ALSTOM's Chemical Looping Combustion Prototype for CO_2 Capture from Existing Pulverized Coal Fired Power Plants

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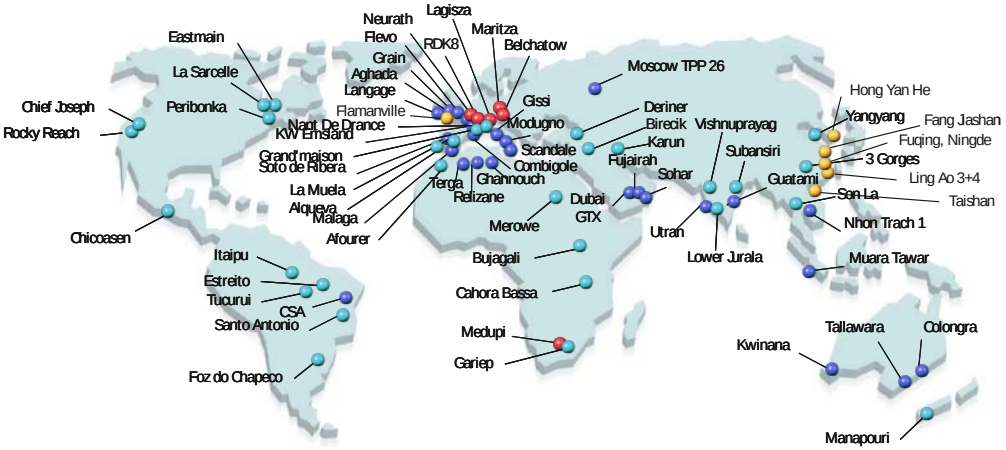
2011 CO_2 Capture Technology Meeting , August 22 – 26, 2011

Agenda

Topic 1	General Project & Technology Background
Topic 2	Phase 0 to III Activities
Topic 3	Phase IV Activities and Status
Topic 4	Next Steps

The Alstom Group: a Worldwide Leader in Power Generation



Over 41 GW under execution

- Nuclear
- Hydro
- Steam
- Gas

Chemical Looping Technology Development

Full Power Systems Portfolio

N°1 in hydro power

N°1 in integrated power plants

N°1 in conventional nuclear power island

Recent acquisitions of solar & wind power

N°1 in air quality control systems

N°1 in services for electric utilities

Project Goals and Objectives

- Chemical Looping Program:
  - Develop and commercialize chemical looping process to meet the goals for existing or new coal-fired power plants.
- Prototype Project:
  - Design (BP1), build, and test (BP2) a 3 MWth Prototype to demonstrate Chemical Looping (40hr auto-thermal operation).
  - Obtain engineering and operating information necessary to design and build a reliable follow-on demonstration plant.

Alstom's Chemical Looping Development

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Targets:

- Over 90% CO_2 capture from coal
- Less than $20/ton avoided cost of CO_2 capture
- Capital cost 20% < conventional steam plant (w/o CO_2 capture)
- Applicable to retrofit and new coal-fired power plants
- Retrofit < 20% increase in COE
- Beat steam power and IGCC performance and economics, world-wide
- Medium-Btu gas or hydrogen without oxygen plant
- Economical H_2 production at low cost

Chemical Looping Prototype Schedule As Planned

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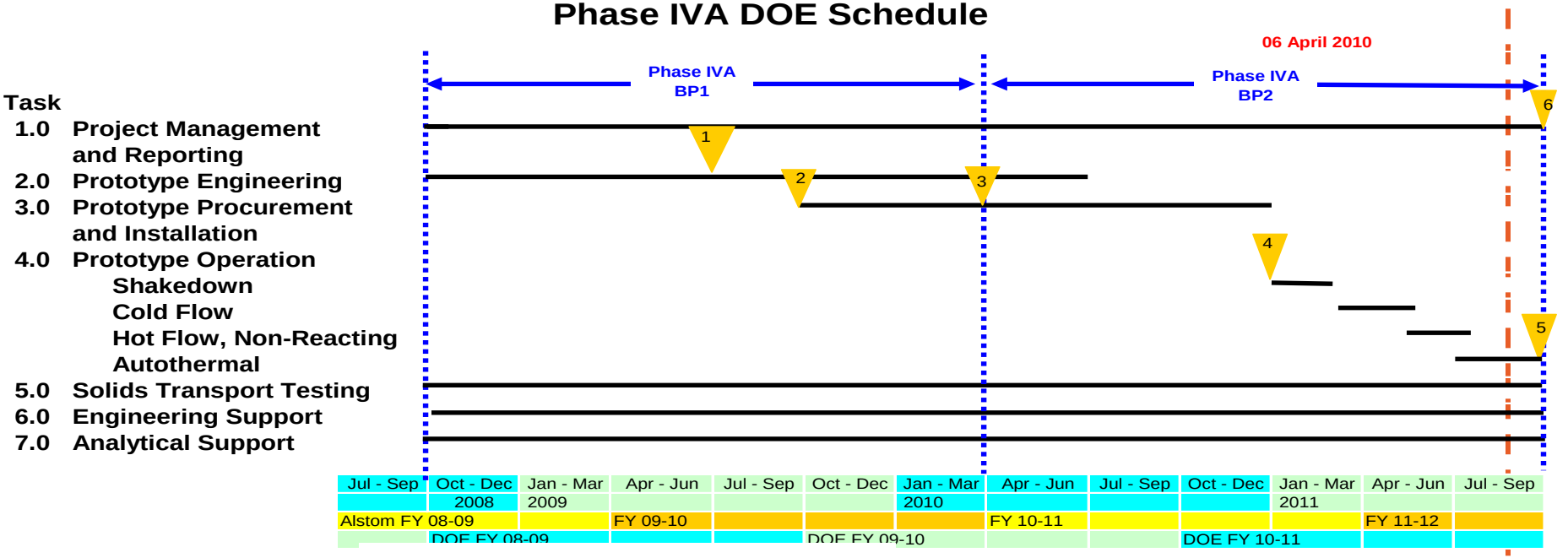
Phase IVA DOE Schedule



Milestones:

1. Complete Preliminary Engineering
2. Deliver Updated Technical and Cost Information to NETL (for BP1 Decision)
3. Start Installation
4. Start Shakedown
5. Complete Phase IVA Testing
6. Deliver Interim Report
7. Deliver Final Report

Phase IVA is on Schedule

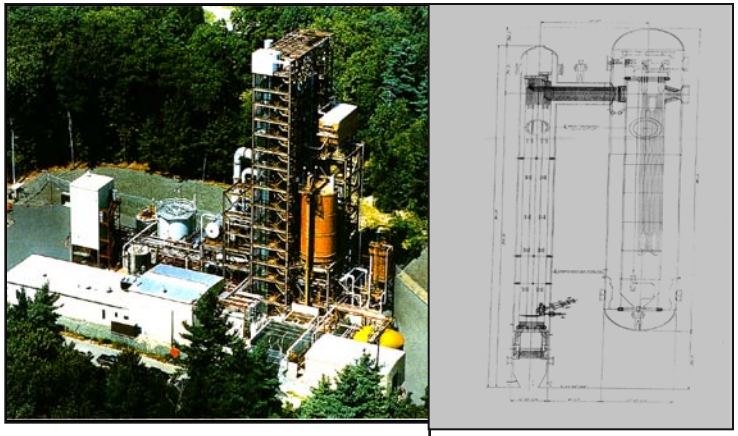
Project Overview – Funding 2008 to 2011

Total Budget Period 1& 2	
DOE Funding	$6,895,624
Alstom Funding	$1,723,906
Total Budget	$8,619,530

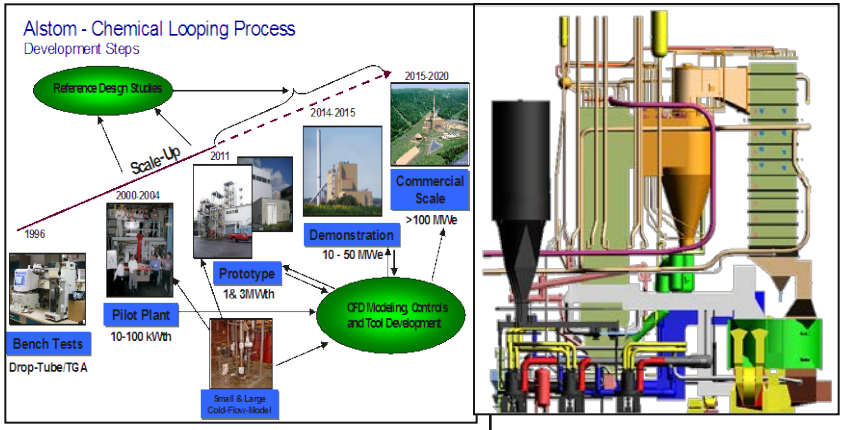
Participants:

Alstom's Limestone Chemical Looping Concept Evolution

Alstom Entrained Gasification Technology (1974 – 1981)



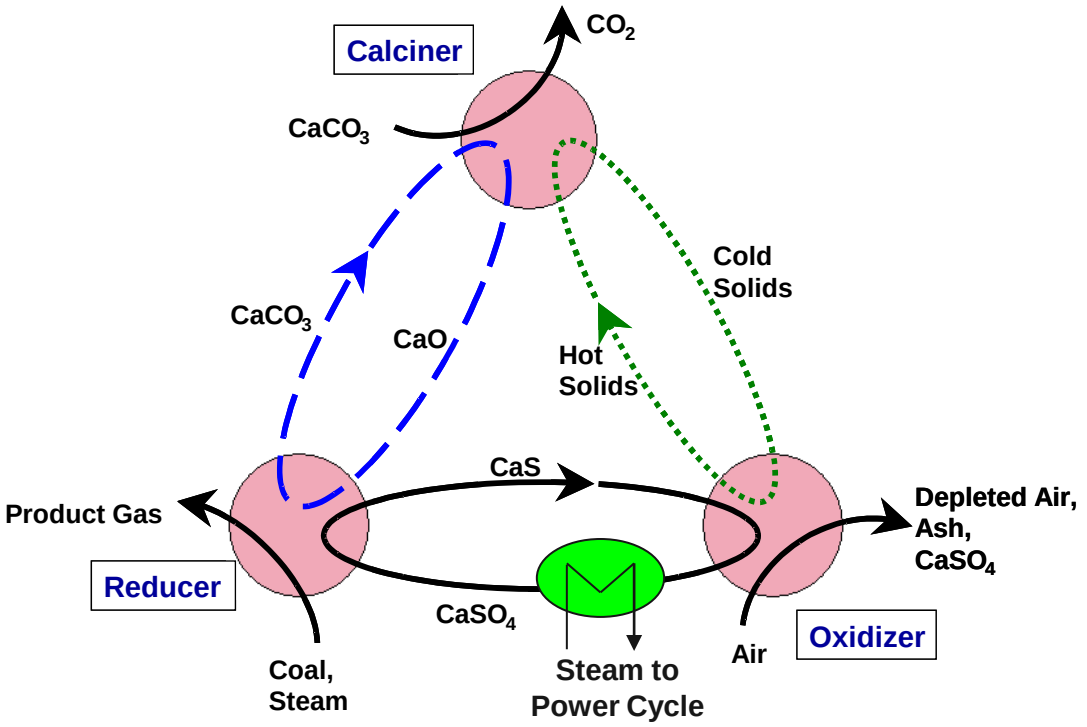
Alstom Fluidized bed Technology (1978 -)



Alstom's Limestone Based Chemical Looping Technology

Alstom's Limestone Chemical Looping Concept

- In Alstom's process, calcium compounds from limestone are used as the reactant
- Coal is indirectly combusted or gasified by hot oxygen carrying reactant
- The Reactant is not consumed and is alternately reduced (oxygen removed) and oxidized (oxygen replenished) as it cycles between reactors
- The Reactant also carries heat where needed



Main Reactions:

Air Reactor (Oxidizer)

$$CaS + 2O_2 \rightarrow CaSO_4 + Heat$$

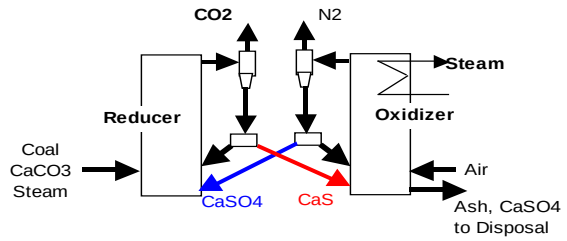
Fuel Reactor (Reducer)

$$2\ C_{fuel} + CaSO_4 + Heat \rightarrow CaS + 2\ CO_2$$

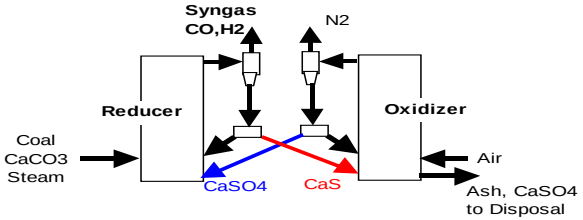
$$8\ H_{fuel} + CaSO_4 + Heat \rightarrow CaS + 4H_2O$$

Alstom's Limestone-based CLC Process

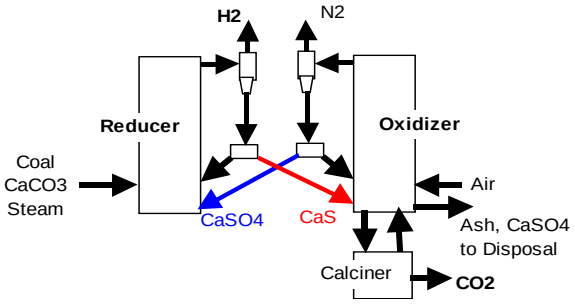
Chemical Looping Process: Options and Applications



Option 1 – Combustion with CO_2 Capture



Option 2 – Syngas with no CO_2 Capture



Option 3 – Hydrogen with CO_2 Capture

Applications

- CO_2 Capture – PC Retrofit
- CO_2 Capture – CFB Retrofit
- CO_2 Capture-Ready Power Plant
- Advanced Steam Cycles with CO_2 capture

- IGCC with Down-Stream CO_2 Capture
- Industrial Syngas production
- Coal-to-Liquid Fuels

- CO_2 Capture – PC Retrofit
- CO_2 Capture – CFB Retrofit
- CO_2 Capture-Ready PC/CFB Power Plant
- Advanced Steam Cycles with CO_2 capture
- IGCC with CO_2 Capture
- Fuel Cell Cycles with CO_2 Capture
- Industrial Hydrogen with CO_2

Flexible technology with low cost

Chemical Looping Overview
Retrofit Options

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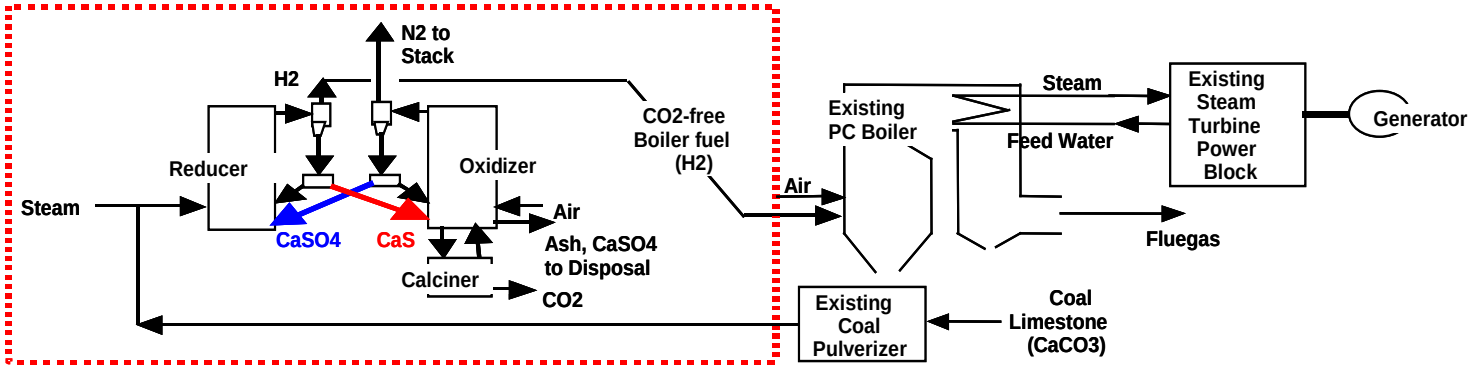
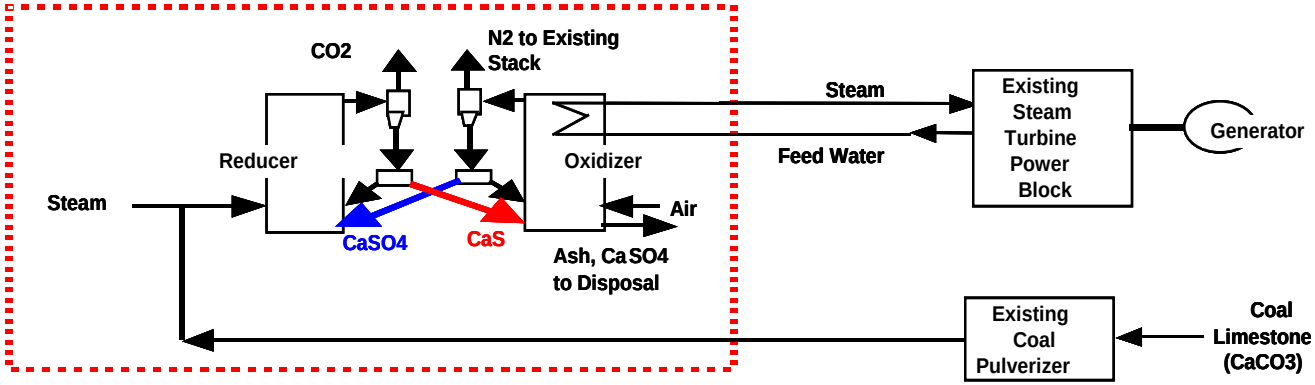
Pulverized Coal Power Plant - Retrofit Concepts



Concept 1 – Chemical Looping CO2-free Fuel; Minimum Boiler Modification



Concept 2 – Chemical Looping Oxidizer Replaces/Modifies Boiler

Retrofit Options at < 20% Increase in COE with CO_2 Capture

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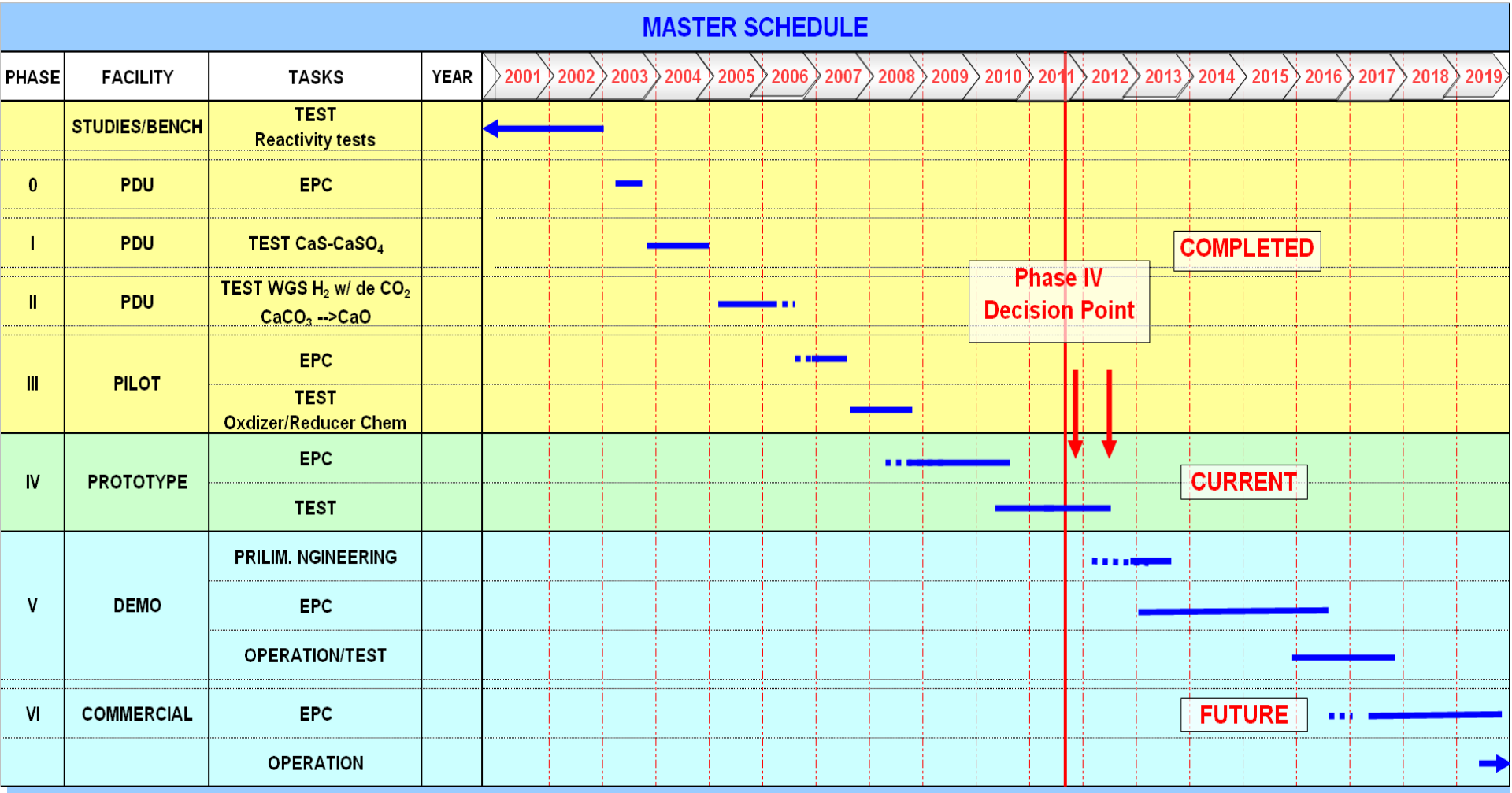
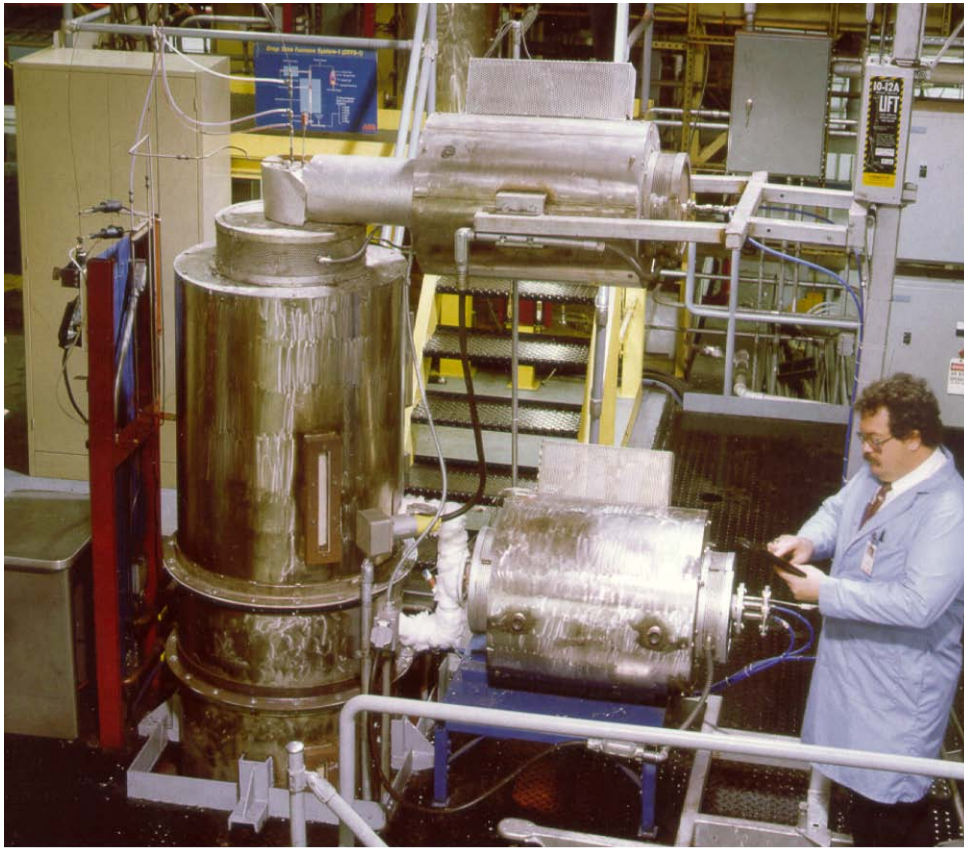
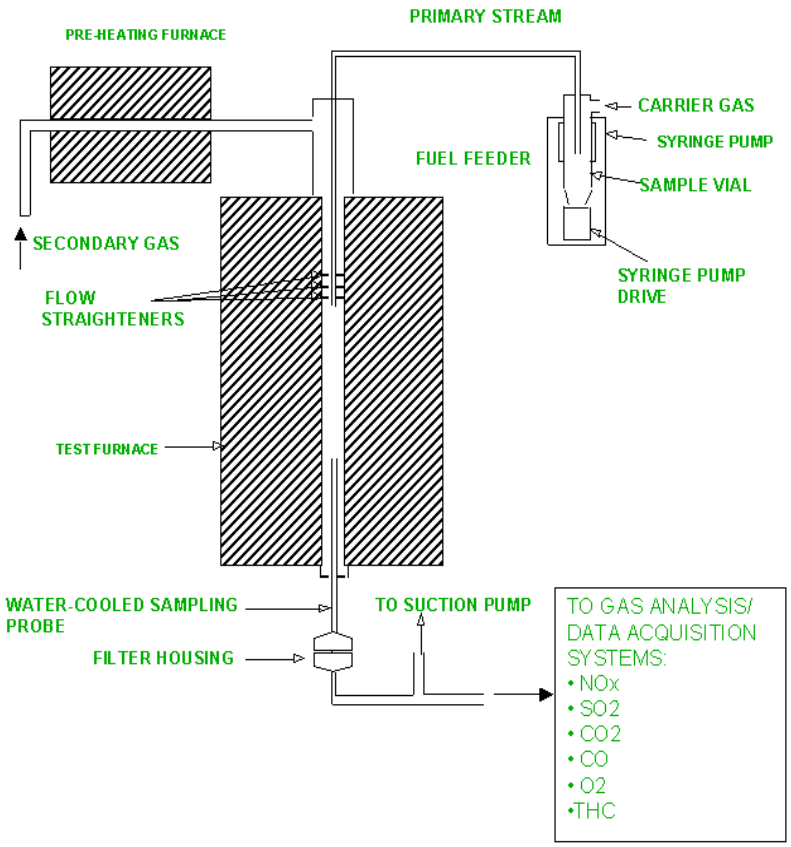
Alstom – DOE Chemical Looping Development Plan



Phases 0, I, II and III Completed Prior to October 2008. Phase IV Began October 2008 – First Coal Fire June 2011 –Autothermal Scheduled for September/October 2011

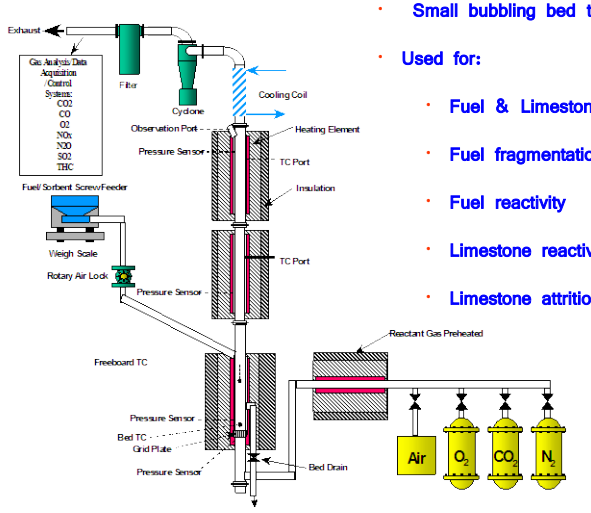
Chemical Looping Program
Drop Tube Furnace System (DTFS) 1997 – 2003





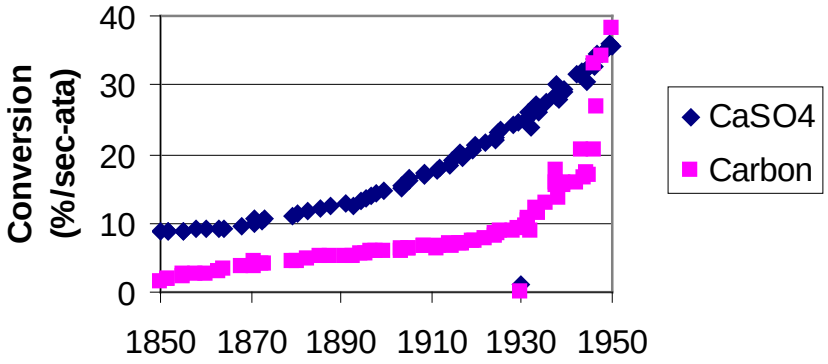
Schematic of Drop Tube Furnace System-1 (DTFS-1)

Chemical Looping Program
4 Inch Fluidized Bed Reactor System (1999 – 2003)



- Small bubbling bed test facility
- Used for:
  - Fuel & Limestone Characterization
  - Fuel fragmentation (FAD)
  - Fuel reactivity
  - Limestone reactivity
  - Limestone attrition

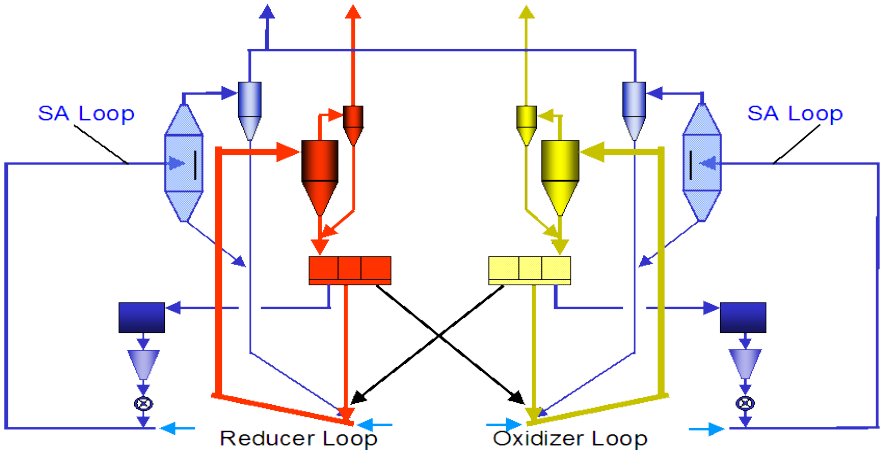
Reducer Kinetics
1000 micron



Work was completed in 2003 and was used together with DTFS data to determine Kinetic Rate Data

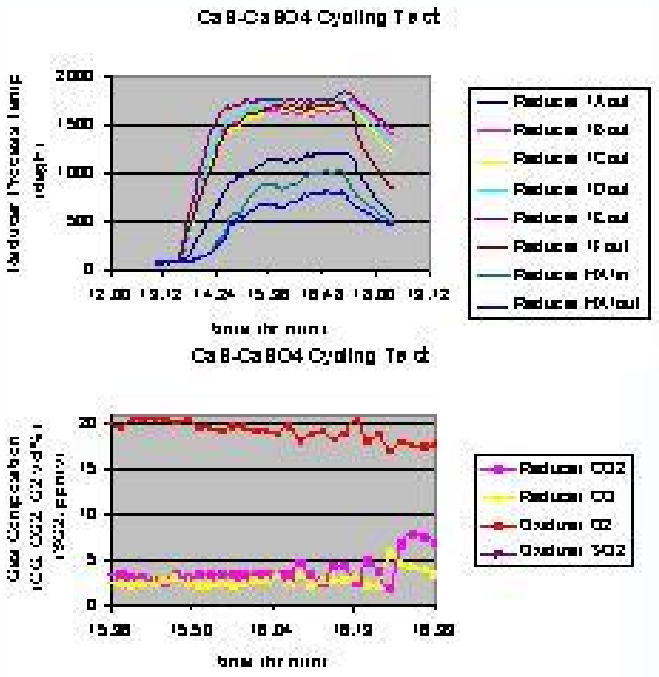
- Batch Tests Yield Reaction Rates Over a Wide Range of Temps and Compositions
- Basis for Equipment Sizing for Plant Cost and Economic Studies
- Basis for Chemical Looping Process Development Unit Design

Chemical Looping Program
Process Development Unit (PDU) 2004 -2008



Chemical Looping Process Development Unit (PDU)

- Designed and Built by Alstom for about $1M
- 2 Year Test Program - $4M – 80% funded by US-DOE
- Allows Testing of Individual Loops and Processes



Chemical Looping Program
Summary of Kinetics Studies

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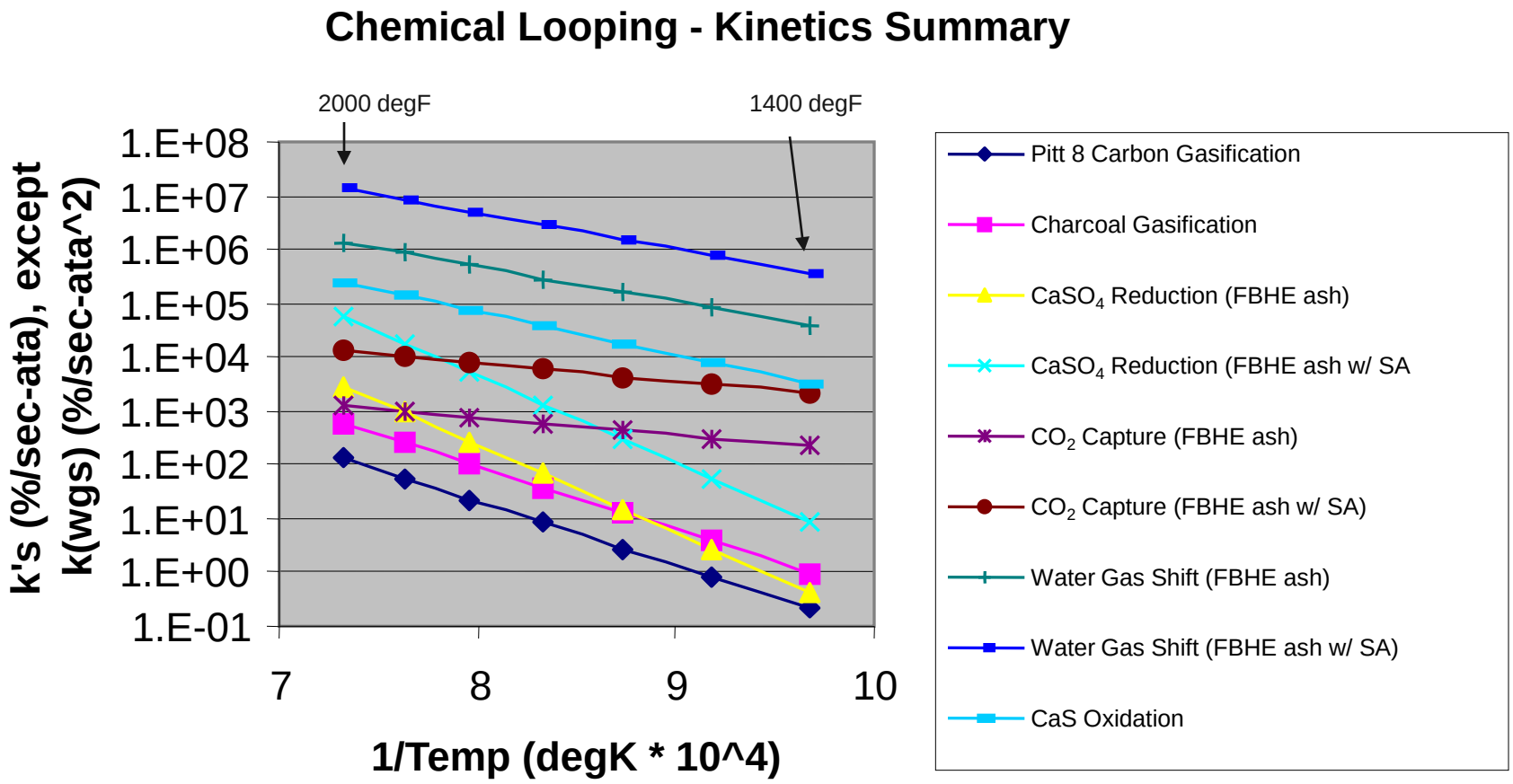
Chemical Looping Reaction Kinetics Studies

Test Equipment	DTFS	4 Inch FBR	ChemLoop PDU	Fuels Tested
Particle size (micron)	50	1000	< 1200	
Reactions Studies				
1 Carbon Gasification (via CO2)	X (4)	X (2)		1. Pitt 8 Char
2 Carbon Gasification (via CaSO4)		X (2)	X (1,3)	2. PRB Char
3 Devolatilization	X (4)	X (1,2)		3. Wood Charcoal
4 CaS Oxidation	X (4)			4. 15 worldwide coals & chars
				5. Gypsum
5 CaSO4 Reduction		X (5)	X (6)	6. CFB Ash
				7. Reduced CFB ash
6 CaO CO2 Capture	X (9)	X (8)	X (8)	8. Chemstone Limestone
				9. Marblewhite Limestone
7 WGS		X	X	
8 WGS (w/ CaO)		X (6)	X (6)	
9 CaS Oxidation	X (6,7)	X (5)	X (7)	

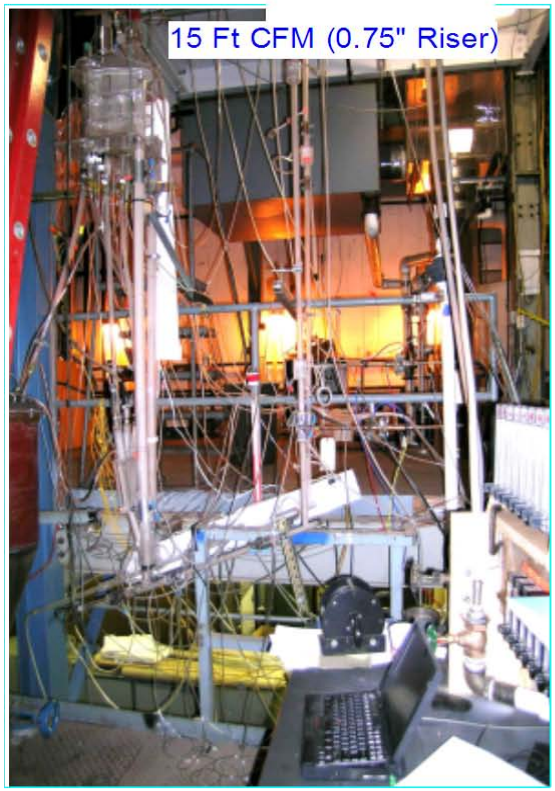
Extensive Kinetic Studies Performed To Size The Prototype

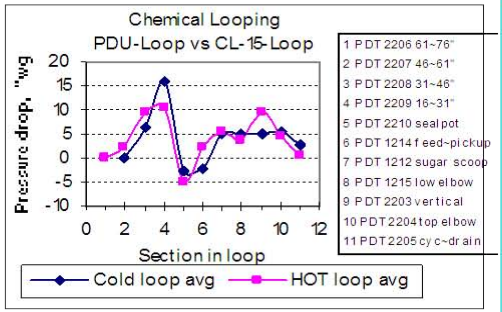
Chemical Looping Program
Chemical Looping Kinetics

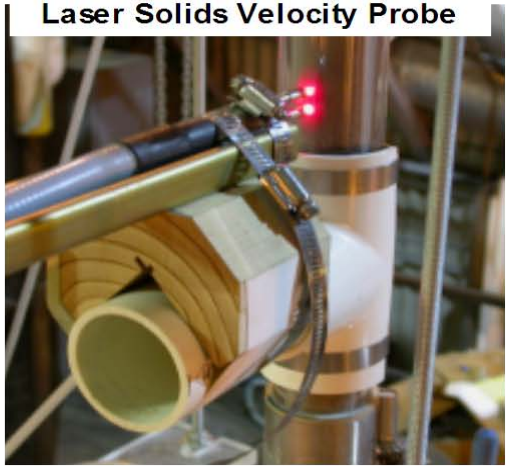


Extensive Kinetic Studies Performed To Size The Prototype

Chemical Looping
Cold Flow Model (CFM)







- Goals for the CFM:
  - Distribute, Transport, and Control Solids Flow
  - Scale-up
  - Training, Operating, and Trouble Shooting

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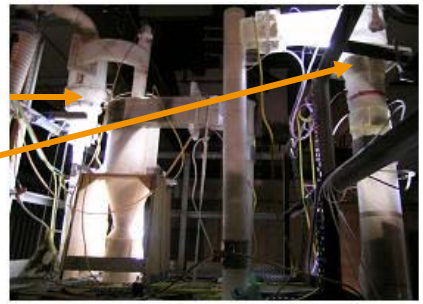
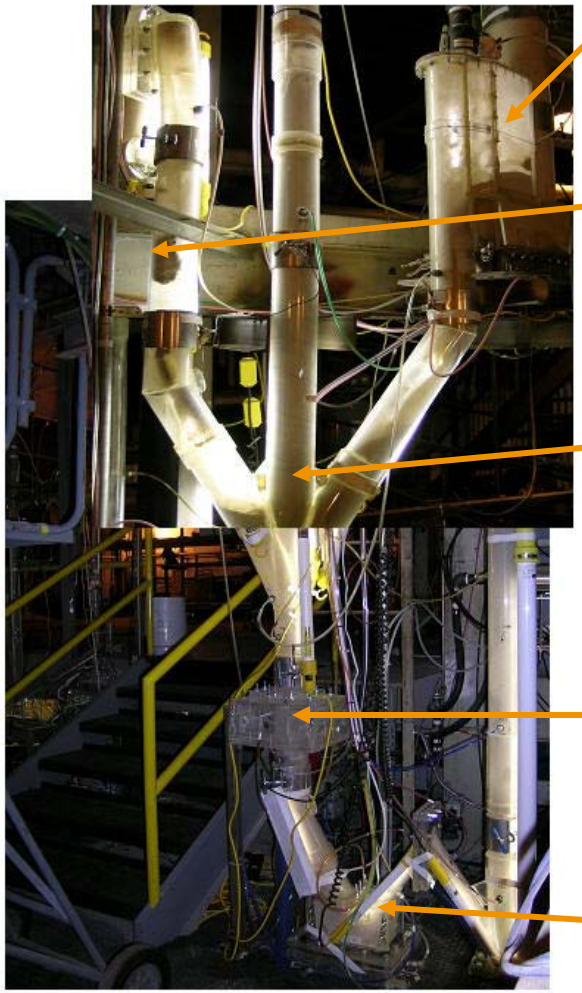
ALSTOM's Chemical Looping 40ft Cold Flow Model (CFM)





Reducer Cyclones

Oxidizer Cyclone

Oxidizer Riser

Pressurizing Column from Oxidizer to Reducer

Reducer Riser

Reducer Dipleg

Reducer SPCV

Pressurizing Column SPCV

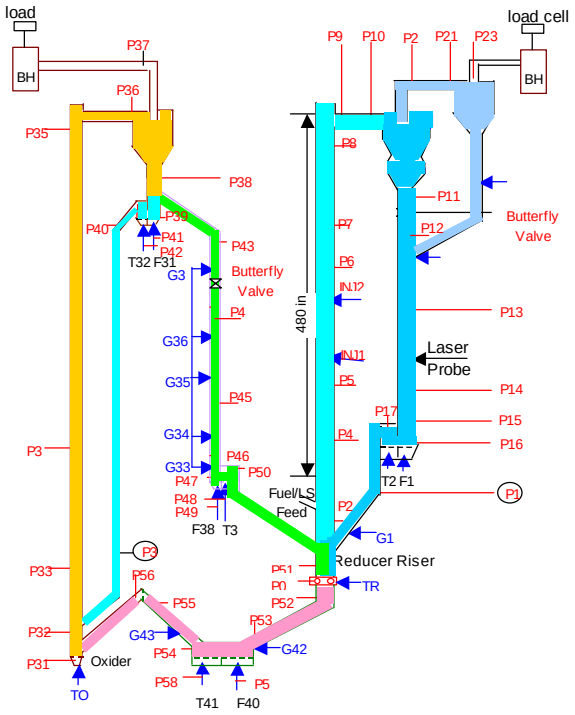
Cactus

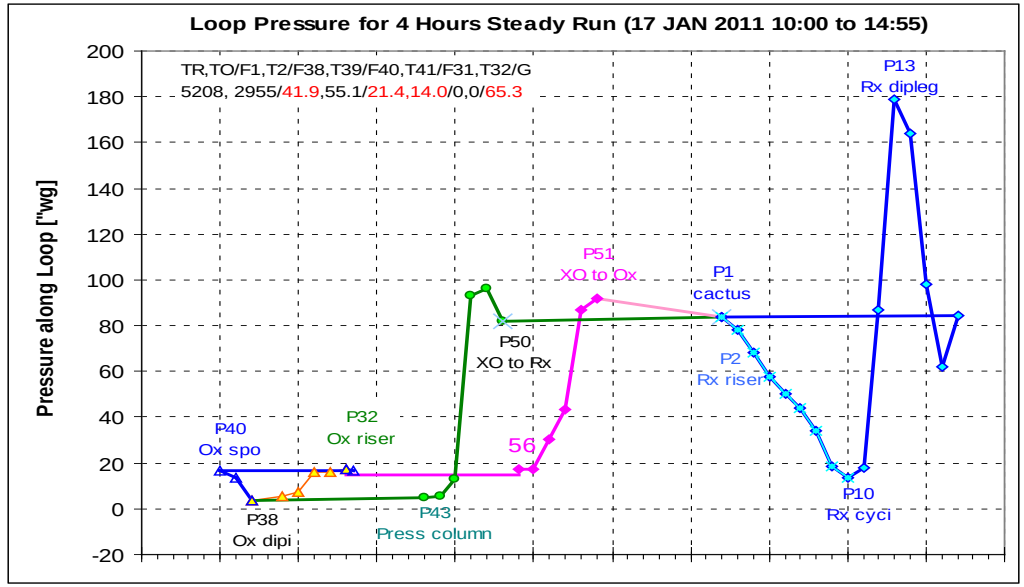
Reducer Inlet Air

Crossover from Reducer to Oxidizer

ALSTOM's Chemical Looping - CFM

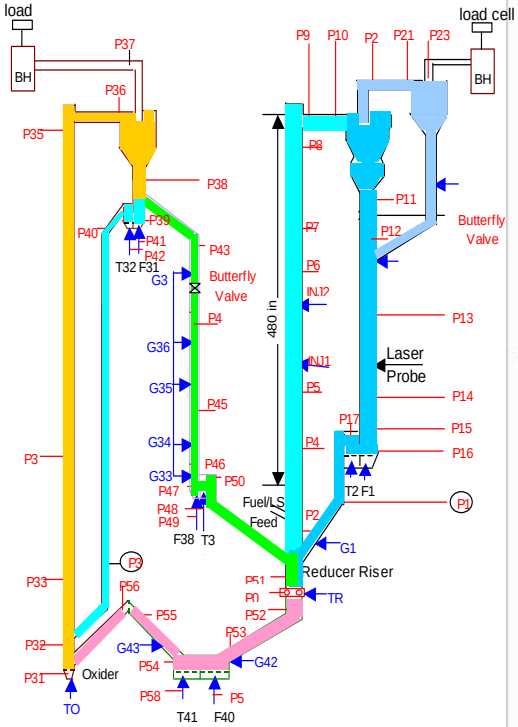
4 Hours Steady Operation – Pressure Balance

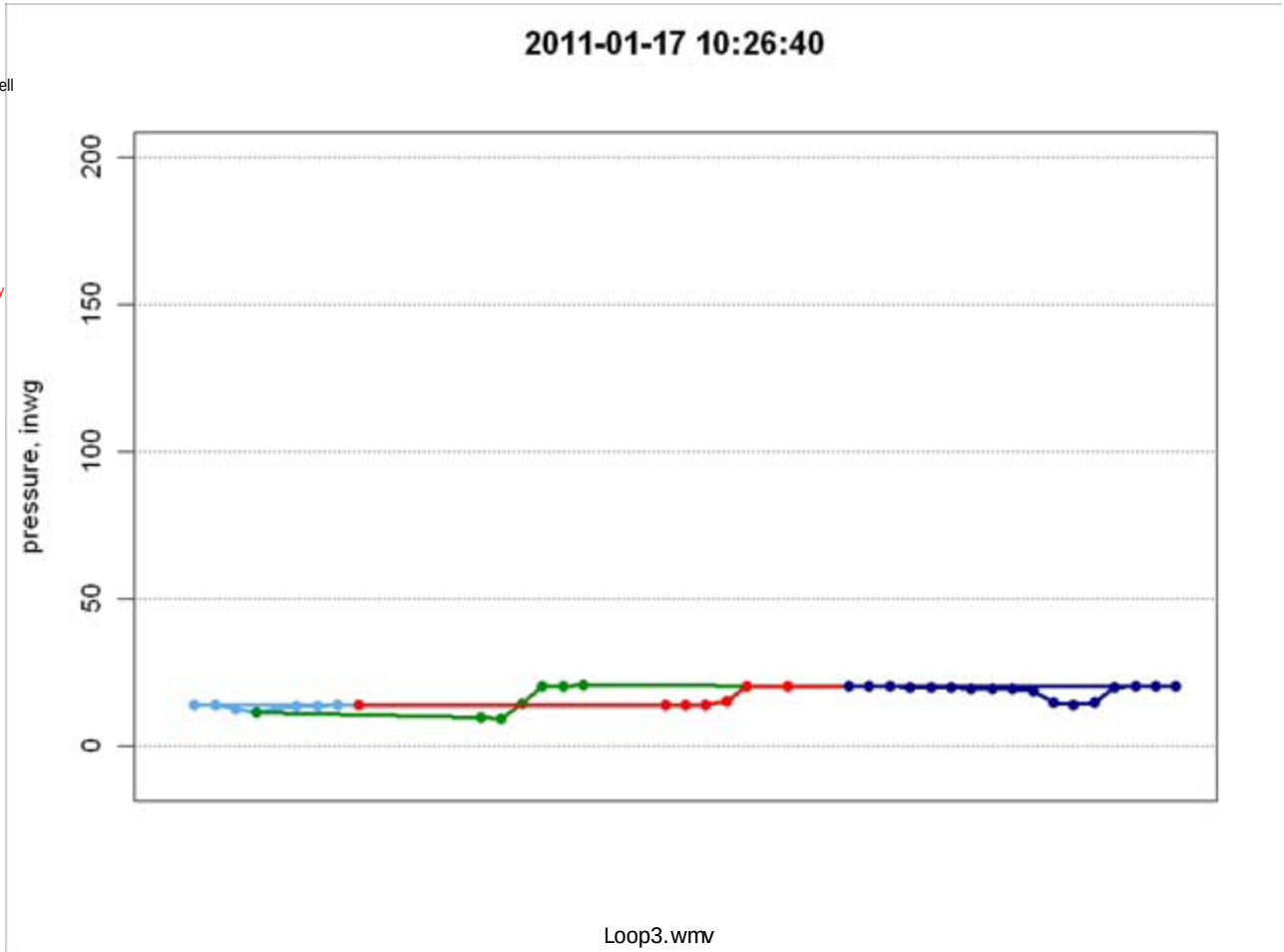




4 Hours of steady Operation

ALSTOM's Chemical Looping - CFM
4 Hours Steady Operation





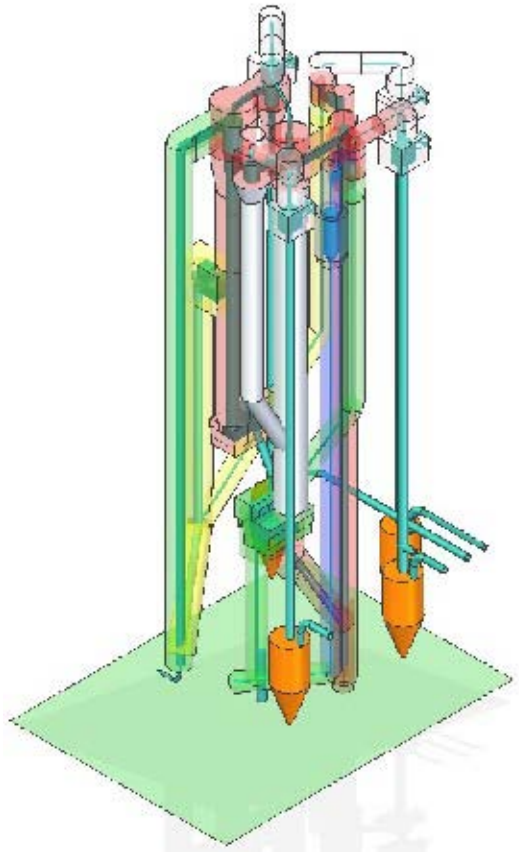
Solids flow and pressures around the loop remain steady during operation.

Chemical Looping - CFM Summary

- CFM validated the Prototype's solids transport concept
- Multi-loop CFM operation was demonstrated:
  - start-up and shutdown
  - control stability of the system
- Data used to verify the scale-up method
- CFM used for the training of operators for the prototype unit
- CFM will be used to trouble shoot Prototype solids transport

Phase IVA - Chemical Looping Prototype

Chemical Looping 3 MWt Prototype Concept

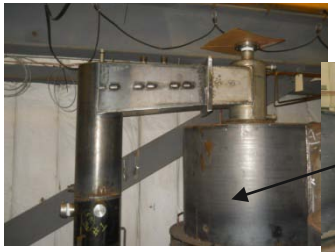


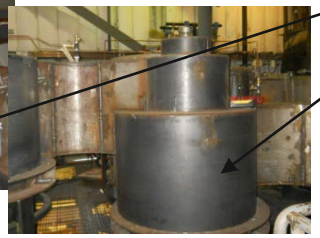
- Up to 1000 lb/hr coal flow
- 1st Integrated Operation
- 1st Autothermal Operation

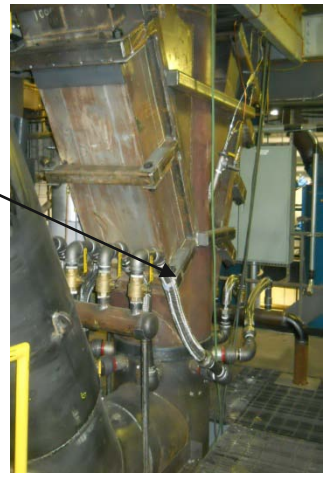
Prototype:

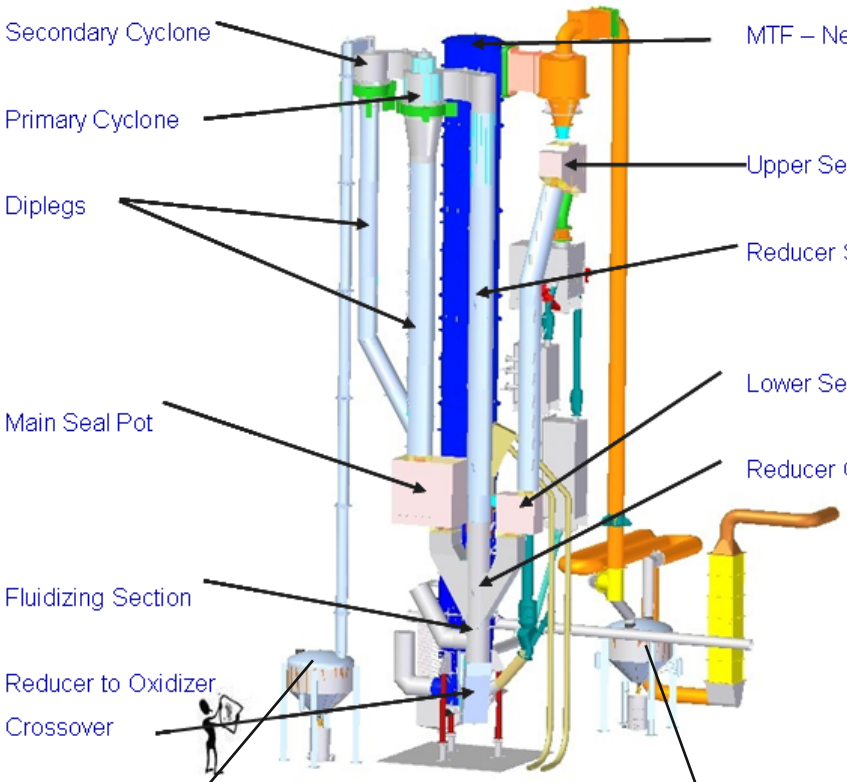
- Location – Alstom Power, Windsor, CT.
- All Equipment Necessary for Viable Demo Design
- Design, Construction, Operation, Maintenance, Modification by Alstom

Chemical Looping Prototype Component Construction









The Prototype was integrated into the existing Multi-use Test Facility (MTF)

Chemical Looping Prototype Components Installed

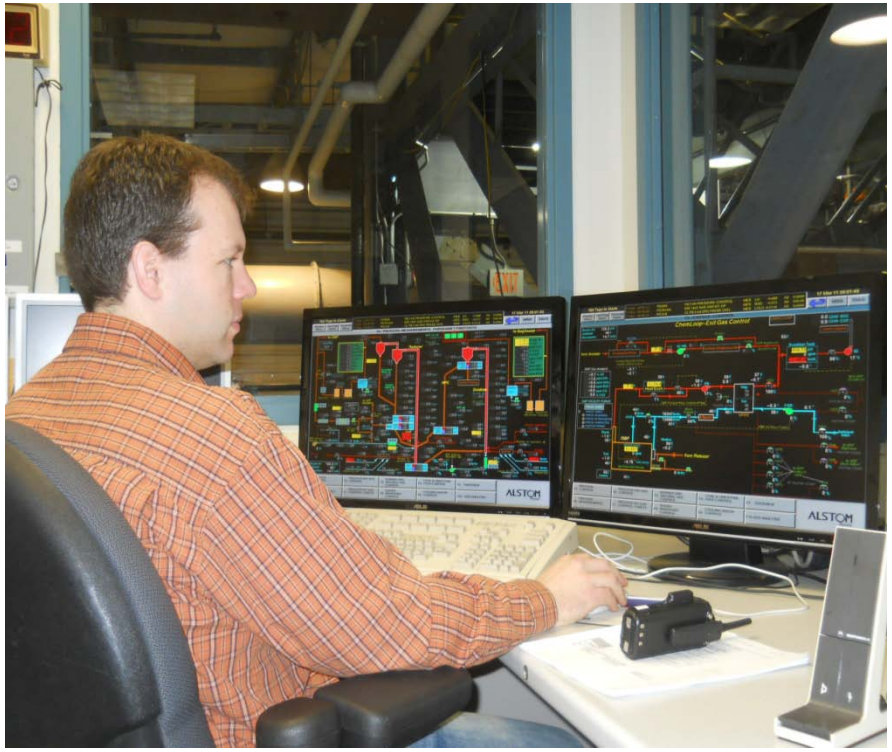
Product Gas Condenser/Chiller

Removes water from the product gas

and protects Recycle Gas Compressors

Recycle Gas Compressor supplies fluidizing gas for the SPCV's

Prototype Startup



Main Control Room Operating station

Control System Programming Station

Prototype startup in progress

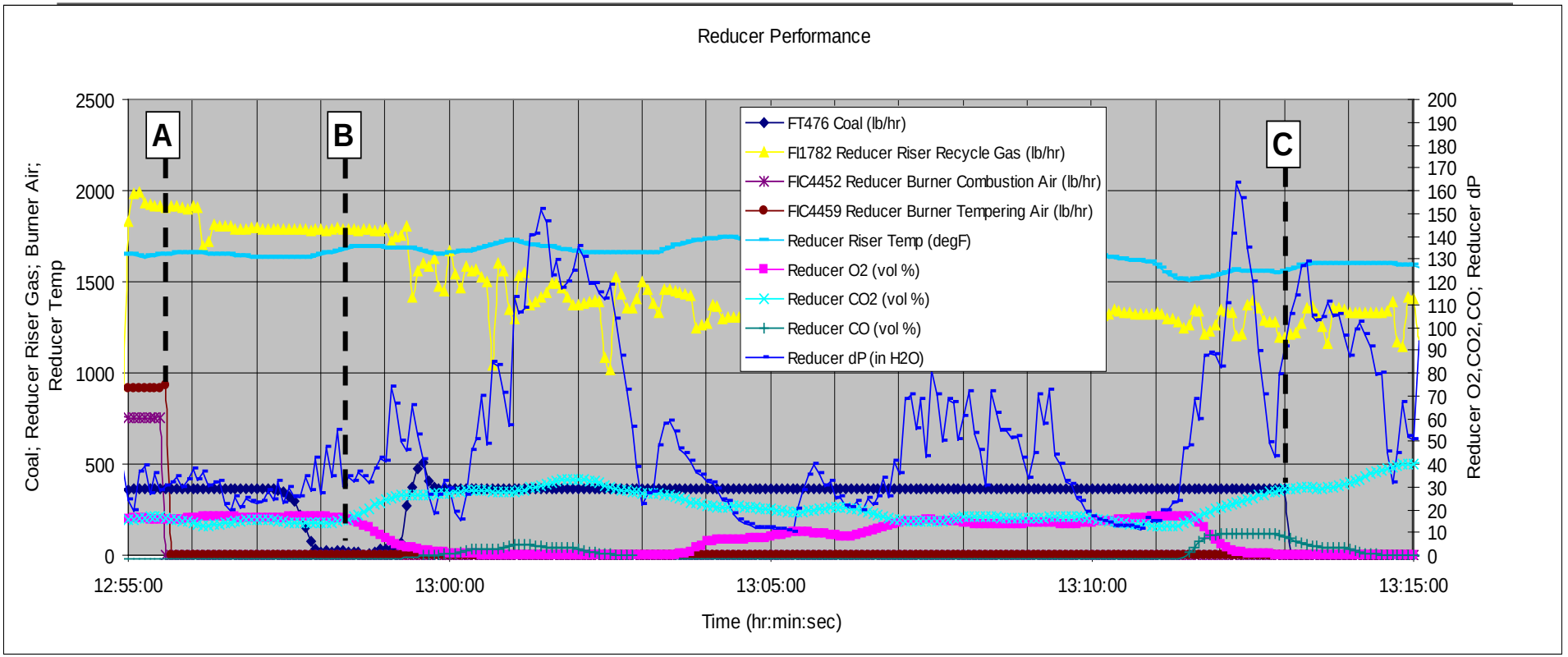
Prototype Progress To Date

The Prototype project has made significant progress toward achieving fully integrated operation.

- Controlled solids recirculation in the cold flow model and the prototype.
- Online heat-up of the process by external electric heaters, external natural gas burners and direct injection of natural gas into the reactors.
- Coal firing at relatively low reactor temperatures with low tar formation.
- Coal firing at design temperature with no evidence of tar formation.
- Coal and sorbent feeding online.
- SAHE operation.
- Hot restart after main fuel trip.
- Production of CO_2 (Option 1) and Syngas (Option 2).
- Combustion reactions with chemical looping reactions.

Chemical looping reactions were achieved on June 11, 2011

CaOx - Chemical Looping Prototype Results



- Point “A” - 360 lb/hr of coal and 1900 lb/hr of air for solids transport were flowing to the reducer
- Point “A” to Point “B” - CO_2 concentration is about 35% vol.
- Point “C” - The recycle intake was switched from air to recycled product gas. The CO_2 slowly rises as N_2 is washed out of the system

Chemical looping reactions were achieved on June 11, 2011

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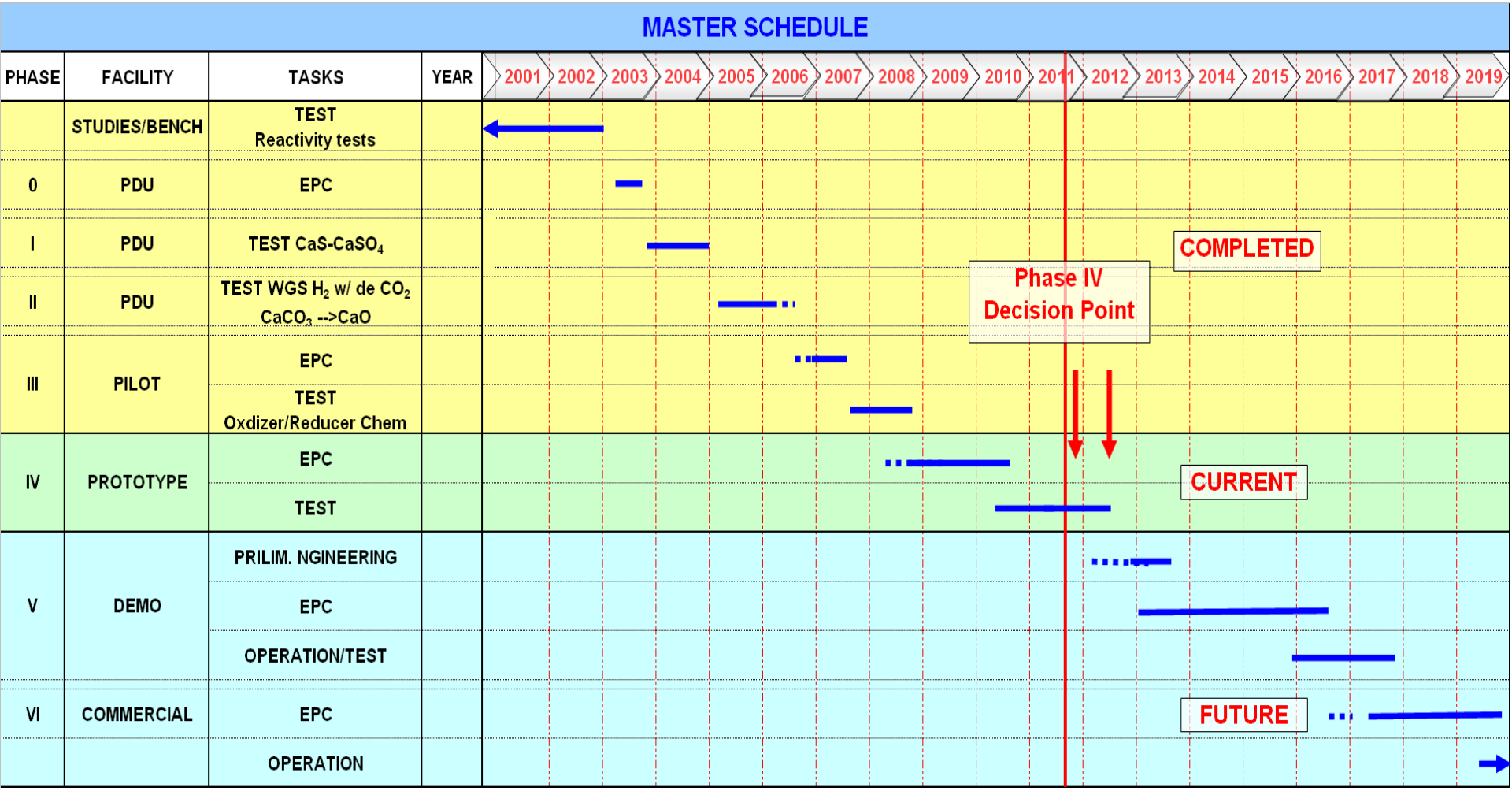
Alstom – DOE Chemical Looping Development Plan



Next Steps – Demonstration and Commercial Projects

Chemical Looping
Path Forward

- Phase IV A
  - Auto-Thermal 40 hour Coal Operation
  - Optimization Test
- Phase IV B
  - Options: Syngas, H_2
  - Add and test Calciner
- Phase V
  - Demonstration Plant
- Phase VI
  - Commercial Plant

Alstom - Chemical Looping Process
Development Steps

Reference Design Studies

Scale-Up

1996

Bench Tests

Drop-Tube/TGA

2000-2004

Pilot Plant

10-100 kWth

2011

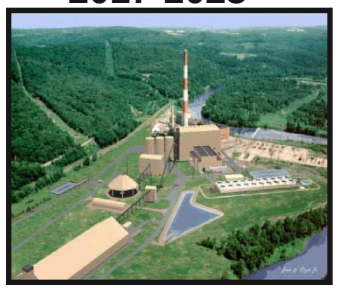
Prototype

1& 3MWth

2014-2016

Demonstration

10 - 50 MWe



2017-2023

Commercial Scale

>100 MWe

Small & Large Cold-Flow-Model

CFD Modeling, Controls and Tool Development

Any Questions?

www.alstom.com

Thanks to DOE-NETL!

ALSTOM