Alstom Chemical Looping
Advanced Oxy – Phase I
US DOE / NETL Kickoff Meeting

US DOE/NETL
Pittsburgh, PA

26 October 2012

POWER | ALSTOM

Limestone Chemical Looping
Advance Oxy Project – Kickoff Meeting

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Agenda

			minutes	Presenter
1.	Participant Background		5	Ray Chamberland
2.	Project Objectives		5	Herb Andrus
3.	Technology / Technical Approach			Herb Andrus / Glen Jukkola
		Chem Loop Technology	10	
		Phase I - Technical/Ecomonic Study	20	
		Prototype Results/Plans	40	
4.	Phase II Approach		5	Herb Andrus
5.	Project Structure/Task Description		5	Ray Chamberland
		Schedule		
		Budget		
		Total	90	
				AdvOxyKickoff.xls
				10 Oct 2012

Agenda

Limestone Chemical Looping Project

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- Team
  - Alstom Boiler R&D – Windsor, CT
    - Prime awardee
    - Systems Analysis
    - Engineering Analysis
  - Alstom – Chattanooga, TN
    - Analytical chemistry and atmospheric TGA support
  - University of British Columbia – Vancouver
    - Pressurized TGA support

- Budget
  - 1.25 MUSD in one budget period
  - 20% Alstom cost share

- Schedule
  - October 2012 to September 2013
  - Major deliverables due June 29, 2013
    - Phase I Topical Report – Draft Final report
    - Final Phase I Technology Engineering Design and Economic Analysis Report
    - Final Phase I Technology Gap Analysis Report
    - Final Phase II Application

Agenda

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Participants

Project Objectives

Technology /Technical Approach
- Chemical Looping Technology
- Phase I – Technical/Economic Study
- Prototype Results & Plans

Phase II Approach

Project Structure / Tasks

Limestone Chemical Looping
Chemical Looping - Advanced Oxy Project Objectives

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FOA 636 Goal:

- **Develop of advanced oxy-combustion systems that can achieve at least 90% CO_2 removal at no more than a 35% increase in COE.**

Chemical Looping Program Objective:

- **Successfully demonstrate and commercialize Alstom's Limestone Chemical Looping System (LCL™)**

Project Objective (Phase I):

- **Complete economic and engineering studies of four LCL-C™ plants to identify & incorporate process and equipment improvements and cost**
- **Submit Phase II (3 MWt Prototype Optimization and Demo Support) based on Phase I results**

Project Objective (Phase II):

- **Optimize 3 MWt Prototype based on Phase I results**
- **Develop LCL™ Demonstration project with the DOE and a US Utility or Oil Company partner(s)**
- **Provide 3 MWt Prototype testing support for demonstration efforts**

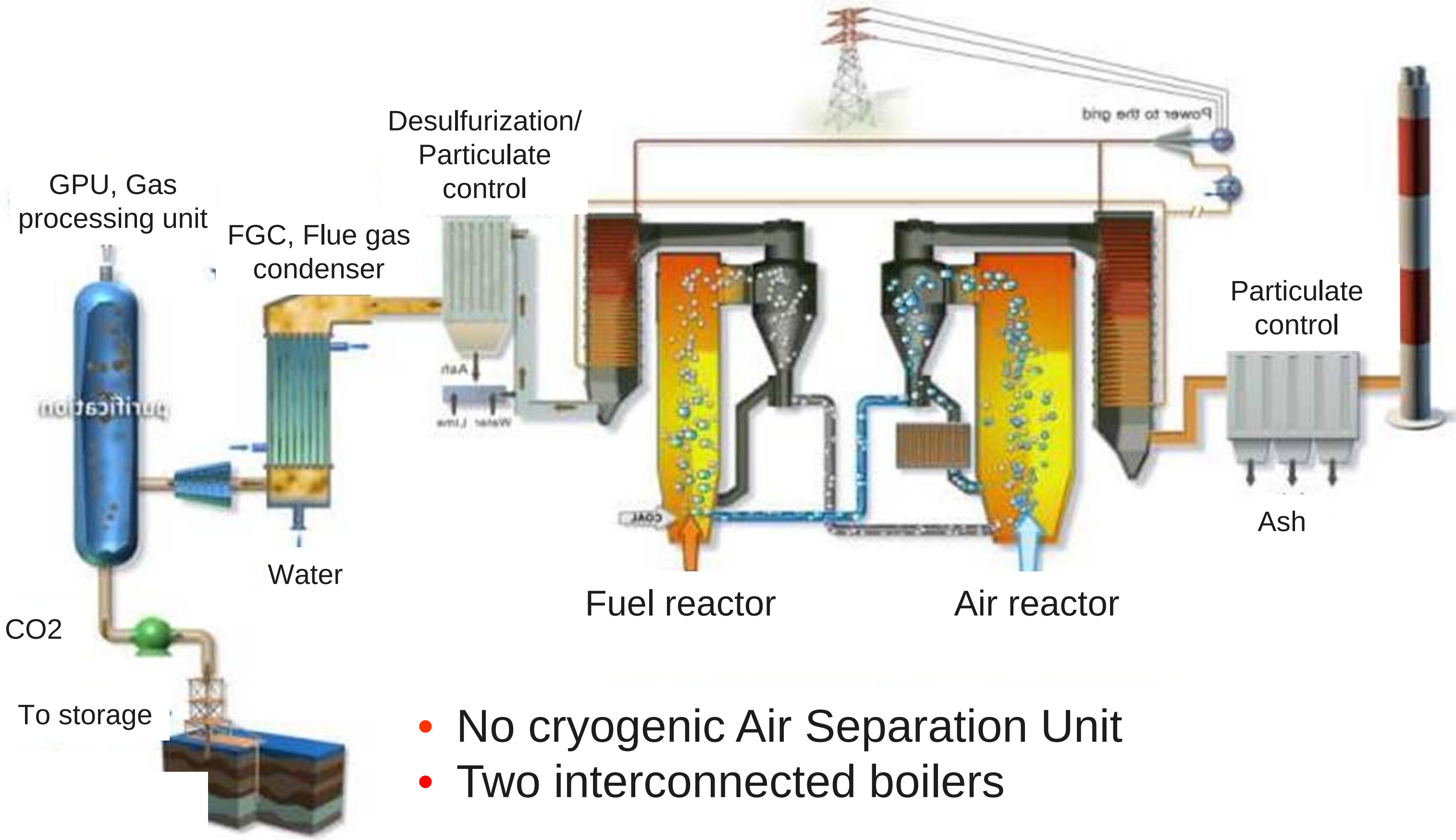
Limestone Chemical Looping Project

- Project Objectives
  - Advance the development of chemical looping technology using economic and engineering studies as a screening tool for process and equipment improvements.
  - Perform engineering and economic analysis on the effects of operating pressure on the cost of electricity (COE) to determine the most practical, cost effective configuration.
  - Perform engineering analysis to determine practical methods and limitations of achieving pressurized operation.
  - Perform engineering analysis and bench-scale testing to investigate possible process improvements.
  - Identify data/technology gaps and process/equipment improvements requiring attention during Phase II testing.
  - Propose Phase II based on Phase I technical and economic results

Agenda

- Participants
- Project Objectives
- Technology /Technical Approach
  - **Chemical Looping Technology**
  - Phase I – Technical/Economic Study
  - Prototype Results & Plans
- Phase II Approach
- Project Structure / Tasks

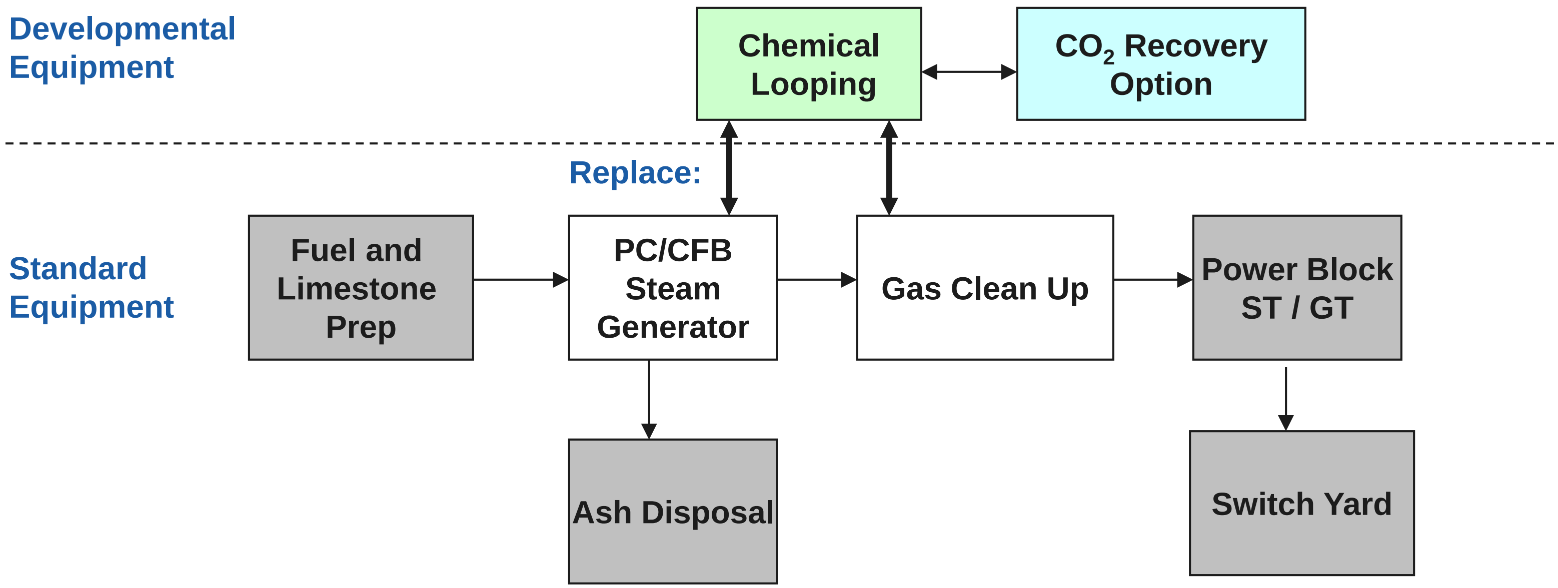
Chemical Looping Concept
What is it?



- No cryogenic Air Separation Unit
- Two interconnected boilers

Advanced oxy-combustion system without Air Separation Unit

Chemical Looping Concept
How it fits in a Powerplant?

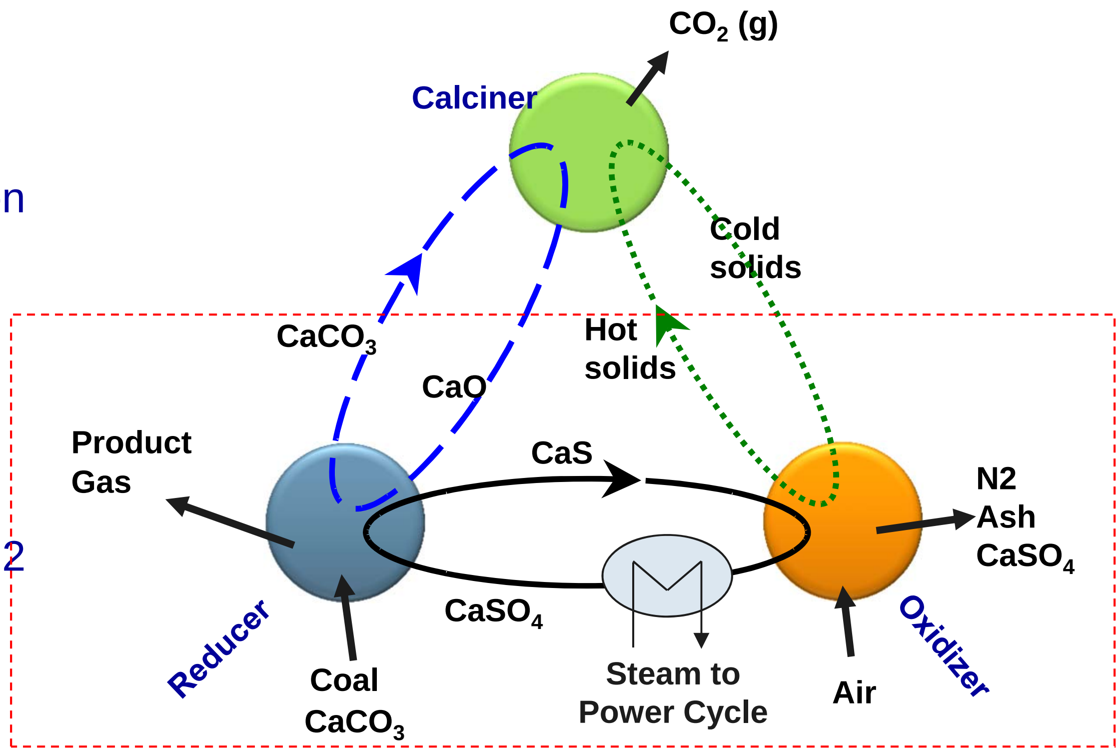


Limestone Chemical Looping Concept

Option 1 – Chemical looping combustion
- Excess air to fuel
- Product gas is CO_2
- Heat produces steam for power

Option 2 – Chemical looping gasification
- Excess fuel to air
- Product gas is Syngas
- No inherent CO_2 capture
- High efficiency, low cost IGCC

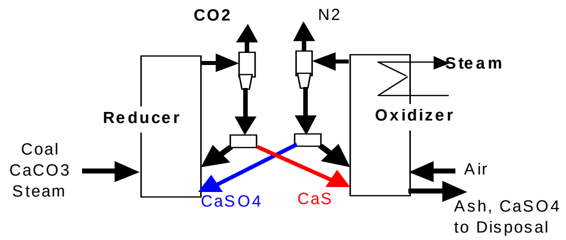
Option 3 – Hydrogen production
- Add $CaO-CaCO_3$ loop to option 2
- Add calciner
- Product gas is low cost H_2
- Calciner off-gas is CO_2



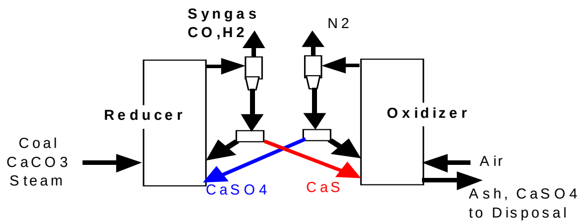
Current prototype setup

Oxygen Carrier:
- Limestone-based : Alstom – US (3 MWt, Alstom PPL, Windsor, CT)
- Metal oxide based: Alston – Europe (1 MWt, Darmstadt University)

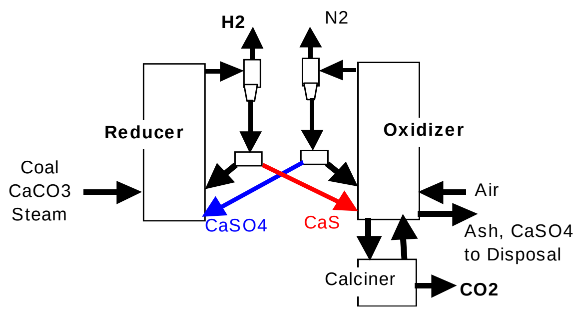
Chemical looping Process:
Options and Applications



Option 1 – Combustion with CO2 Capture



Option 2 – Syngas with no CO2 Capture



Option 3 – Hydrogen with CO2 Capture

Applications

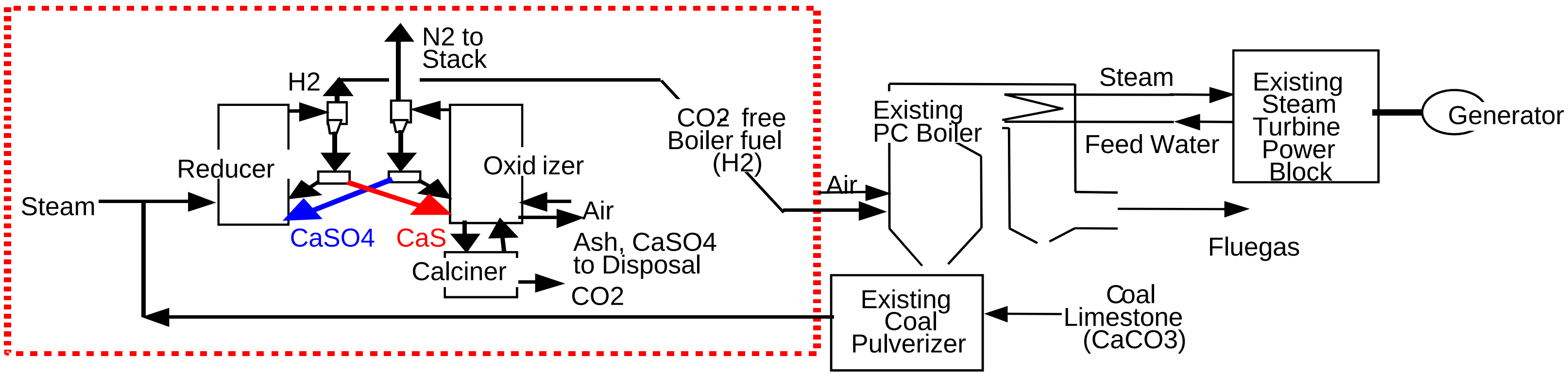
- CO2 Capture – PC Retrofit
- CO2 Capture – CFB Retrofit
- CO2 Capture-Ready Power Plant
- Advanced Steam Cycles

- ICGG with Down-Stream CO2 Capture
- Industrial Syngas
- Coal-to-Liquid Fuels

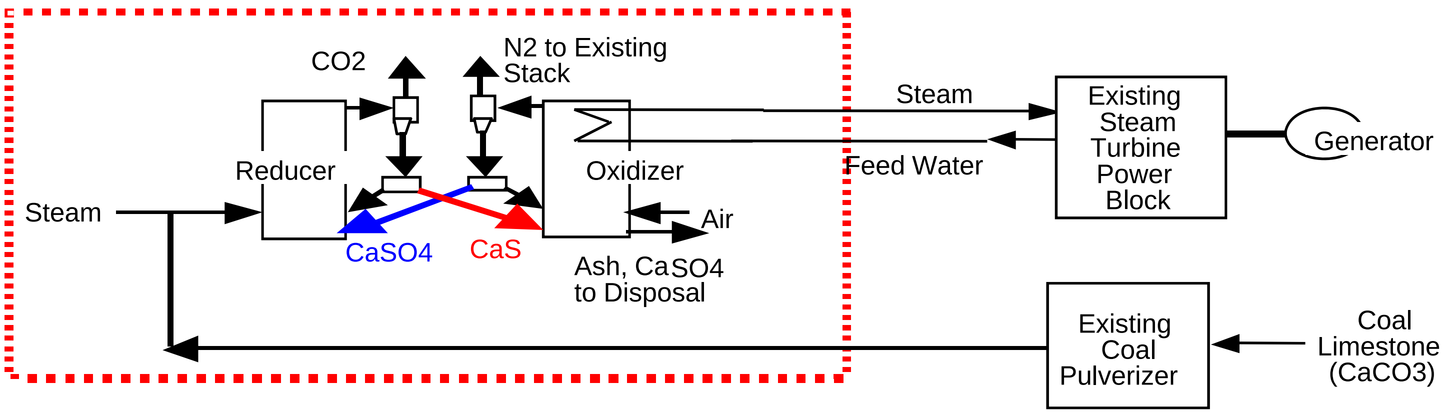
- CO2 Capture – PC Retrofit
- CO2 Capture – CFB Retrofit
- CO2 Capture-Ready PC/CFB Power Plant
- Advanced Steam Cycles
- IGCC with CO2 Capture
- Fuel Cell Cycles
- Industrial Hydrogen, CO2

- Lowest Cost CO2 Capture Option
- Competitive with or without CO2 Capture

Chemical looping Process:
PC Power Plant - Retrofit Concepts



Concept 1 – Chemical Looping – CO2 Free Fuel; Minimum Boiler Modification



Concept 2 – Chemical Looping Oxidizer Replaces / Modifies Boiler

Chemical Looping Economics
Why do we do it?

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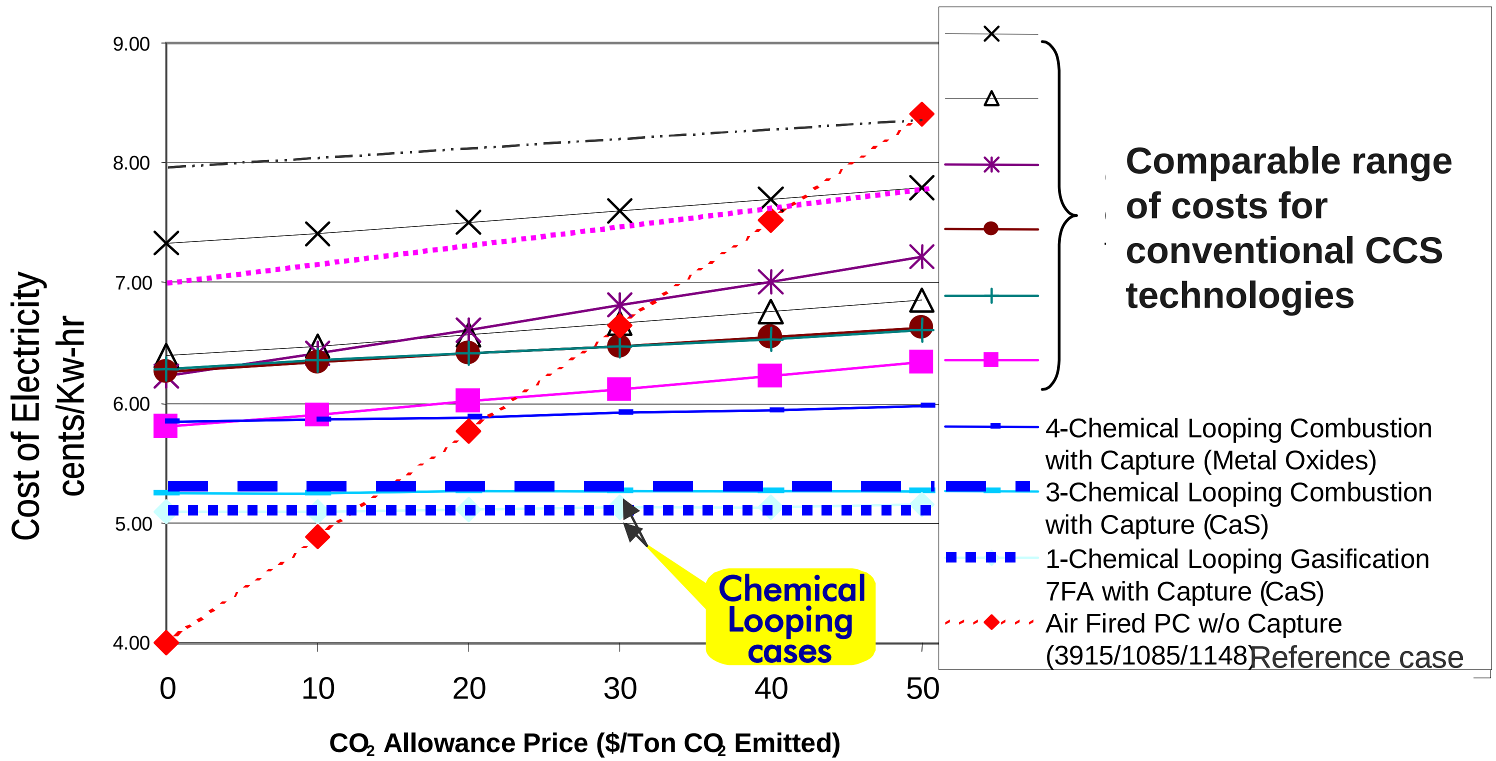


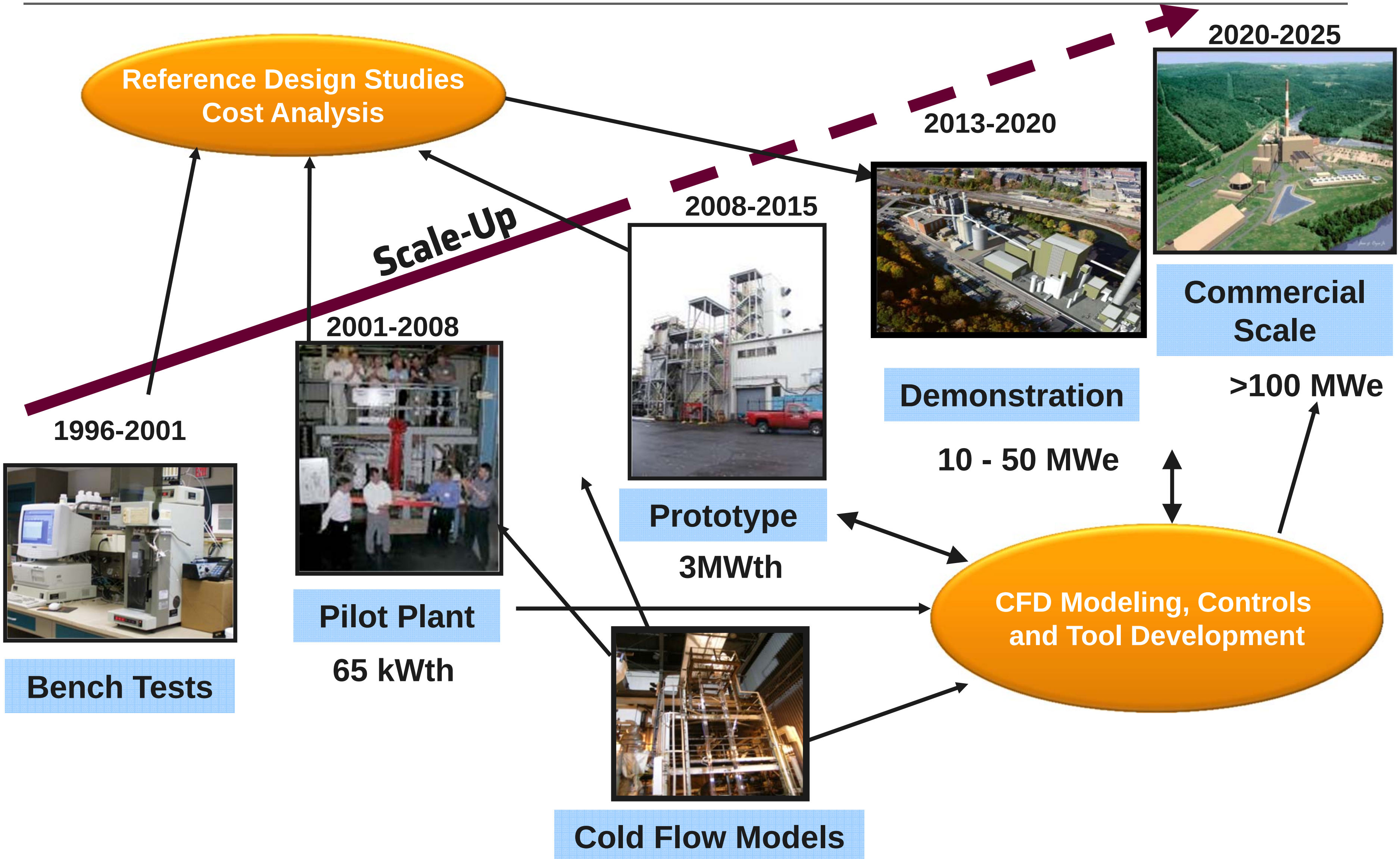
Basis:

- Plant size 400 MWe
- Steam conditions 3915 psia/1085 degF/1148 degF/2.5in Hga
- Cost basis 2006, $US
- Coal cost 1.5 $/MMBtu
- Levelized capital charge 13.8%
- Capacity factor 85%

Source: 2006 CO2 Product Gas Study

Chemical Looping provides the lowest potential COE

Limestone Chemical Looping
Commercialization Plan



Phase IV A – Prototype Testing (3 MWt)

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- Main objectives:
  - Design, engineering, construction and operation
  - Autothermal operation of prototype
  - Provide data required to design, build and operate a reliable demonstration plant

- Status
  - Engineering & go/no-go (Oct 2008 – Apr 2010)
  - EPC, Shakedown (Apr 2010 – Dec 2010)
  - First coal firing - May 2011
  - **Autothermal operation achieved in July 2012**
  - Current activity: data/sample analysis and final report preparation – Dec 2012

- Total DOE-funded budget: $9.2 million (80% DOE)
  - 8.2 for preliminary engineering and EPC
  - 1.0 for preliminary testing
- Additional Alstom funding of $2.1 million to achieve autothermal operation
- Near term Alstom funding of ~$1.0 million for prototype improvements and 40hr Autothermal operation

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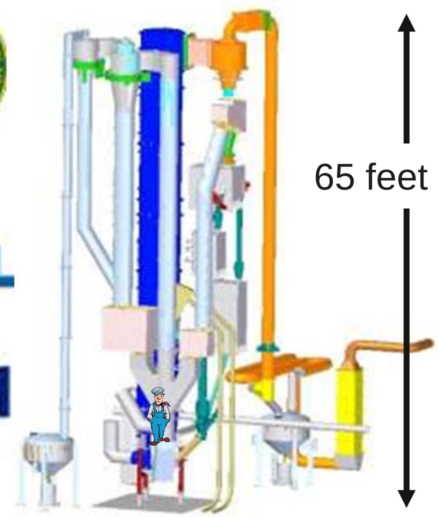
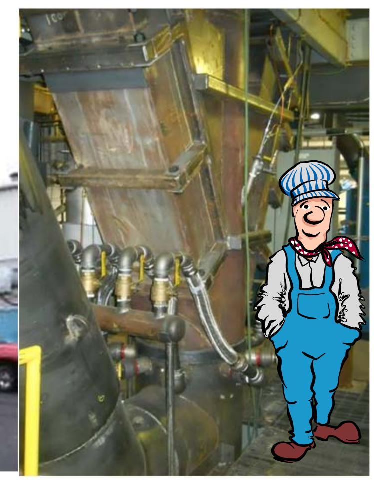
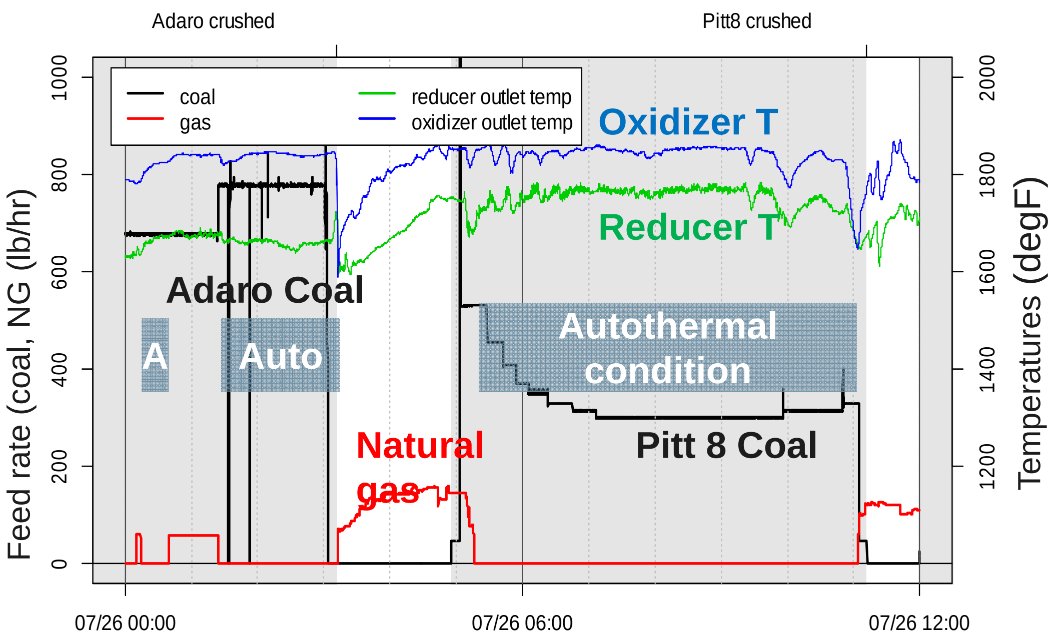


Prototype (3 MWt)

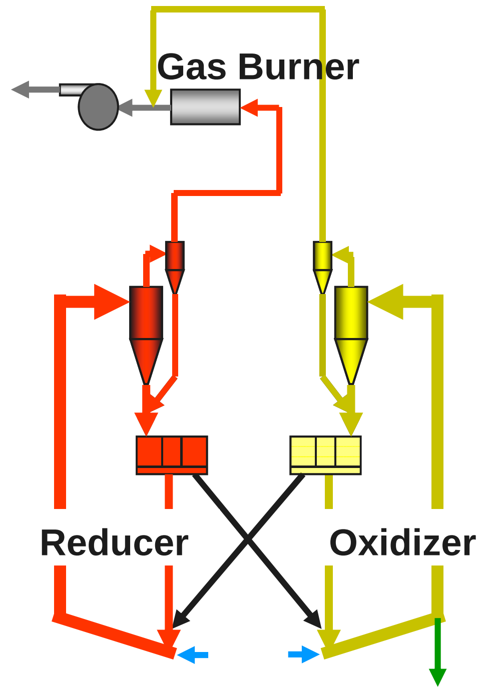


Autothermal Operation
Adaro and Pitt 8 crushed



3MWt Prototype – Autothermal Test
Coal-only – No other heat source
Chemical Looping Reactions are self-sustained

Vs



65 kWt PDU
Electrically Heated
Not Autothermal

- Autothermal operation – self-sustained CLC reactor operation
- Natural gas turned off; coal to reducer; and replenishment ash (CFB)
- Stable reducer and oxidizer temperatures at sufficient coal flows

Agenda

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Participants

Project Objectives

Technology /Technical Approach

- Chemical Looping Technology
- **Phase I – Technical/Economic Study**
- Prototype Results & Plans

Phase II Approach

Project Structure / Tasks

Task 2 Schedule – Technical and Economic Studies

Model Development
- *Develop Aspen CLC Model*
- *Link Aspen and Thermoflow Models*

Baseline Case
- *Thermoflow modeling - SCPC w/o capture*
- *Thermoflow modeling - GPU for capture*
- *Setup Output format for all cases*

Design Basis Report

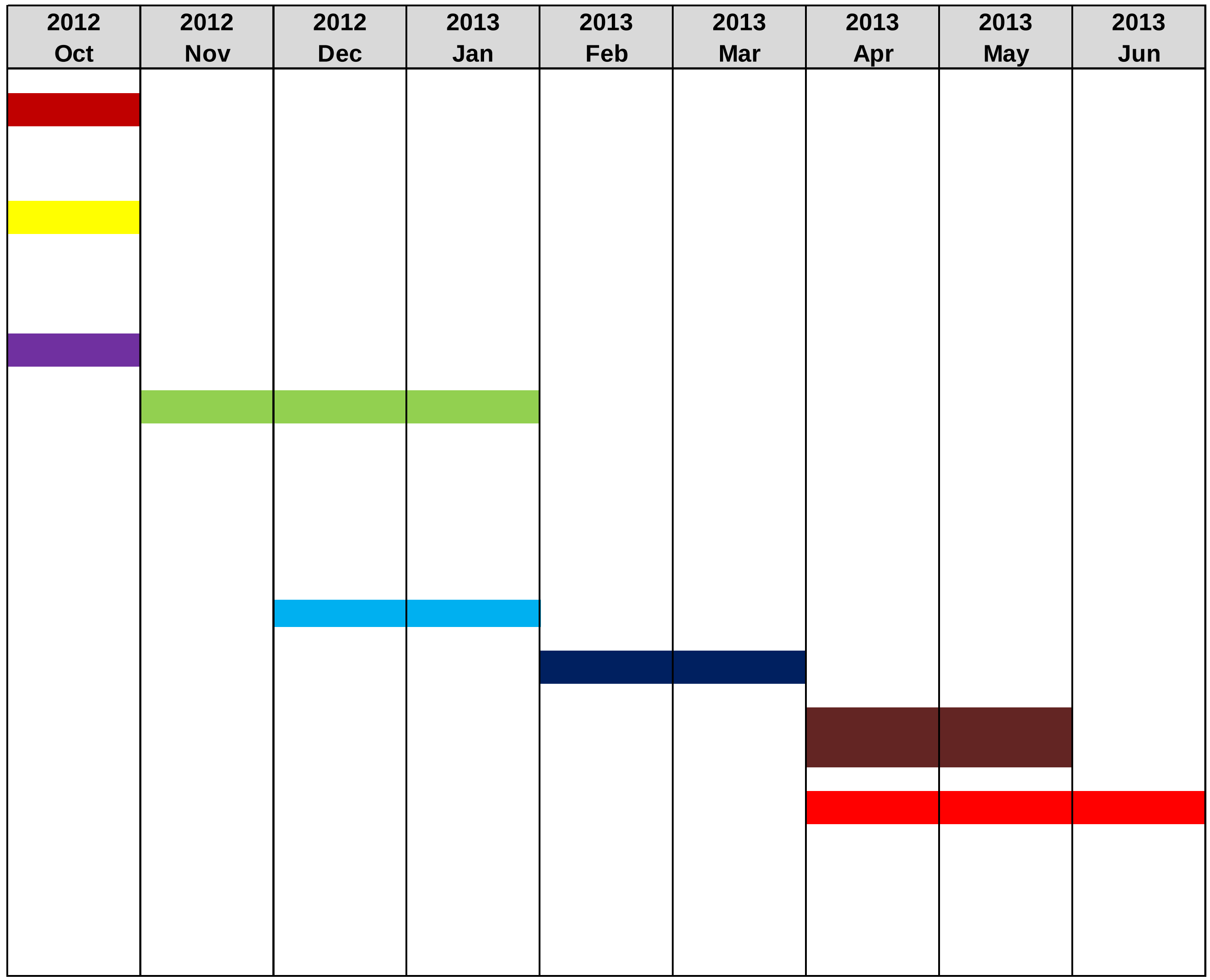
Case 1 - Transport Reactor CLC
- *Process Flow Diagram, P&ID*
- *Develop CLC Boiler Island Process Inputs*
- *Thermoflex Modeling*
- *Component Design & Sizing*
- *Design Graphics*
- *Cost Estimating*

Case 2 - CFB Based CLC

Case 3 - Pressurized CLC

Case 4 - Pressurized CLC with A-USC Steam Conditions

Economic Analysis & Report Writing
- *Define economic assumptions*
- *Capital Cost evaluation with contingencies*
- *O&M Costs*
- *Cost of Electricity*
- *CO2 Avoided Costs*
- *Sensitivity Analysis (3 pressure variations)*



Aspen Plus Reactor Modules

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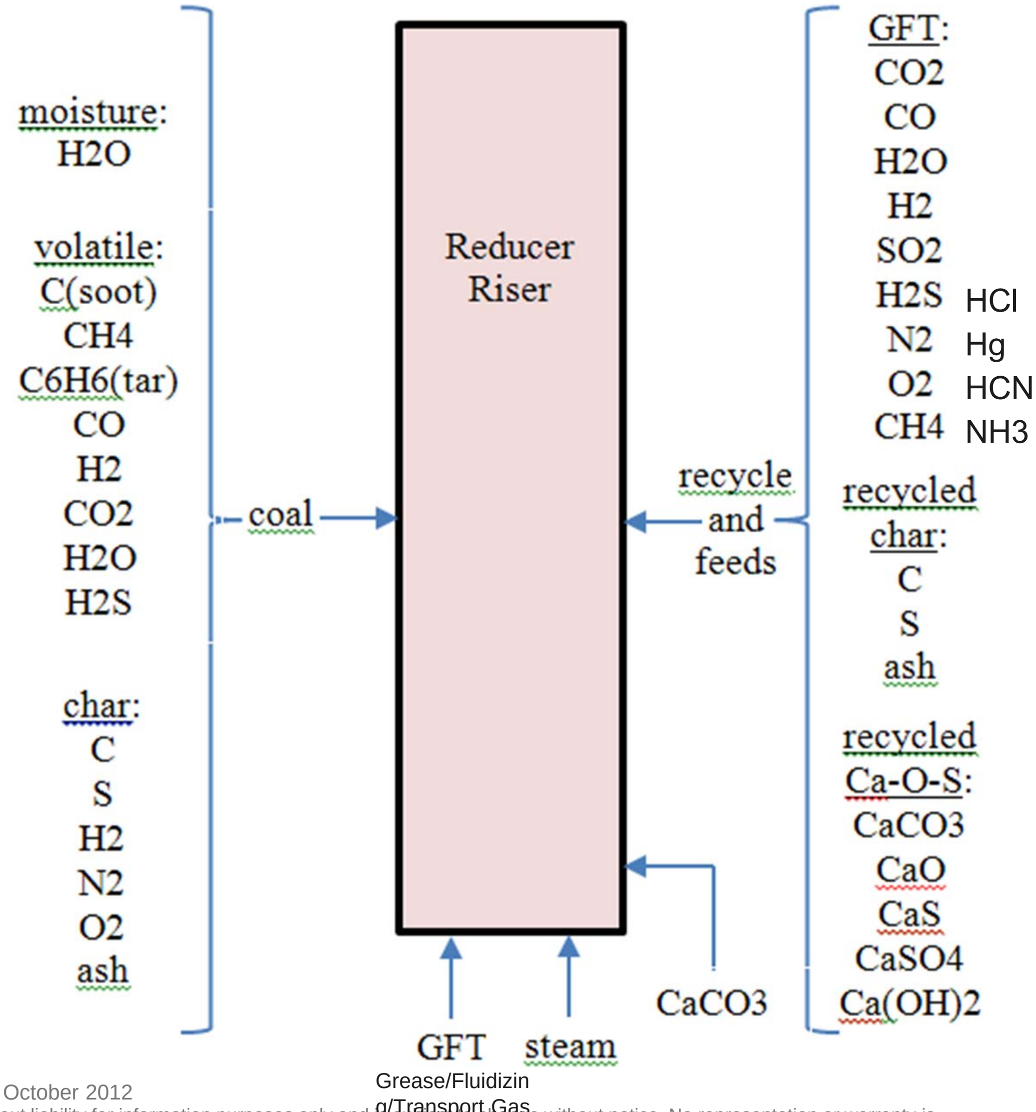
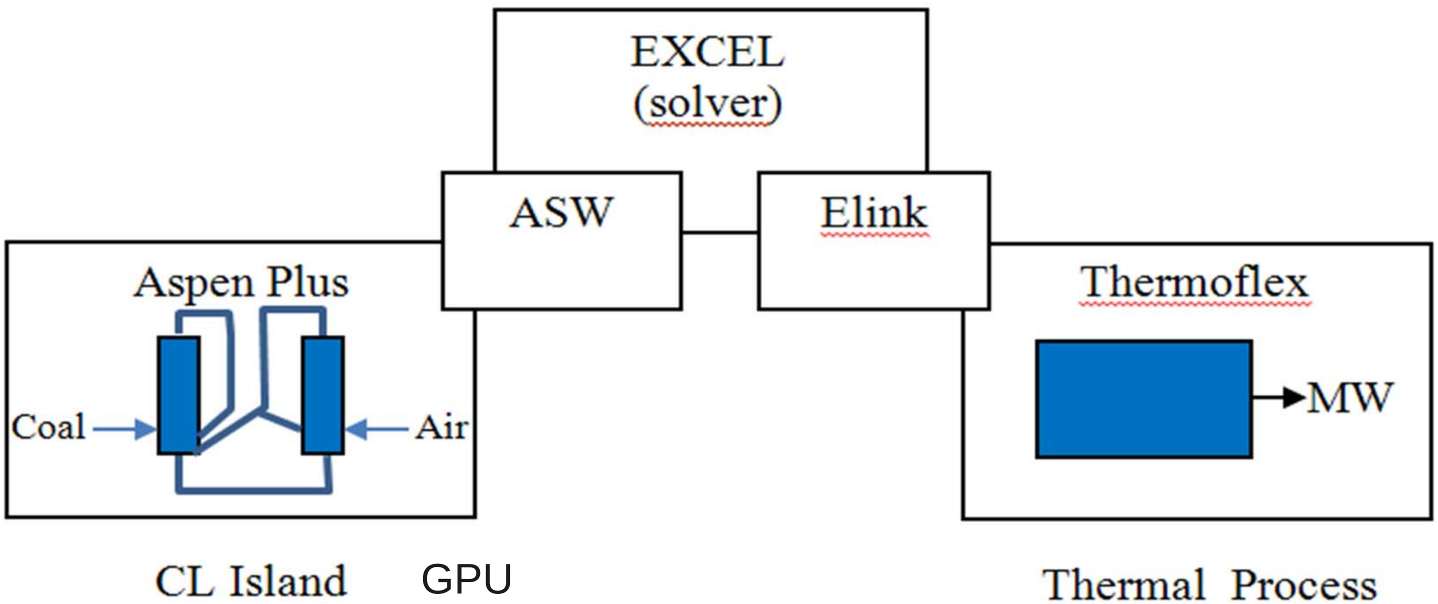
- The reactor modules for the oxidizer and reducer will be represented by native library modules:
  - plug flow reactor (RPLUG)
  - continuous stirred tank reactor (RCSTR).
- Kinetics for coal gasification and the Ca-O-S system will be provided in a user subroutine.
- Coal drying and pyrolysis assumed to occur instantaneously.

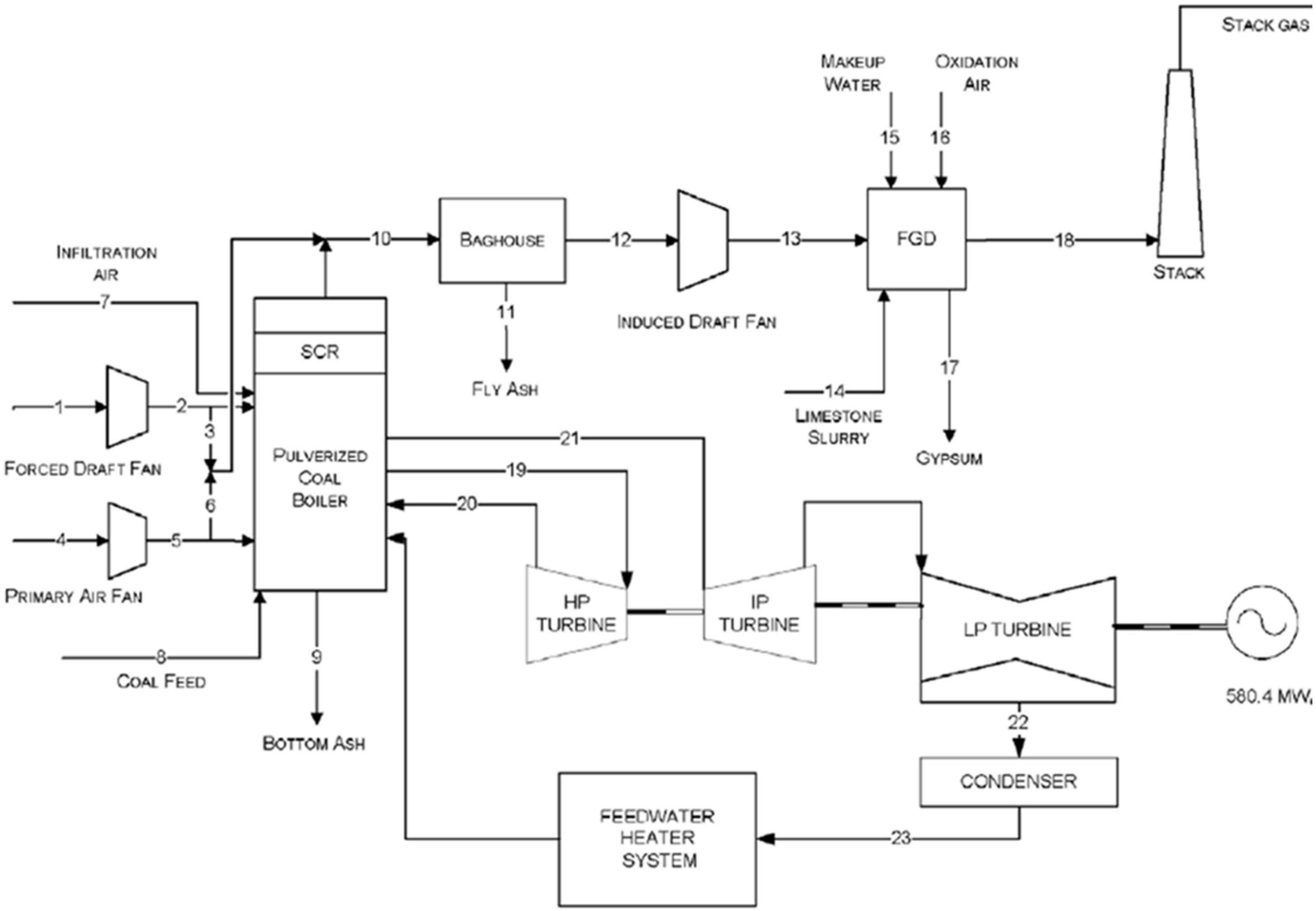


Process Modeling Environment (PME)

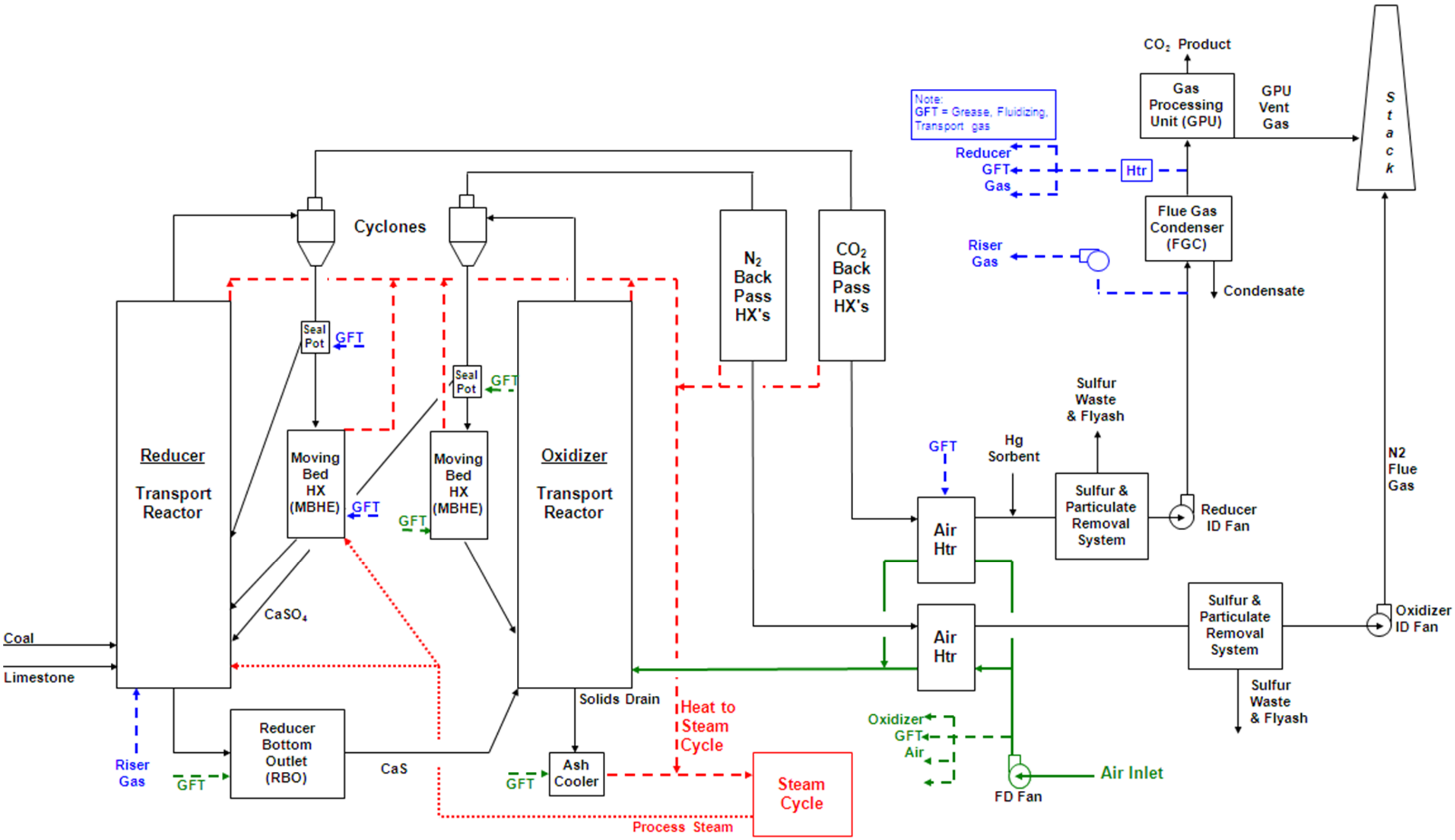
- The two PME flowsheets will communicate through EXCEL.
- The Thermoflex-EXCEL interface will be provided through an Elink utility (a Thermoflow product)
- The Aspen Plus-EXCEL interface will be provided via an Aspen Simulation Workbook (ASW) add-in (an AspenTech product).



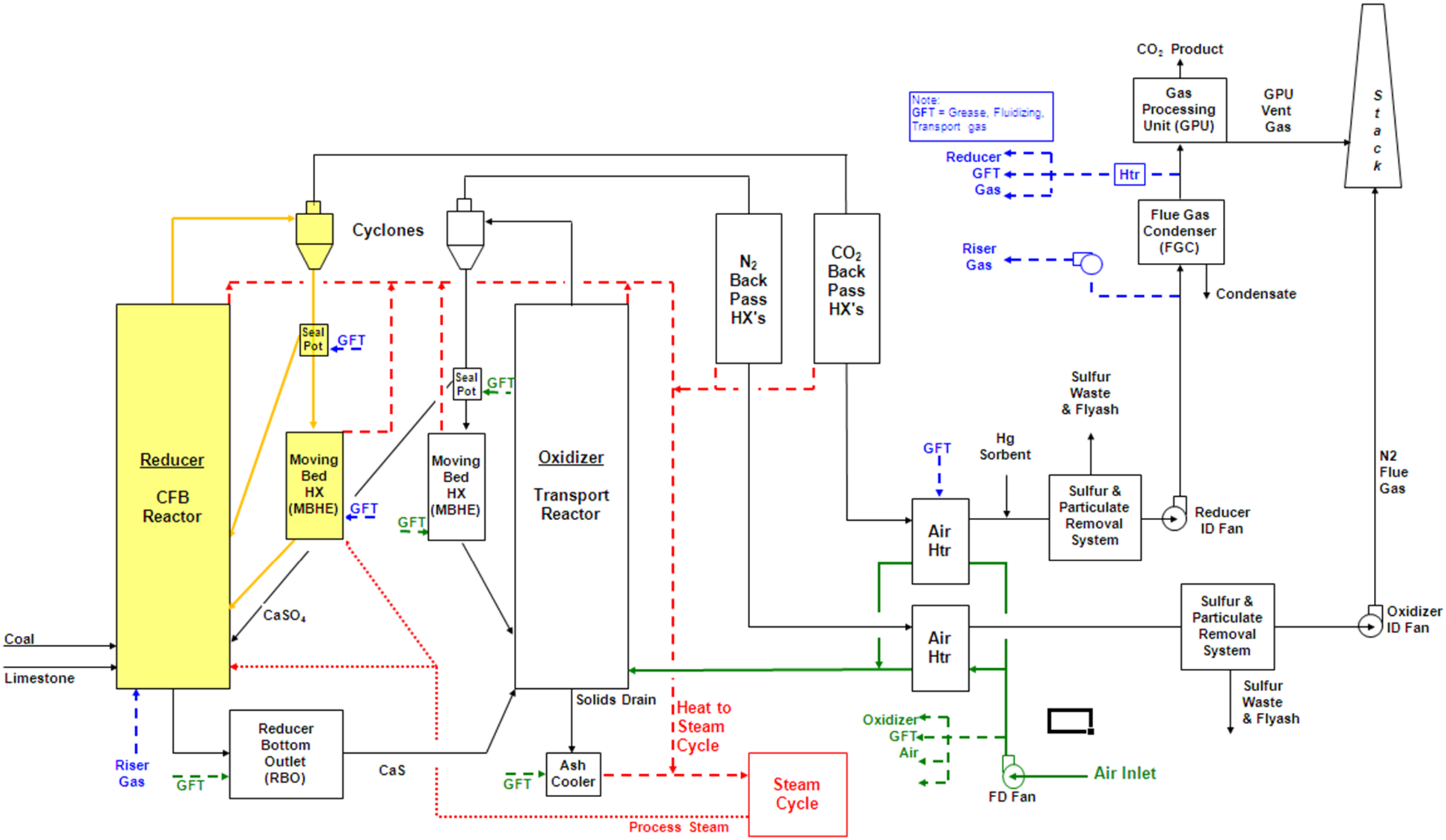
SCPC w/o Capture – Base Case
DOE Baseline Report Case 11



LCL™ System with Transport Reactor
Case 1



LCL™ System with CFB Reactor
Case 2



LCL™ System with Pressurized Reactor
Case 3

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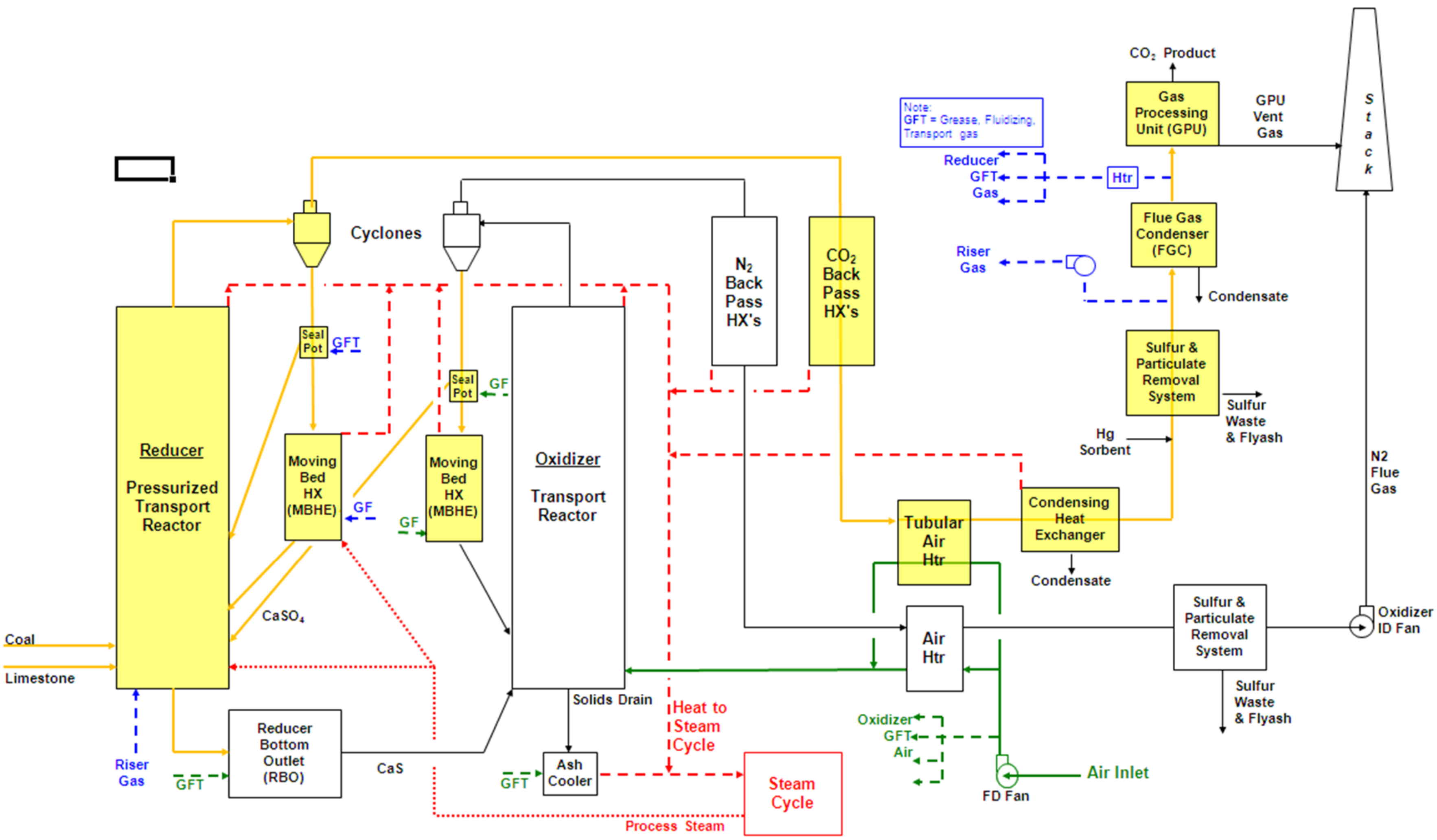

LCL™ System with A-USC Steam System
Case 4

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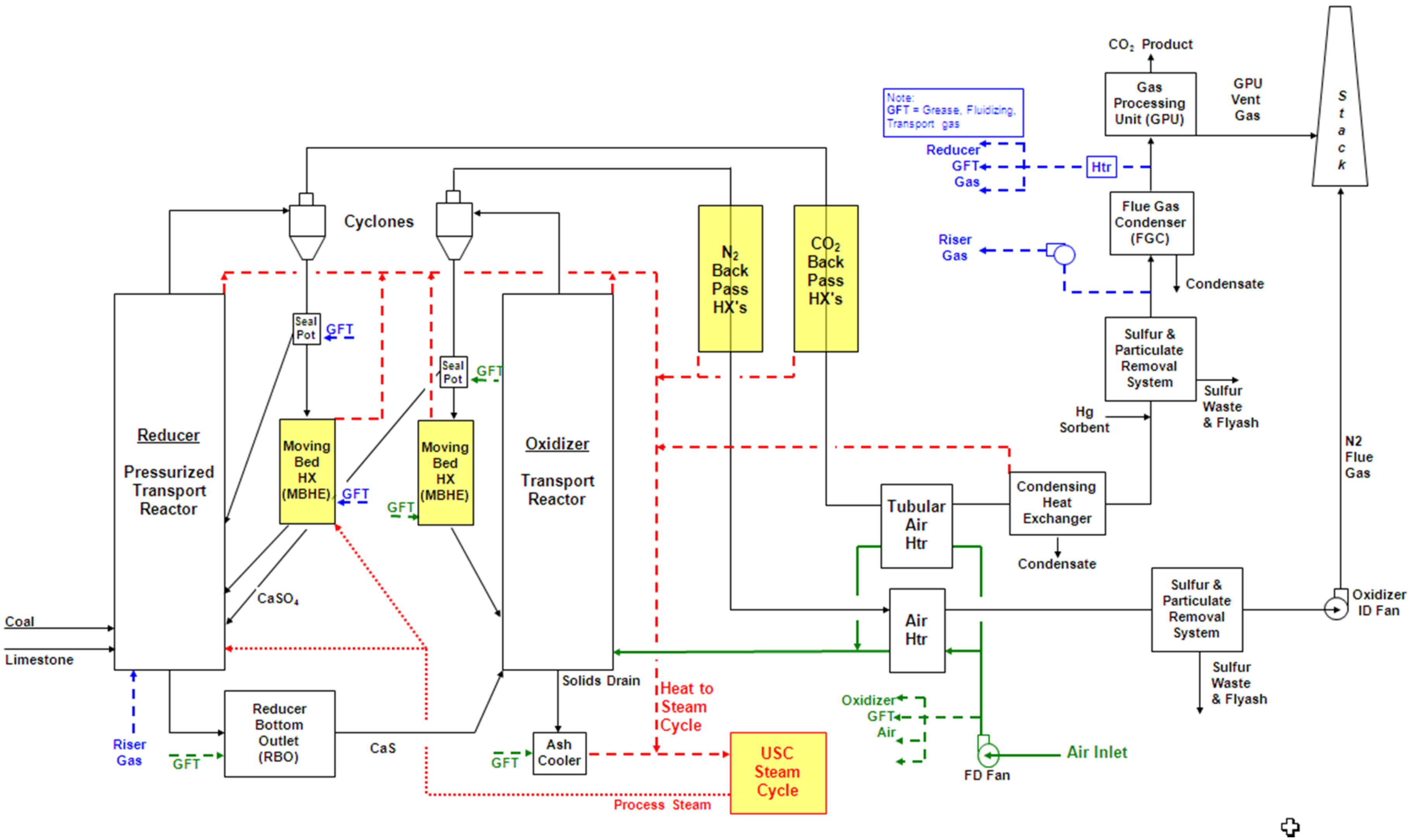

Key System Assumptions

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	Base Case DOE Case 11 SCPC w/o capt	Case 1 LCL-C™ with transport reactors	Case 2 LCL-C™ with CFB reducer	Case 3 LCL-C™ with pressurized reducer	Case 4 LCL-C™ with pressurized reducer and A-USC
Capacity	$550MW_{net}$	$550MW_{net}$	$550MW_{net}$	$550MW_{net}$	$550MW_{net}$
Capacity Factor, %	85	85	85	85	85
Coal	Illinois No. 6	Illinois No. 6	Illinois No. 6	Illinois No. 6	Illinois No. 6
Reactor Pressure, Mpa (atm)	0.10 (1)	reducer 0.10 (1) oxidizer 0.10 (1)	reducer 0.10 (1) oxidizer 0.10 (1)	reducer 0.71 (7) oxidizer 0.10 (1)	reducer 0.71 (7) oxidizer 0.10 (1)
Steam Cycle, Mpa/°C/°C (psig/°F/°F)	24.1/593/593 (3500/1100/1100)	24.1/593/593 (3500/1100/1100)	24.1/593/593 (3500/1100/1100)	24.1/593/593 (3500/1100/1100)	35.0/730/760 (5076/1346/1400)
Condenser pressure, mm Hg (in Hg)	50.8 (2)	50.8 (2)	50.8 (2)	50.8 (2)	50.8 (2)
Cooling water to condenser, °C (°F)	16 (60)	16 (60)	16 (60)	16 (60)	16 (60)
Cooling water from condenser, °C (°F)	27 (80)	27 (80)	27 (80)	27 (80)	27 (80)
Boiler Efficiency, %	88	TBD	TBD	TBD	TBD
Stack temperature, °C (°F)	57 (135)	TBD	TBD	TBD	TBD
SO_2 Control	Wet Limestone Forced oxidation	In reducer NID - reducer stream NID - oxidizer stream	In reducer NID - reducer stream NID - oxidizer stream	In reducer NID - reducer stream NID - oxidizer stream	In reducer NID - reducer stream NID - oxidizer stream
FGD Efficiency, % (A)	98	98% overall	98% overall	98% overall	98% overall
NO_x Control	LNB w/OFA and SCR	controlled by LCL-C™ process	controlled by LCL-C™ process	controlled by LCL-C™ process	controlled by LCL-C™ process
SCR Efficiency, % (A)	86	not required	not required	not required	not required
Particulate Control	Fabric Filter	NID in reducer stream NID in oxidizer stream	NID in reducer stream NID in oxidizer stream	NID in reducer stream NID in oxidizer stream	NID in reducer stream NID in oxidizer stream
Fabric Filter efficiency, % (A)	99.8	99.8	99.8	99.8	99.8
Ash Distribution, Fly/Bottom	80% / 20%	TBD	TBD	TBD	TBD
Mercury Control	Co-benefit capture	Co-benefit capture	Co-benefit capture	Co-benefit capture	Co-benefit capture
Mercury removal efficiency, % (A)	90	90	90	90	90
CO_2 Control	N/A	LCL-C™ & GPU	LCL-C™ & GPU	LCL-C™ & GPU	LCL-C™ & GPU
Overall CO_2 Capture (A)	N/A	>90%	>90%	>90%	>90%
CO_2 Sequestration	N/A	saline acquifer	saline acquifer	saline acquifer	saline acquifer

Design Basis Document

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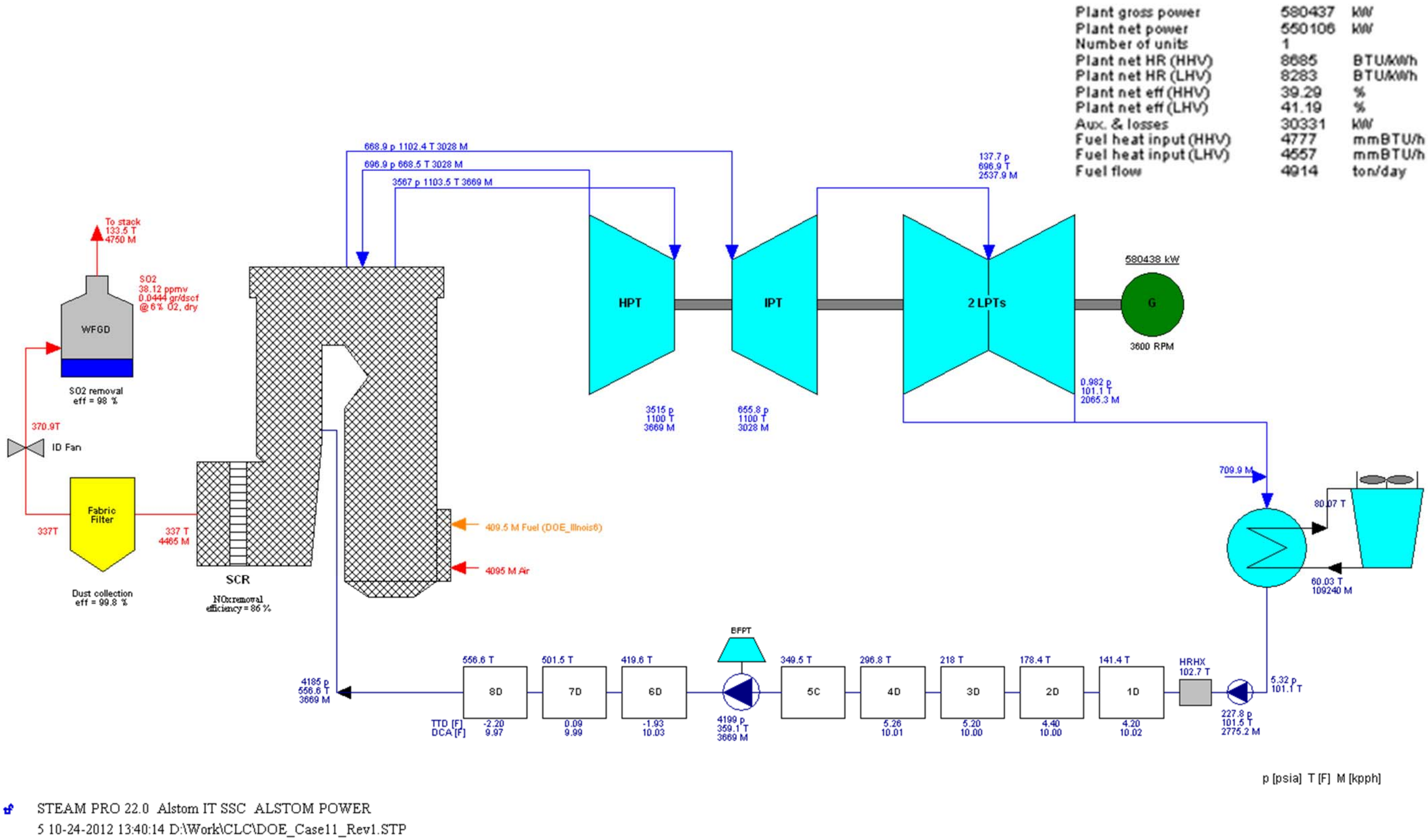
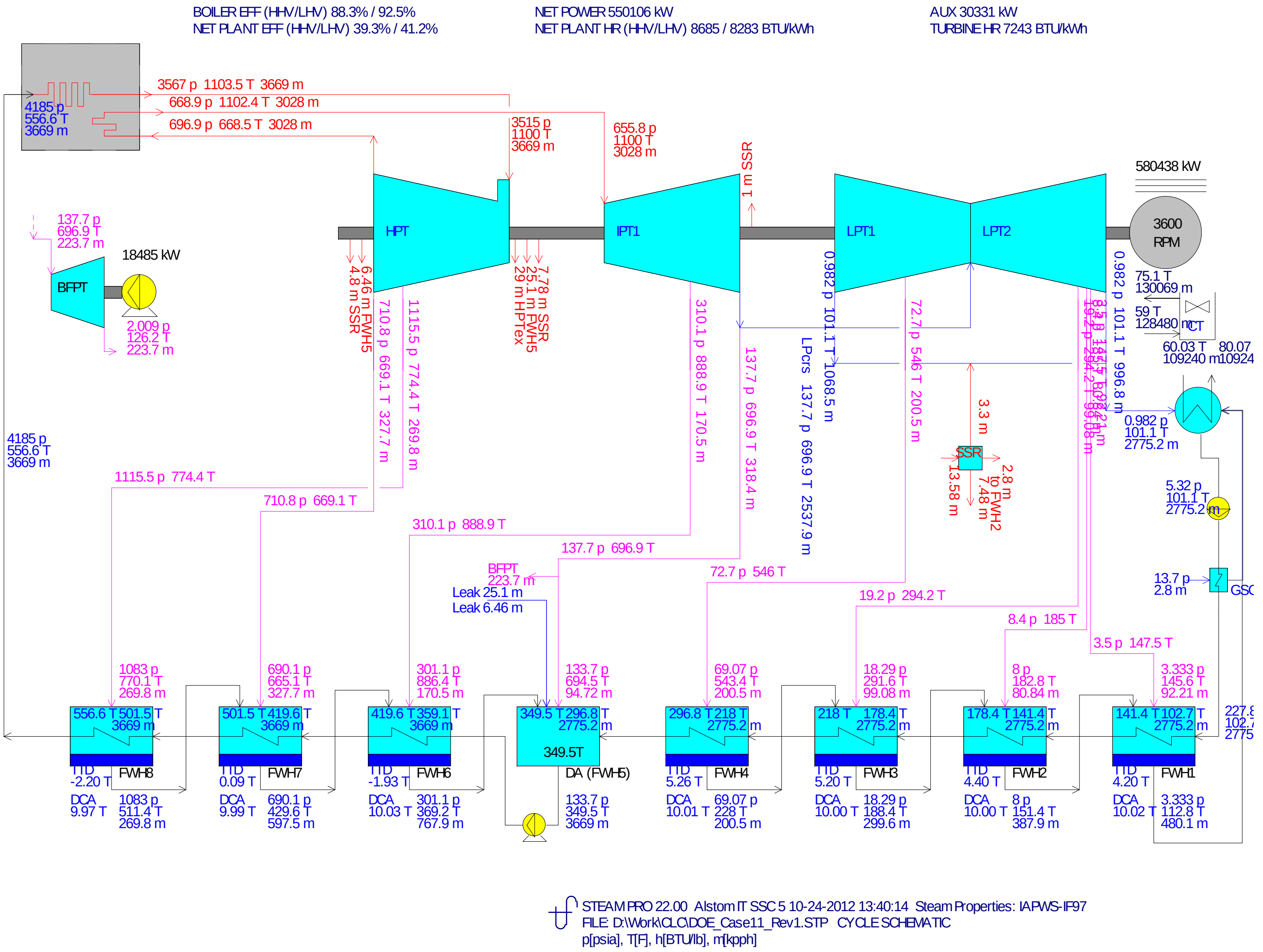
Status: Draft report completed

SCPC w/o Capture – Base Case
Thermoflow Model



SCPC w/o Capture – Base Case

Thermoflow Model



Re-Calculate Excess Air Ratio in Case 11

Total Air In (lb/hr)	4,097,326
APH Leakage (lb/hr)	221,439
Combustion Air (lb/hr)	3,875,887
Coal Flow (lb/hr)	409,528
Actual Air/Fuel Ratio	9.464
Theoretical Air/Fuel Ratio	8.817
Excess Air	**7.3%**

Issue With Case 11 Turbine Heat Balance

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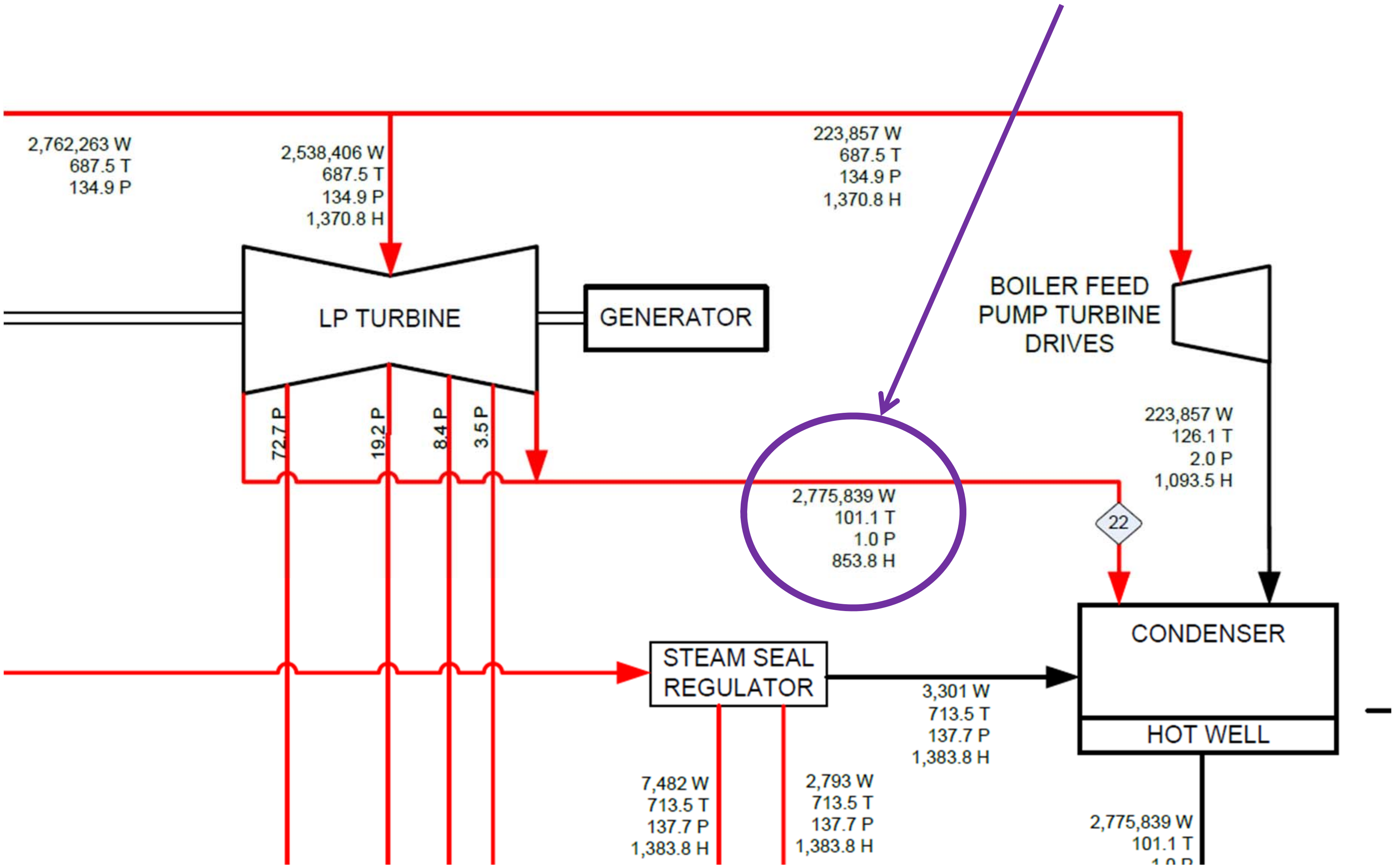
More than 130% Isentropic Turbine Efficiency



Issues Requiring Clarification

Base SCPC Case

- Modeled Case 11 – able to match case well in SteamPro Version 22
- But there were some inconsistencies in the Case 11 data
- Excess Air Issue – case showed excess air at only 7.3%. Much lower than would commercially design for. All downstream equipment sizing and costs will be too low.
- LP Turbine efficiency too high – 130% isentropic effic (typically 70-80%)

GPU Model

- Preferred Approach - Use DOE GPU from oxy case (allows comparison to other technologies on consistent basis
- Alternate Approach - Use generic GPU model
- Can the DOE GPU Aspen model be shared?

O&M, Fuel, Commodity Prices

- Shouldn't there be a consistent price for fuel, sorbent, water, additives?
- What about commodity prices – steel, refractory, etc.?

Agenda

Participants

Project Objectives

Technology /Technical Approach

- Chemical Looping Technology
- Phase I – Technical/Economic Study
- **Prototype Results & Plans**
  - **Construction**
  - **Operating Lessons**
  - **Performance Results**

Phase II Approach

Project Structure / Tasks

Agenda

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- Chemical Looping Technology
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Phase II Approach

Project Structure / Tasks

Prototype Construction

Chemical Looping 3 MWt Prototype
Component Construction

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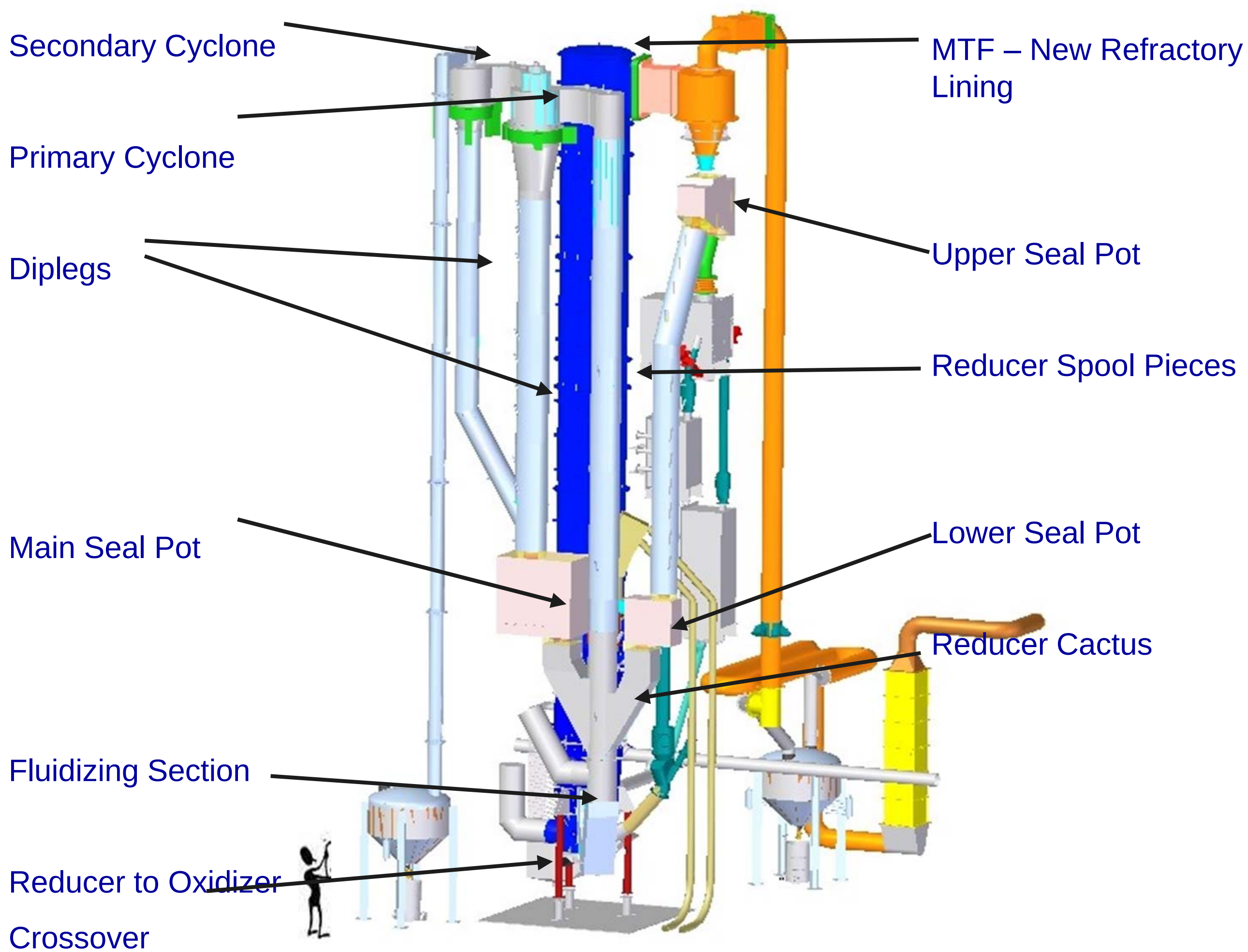

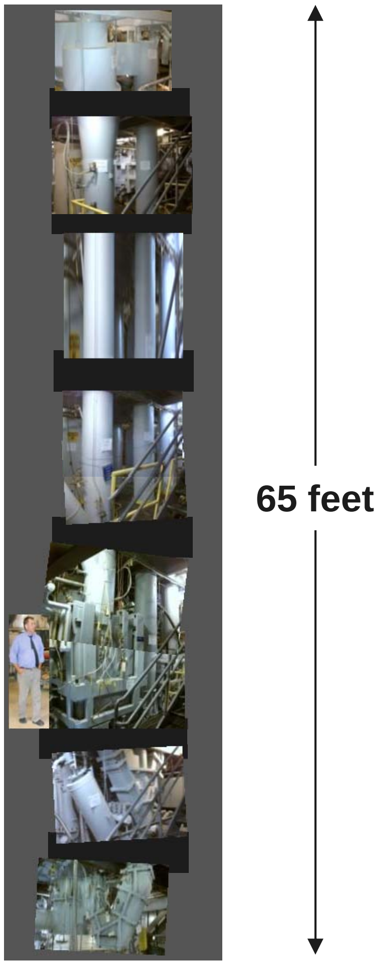

Retrofit of Alstom's existing Multi-use Test Facility (Windsor, CT)

Chemical Looping
3 MWt Prototype Schematic

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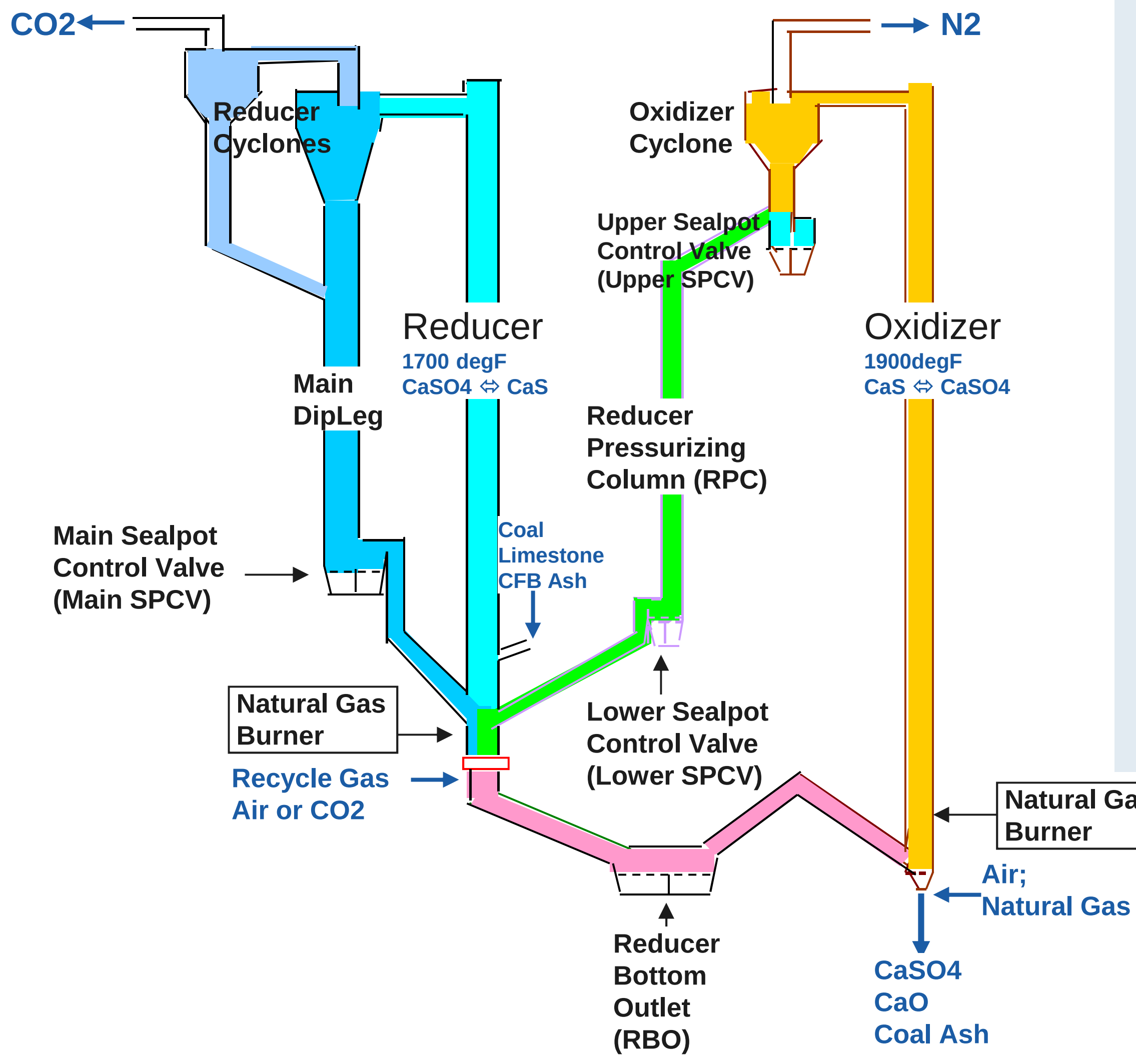


Design Flow Rates:

Coal	700 lb/hr
Limestone	125 lb/hr
Air	8,000 lb/hr
RPC flow	170,000 lb/hr
Inventory	6,000 lb

Sorbent Constituents:

$CaSO_4$ ⇔ CaS

CaO

Coal ash

Reactions:

Reducer:

$CaSO_4$ + Coal ⇔ CaS + 2 CO_2

Oxidizer:

CaS + Air ⇔ CaSO4 + heat

Reducer "Combustion"

$CaSO_4$ + 4 CO ⇔ CaS + 4 CO2

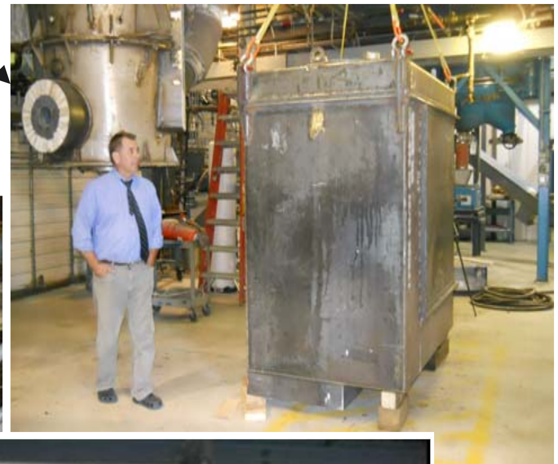
4 C(coal) + 4 CO2 ⇔ 8 CO

CaSO4 + 4 CO ⇔ CaS + 8 CO

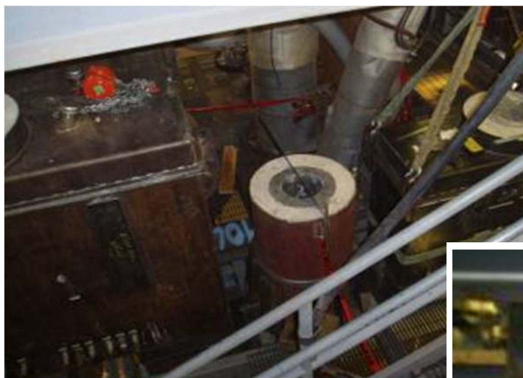
Chemical Looping Prototype
Reducer Components

Main Sealpot Control Valve (SPCV)

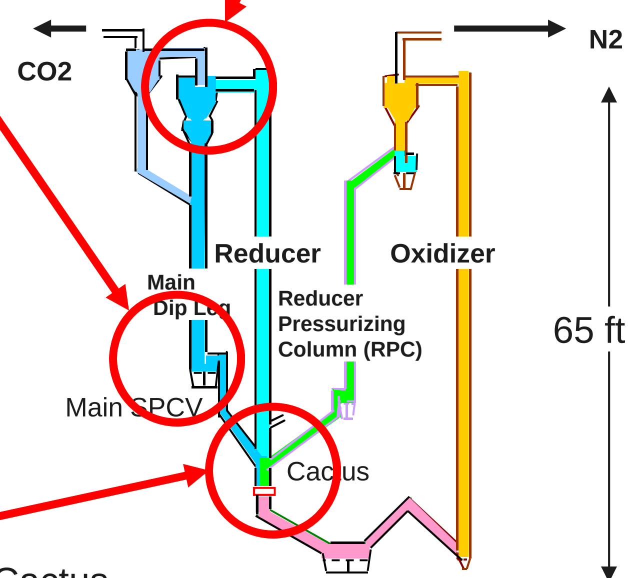
Oxidizer
Burner
Outlet



Reducer Primary Cyclone



Main SPCV and
Reducer
Cactus in place



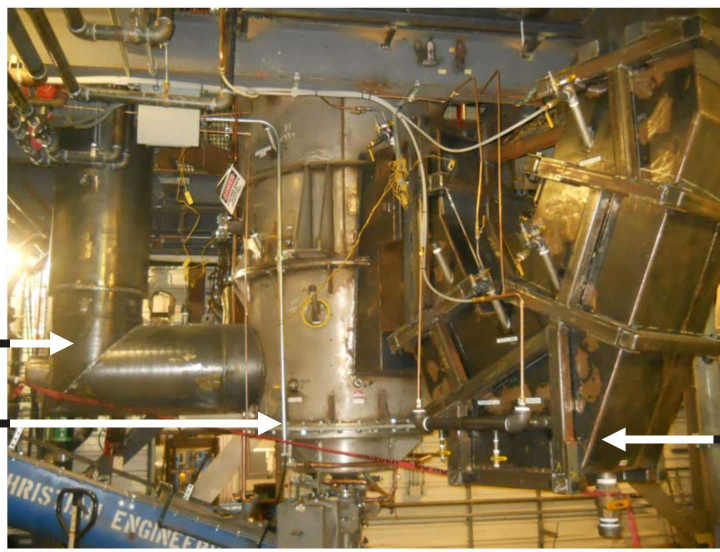
Reducer Cactus
after assembly

Chemical Looping Prototype
Oxidizer Components

Top of oxidizer after refrax liner installed

Oxidizer burner

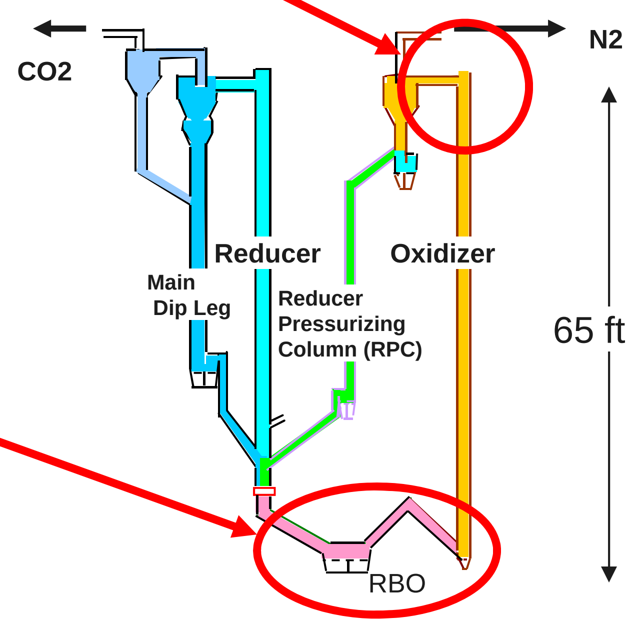
Oxidizer



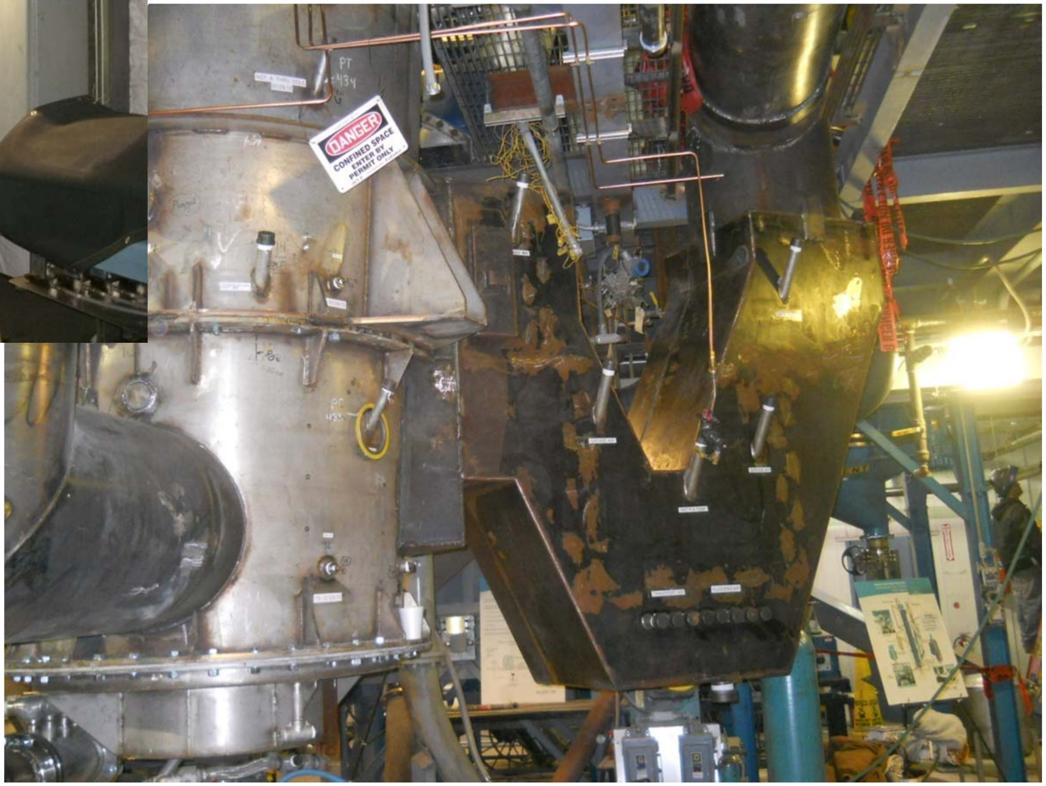
12 ft

Reducer Bottom Outlet

Oxidizer, Startup Burner & RBO



Chemical Looping Prototype
Component Construction



Chemical Looping Prototype
Component Construction

Cyclones

Chemical Looping Prototype
Component Assembly

Chamber Pots

Chemical Looping Prototype
Component Assembly

Product Gas Condenser/Chiller

Agenda

ALSTOM

Participants

Project Objectives

Technology /Technical Approach
- Chemical Looping Technology
- Phase I – Technical/Economic Study
- **Prototype Results & Plans**

Phase II Approach

Project Structure / Tasks

Prototype Operation

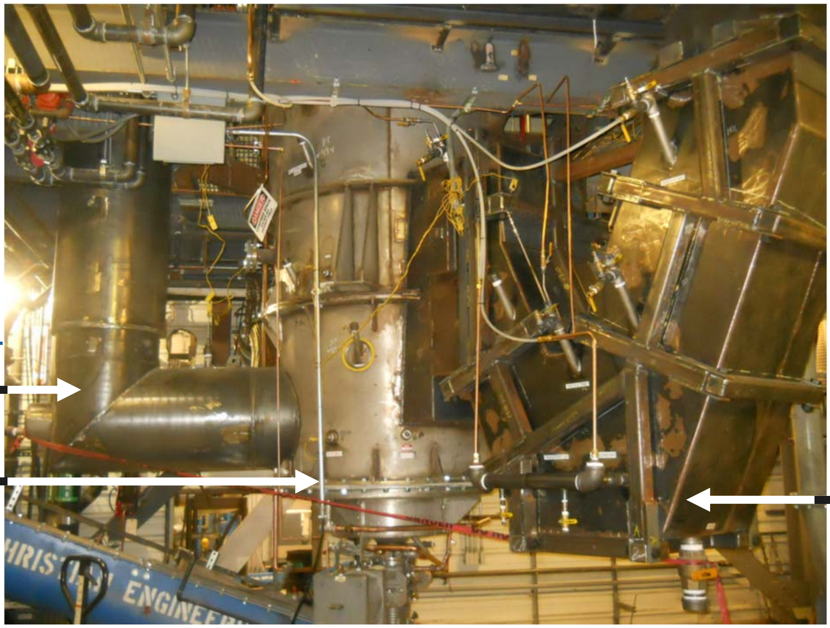
Prototype Current Status - Phase IV A
2011 Test Results

ALSTOM

1st Solids Recycle: April 2011
- Cold flow operation
- Stable solids circulation

Prototype Current Status - Phase IV A
Test Results

1st Coal Feed: 11 May 2011
- Reducer w/air transport; Coal to 100 lb/hr; Reducer temp to 1450 F
- Oxidizer temp limited to < 1000 F by startup burner
- Startup burners were upgraded



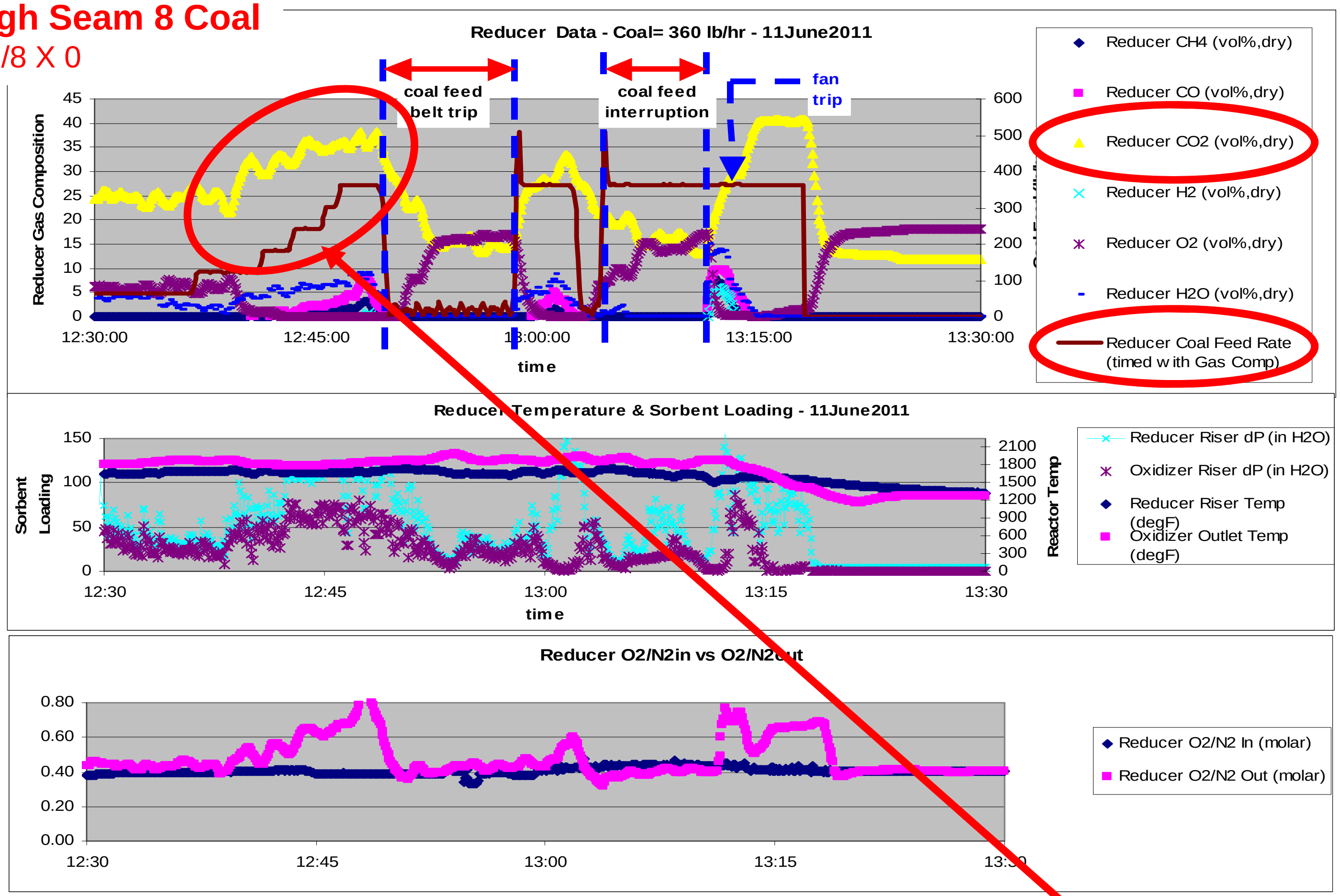
Initially Natural Gas flow too low

Prototype Current Status - Phase IV A

Test Results – 11 June 2011 – Aux Natural Gas

Pittsburgh Seam 8 Coal

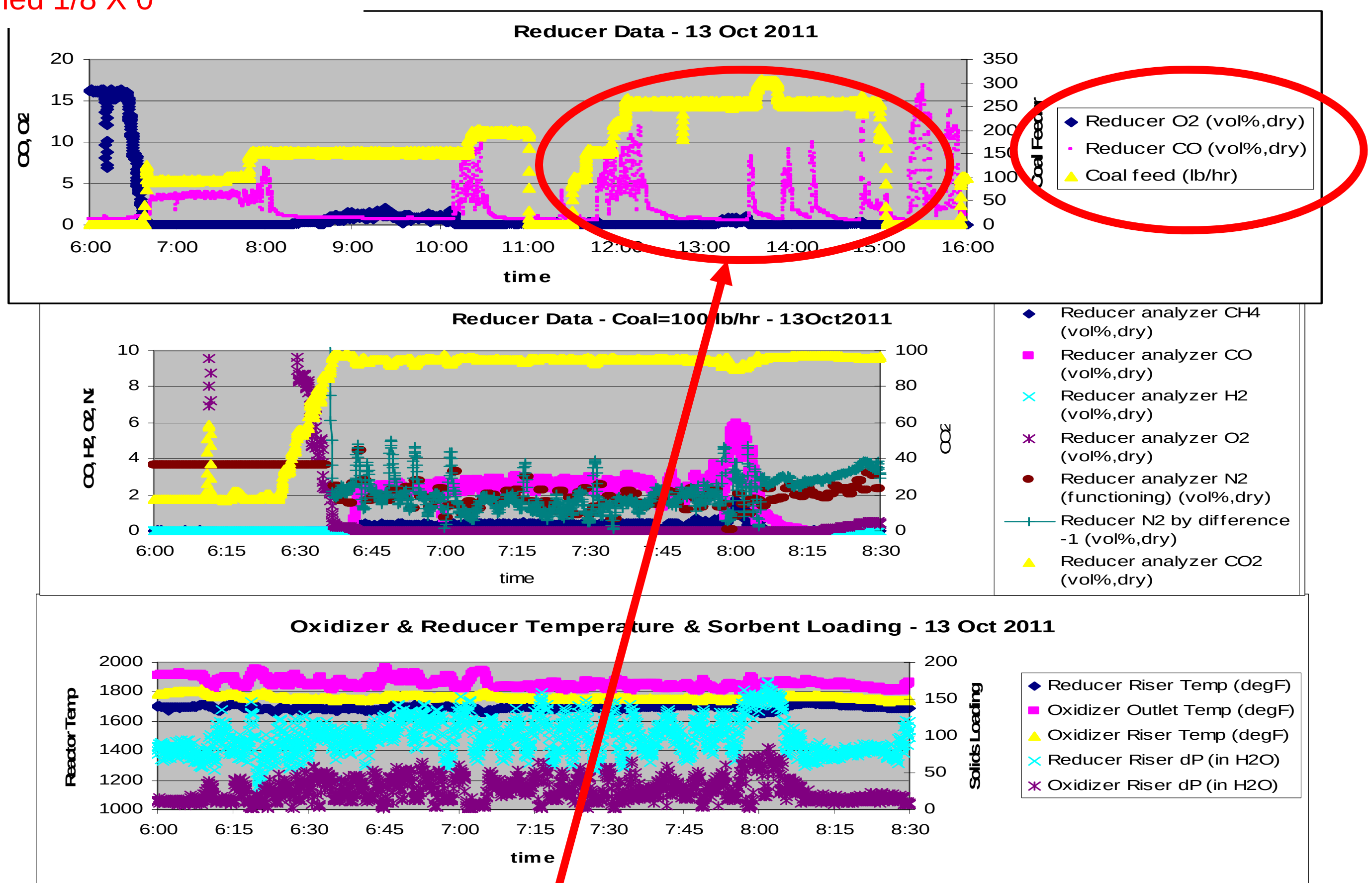
Crushed 1/8 X 0



Initial results: LCL™ reactions work with rapid response to coal flow

Prototype Current Status - Phase IV A
Test Results – 13 October 2011 – Aux Natural Gas

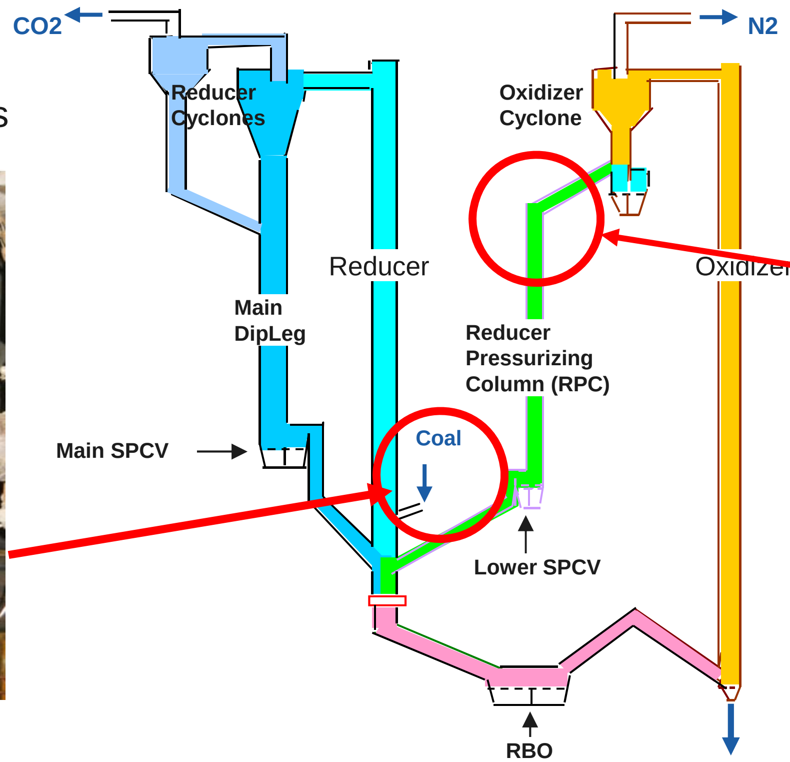
Pittsburgh Seam 8 Coal
Crushed 1/8 X 0



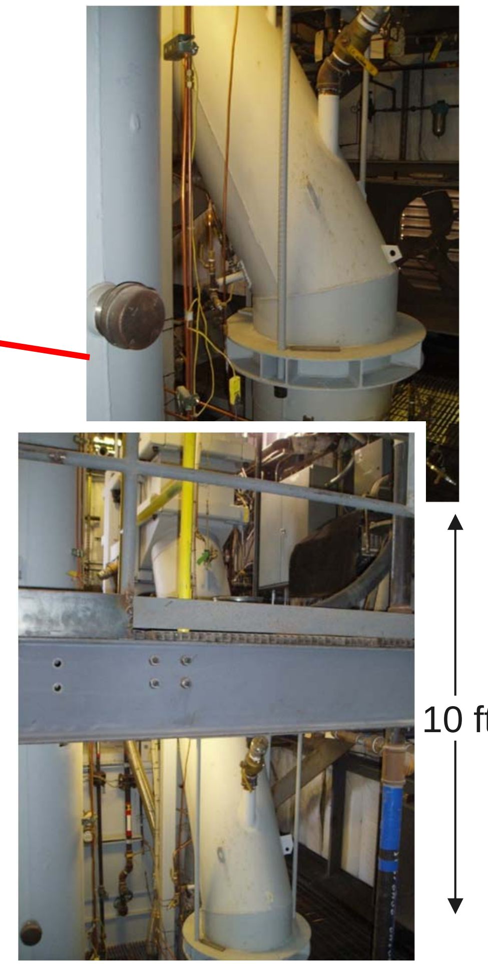
Results: Coal Feed & Solids Circulation Interruptions

Prototype Current Status - Phase IV A
2011 Test Results

Coal Feed interruptions



Reducer Pressurizing Column
Solids recirculation interruptions

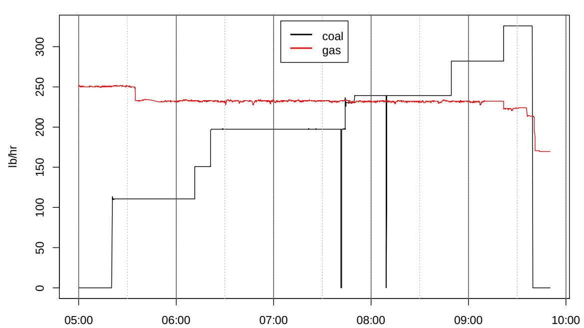


Prototype Testing

Coal Testing 2012 – Design of Experiments

- Three test campaigns started – May 2012
- Two campaigns for characterization of each of the reactors: reducer, oxidizer
  - Verify reducer reactions
  - Verify oxidizer reactions
  - Use fuels of varying reactivity (charcoal, Adaro, Ill 6, Pitt 8) and size
  - CFB ash as $CaSO_4$ source - limestone, hydrated lime
- Objective: Integrated operation to achieve autothermal condition

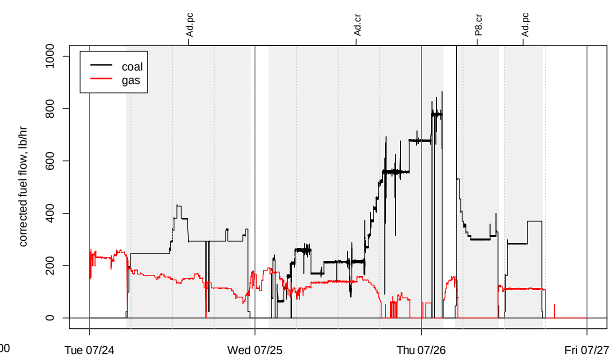
Reducer Test



May/June

Slagged with Charcoal & Water Leaks

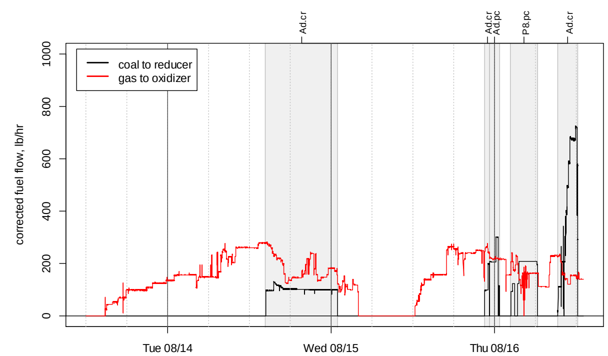
Oxidizer Test – 1st Autothermal



July

Scheduled Shutdown

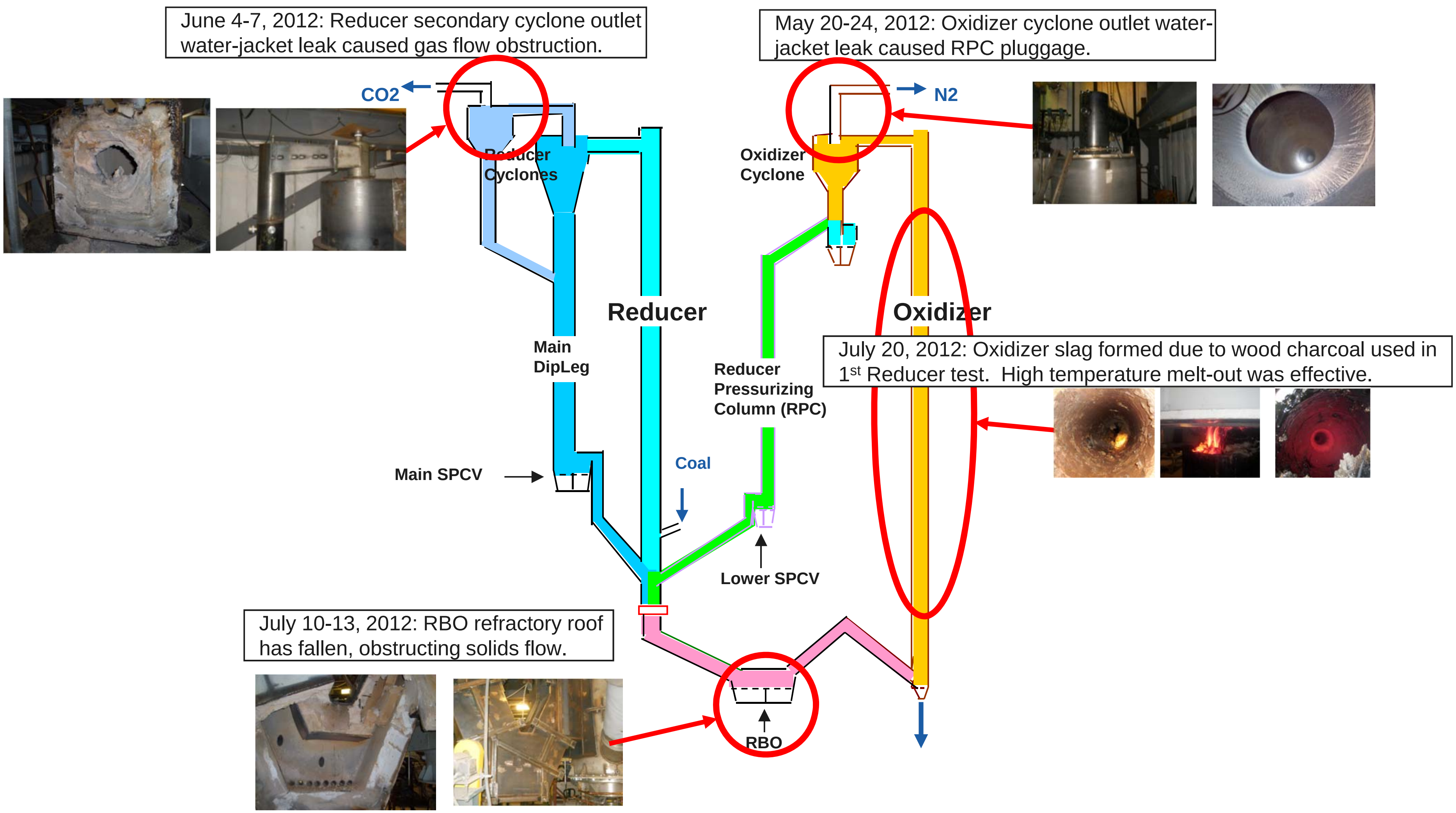
Sulfur Retention Test



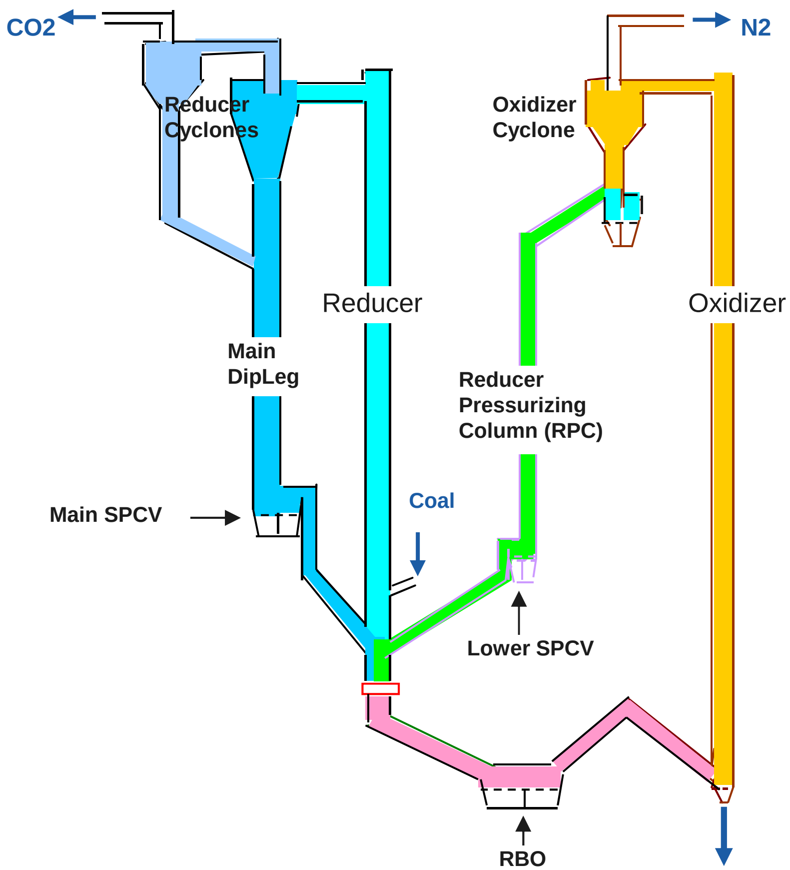
August

Oxidizer Refractory break

3 MWt Prototype
2012 Testing Issues

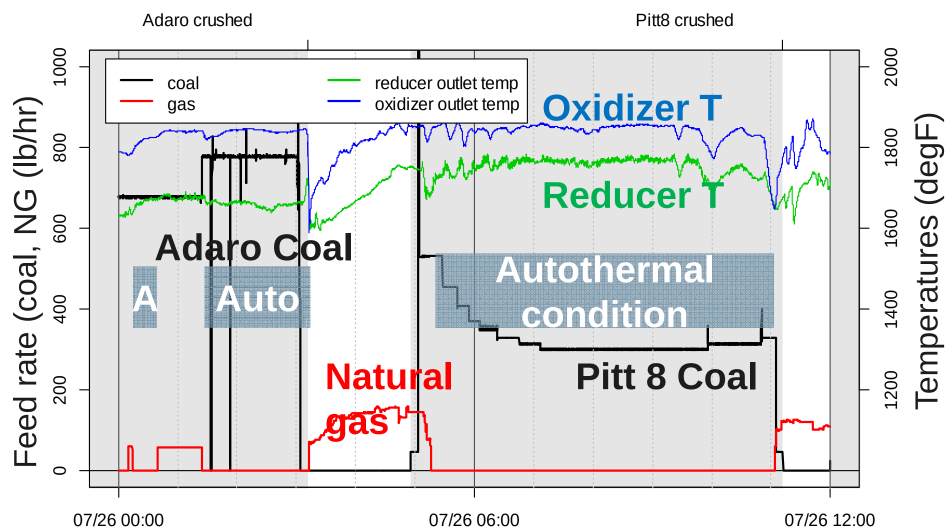


Prototype 1st Autothermal Operation – Coal-only
2nd Oxidizer Test Week – July 23-26, 2012



No equipment failures, intentional shut-down
- Executed all conditions in test matrix
- Achieved all intended test week objectives

Achieved Autothermal operation!!



3MWt Prototype – Autothermal Test
Coal-only – No other heat source
Chemical Looping Reactions are self-sustained

Agenda

Participants

Project Objectives

Technology /Technical Approach

- Chemical Looping Technology
- Phase I – Technical/Economic Study
- **Prototype Results & Plans**

Phase II Approach

Project Structure / Tasks

Prototype Performance

Prototype Testing
Coal Testing 2012 – Design of Experiments

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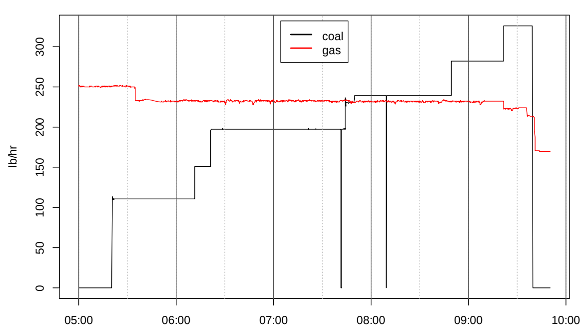
  – Verify reducer reactions
  – Verify oxidizer reactions
  – Use fuels of varying reactivity (charcoal, Adaro, Ill 6, Pitt 8) and size
  – CFB ash as initial $CaSO_4$ source - limestone, hydrated lime

- Objective: Integrated operation to achieve autothermal condition

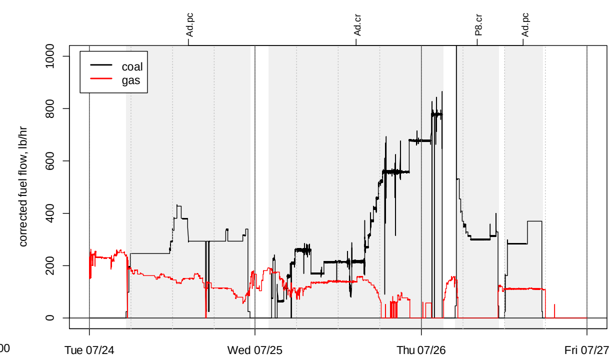
Reducer Test



May/June

Slagged with Charcoal & Water Leaks

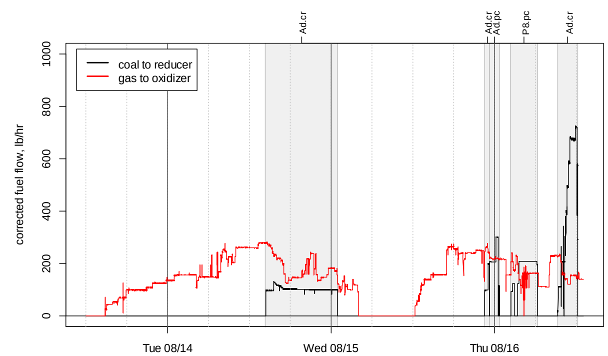
Oxidizer Test – 1st Autothermal



July

Scheduled Shutdown

Sulfur Test

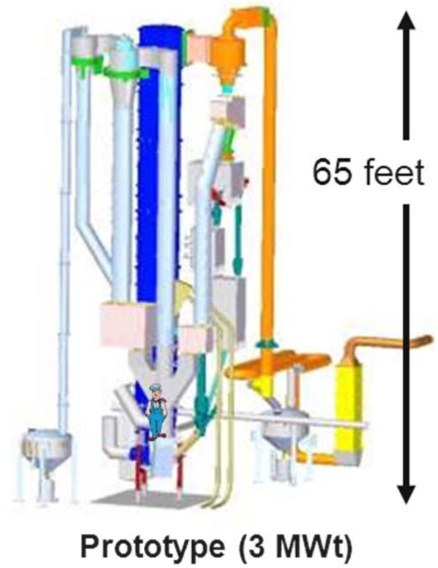


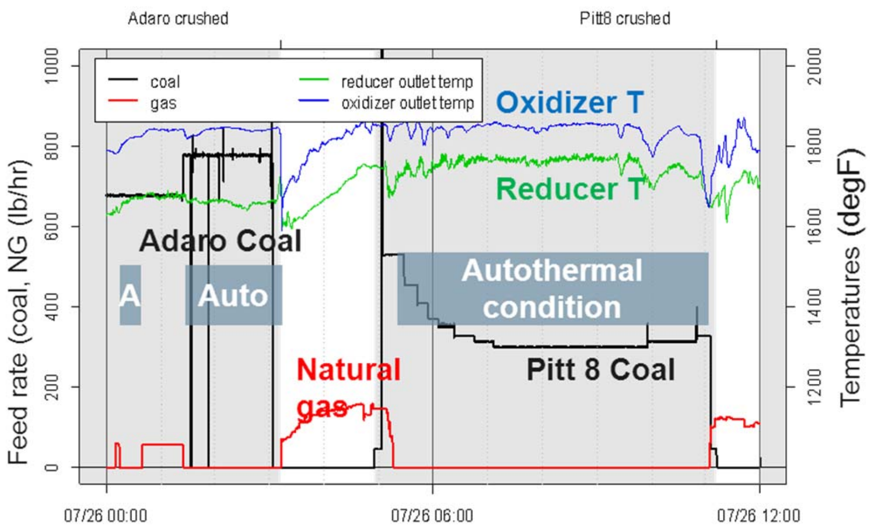
August

Oxidizer Refractory break

3 MWt Performance
Highlights

- Achieved 1st autothermal operation on two crushed coals.
- Performance is not perfect, but good enough to see:
  - Prototype size and configuration are correct
  - Test results indicate directions for improvement
- No major concept changes have been required.

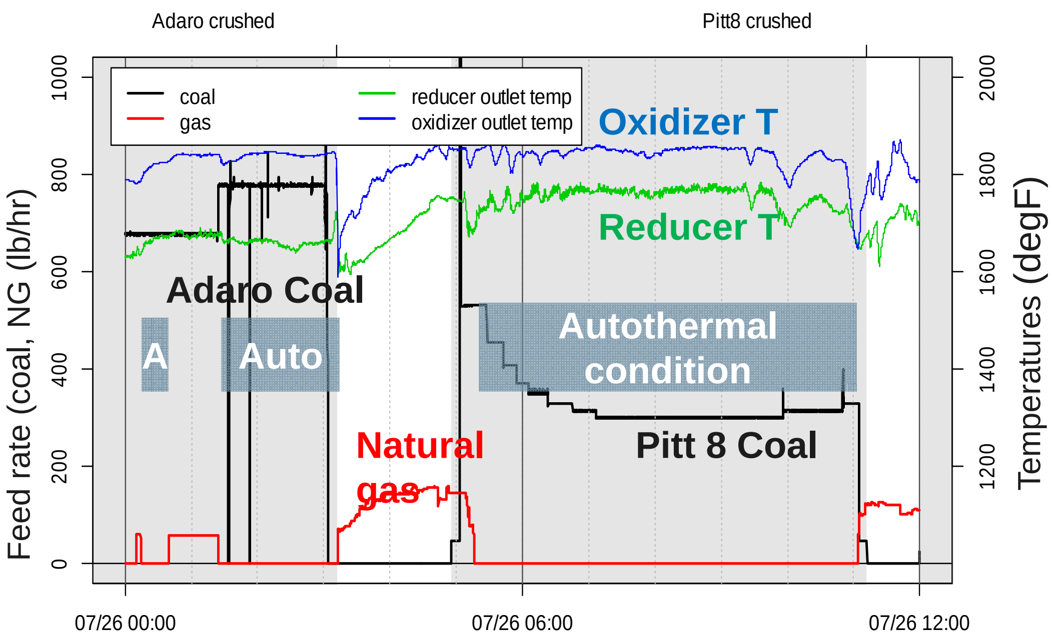




3MWt Prototype – Autothermal Test
Coal-only – No other heat source for 12 hours
Chemical Looping Reactions are self-sustained

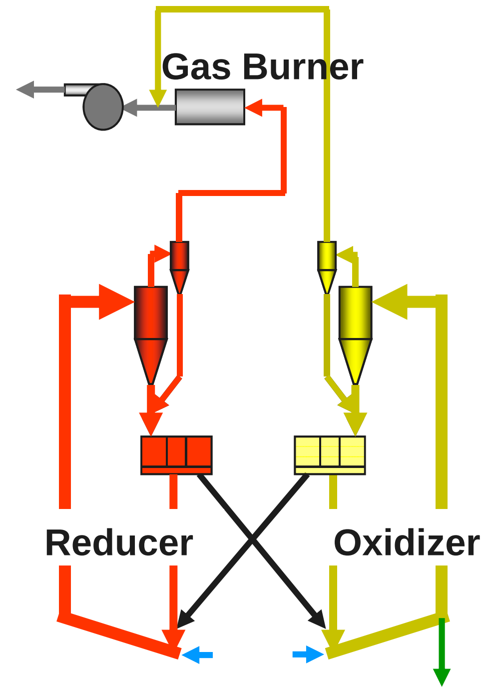
Highlights:
- 1st Autothermal Operation for 12 hours
- Coal-only operation (Pittsburgh & Adaro)
- All chemical looping reactions working
- Unburned carbon < 0.5%
- Up to 96% carbon capture achieved
- Sulfur controllable to near zero
- Stable operation for long periods

Autothermal Operation
Adaro and Pitt 8 crushed



3MWt Prototype – Autothermal Test
Coal-only – No other heat source for 12 hours
Chemical Looping Reactions are self-sustained

Vs



65 kWt PDU
Electrically Heated
Not Autothermal

- Autothermal operation – self-sustained CLC reactor operation
- Natural gas turned off; coal to reducer; and replenishment ash (CFB)
- Stable reducer and oxidizer temperatures at sufficient coal flows

Summary of Performance Achievements
Preliminary

ALSTOM

- **Completion of autothermal operation**
  - Reducer and oxidizer characterization test campaigns
  - Integrated autothermal operation with Pittsburgh Seam 8 and Adaro (1/8” X 0”)

- **High carbon conversion:**
  - Over 95% of fuel conversion efficiency to gaseous products were achieved while firing Adaro coal.
  - CO level could be maintained low by changing fuel-to-oxygen carrier ratio (i.e., fuel-to-air ratio) – Result: low CO means high CO2 purity.
  - Integrated operation
  - Reaction rates exceed requirements

- **Moderate sulfur emissions:**
  - Moderate levels of sulfur release observed from reducer and oxidizer;
  - Sulfur release correlates with CO content and temperature
  - Reducer sulfur release could be lowered to close to zero by lowering reducer temperature and/or injecting limestone (or $Ca(OH)_2$)

- **Stable solids transport**
  - Long period of stable operation were maintained
  - Carbon carryover from reducer to oxidizer could be maintained at low levels

Agenda

Participants

Project Objectives

Technology /Technical Approach
- Chemical Looping Technology
- Phase I – Technical/Economic Study
- Prototype Results & Plans

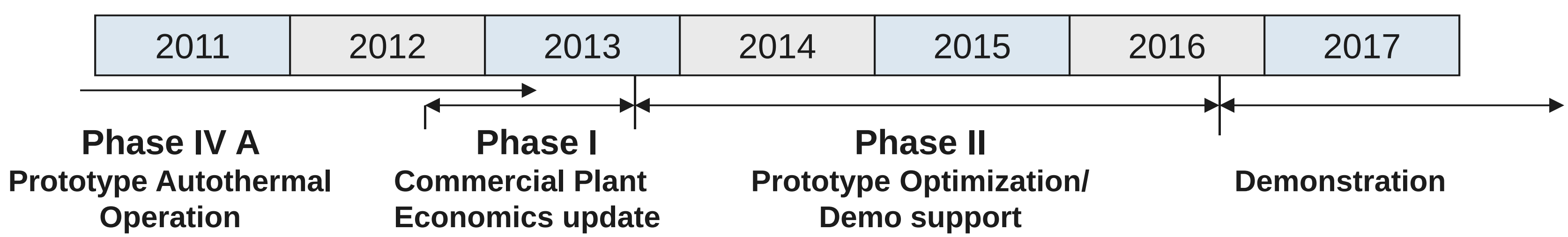
Phase II Approach

Project Structure / Tasks

Next Steps
Execution of DOE-funded programs

- DOE/NETL-funded program – **Awarded** (Phase I)
  - Total = 1.25 MUSD (DOE share = 1 MUSD)
  - Performance period: October 2012 through September 2013
  - Objectives are:
    1. Re-evaluated commercial plant economics;
    2. Engineering study – equipment improvement, system optimization
  - Submit Phase II proposal in June 2013

- DOE/NETL-funded program – **Submit Proposal** (Phase II)
  - DOE program 3 years starting Oct 2013
  - Objectives are:
    1. Optimize process through Prototype testing
    2. Support a demo project



Limestone Chemical Looping
Further Prototype Testing

3 MWt Prototype - Further testing (based on results to date) **:**

- Phase IVA 40 hr Autothermal run
- Sulfur control (SAHE; limestone testing)
- Main DipLeg gas generation control – solids control
- RBO gate (counter-current gas (up) and solids (down)
- Full load
- Condensing HX
- Automatic solids control
- Commercial startup and operating (Full load/ Part load/ Load change/Long Runs/Demo coal test)
- Maximum pressure tests
- Cold flow modeling support
- Other tests indicated by Phase I

Agenda

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Participants

Project Objectives

Technology /Technical Approach

- Chemical Looping Technology
- Phase I – Technical/Economic Study
- Prototype Results & Plans

Phase II Approach

Project Structure / Tasks

Limestone Chemical Looping Project
Organization

U.S. DOE NETL Program Manager
Bruce Lani

Manager, Contract R&D
Ray Chamberland

ALSTOM BOILER R&D EXECUTION MANAGEMENT
Director - Boiler R&D Execution
John Marion

ALSTOM MANAGEMENT
President Alstom Power Inc.
Managing Director, Boiler US
Tim Curran

ALSTOM BOILER R&D EXECUTION
CL R&D Program Manager
Iqbal Abdulally

ALSTOM BOILER R&D EXECUTION MANAGEMENT
Director – Combustion
Dr. Shin Kang

Principal Investigator
Herb Andrus

Task 1.0 Project Management
Carl Edberg

Task 2.0 Technical and Economic Studies
Glen Jukkola

Task 3.0 Engineering Studies
Carl Edberg

Task 4.0 Bench Testing
Jim Kenney

- Alstom – Chattanooga
- U. British Columbia

Limestone Chemical Looping
Project Workscope & Schedule

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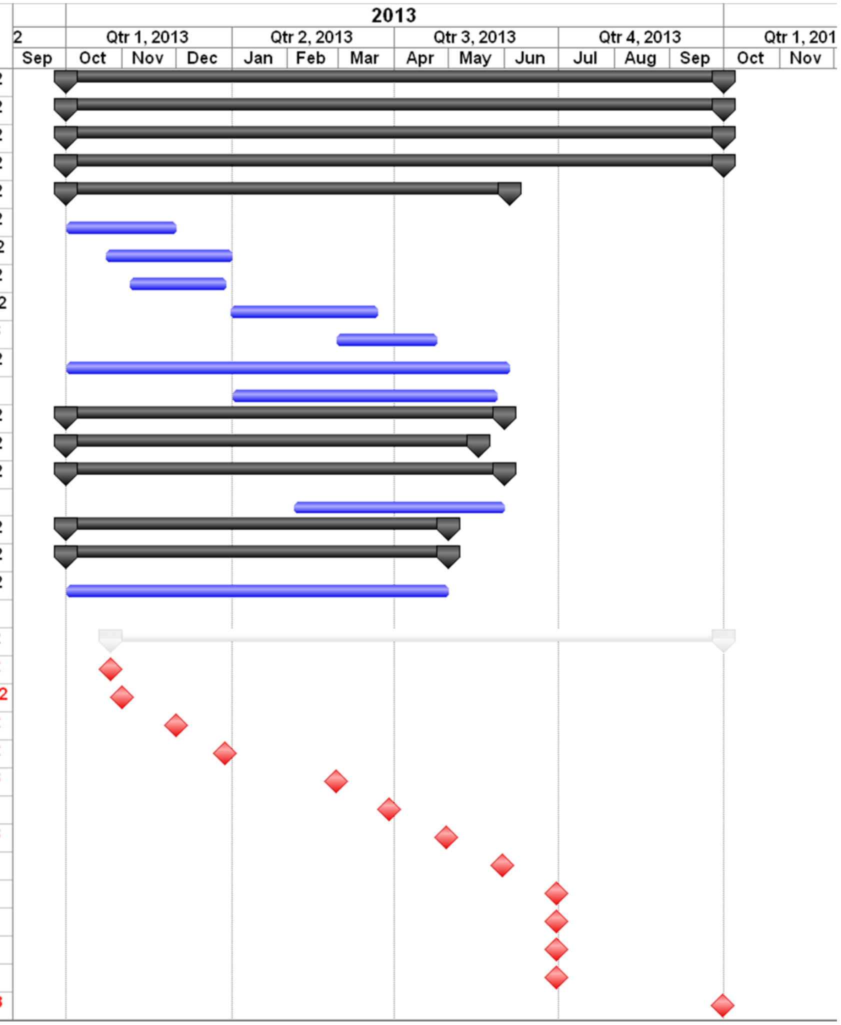
ID	Task Name	Start
1	DE-FE0009484	Mon 10/1/12
2	1.0 Project Management and Reporting	Mon 10/1/12
3	1.1 Project Management	Mon 10/1/12
9	1.2 Project Reporting	Mon 10/1/12
20	2.0 Technical Economic Studies	Mon 10/1/12
21	2.1 Case 0 - DOE Baseline Model (SCPC Case 9)	Mon 10/1/12
22	2.2 Case 1 - Transport Reactor Sizing (Update GHG Report (	Tue 10/23/12
23	2.3 Case 2 - CFB Reactor Sizing (Update ENCAP Study)	Mon 11/5/12
24	2.4 Case 3 - Pressurized CLC Case	Mon 12/31/12
25	2.5 Case 4 - Pressurized CLC Case with A-USC Steam Conc	Thu 2/28/13
26	2.6 Economic Model and Analysis	Mon 10/1/12
27	2.7 Chemical Looping 'Black Box' Model Generation	Tue 1/1/13
28	3.0 Engineering Studies	Mon 10/1/12
29	3.1 Equipment Specifications	Mon 10/1/12
34	3.2 Process Improvements	Mon 10/1/12
40	3.3 Technology Gap Analysis	Mon 2/4/13
41	4.0 Bench Scale Testing	Mon 10/1/12
42	4.1 TGA Testing	Mon 10/1/12
45	4.2 Four Inch Bubbling Bed Testing	Mon 10/1/12
46		
47	MILESTONES	Fri 10/26/12
48	Kick-off Meeting at NETL	Fri 10/26/12
49	Technology Engineering Design Basis Report	Wed 10/31/12
50	Updated Project Management Plan	Fri 11/30/12
51	Transport CLC Performance Summary	Fri 12/28/12
52	CFB Based CLC Performance Summary	Thu 2/28/13
53	Technology Engineering Design Interim Report	Fri 3/29/13
54	Pressurized Reducer CLC Performance Summary	Tue 4/30/13
55	USC CLC Performance Summary	Fri 5/31/13
60	Phase I Topical Report - Draft Final Report	Sat 6/29/13
56	Final Phase I Technology Gap Analysis Report	Sat 6/29/13
57	Final Phase I Tech. Eng. Design and Economic Analysis Re|	Sat 6/29/13
58	Final Phase II Application	Sat 6/29/13
59	Final Report (if required)	Mon 9/30/13



Limestone Chemical Looping Project
Budget

kUSD	Total
Task 1 – Program Management & Reporting	214
Task 2 – Technical Economic Studies	563
Task 3 – Engineering Studies	300
Task 4 – Bench Scale Testing	173
	1,250

Limestone Chemical Looping
Project Milestones & Deliverables

Milestone No.	Budget Period	Task / Subask No.	Milestone Description	Deliverable	Planned Completion	Actual Completion	Verification Method
1	1	1.2	Project Kickoff Meeting		10/26/12		Presentation File
2	1	1.2	Technology Engineering Design Basis Report	1	10/31/12		Report File
3	1	1.2	Updated Project Management Plan	2	11/30/12		Plan File
4	1	2.2	Transport CLC Performance Summary		12/28/12		Report Table
5	1	2.3	CFB based CLC Performance Summary		02/28/13		Report Table
6	1	4.1	Preliminary TGA Results		02/28/13		Quarterly Project Report
7	1	4.1	Preliminary 4" FBC Results		02/28/13		Quarterly Project Report
8	1	3.2	Technology Engineering Design Interim Report	4	03/29/13		Report File
9	1	2.4	Pressurized Reducer CLC Performance Summary		04/30/13		Report Table
10	1	2.5	USC CLC Performance Summary		05/31/13		Report Table
11	1	4.1	Final TGA Results		05/31/13		Quarterly Project Report
12	1	4.1	Final 4" FBC Results		05/31/13		Quarterly Project Report
13	1	3.3	Final Phase I Technology Gap Analysis Report	7	06/29/13		Report File
14	1	3.2	Final Phase I Technology Engineering Design and Economic Analysis Report	6	06/29/13		Report File
15	1	1.2	Final Phase II Application	8	06/29/13		Application File
16	1	1.2	Phase I Topical Report - Draft Final Report	5	06/29/13		Report File
17	1	1.2	Final Report (if required)	9	09/30/13		Report File
	1	1.2	Quarterly Project Reports	3			Report File

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