Coal Direct Chemical Looping Retrofit for Pulverized Coal-fired Power Plants with In-Situ CO_2 Capture

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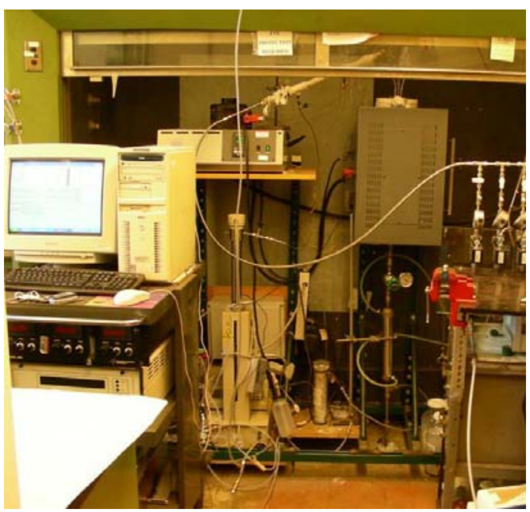
Clean Coal Conversion Program at The Ohio State University

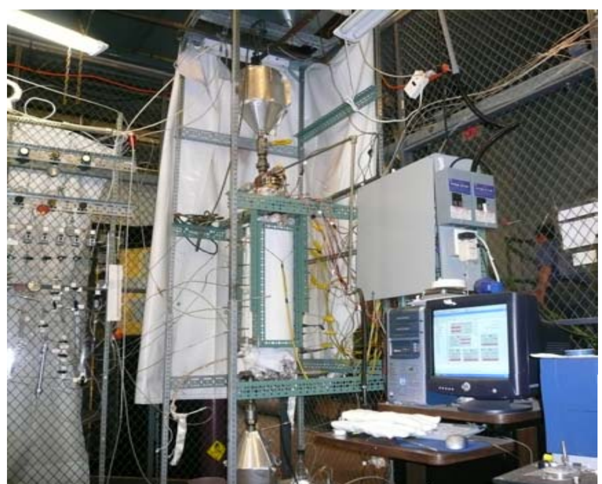
A. HPHT Slurry Bubble Column Reactor

B. 120 kW_{th} CCR Demonstration Unit

E. 25 kW_{th} Syngas Chemical Looping Demonstration Unit



C. Lab Scale Calcium Looping Unit



D. 2.5 kWth Chemical Looping Unit

Project Overview

Project Funding

Participant	Cash	In-Kind	Total
DOE	$2,860,143		$2,860,143
OCDO	$300,000		$300,000
OSU	$363,628	$113,272	$476,900
CONSOL		$52,284	$52,284
CRI/Shell		$120,000	$120,000
B&W		$90,000	$90,000
Air Products		$50,000	$50,000
Clear Skies		$27,000	$27,000
Total			***$3,976,327***

DOE $2.86 million, Participants Cost Share $1.12 million

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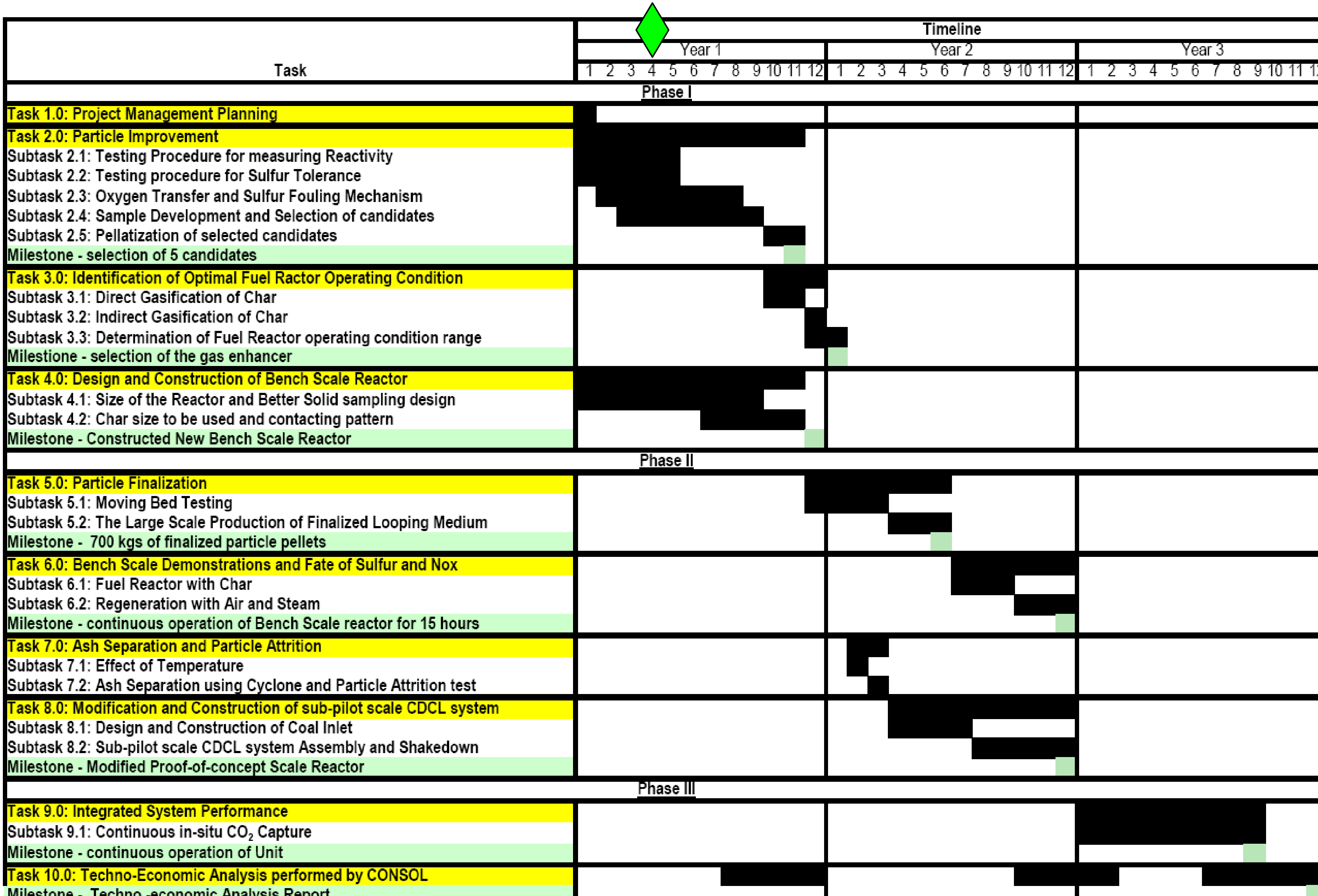
Project Timeline



Project Participants

- Project Manager: Timothy Fout
- Lead Applicant
  - **The Ohio State University**
    - Prof. Liang-Shih Fan (PI) & Research Associates
    - Planning, Experiments, and Demonstrations
- Partners
  - **Clear Skies Consulting**
    - Organization and Coordination
  - **Shell/CRI Inc.**
    - Particle Synthesis Procedure Scale up and Economics
  - **CONSOL Energy Inc.**
    - Techno-Economic Study of the Overall CDCL System
  - **The Bobcock and Wilcox Company**
    - Engineering Consultation and Support on PC Plant Retrofit
  - **Air Products and Chemicals Inc.**
    - Gas Handling

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Process Review

Overall CDCL Scheme

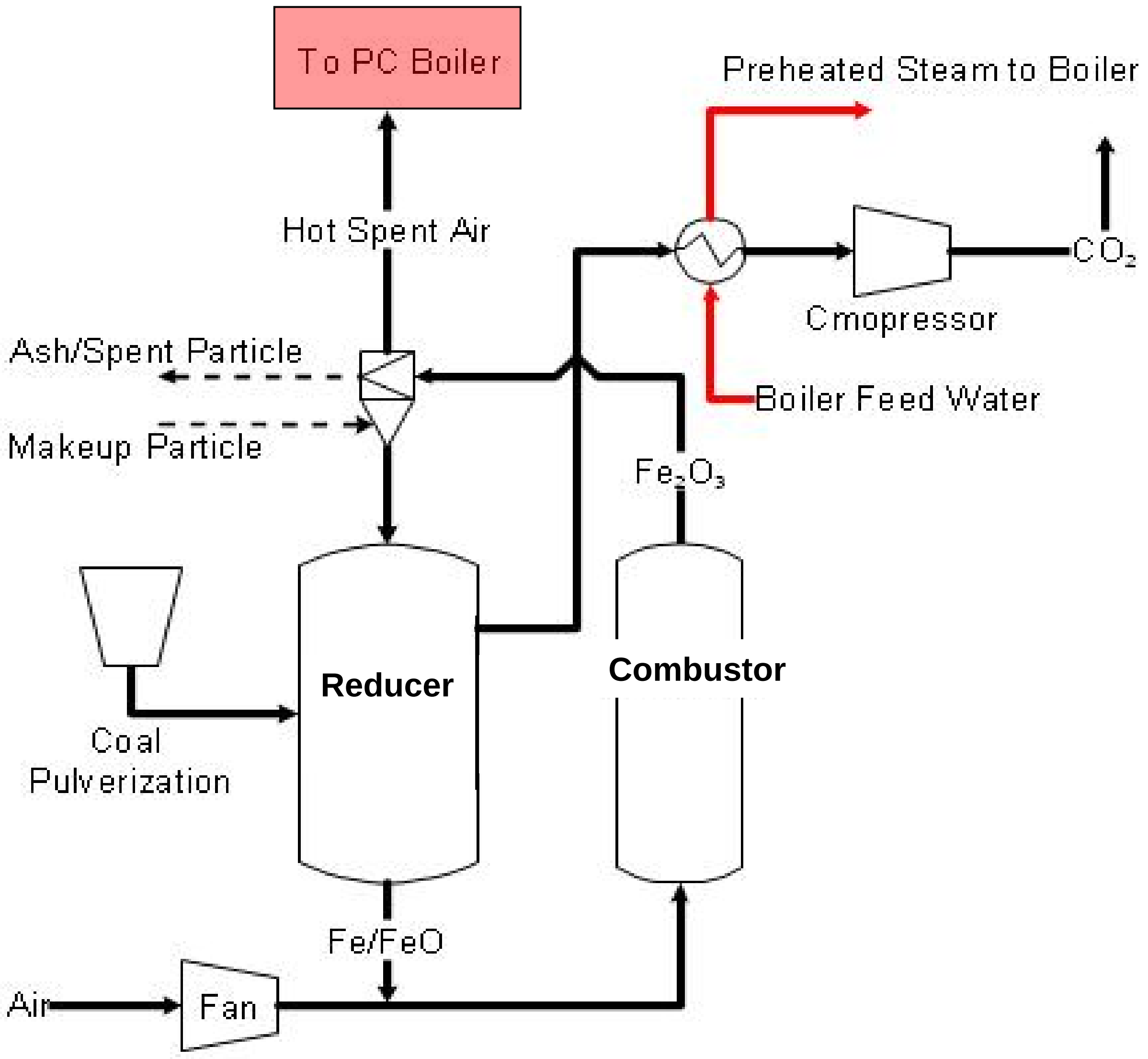
Step I: $\text{Coal} + Fe_2O_3\ (\text{Hot}) \rightarrow Fe/FeO + H_2O + CO_2$

Step II: $\text{Air} + Fe/FeO \rightarrow Fe_2O_3\ (\text{Hot}) + \text{Spent Air}\ (\text{To boiler})$

Overall reaction

$$\text{Coal} + \text{Air} \rightarrow CO_2 + H_2O + \text{Spent Air (Heat)}$$

Process Flow Diagram



Key Challenge: Particle Selection and Development

	Fe_2O_3	NiO	CuO	CoO
Cost	+	–	~	–
Oxygen Capacity[2] (wt %)	30	21	20	21
Thermodynamics	+ (+)	+ (–)	+ (–)	+ (+)
Kinetics/Reactivity	–	+	+	–
Melting Points	+	~	–	+
Strength	+	–	~	~
Environmental& Health	~	–	~	–

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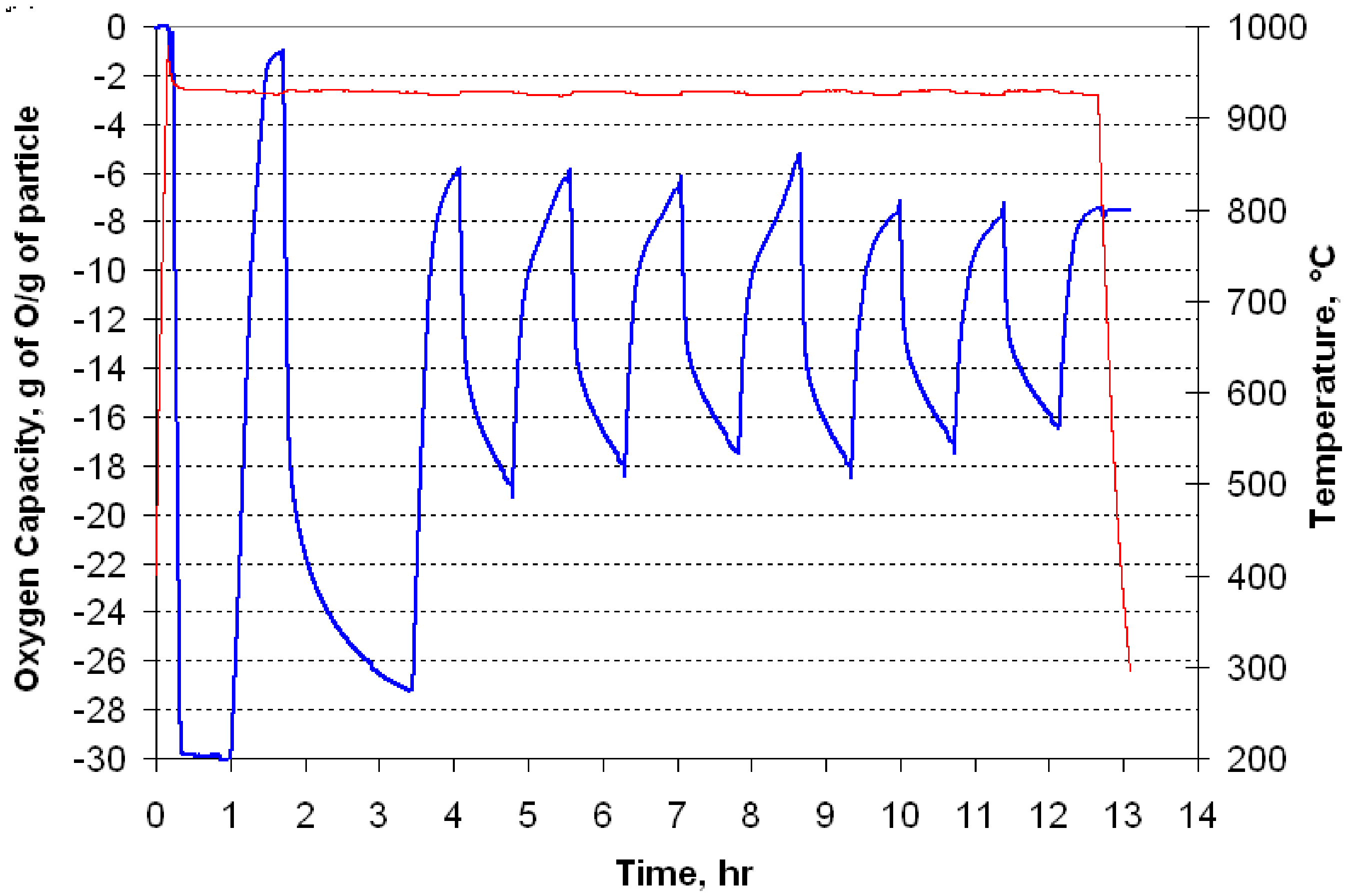
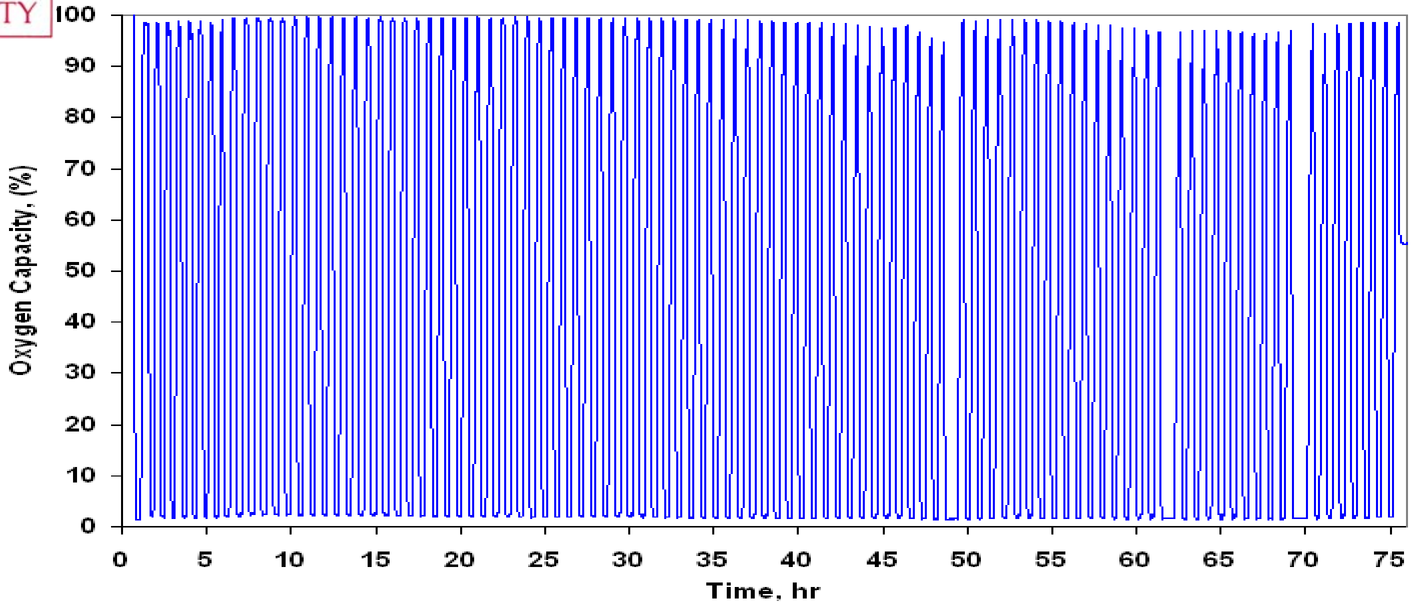
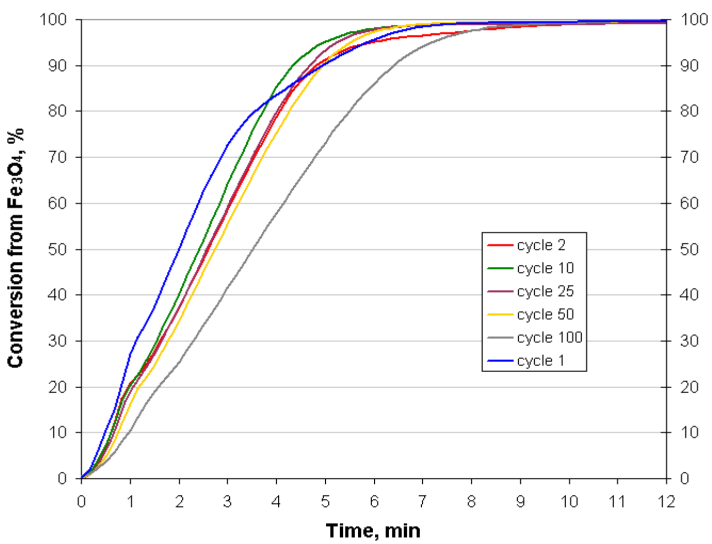
Recyclability of Commercial Fe_2O_3

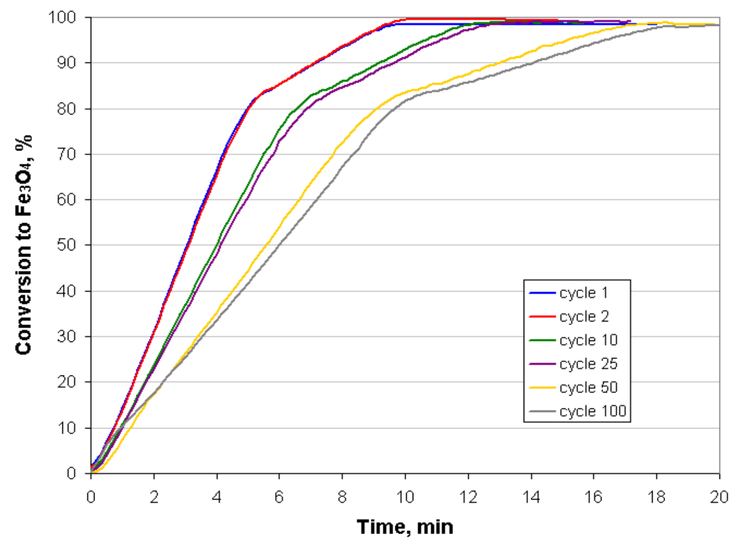


Recyclability of Composite Fe_2O_3 Particles





Reduction



Oxidation

Iron Based Composite particles are completely recyclable for more than 100 cycles

Pelletization

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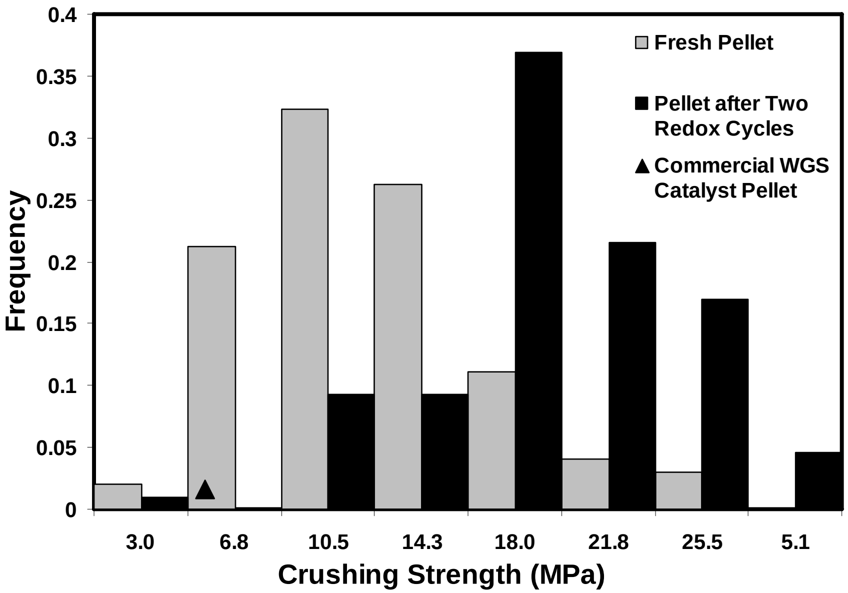
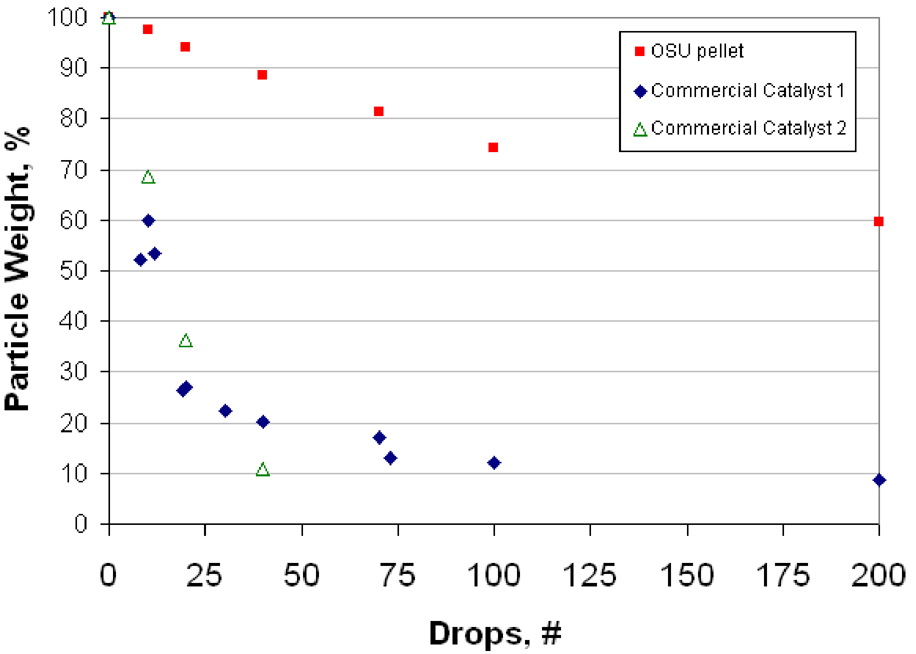
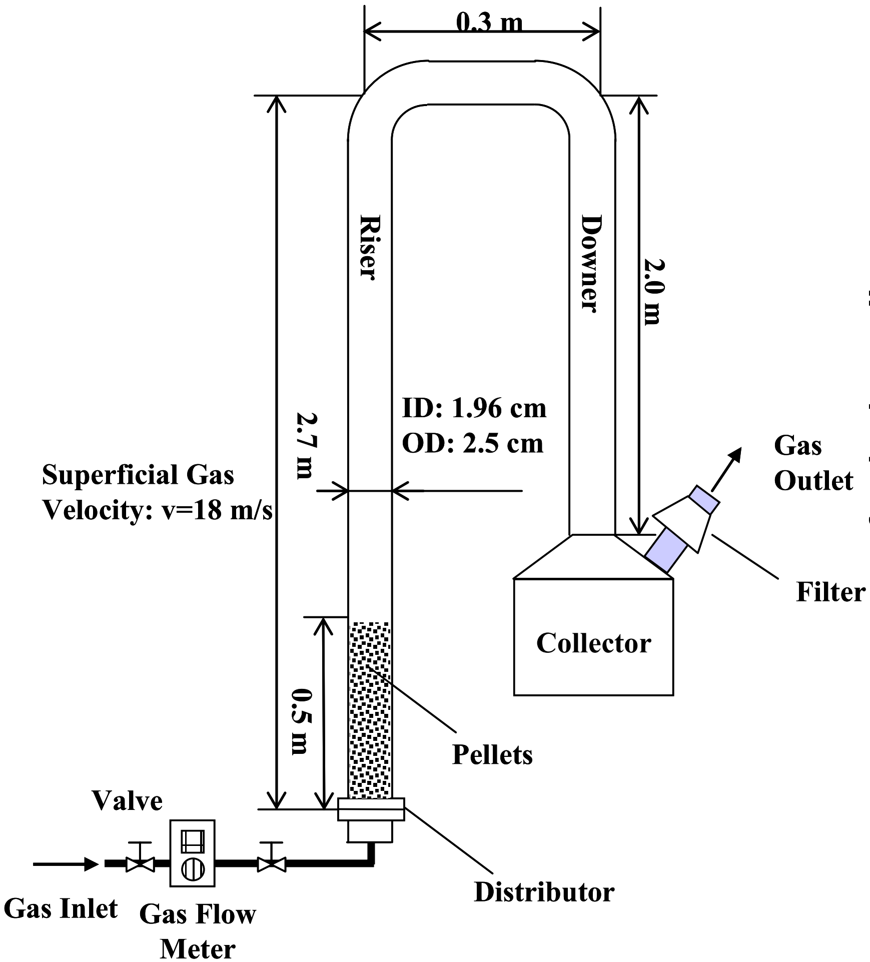
Pellet Strength: Compression Strength Test and Dropping Test (ASTM D4179)

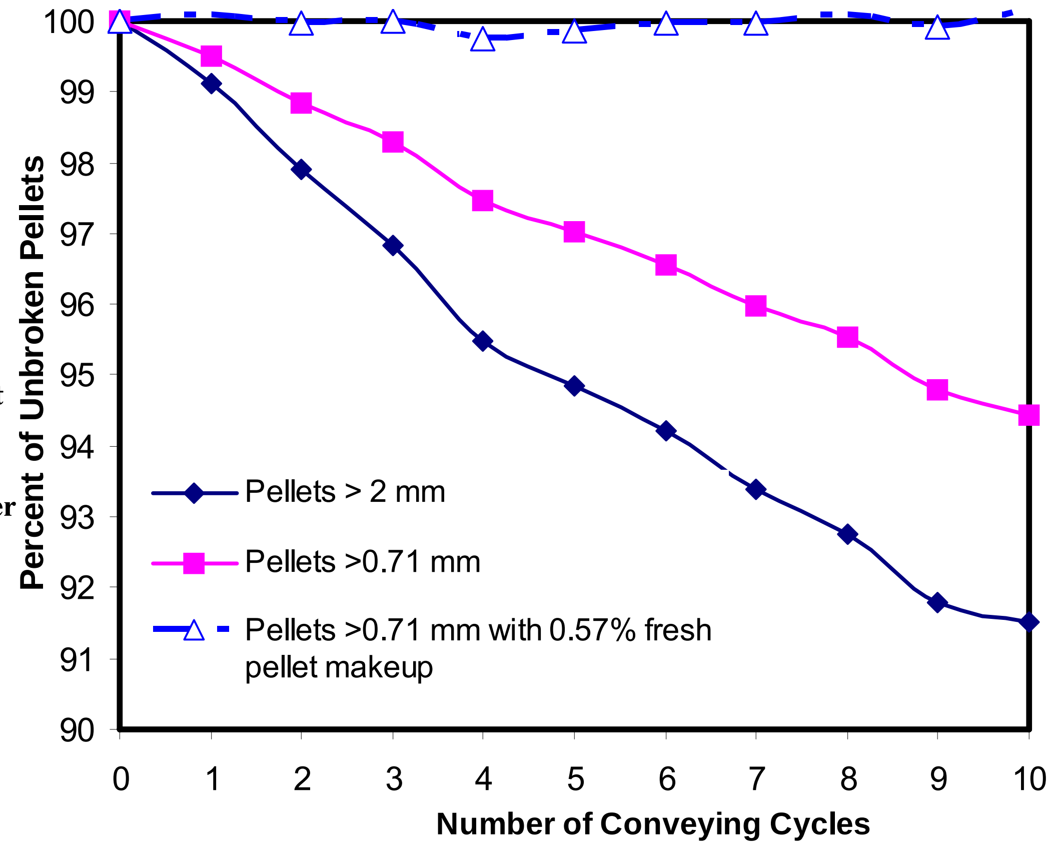




Pellets have Good Strength

Pellet Strength: Attrition Test

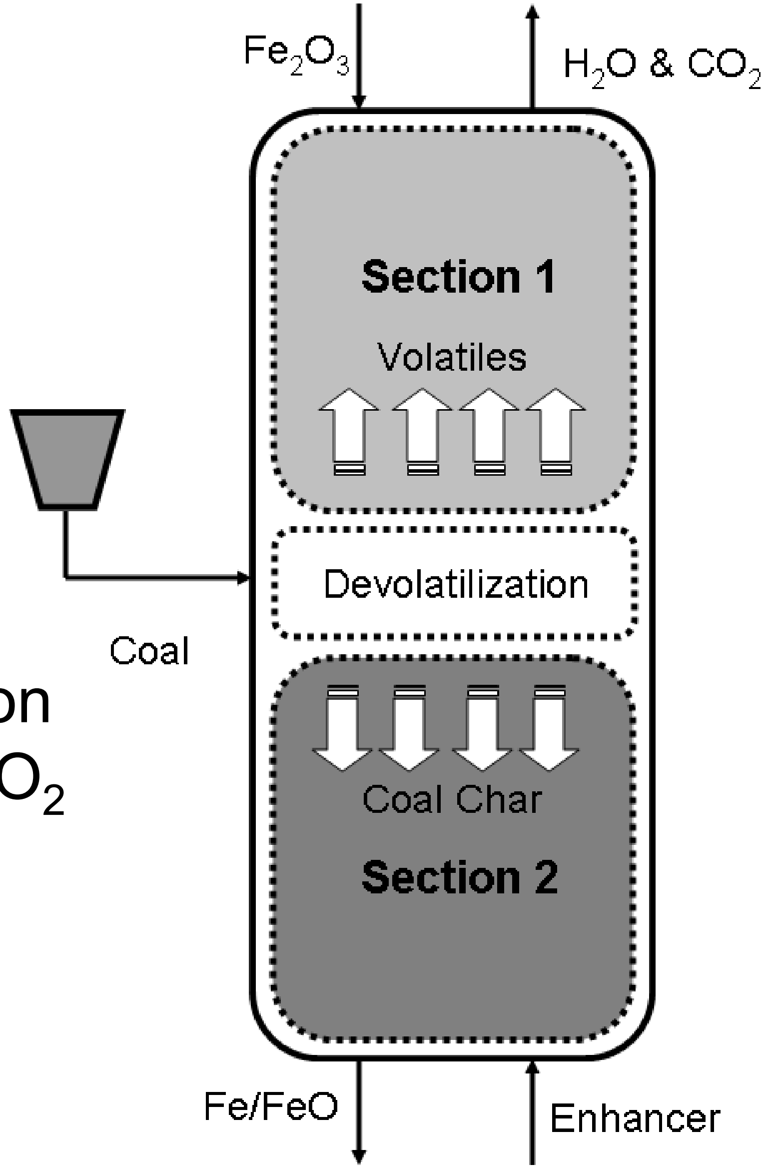




0.57% fresh pellet makeup is sufficient

Key Challenge: Reducer

- 2-Stage Moving Bed
  - Counter-current flows
  - Gaseous volatiles
  - Coal char
- Reaction Enhancer
  - Initiates the solid-solid reaction
  - Direct enhancer : CO_2, H_2O, O_2
    - $CO_2 + C \rightarrow 2CO$
  - Indirect enhancer : H_2
    - $3H_2 + Fe_2O_3 \rightarrow 2Fe + 3H_2O$



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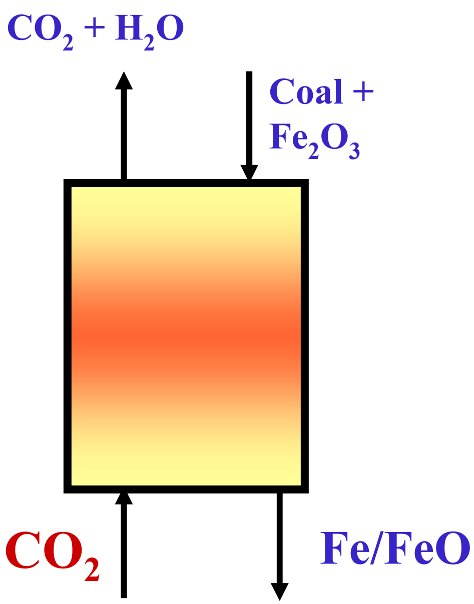
Key Challenge: Solid Fuel Conversion Enhancement

"Chain Reaction" Effect



Contacting Pattern

$1CO_2$ — 1 CO_2

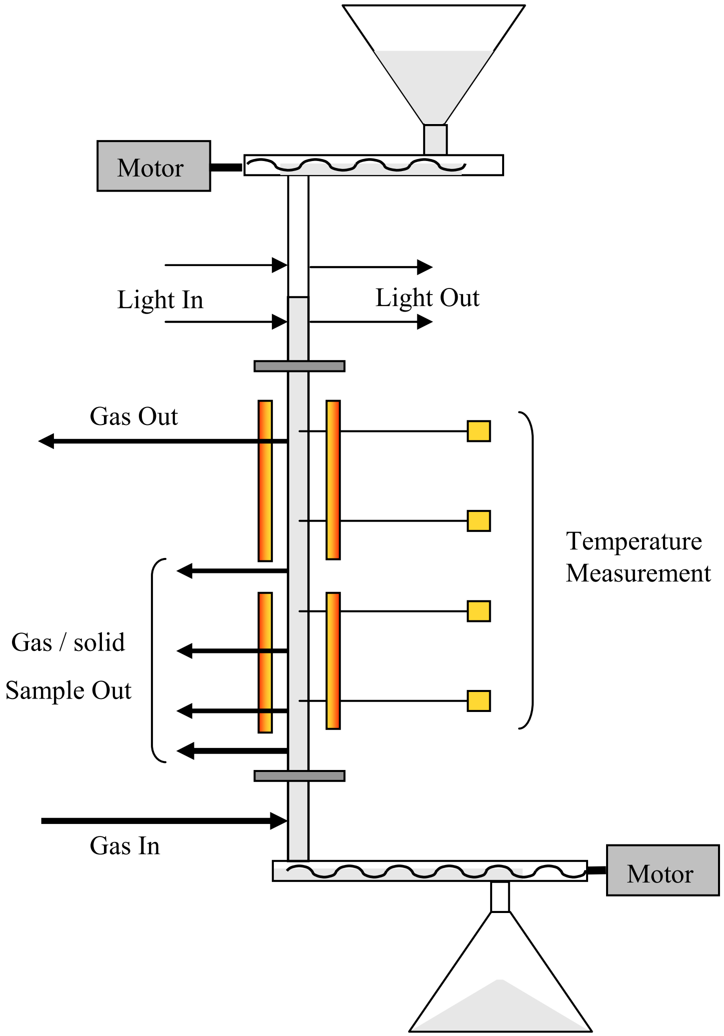
$CO_2 + C \rightarrow 2CO$

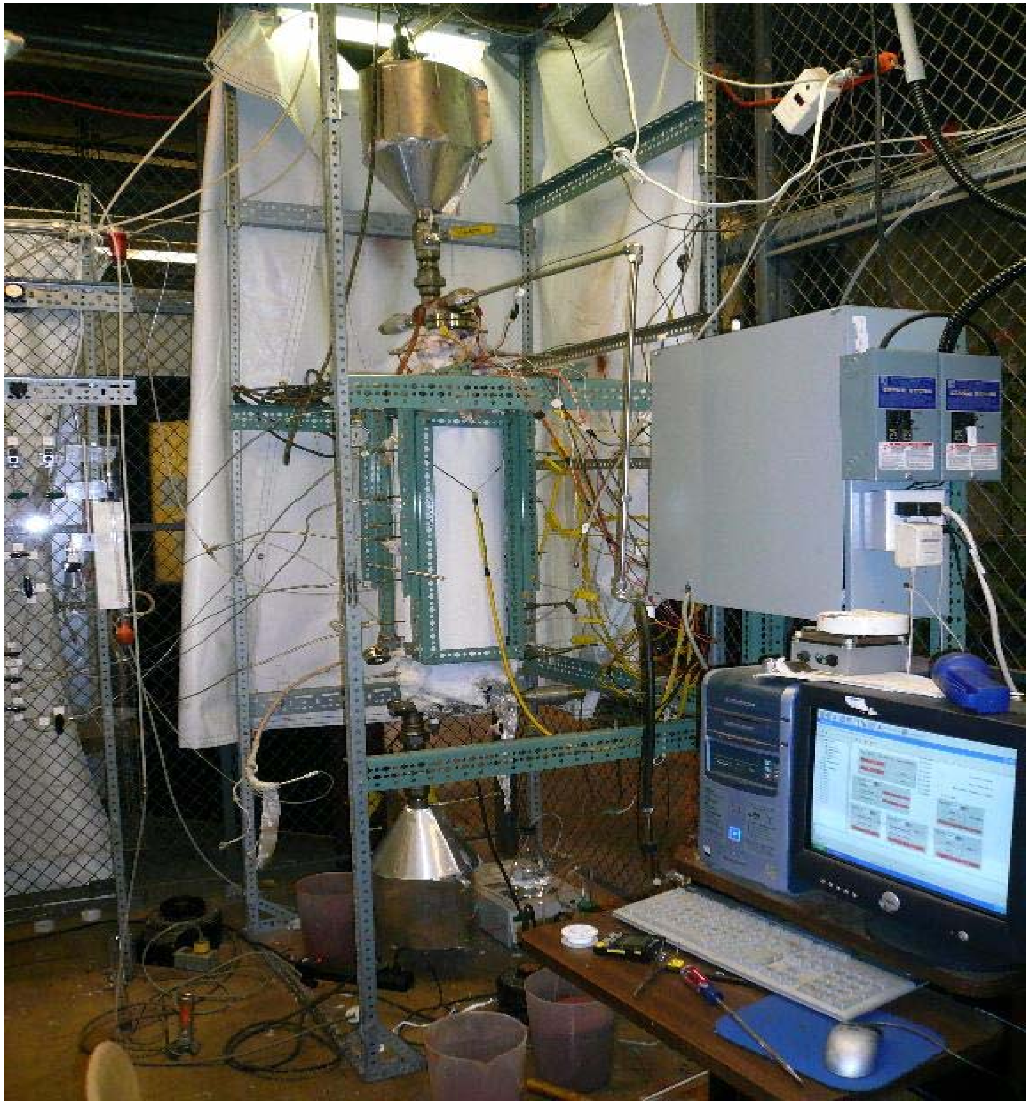
$2CO + 2FeO_x \rightarrow 2FeO_{x-1} + 2CO_2$ — 2 CO_2

$2CO_2 + 2C \rightarrow 4CO$

$4CO + 4FeO_x \rightarrow 4FeO_{x-1} + 4CO_2$ — 4 CO_2

Reducer Bench Scale Demonstrations





Reducer Tests with Various Fuels

Type of Fuel	Coal Volatile (CH_4)	Lignite Char	Ohio Coal Char	Anthracite Coal
Fuel Conversion (%)	99.8	94.9	90.5	95.5
CO_2 Concentration in Exhaust (% Dry Basis)	98.8	99.23	99.8	97.3

High Conversions of various types of fuels are achieved

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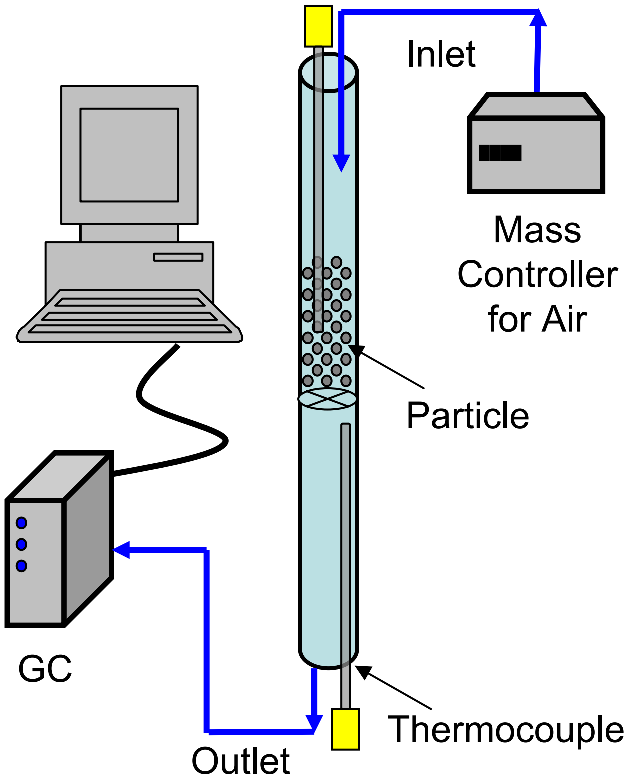
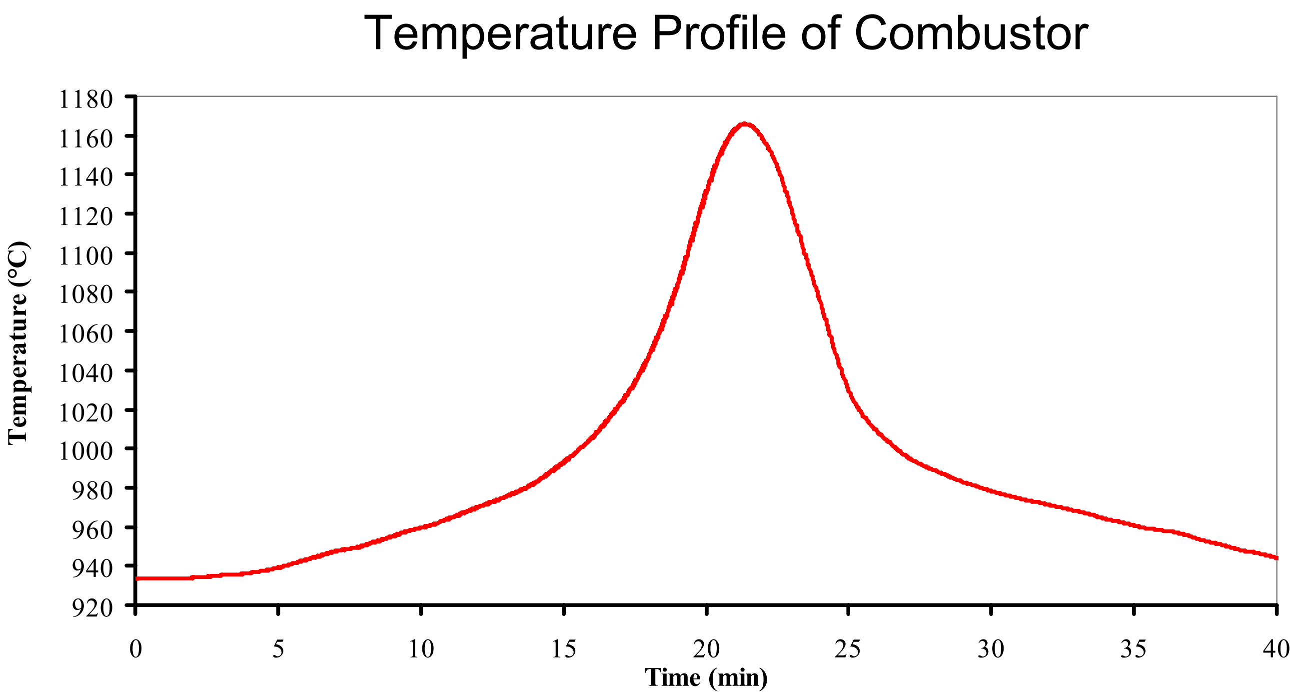
Combustor Tests





- Particle Temperature - 933°C → 1166°C
- Gas Temperature - 924°C → 971°C
- Particle Recyclable After Three Cycles

System Performance

	PC Plant	Retrofit with CDCL
CO_2 Captured, %	0	100
HP Steam Turbine Power	103.48	113.25
IP Steam Turbine Power	90.75	97.76
LP Steam Turbine Power	192.15	202.97
Gross Power Summary, MW	386.38	413.98
Pump + Fan	13.03	35.13
CO_2 Compressor	0	31.41
Auxiliary Load Summary, MW	13.03	78.92
Net Power, MW	373.35	347.45
Efficiency, HHV%	36.43	33.93
Retrofit System Cost (Estimated, Million Dollar)	0	103
Cost of Electricity ($/MWh)	56.6	67.16

Very low CO_2 capture penalty in the retrofit scenario, much higher efficiency can be obtained in the case of a new CDCL plant (close to 50%)

Upcoming Project

Project Objectives

- Develop the CDCL Process for Retrofit to PC Plant
  - CDCL process Demonstration
    - Further Optimization of the Working Oxygen Carrier Particle
    - Lab, Bench (2.5kWt), Sub-pilot Scale (25kWt) Demonstrations
  - Sulfur, Mercury, and NO_x control
- Demonstrate the Techno-Economic Performance
  - Low Energy Penalty
  - Low Carbon Capture Cost

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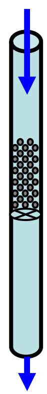
Coal Direct Chemical Looping Retrofit to PC Plant

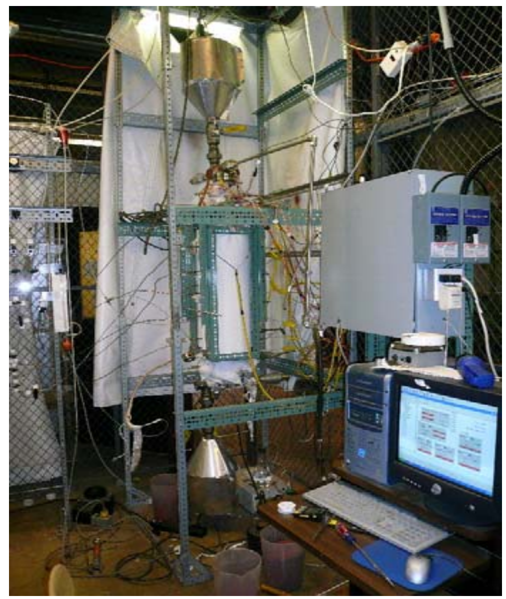
Scale

Particle

Optimization and TGA Tests



Fixed Bed Tests



Bench Scale Tests

Sub-Pilot Tests after Modification to Current Chemical Looping Demonstration System

Time

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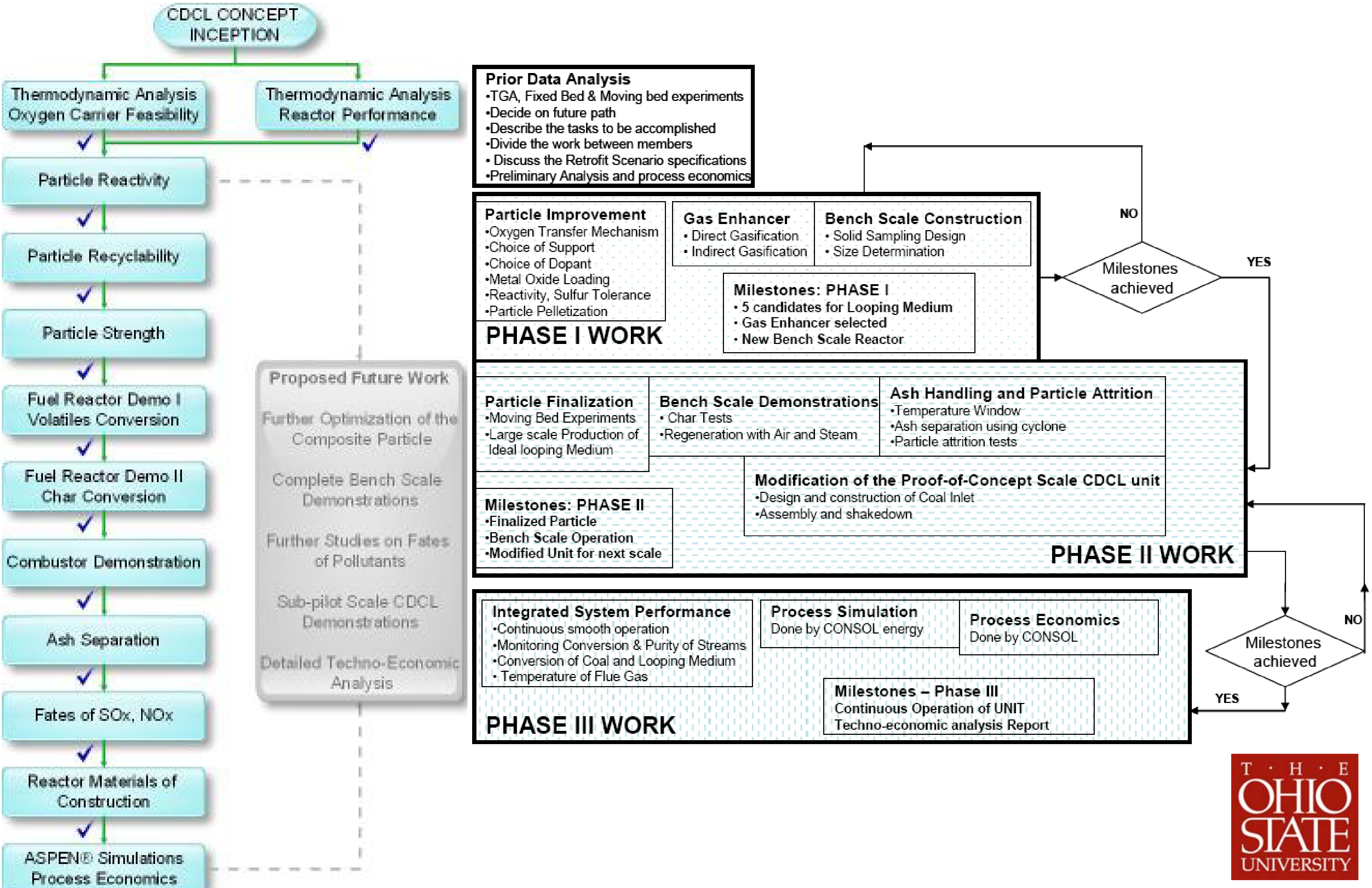
Technical Approach



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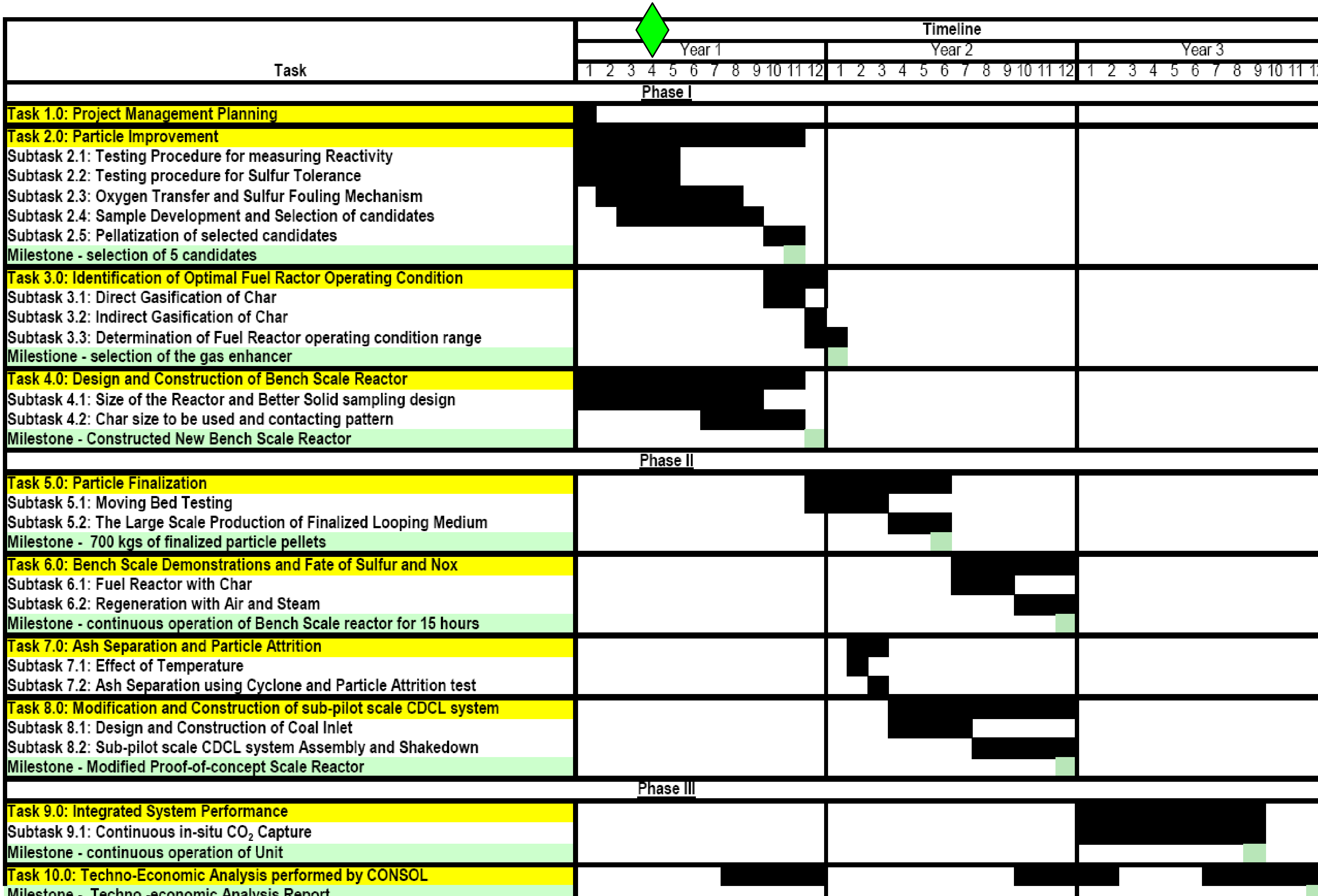
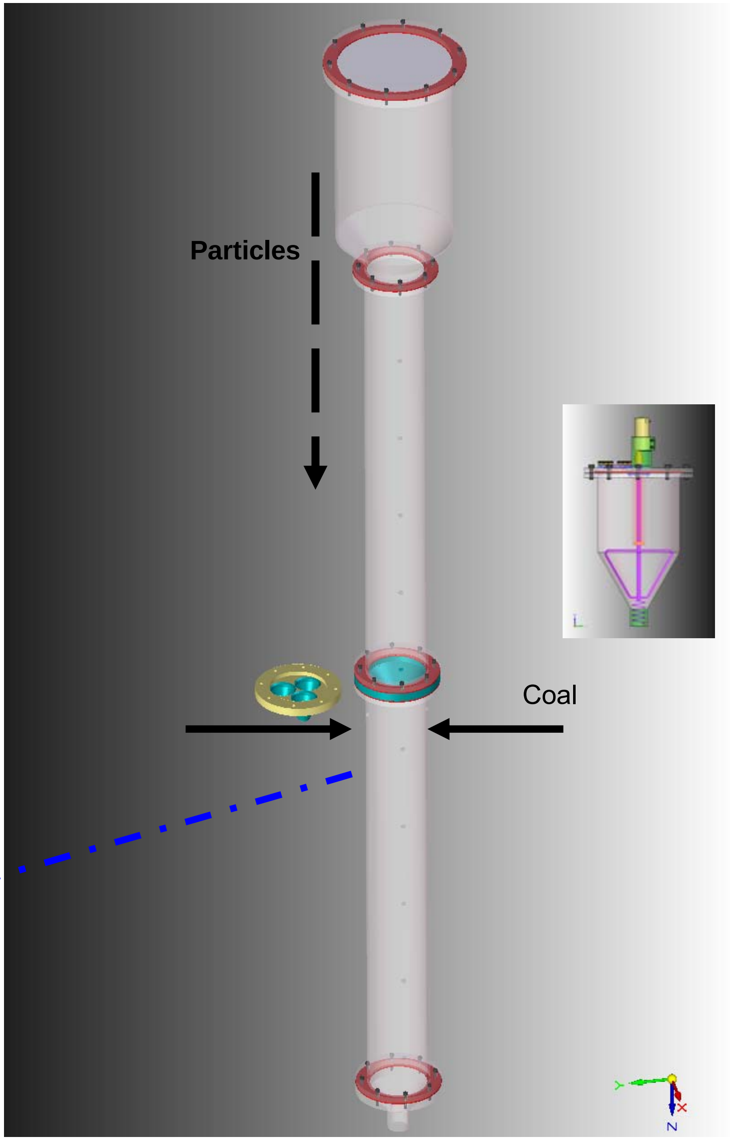
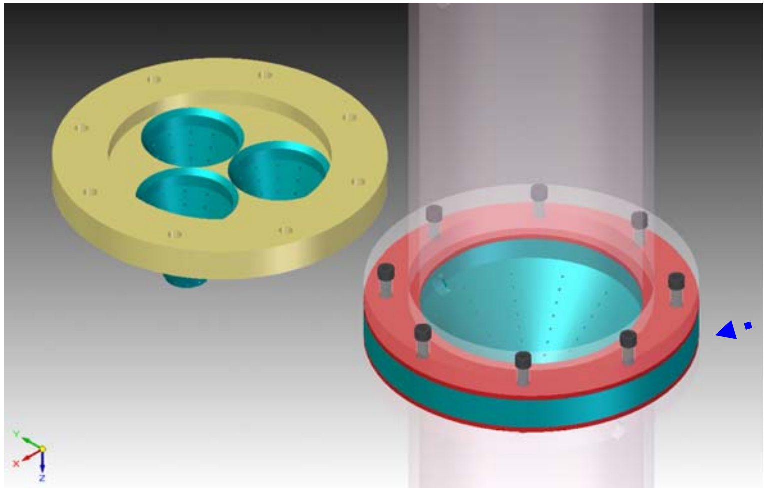
Project Timeline



Current Status

- Particle Test Protocol Finalized
- Base Particle Tested with the Standard Protocol
- Multiple Particles are being Synthesized
- Fixed Bed Studies Performed
- A Cold Model for the CDCL Reducer is Designed and Fabricated





We are on Track ^_^

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Current Status

We will be on Track ^_^

Future Demonstrations and Commercialization Plan

- Further Scale up to an Autothermal 1 – 5 MW_{th} Scale CDCL System
- Detailed Updated Techno-Economic Analysis based on Scale Up Demonstrations
- Collaboration with Shell/CRI on Mass Production of Oxygen Carriers
- Commercialization with Industrial Partners

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Questions?

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