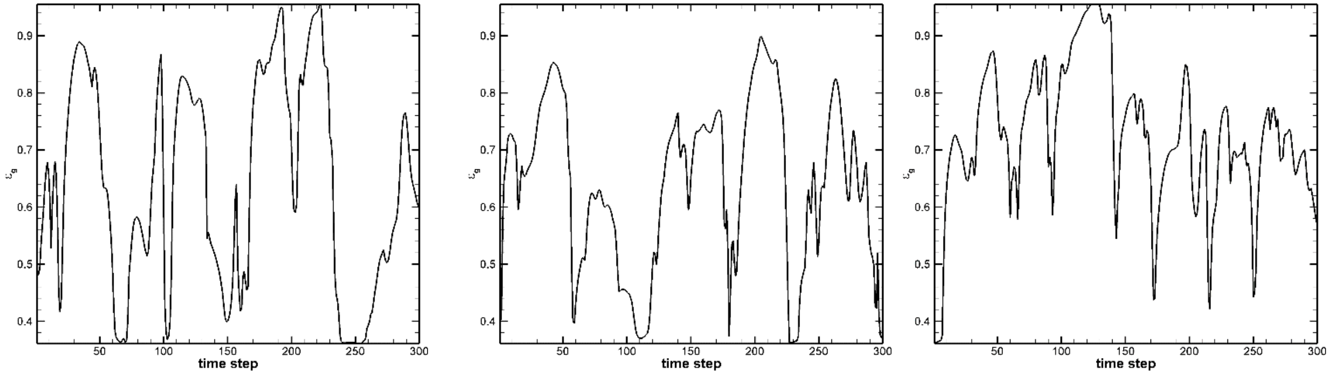
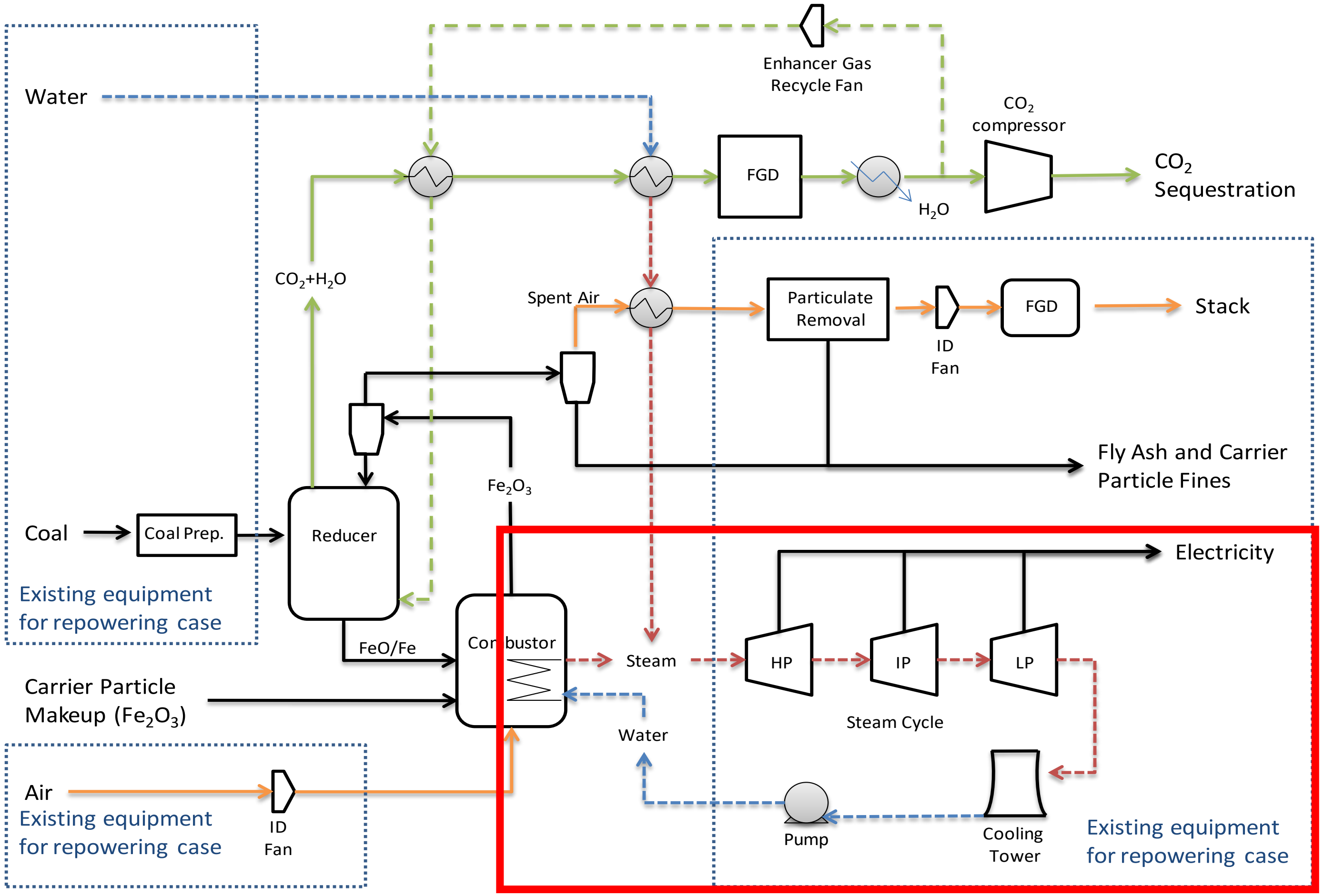




Task 3: HEN Integration and Optimization

- CDCL Process Simulation in ASPEN Plus
  - 550 MW_e plant
  - In-bed heat exchanger
  - Industrial relevant constrains
- Integration with Steam-Cycle
  - Multiple heat exchanging surfaces
- HEN Optimization
- Cost Estimation



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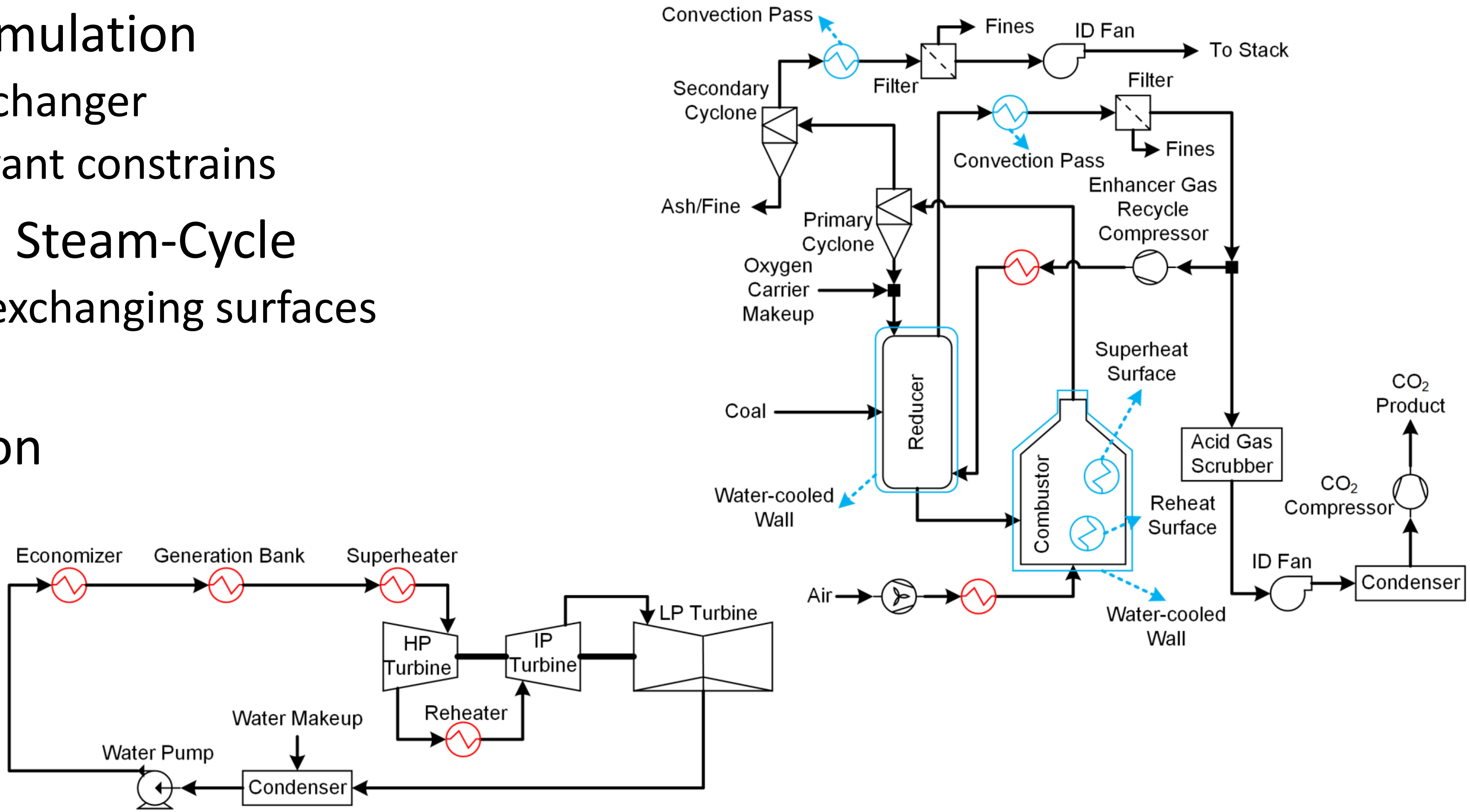

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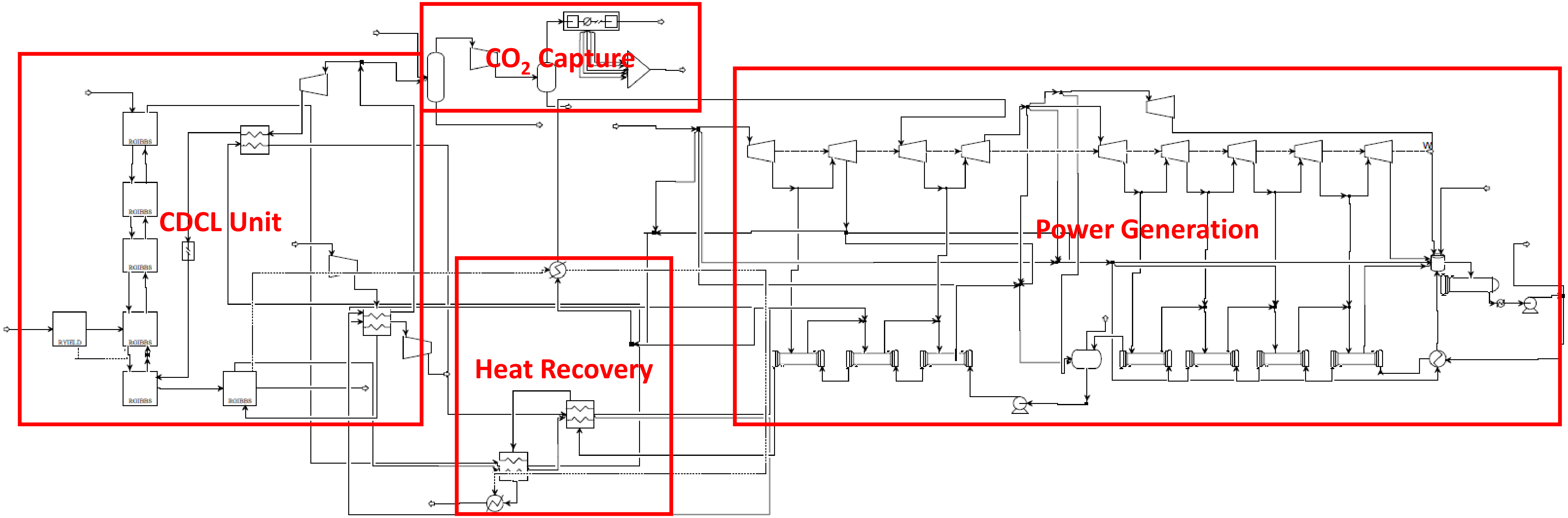


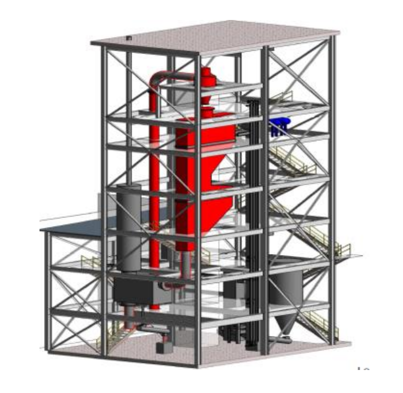
Task 3: HEN Integration and Optimization

- Simulation settings
  - Coal: Illinois #6
  - Steam cycle
    - Supercritical cycle
    - 24.1 MPa/593 ^oC/593 ^oC
    - Adapted based on prior studies from B&W
- Preliminary results of HHV efficiency
  - Baseline: 32.5%
  - CDCL process: 37.6%

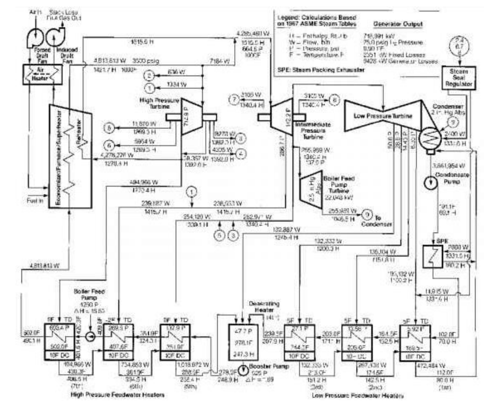
	CDCL Preliminary Design
Total Gross Power, MW_e	643
Total Auxiliaries, MW_e	93
Net Power, MW_e	550
HHV Thermal Input, MW_t	1462
HHV Net Plant Efficiency (%)	37.6
As- Received Coal Feed, kg/hr	194,110

Task 4: Dynamic Modeling of Integrated Power Plant

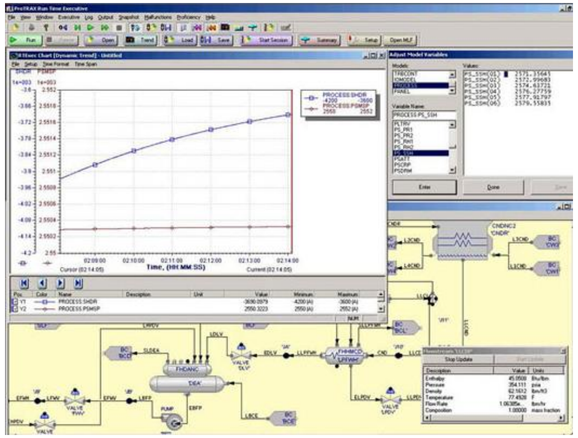
- Dynamic Modeling in ProTRAX
- 10 MW_e CDCL pilot plant
  - Preliminary design from DE-FE0027654
- Existing 20 MW_e steam cycle at Dover, OH
  - Based on data obtained from Dover Light & Power
- Startup and operation simulation



CDCL Dynamics

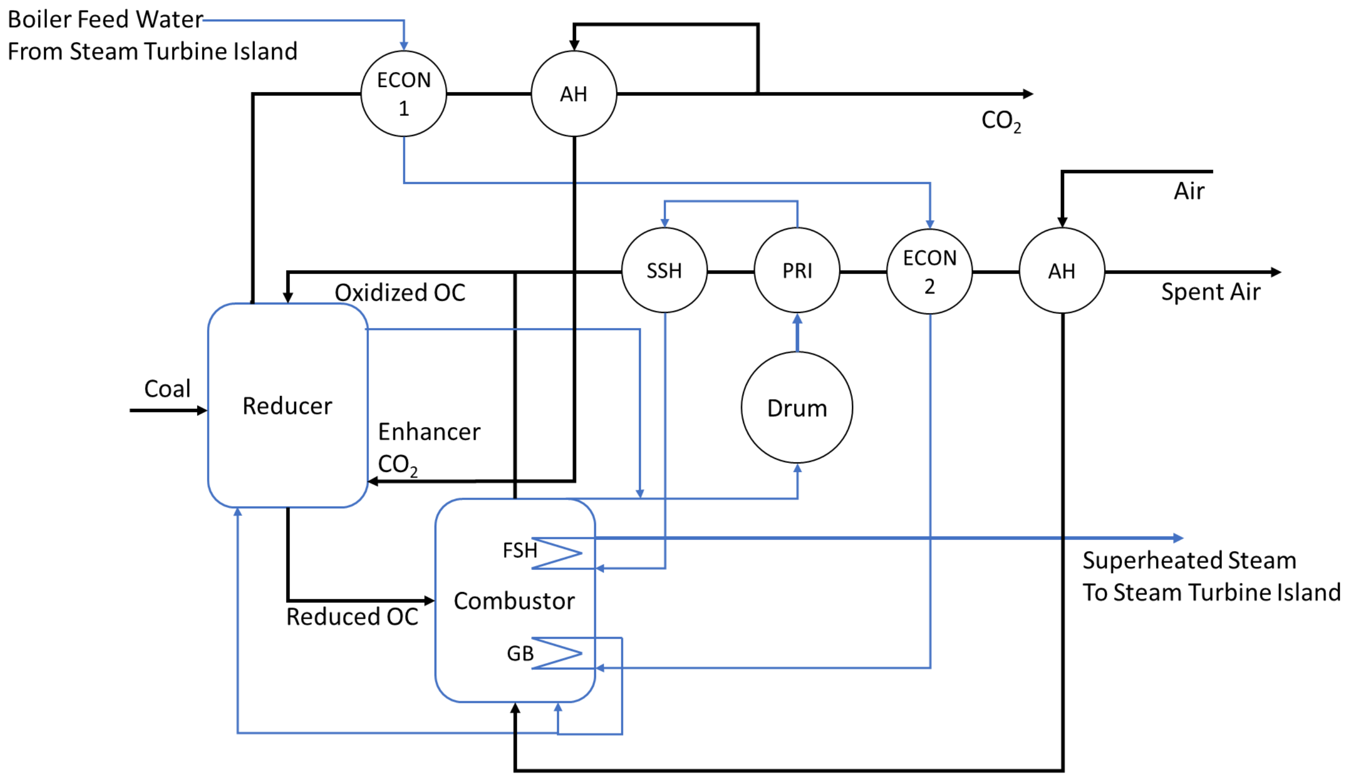


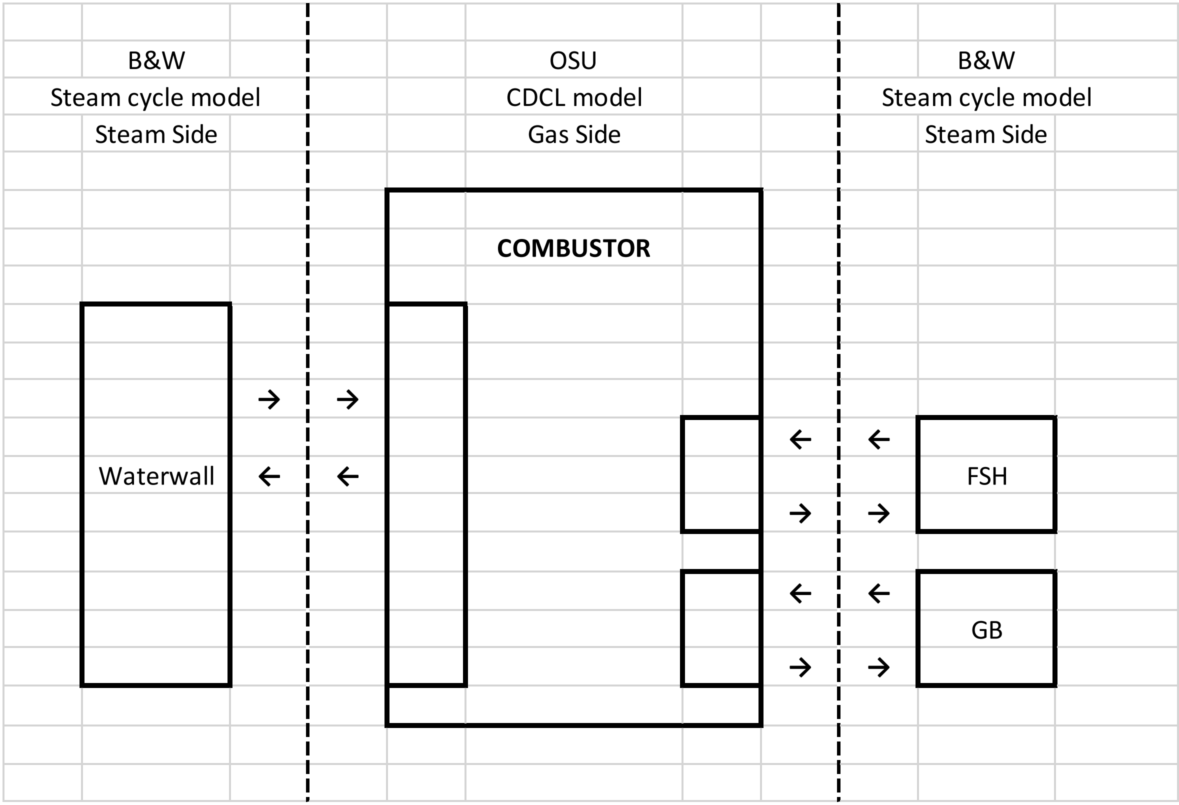
Steam Cycle Dynamics



Integrated Dynamic Model

Task 4: Dynamic Modeling of Integrated Power Plant

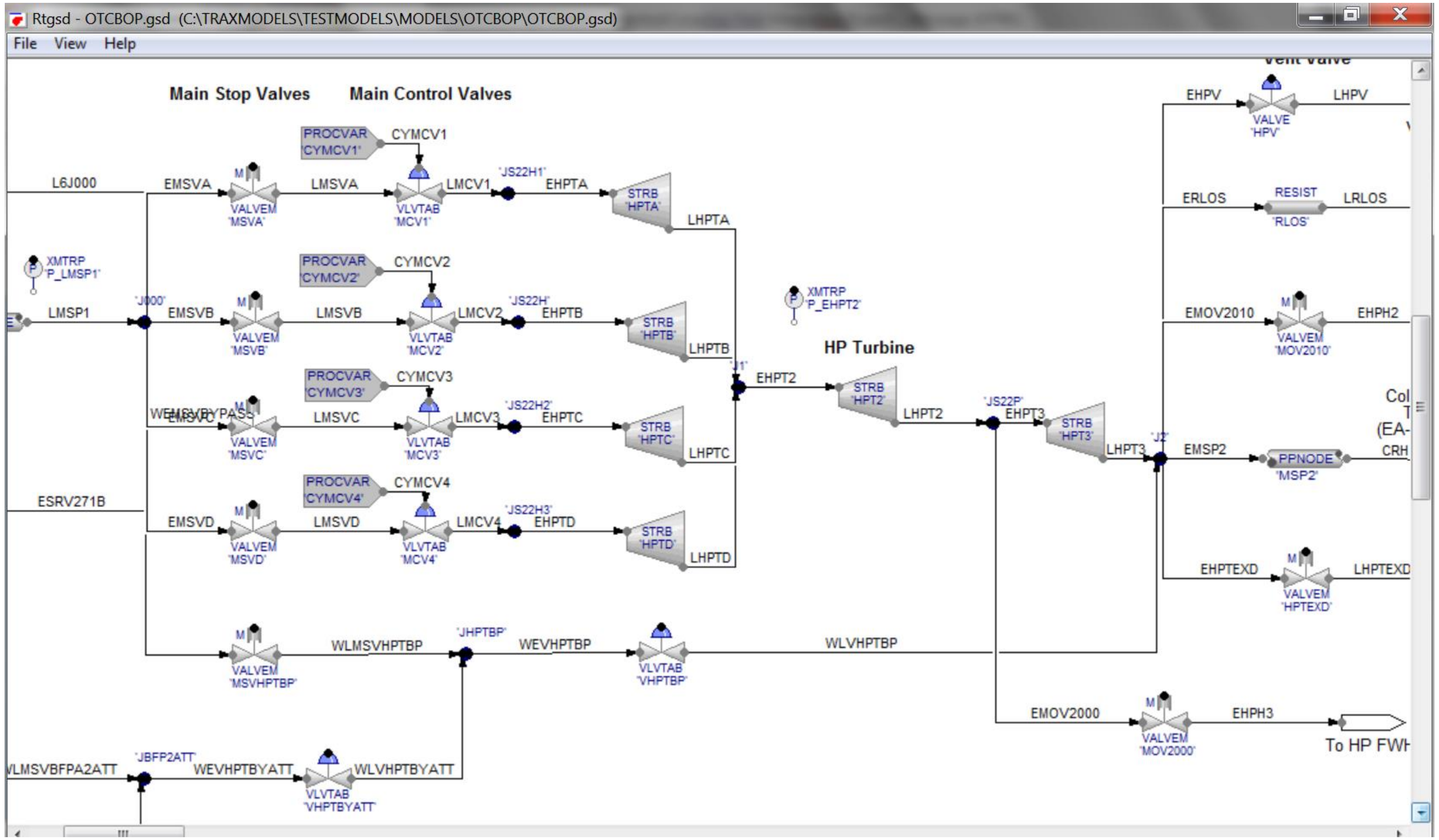




Task 4: Dynamic Modeling of Integrated Power Plant

- Dynamic Model for CDCL
  - Mass and Energy Balance
  - Hydrodynamic Correlation
  - Chemical Reactions

- Dynamic Model for Steam Cycle
  - Obtained steam cycle design and parameter from Dover Light & Power



Conclusion

- Combustor performance model will be developed in this project to support HEN integration and system dynamic studies
- HEN integration and optimization will be performed to enable the commercialization of the CDCL process
- Dynamic modeling will be performed to enable the scale-up of the CDCL process

- Kinetic model for oxygen carrier oxidation in CDCL combustor is developed to simulate the oxidation of fully- and partially- reduced oxygen carrier particles
- MFiX CFD model is being developed to study the effect of bed geometry and in-bed heat exchanger on fluidization properties of the combustor reactor
- ASPEN Plus model of 550 MW_e integrated CDCL-steam cycle plant is developed for HEN optimization
- ProTRAX dynamic model is being developed for 10 MW_e CDCL pilot plant at Dover

Thank You

Disclaimer