10 Megawatts Electric Coal Direct Chemical Looping Large Pilot Plant - Pre-FEED Study

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June 6, 2018

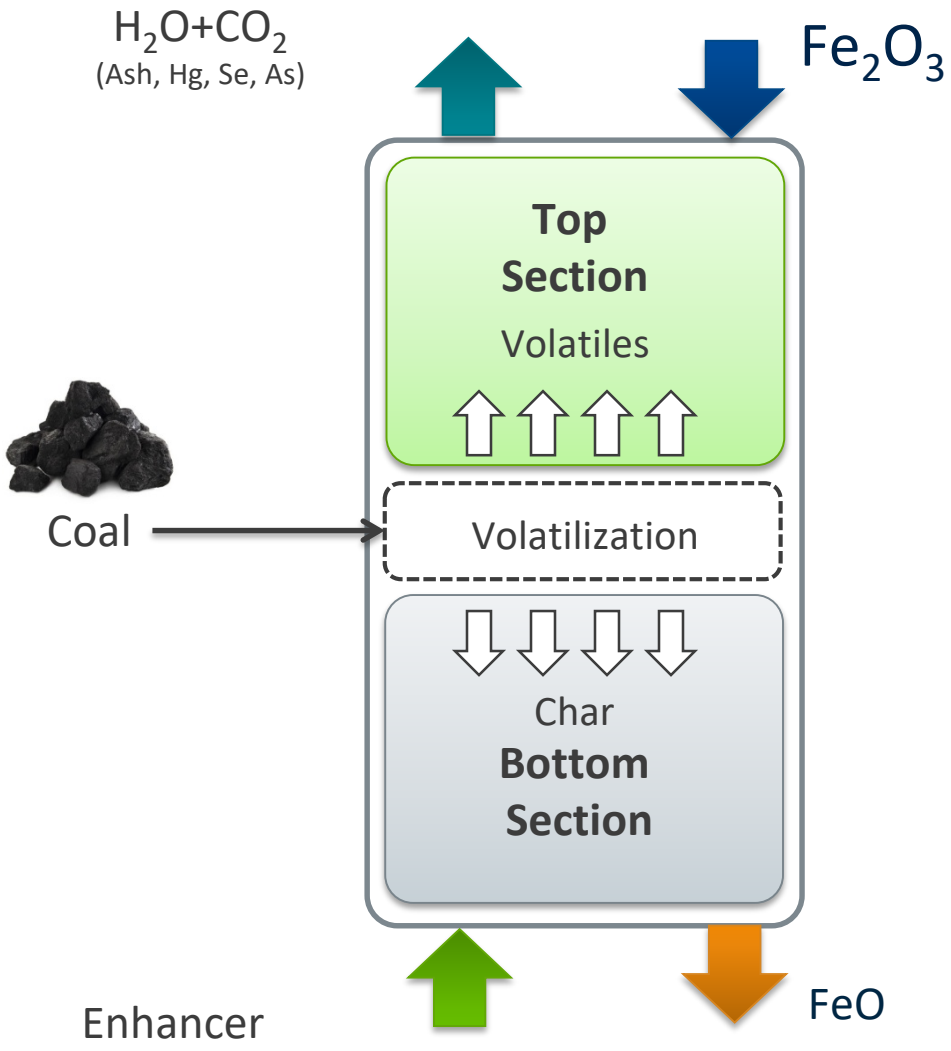
Outline

- Background
  - Project Participants
  - Process Concept
  - Commercialization Path
- 250 KWth Pilot Facility
  - Update on 250 kWth pilot testing
  - CFM Testing & Particle Synthesis
- 10 MWe Pilot Plant pre-FEED
  - H&M Balances
  - Steam Cycle Integration
  - 10 Mwe Pre-FEED Study
  - Schedule
- Acknowledgements

Project Participants

- Federal Agencies
  - DOE/NETL
- State Agency
  - Ohio Development Services Agency
- Project Participants
  - Babcock & Wilcox (B&W)
  - Ohio State University (OSU)
  - Clear Skies Consulting
  - Dover Light & Power (DPL)
    - Trinity Consultants
    - Worley Parsons
  - Electric Power Research Institute (EPRI)
  - Johnson Matthey (JM)
- Industrial Review Committee
  - American Electric Power
  - Duke Energy
  - FirstEnergy
  - CONSOL Energy

CDCL Reducer Concept



Section 1

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

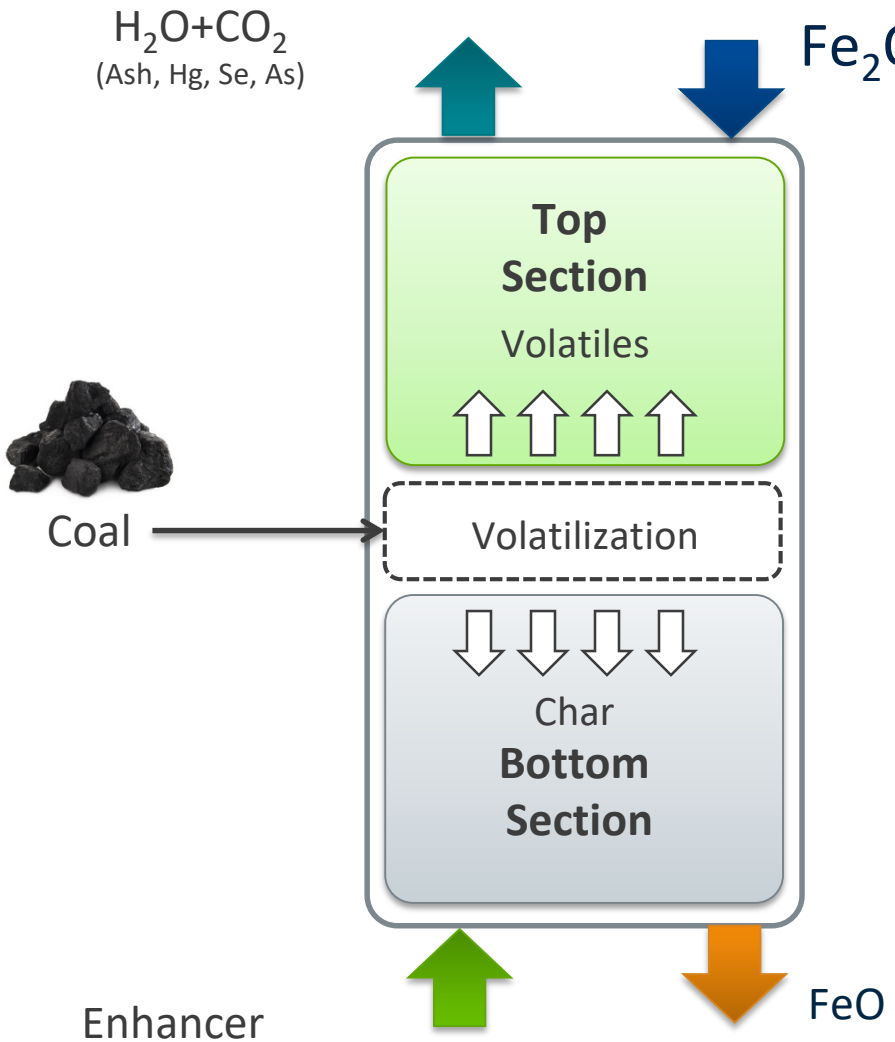
Devolatilization

Coal $\rightarrow$ C + C_xH_y

Section 2

$C + CO_2 \rightarrow 2\ CO$

CDCL Reducer Concept



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Devolatilization

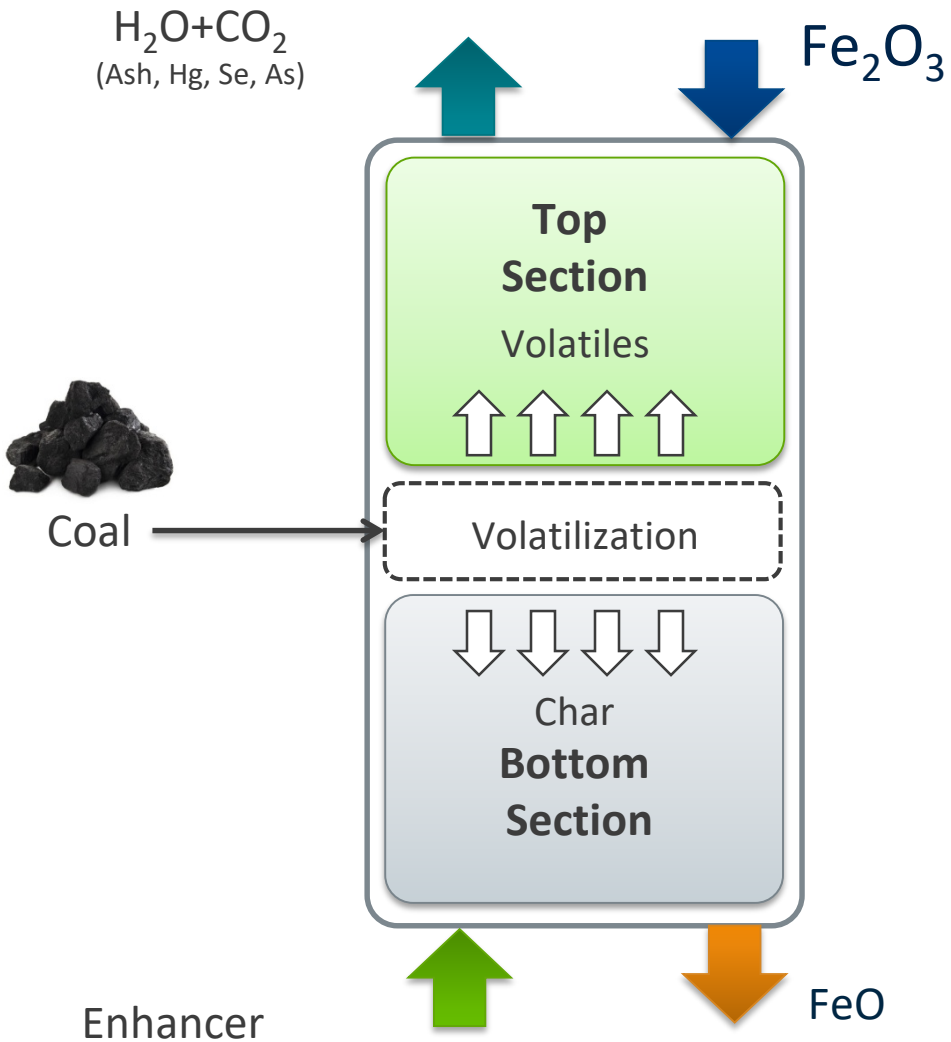
Coal → $C + C_xH_y$

Section 2

$C + CO_2 \rightarrow 2\,CO$

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

CDCL Reducer Concept



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Section 2

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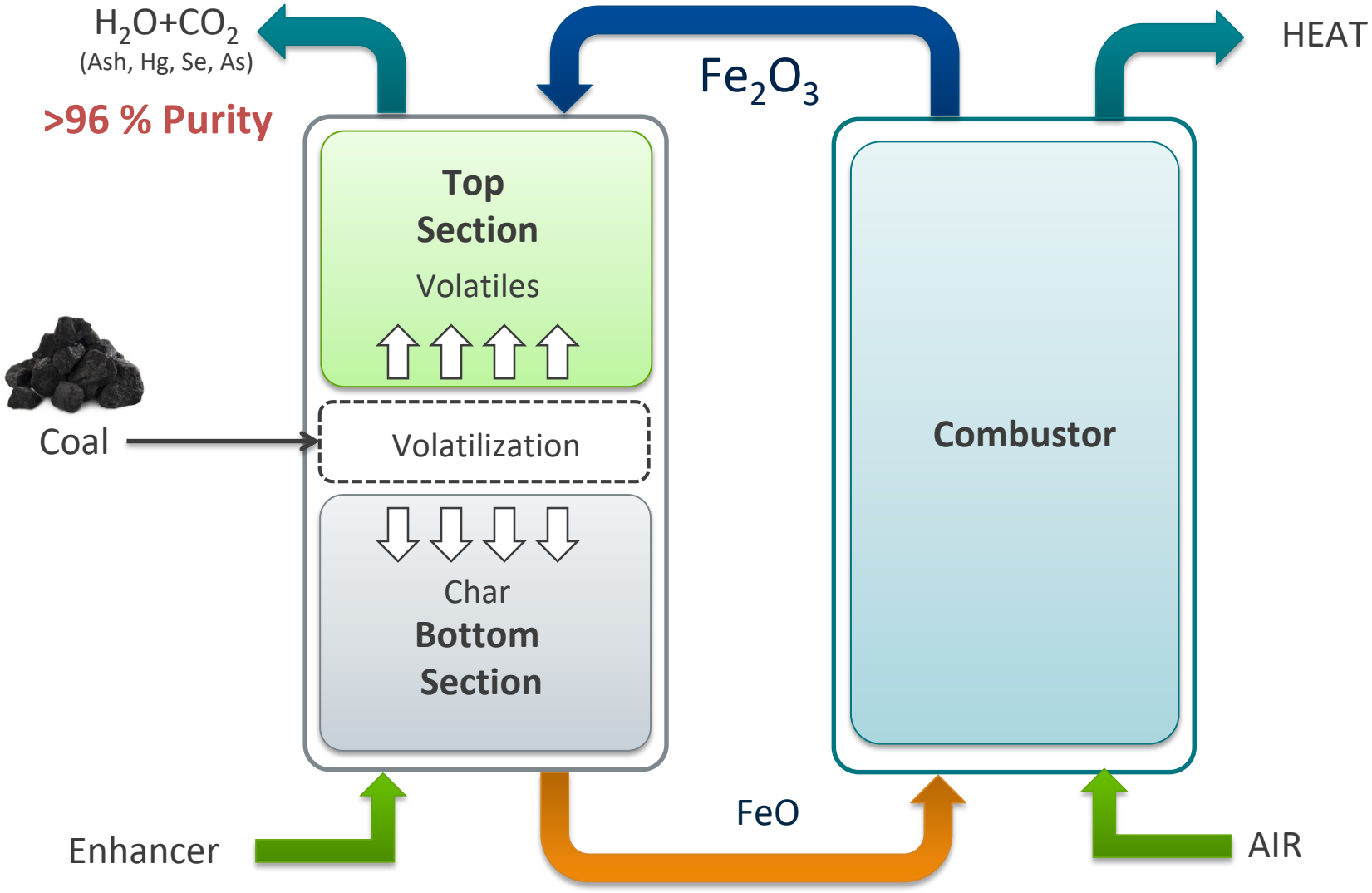
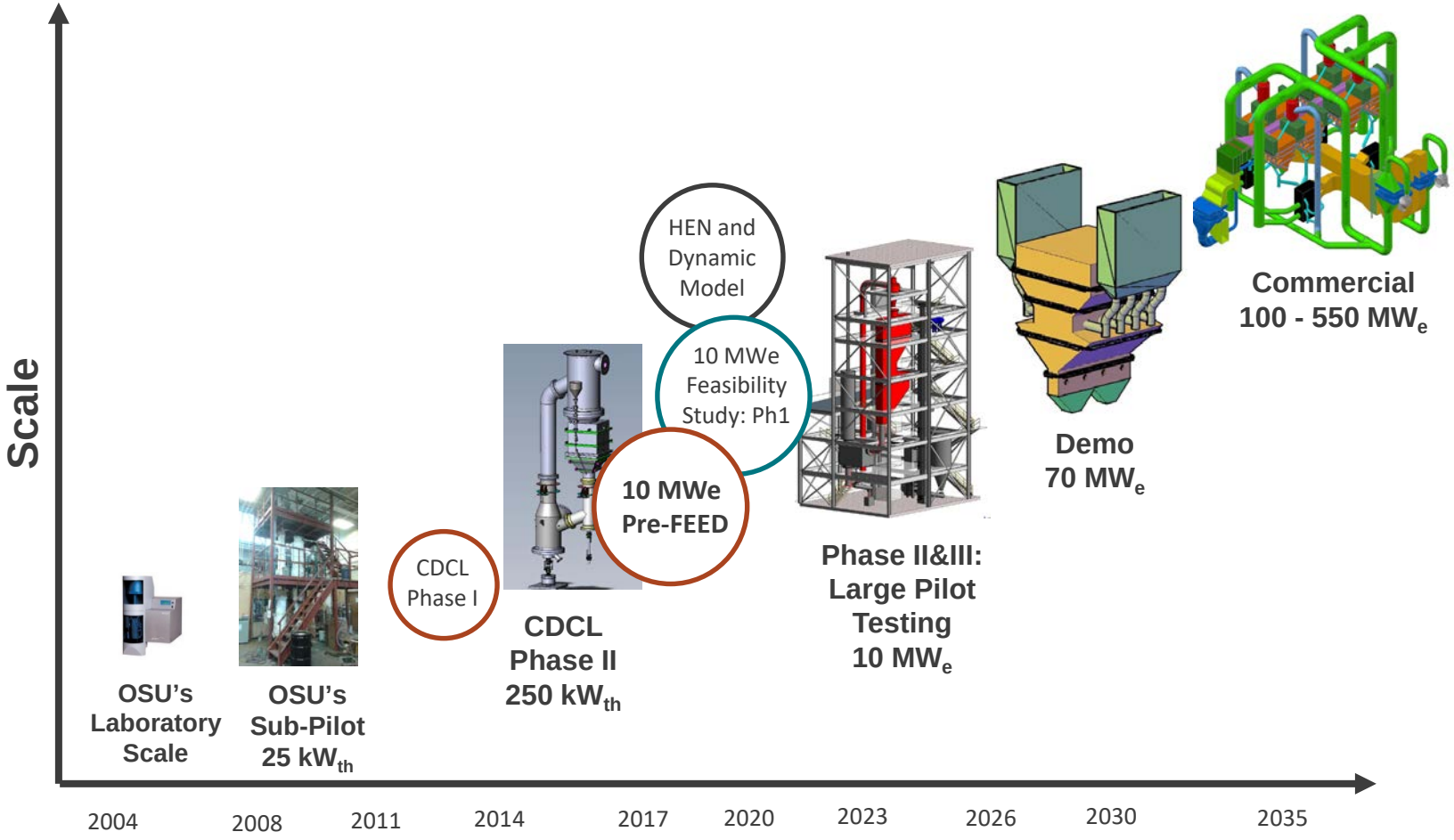
$CO + Fe_2O_3 \rightarrow CO_2 + FeO/Fe$

CDCL Process



Two-stage Counter-current Moving Bed

CDCL Commercialization Path



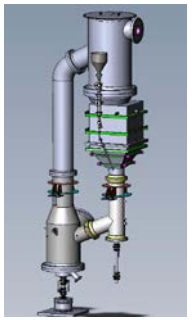
CDCL Technology Development

Laboratory 2.5 kWth

- Particle recyclability and reactivity
- Individual reactions in the reducer and combustor

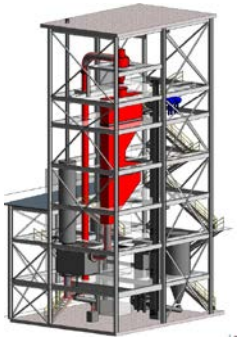
25 kWth

- Integrated operation reducer and combustor for more than 200 hours
- Coal conversions
- CO_2 Purity



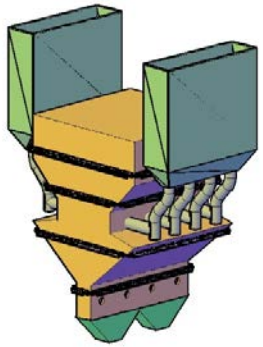
250 kWth

- Adiabatic reducer operation for more than 250 hours
- Process efficiency
- Evaluate emissions
- Large scale particle manufacturing
- Particle attrition



4 x 2.5 MWe

- Long Term operation
- Coal distribution
- Modular integration and operation - Start up, turn down, shutdown cycles
- Steam generation
- Economics



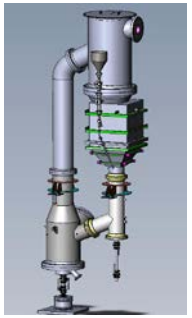
1 x 70 MWe

- Commercial Operation of a single module
- Fabrication

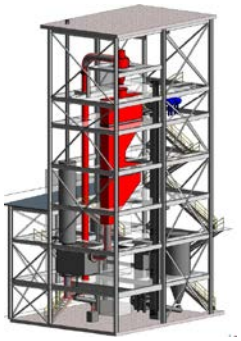
Scale Up Plan

x10

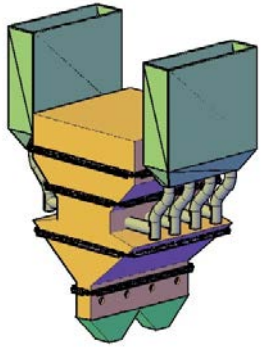
x10

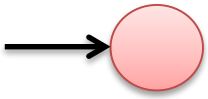
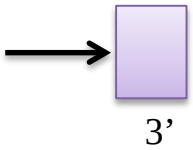
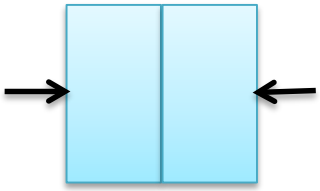
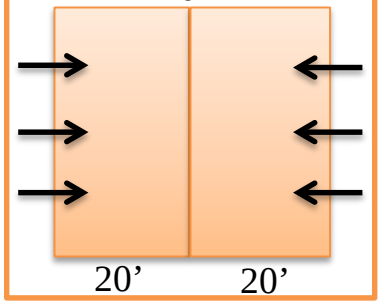


x30

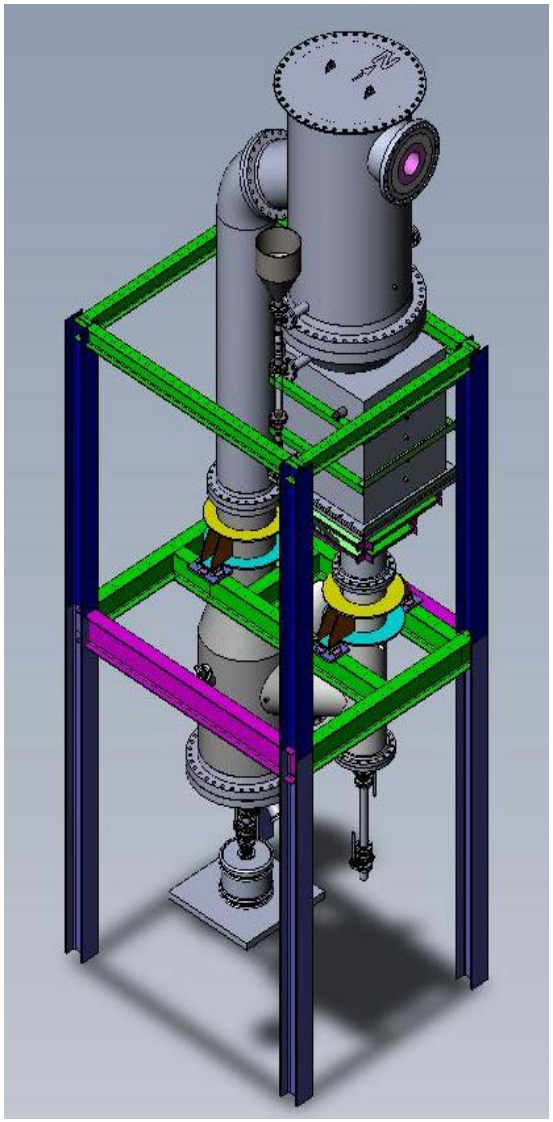


x30



Laboratory 2.5 kWth	25 kWth	250 kWth	4 x 2.5 MWe	1 x 70 MWe
Critical Dimension Scale up Factor: **x1**	Critical Dimension Scale up Factor: **x4**	Critical Dimension Scale up Factor: **x6**	Critical Dimension Scale up Factor: **x2.3**	Critical Dimension Scale up Factor: **x2.8**
Reducer reactor Critical Dimension: 1.5”	Reducer reactor Coal distribution Distance: 6”	Reducer reactor Coal distribution Distance : 3’	Reducer reactor Coal distribution Distance : 7’	Reducer reactor Coal distribution Distance: 20’
		 3’	 7’ 7’	 20’ 20’

250 kW_{th} Pilot Plant - Design



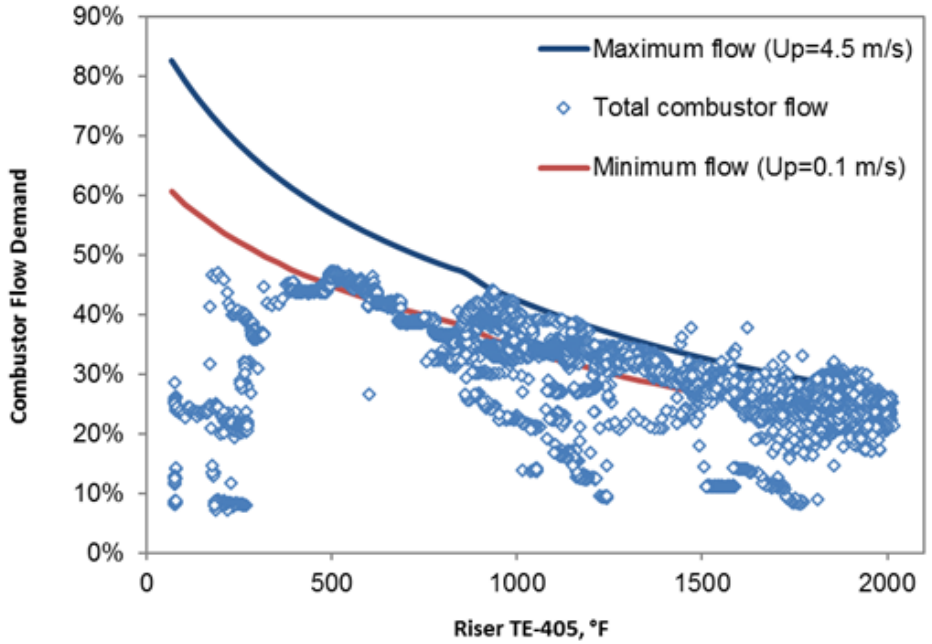
Specifications

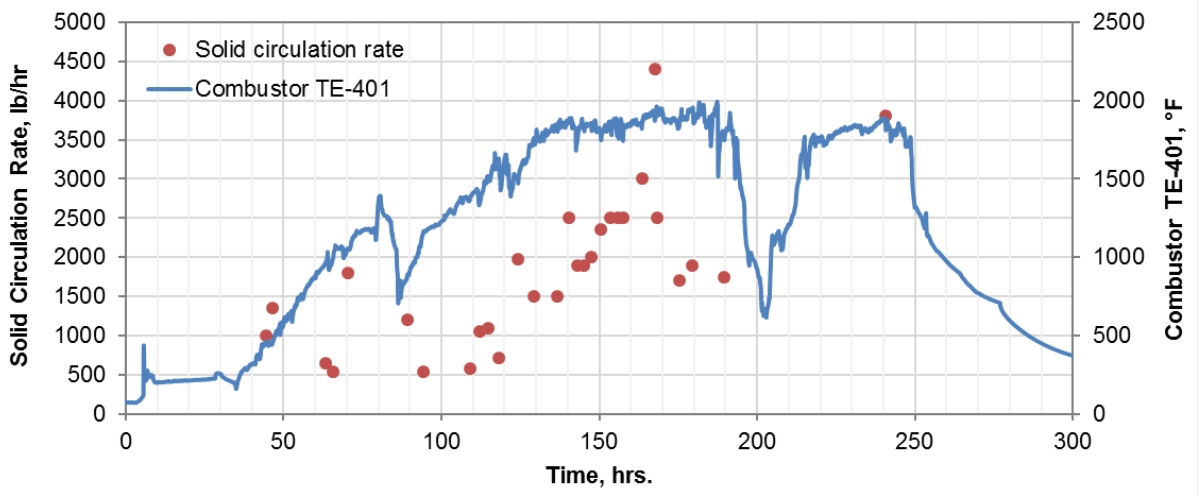
- Materials: Refractory lined Carbon Steel
- Max Operating Temperature: 2012 ^{o}F
- Reducer : Counter-current moving bed
- Combustor : Bubbling bed
- Overall Height: 32 ft
- Footprint = 10’ x 10’
- Thermal Rating: 250 kWth
- Coal Feed Rate: 10 to 70 lb/hr
- Coal Size: Pulverized coal
- Particle Transport: Pneumatic
- Oxygen Carrier: Iron based
- Oxygen Carrier Size: 1.5 mm

250 kW_{th} Test Campaign Summary

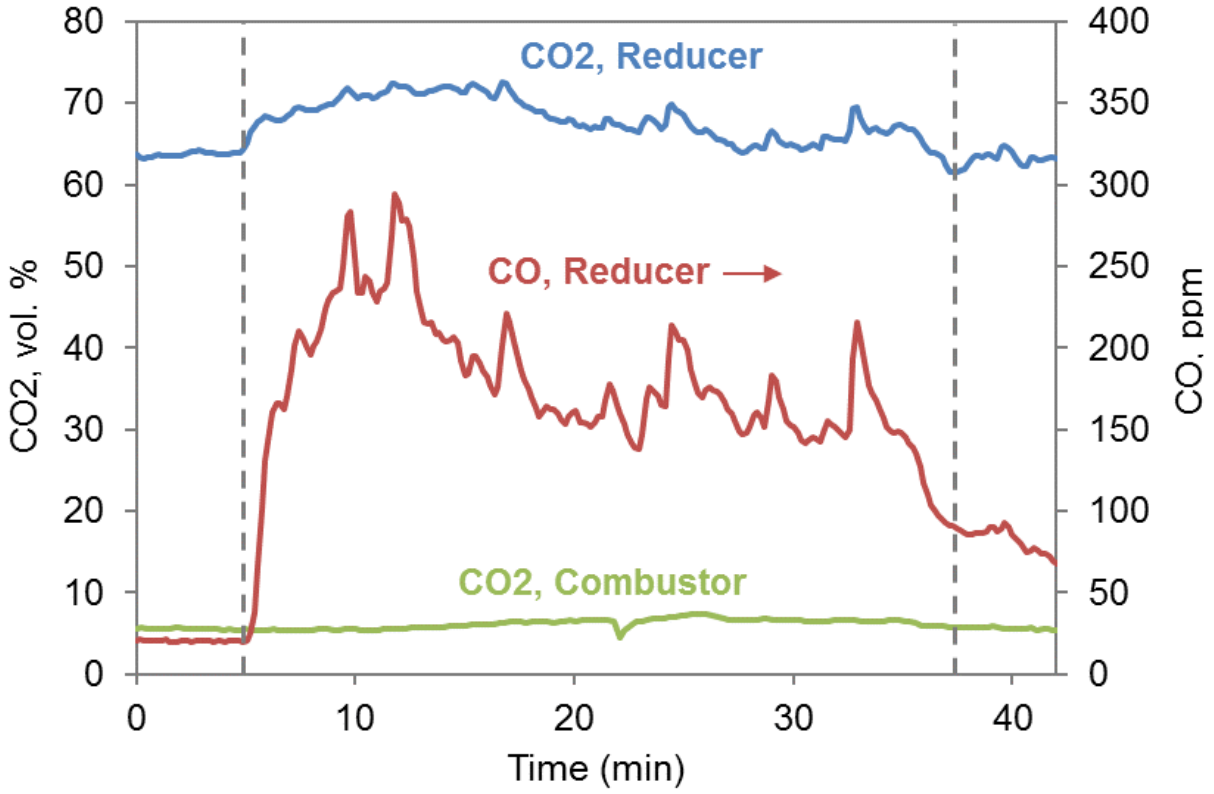
Test Campaigns		Main Achievements	Lessons Learned
#1	Initial Heat up (DE-FE-0009761)	Heated up to 1600 °F for more than 24 hrs	o Quench system o Need extra NG injection
#2	Unit shake down, start up and operation (DE-FE-0009761)	• Reached 1800 °F • Achieved expected solid circulation • Characterization of temperature/pressure distributions, gas sampling and analysis	o Coal injection pressure unbalance o Blower capacity low at startup
#3	Coal injection test (DE-FE-0037654)	• Reached 1950 °F • Injected coal successfully • High volatile conversion	o Air infiltration o Flame temperature startup sensitivity

250 kW_{th} Pilot – Test Results





250 kW_{th} Pilot – Test Results



high coal volatile conversion

Modifications to the Pilot Facility

Hardware

1. Air Compressor
2. Electric air pre-heaters
3. Natural gas distributor for direct injection
4. Modified gas sampling system to prevent leaks
5. Modified access port to the reducer to allow hot gas injection
6. Forced-air fan to quench system
7. Insulate reactor shell to reduce heat losses

Operation

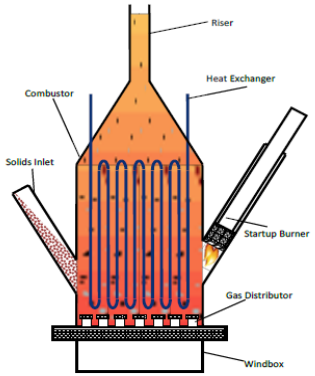
1. pre-heating reducer
2. Positive pressure operation
3. Using quench air instead of water

NEXT TEST RUN SCHEDULED ON AUGUST 20th

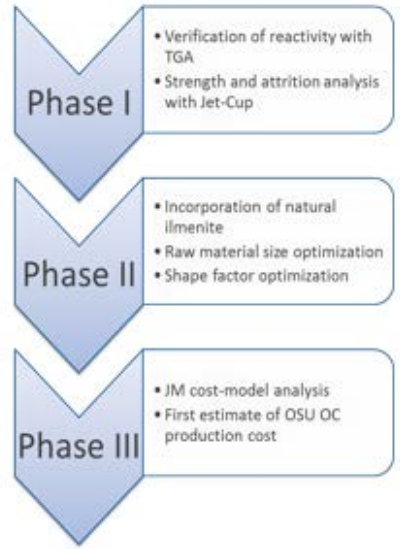
CFM Testing

Reducer Reactor
- PSRI: adapting existing CFM units
- Coal distribution in reducer reactor

Combustor Reactor
- Particle mixing and distribution
- In-bed Heat Exchanger



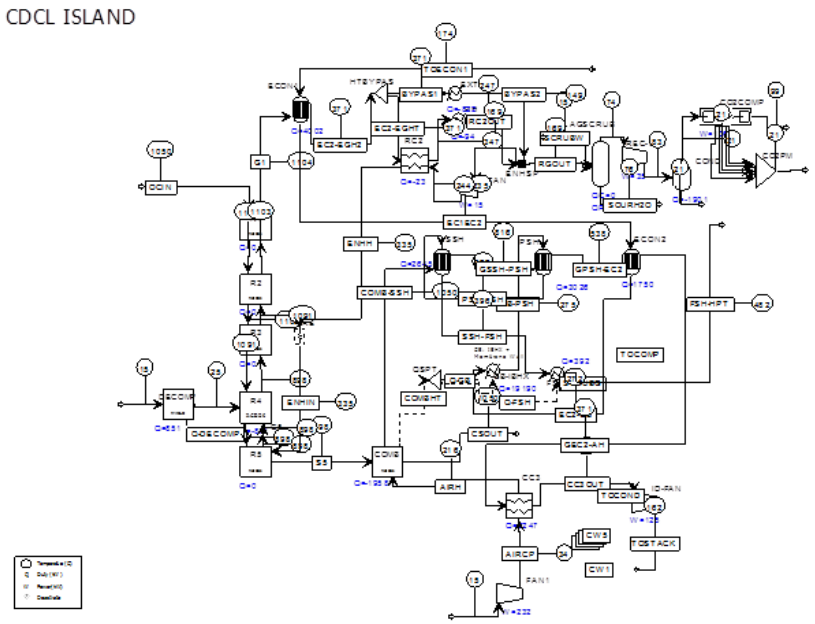
Oxygen Carrier Manufacturing



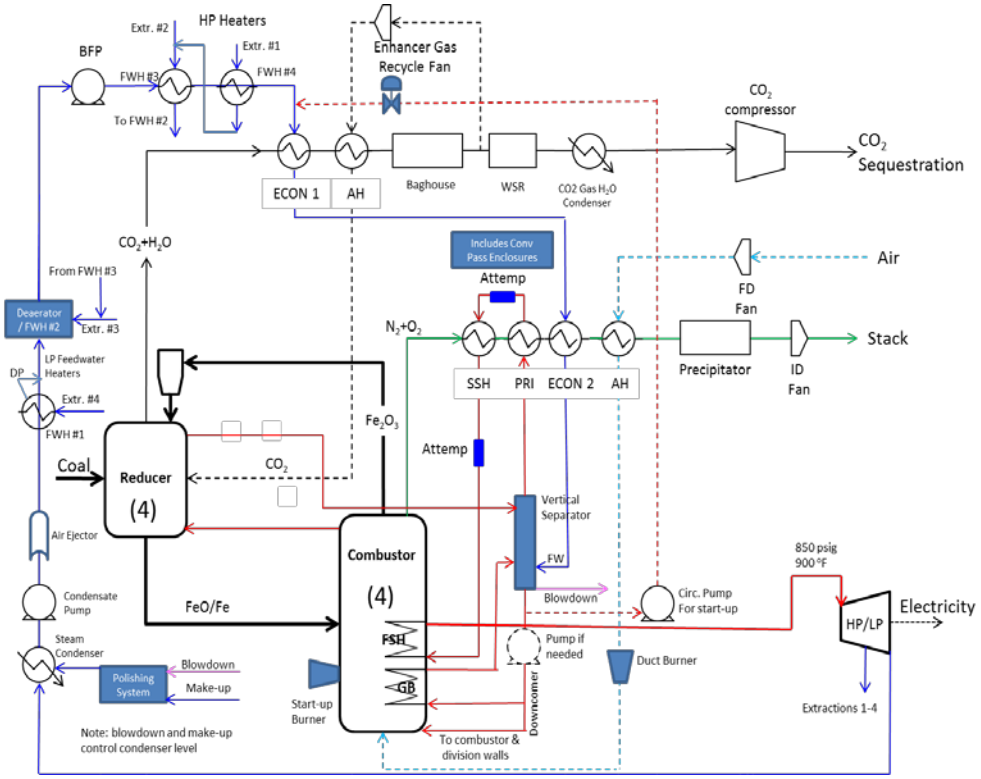
Pre-FEED Study

- Heat & Material Balances
- Functional Specifications
  - Mechanical
  - Electrical, Instrumentation & Controls
  - System specifications (CDCL Operation & Steam Cycle)
- Piping & Instrumentation Diagrams
- General Arrangement Drawings
- Foundation and Steel Structural Supports
- Balance of Plant Equipment
  - Coal Handling System
  - Oxygen Carrier Handling System
  - Ash and Fines Handling System
  - Environmental Control Equipment
  - CO_2 Compression System

Heat & Material Balance

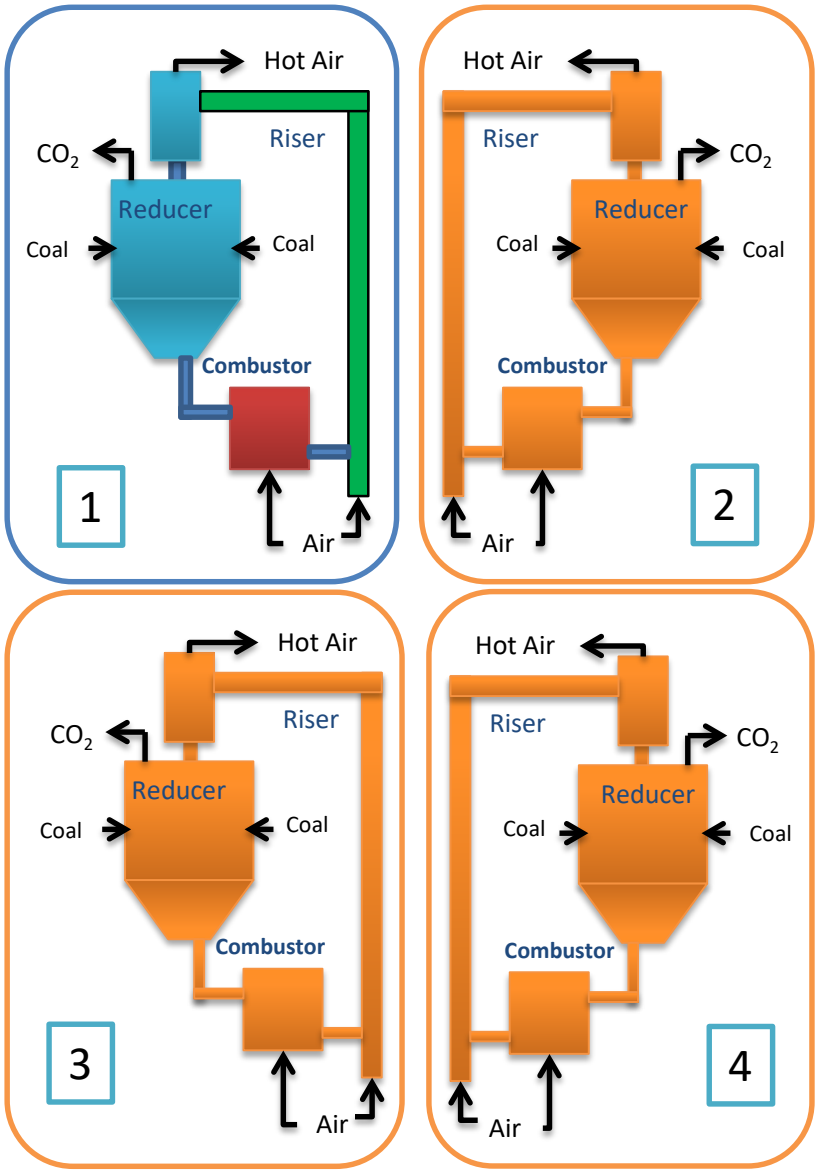


Primary Loop Cycle



Steam Cycle

10 MWe Modular Pilot Design



- 4 Modules of 2.5 MWe
- 1st module will be built and operated to validate the design.
- Following modules will be constructed
- Integration of the modules operation and controls

Advantage of Modular Design and Sparing Philosophy

- Startup
  - Sequential module startup with sharing resources
- High Reliability
  - Independent steam generation
  - Easier for scheduling maintenance
  - 4-33% modules provide full load capacity with module-out of service
- Flexible Operation
  - Fast response
  - Turn down/up
  - Particle exchange among modules

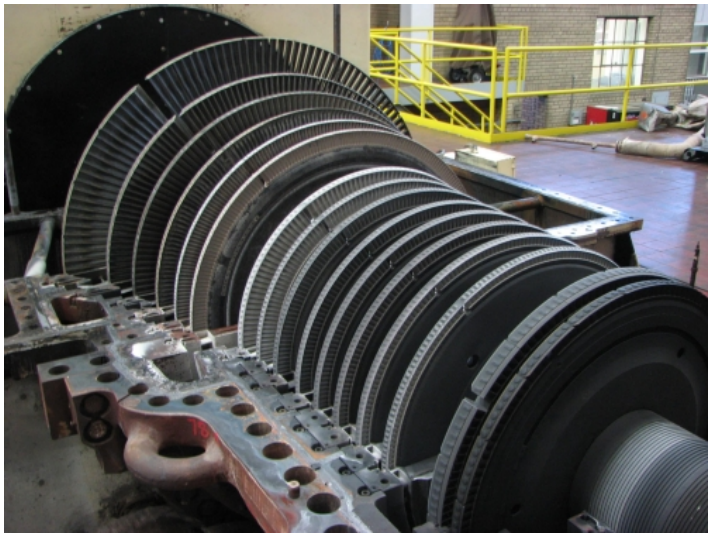
Host Site: Dover Light & Power

Existing

- 20 MWe Stoker coal fired boiler
- 20 MWe Steam turbine

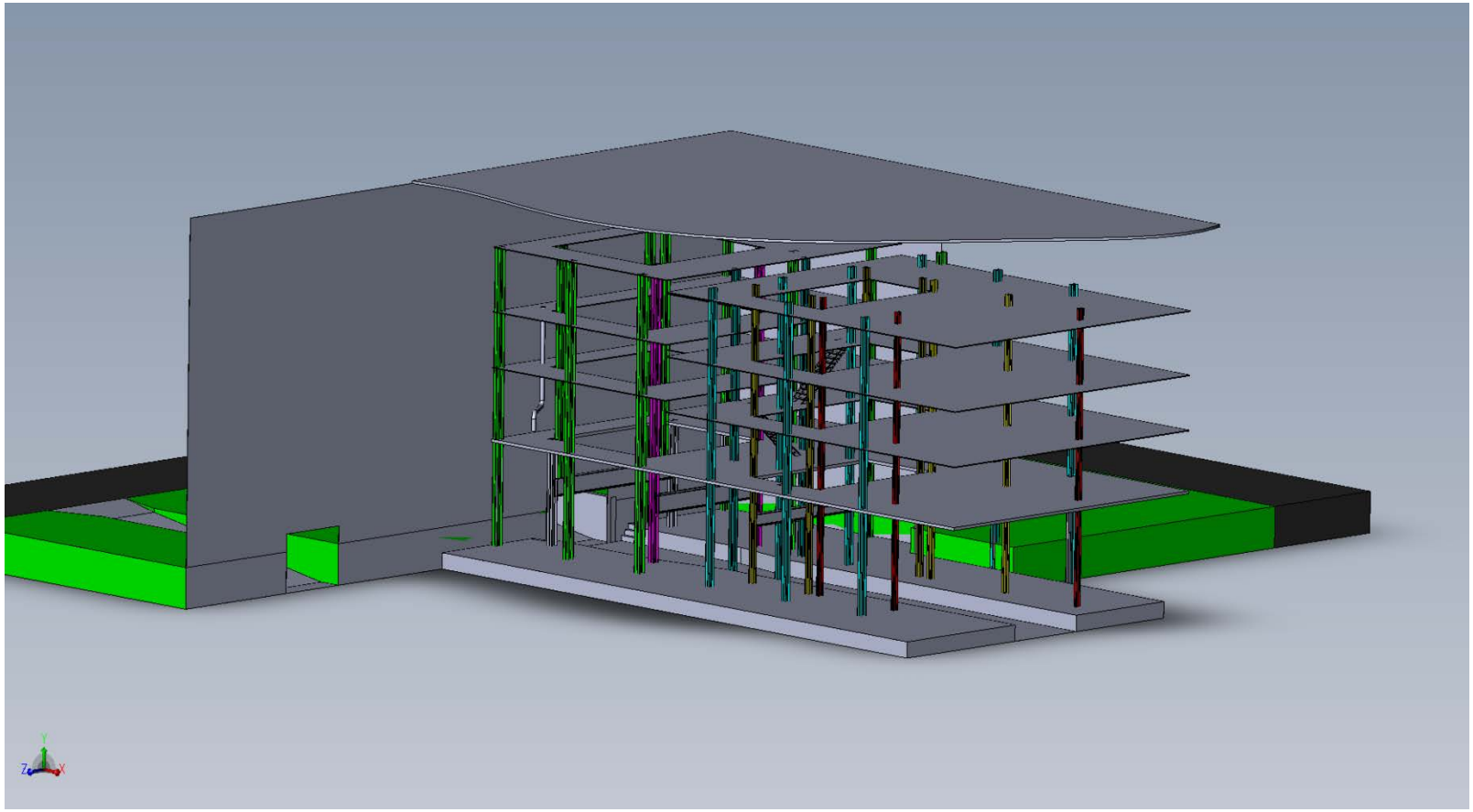
Planning

- 10 MWe natural gas package boiler
- 10 MWe CDCL unit
- 20 MWe Steam turbine
- Increase power capacity
- Preserve a balance between coal and natural gas
- Potential CO_2 market from local industries

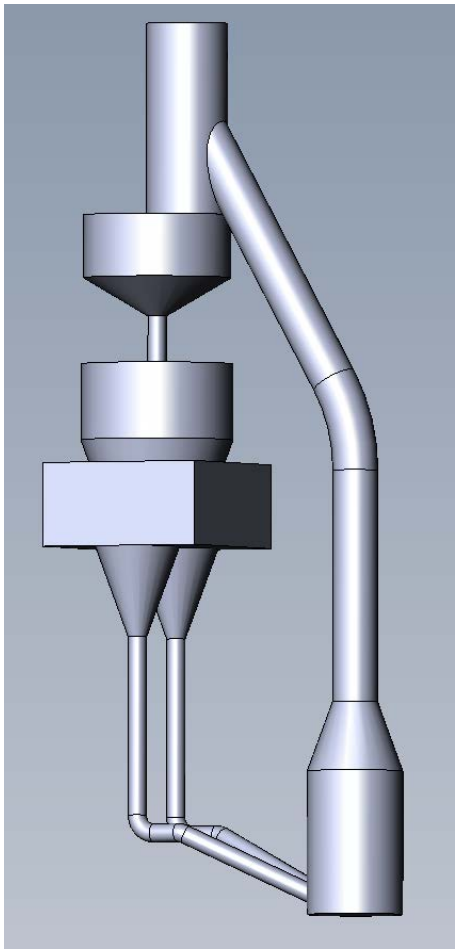


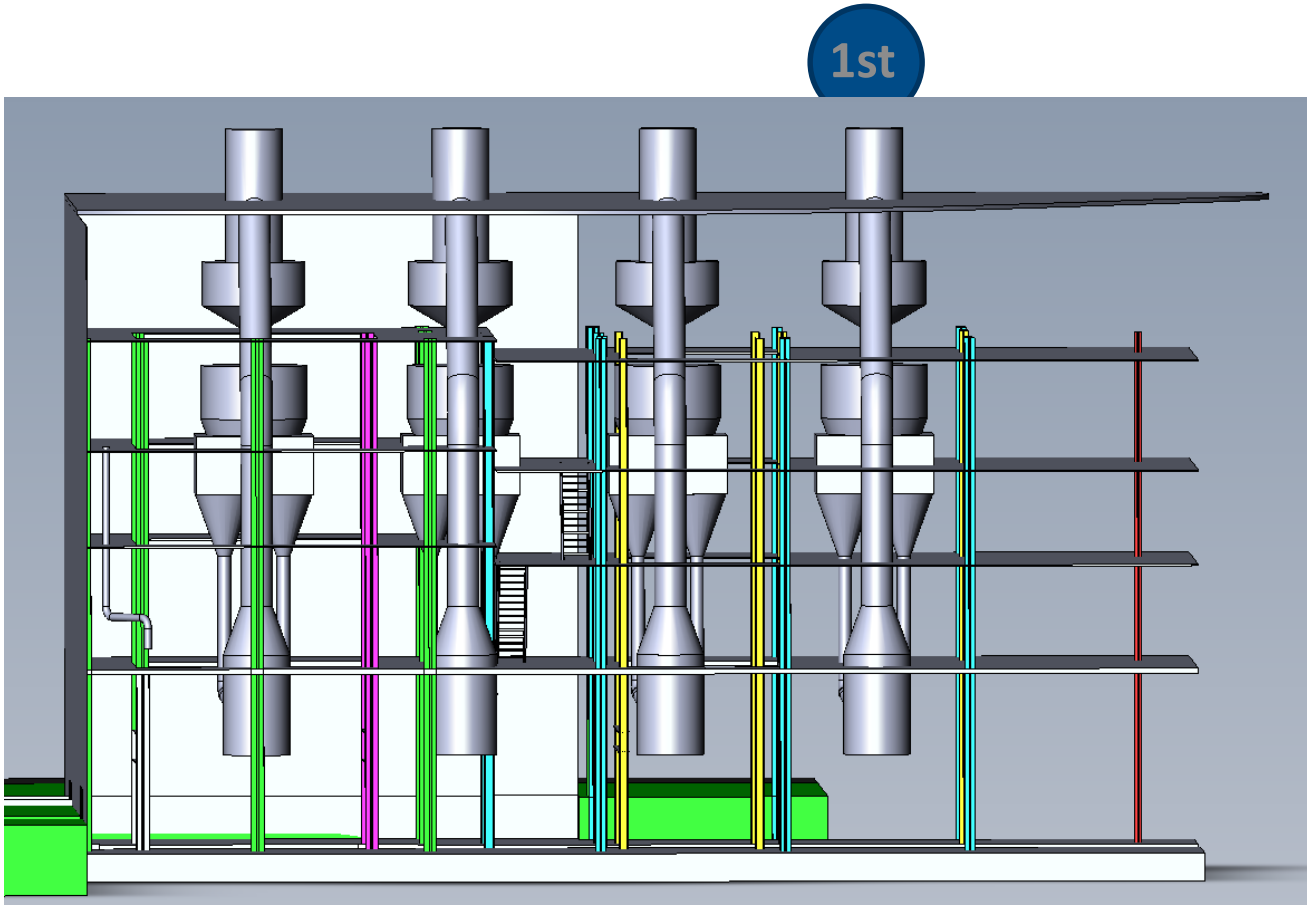
20 MWe Steam Turbine

Dover Plant Layout

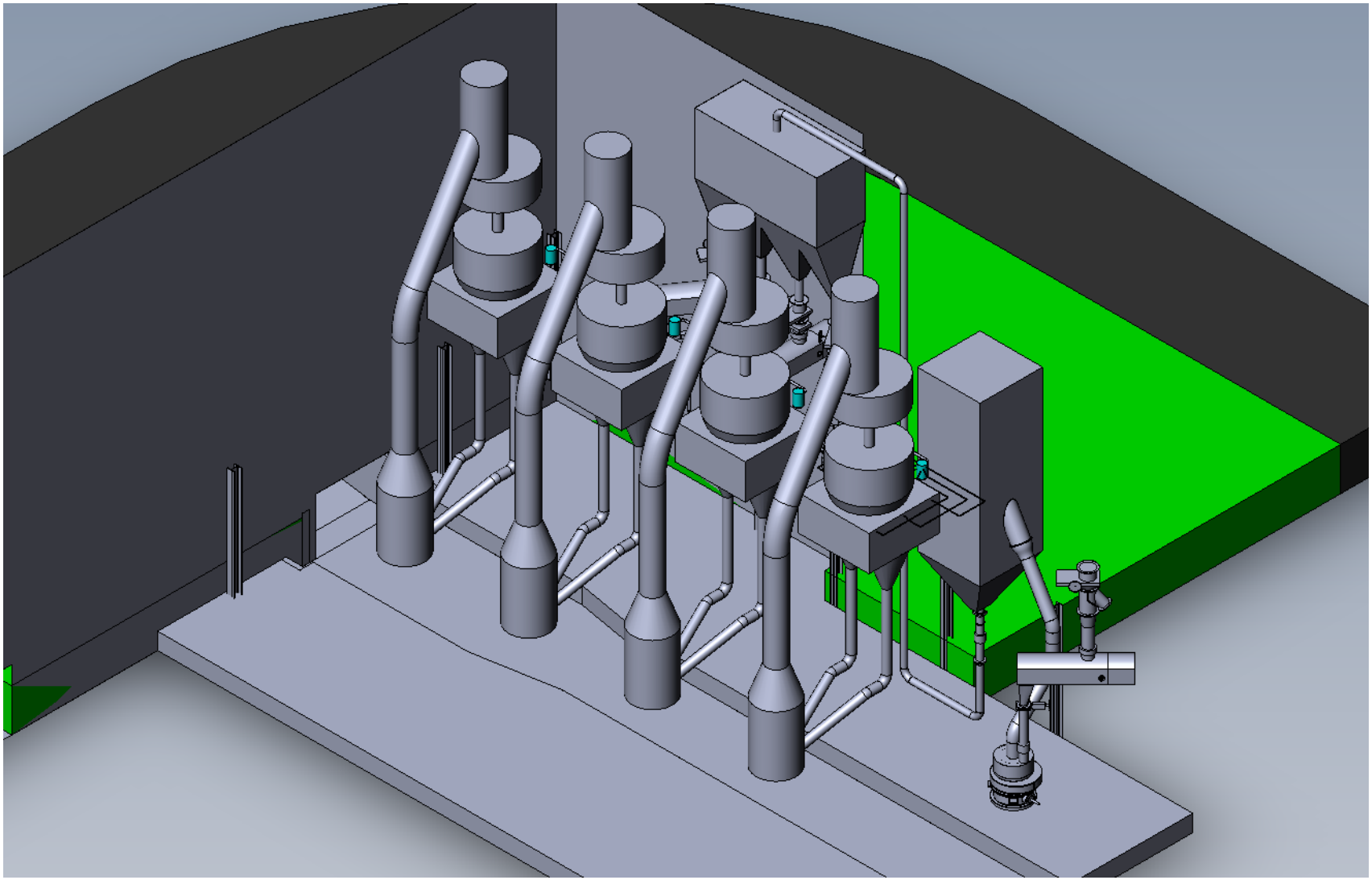


CDCL Module Design





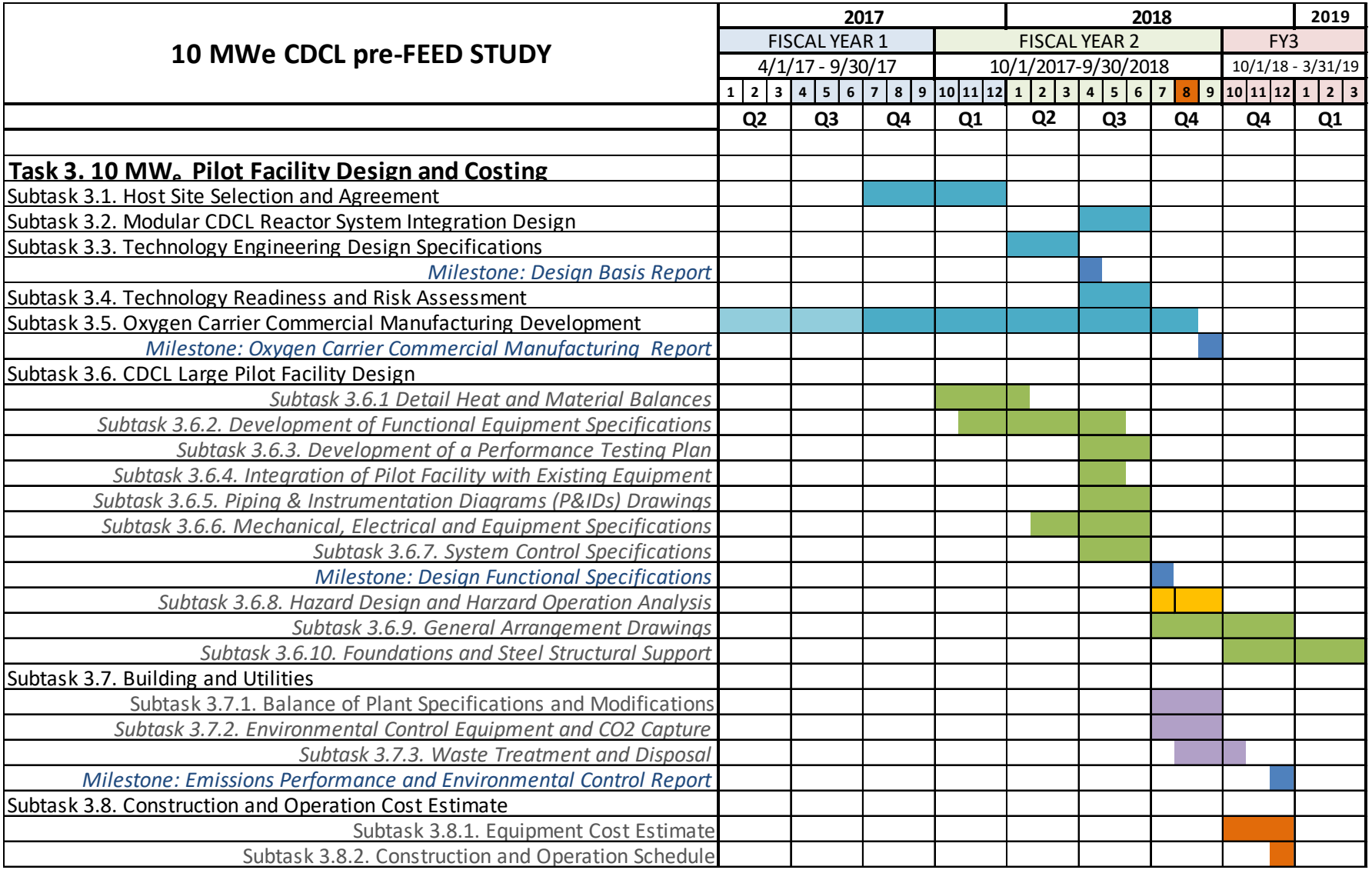
10 MWe Pilot Facility



Schedule

10 MWe CDCL pre-FEED STUDY	2017									2018										2019		
	FISCAL YEAR 1									FISCAL YEAR 2										FY3		
	4/1/17 - 9/30/17									10/1/2017-9/30/2018										10/1/18 - 3/31/19		
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
	Q2			Q3			Q4			Q1			Q2			Q3			Q4			Q4			Q1		
Task 1. Project Management and Planning																											
Task 2. 250 kW_t Pilot Facility & CFM Testing																											
Subtask 2.1. 250 KW_t Pilot Testing																											
Milestone: 250 kW_t Pilot Testing Report																											
Subtask 2.2. Design, Construction and Testing of Modular CFM																											
Milestone: Cold Flow Model Testing Report																											

Schedule


10 MWe CDCL pre-FEED STUDY
2017
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FISCAL YEAR 1
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1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3
Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q4 Q1
Task 3. 10 MWe Pilot Facility Design and Costing
Subtask 3.1. Host Site Selection and Agreement
Subtask 3.2. Modular CDCL Reactor System Integration Design
Subtask 3.3. Technology Engineering Design Specifications
Milestone: Design Basis Report
Subtask 3.4. Technology Readiness and Risk Assessment
Subtask 3.5. Oxygen Carrier Commercial Manufacturing Development
Milestone: Oxygen Carrier Commercial Manufacturing Report
Subtask 3.6. CDCL Large Pilot Facility Design
Subtask 3.6.1 Detail Heat and Material Balances
Subtask 3.6.2. Development of Functional Equipment Specifications
Subtask 3.6.3. Development of a Performance Testing Plan
Subtask 3.6.4. Integration of Pilot Facility with Existing Equipment
Subtask 3.6.5. Piping & Instrumentation Diagrams (P&IDs) Drawings
Subtask 3.6.6. Mechanical, Electrical and Equipment Specifications
Subtask 3.6.7. System Control Specifications
Milestone: Design Functional Specifications
Subtask 3.6.8. Hazard Design and Harzard Operation Analysis
Subtask 3.6.9. General Arrangement Drawings
Subtask 3.6.10. Foundations and Steel Structural Support
Subtask 3.7. Building and Utilities
Subtask 3.7.1. Balance of Plant Specifications and Modifications
Subtask 3.7.2. Environmental Control Equipment and CO2 Capture
Subtask 3.7.3. Waste Treatment and Disposal
Milestone: Emissions Performance and Environmental Control Report
Subtask 3.8. Construction and Operation Cost Estimate
Subtask 3.8.1. Equipment Cost Estimate
Subtask 3.8.2. Construction and Operation Schedule

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	Q2			Q3			Q4			Q1			Q2			Q3			Q4			Q4			Q1		
Task 4. Commercial Design & Economic Evaluation																											
Subtask 4.1. Update Commercial Plant Design and Evaluation																											
Subtask 4.2. Update Commercial Cost Analysis and Comparison																											
Subtask 4.3. CDCL Commercialization Roadmap and Risk Assessment																											
Task 5. Final Report and Close Out Documents																											
Subtask 5.1. Final Report and Close Out Documents																											
Pilot Demonstration Decision Point Go/No-Go																											
Phase II Final Report and Close Out Documents																											

Acknowledgements

This presentation is based upon work supported by the Department of Energy under the Award: DE-FE-0037654 and the Ohio Development Services Agency under the Award: OER-CDO-D-17-03.