# Chemical Looping Combustion Coal Power Technology Development Prototype

$CO_2$ Capture Technology Conference
US DOE/NETL, Pittsburgh
24-26 March 2009

Herb Andrus

ALSTOM

# Chemical Looping Development

- Project Overview
- Technology
- Project Objectives
- Project Methodology
- Future Plans

# The Alstom Group – Two main activities

## Equipment & services for power generation & rail transport

N°1 worldwide
**in turnkey power plants**

N°1 worldwide
**in hydroelectric**

N°1 worldwide
**in environmental control systems**

N°1 worldwide
**in services for electricity utilities**

N°1 worldwide
**in high speed and very high speed**

N°2 worldwide
**in urban transport (metro and trams)**

***Alstom makes 1 metro in 4 and 1 tram in 3***

***> 76,000 staff in > 70 countries***

Total orders 2007/08 :
€23.5 bn

# Project Overview

- US DOE Program:

  Plants Capture and Emissions Program

- Funding: $6.3MM
  - Cooperative Agreement: September 2008
  - US DOE: 80%
  - Alstom: 20%

- Performance dates:
  - Budget Period 1: Sept '08 - Sept '09
  - Budget Period 2: Oct '09 - Mar '11

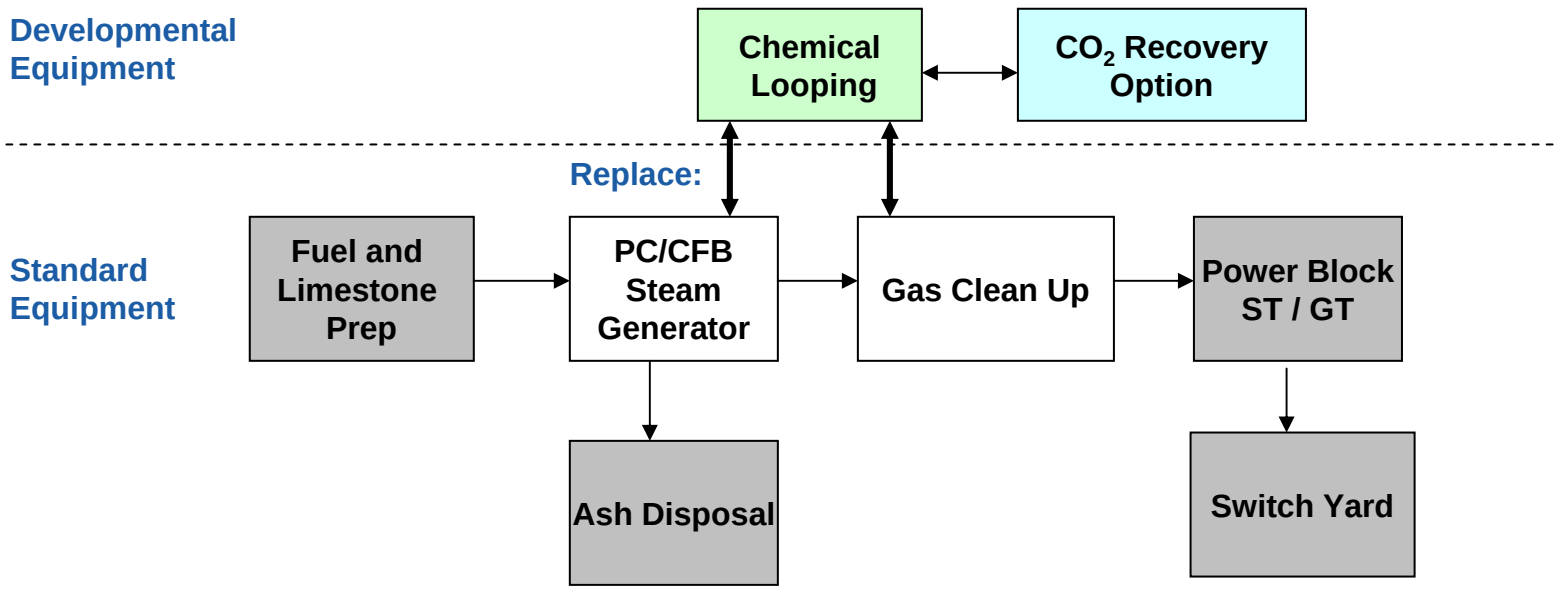
- Project Participants:
  - Alstom
    - PEMM Corp
    - Univ. of British Columbia

## Overall Objective:

Develop, test and commercialize a limestone-based chemical looping system for existing and new pulverized coal-fired power plants, for the following performance:

- Over 90% $CO_2$ capture from Coal
- Less than 20% increase in COE for Existing Coal-fired Plant
- Capital cost – 20% lower than Conventional Boiler Island for new plant (not including $CO_2$ compression)
- Less than $20/ton, avoided cost of $CO_2$ capture (with $CO_2$ compression)

# Chemical Looping Program
## Developmental Status



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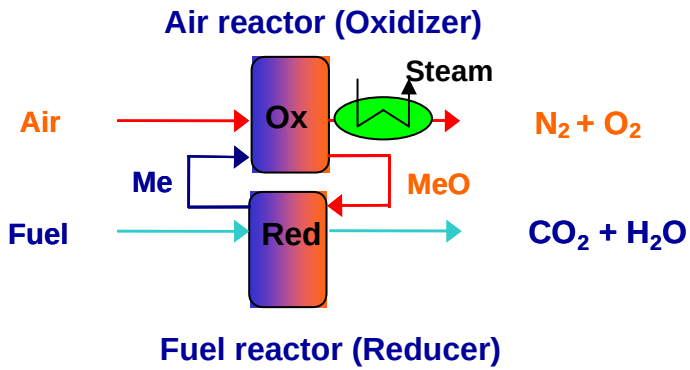
# Chemical Looping Concept

- **Why do it?:** **Lowest Cost Option for Capturing $CO_2$ from Coal**

- **What is it?:** **Oxy-Firing without Oxygen Plant**
  - **Solid Oxygen Carrier Circulates** between **Oxidizer** and **Reducer**
  - **Oxygen Carrier:** Carries Oxygen, Heat and Fuel Energy
  - **Carrier picks up $O_2$** in the Oxidizer, leaves N2 behind
  - **Carrier Burns** the **Fuel** in the Reducer
  - **Heat** produces **Steam for Power**




**METAL OXIDE**

- **Oxygen Carrier:**
  - **Metal Oxide:** Fe, Ni, Mn, Cu…Ores or on Substrates
  - **Limestone-based** carriers

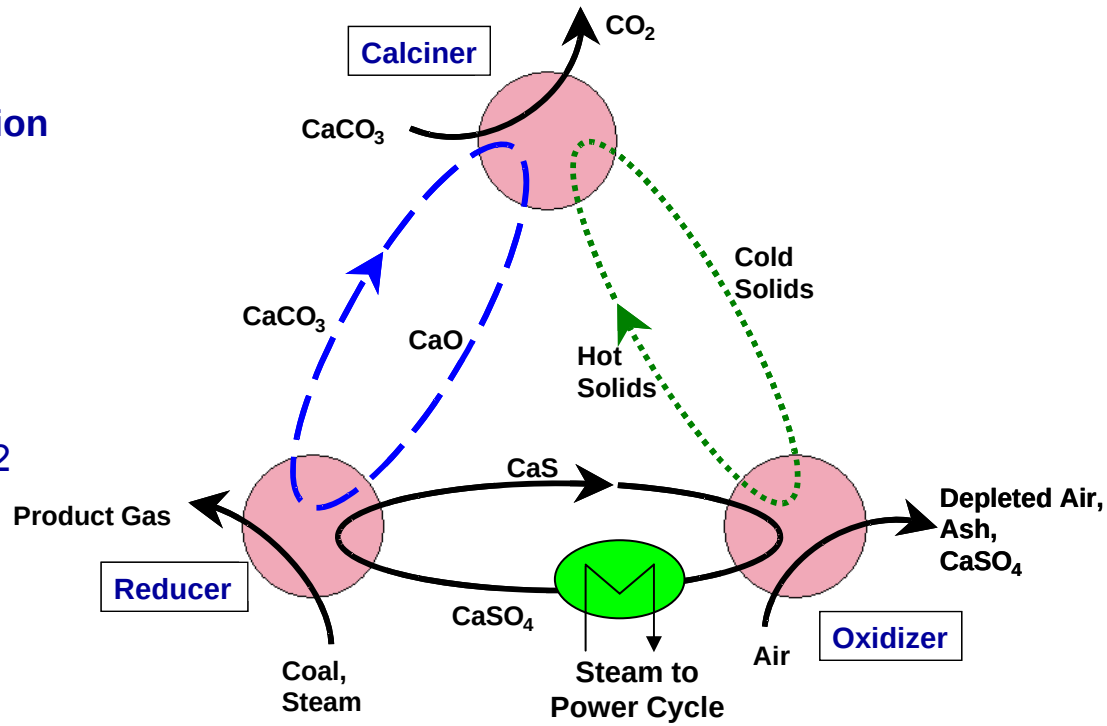
- **Metal Oxides:**
  - Process Development: **CHALMERS UNIVERSITY**
  - Equipment Development: **ALSTOM**

- **Limestone-based:** **ALSTOM**

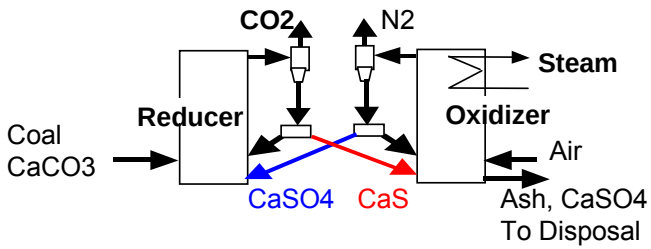
# Chemical Looping Concept

- **Chemical Looping Flexibility**
  - 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
  - Option 3: **Hydrogen Production**
    - Add CaO – $CaCO_3$ Loop to Option 2
    - Add Calciner
    - Product Gas is **Hydrogen**
    - Calciner Off-Gas is **$CO_2$**

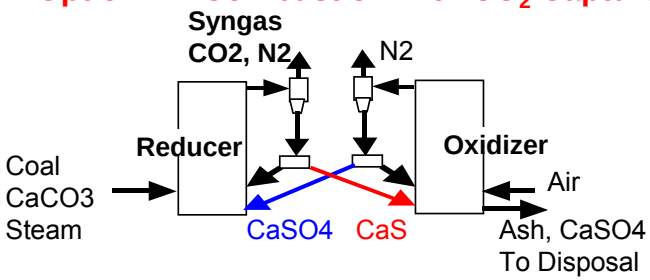
**Limestone-based**



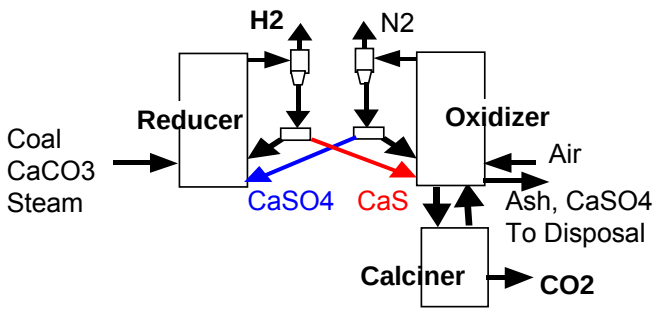
# Chemical Looping
## Options and Applications




**Option 1 – Combustion with $CO_2$ Capture**




**Option 2 – Syngas with no $CO_2$ Capture**




**Option 3 – Hydrogen with $CO_2$ Capture**

## Applications

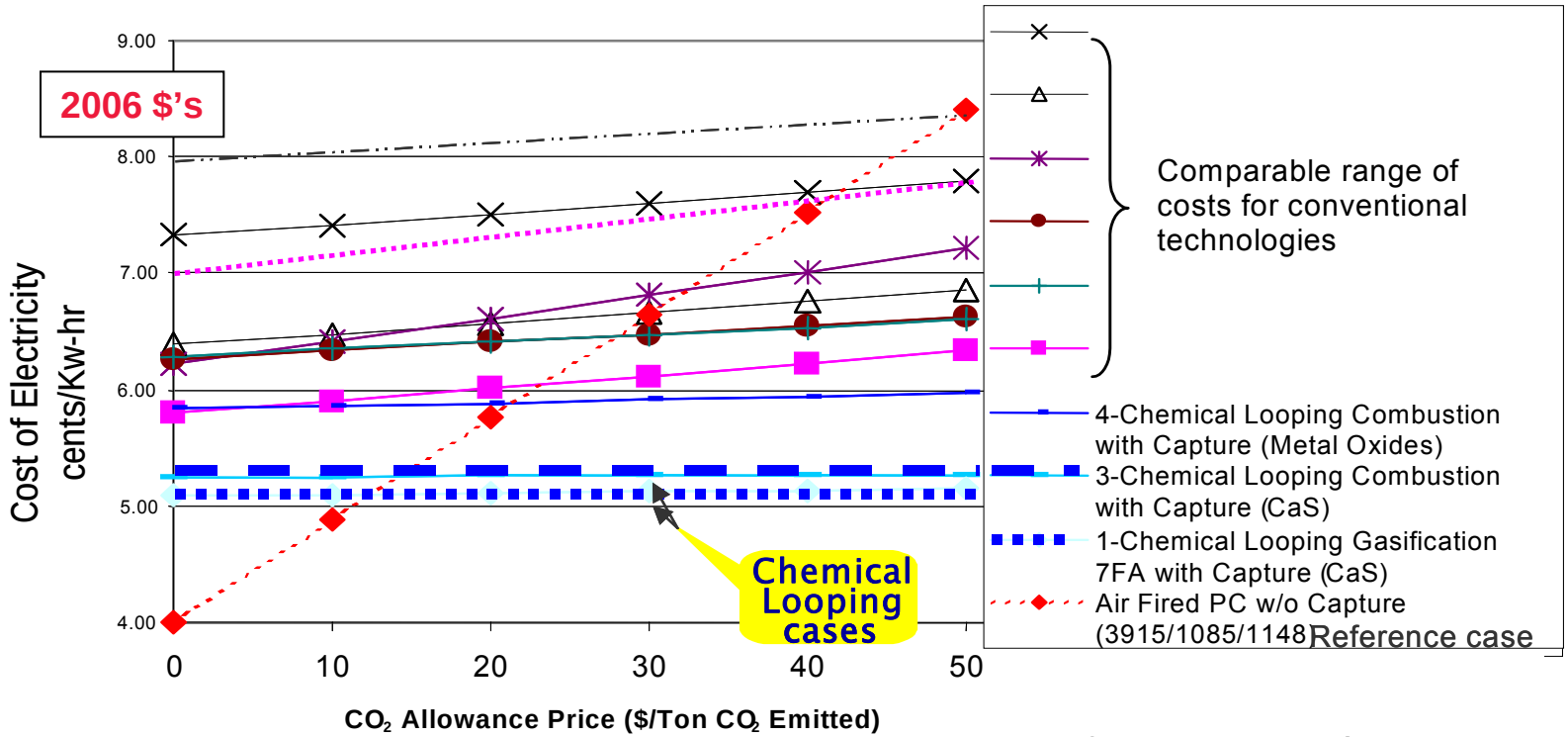
- $CO_2$ Capture - PC/CFB Retrofit
- $CO_2$ Capture - Ready Power Plant
- Advanced Steam Cycles

- IGCC with Downstream $CO_2$ Capture
- Industrial SynGas
- Coal-to-Liquid Fuels

- $CO_2$ Capture - PC/CFB Power Plant
- $CO_2$ Capture - Ready PC/CFB Power Plant
- Advanced Steam Cycles
- IGCC with $CO_2$ Capture
- Fuel Cell Cycles
- Industrial Hydrogen, $CO_2$

- **Lowest Cost $CO_2$ Capture Option**
- **Competitive with or without $CO_2$ Capture**

# CO2 Capture in Power Plants
## Relative Economics




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%

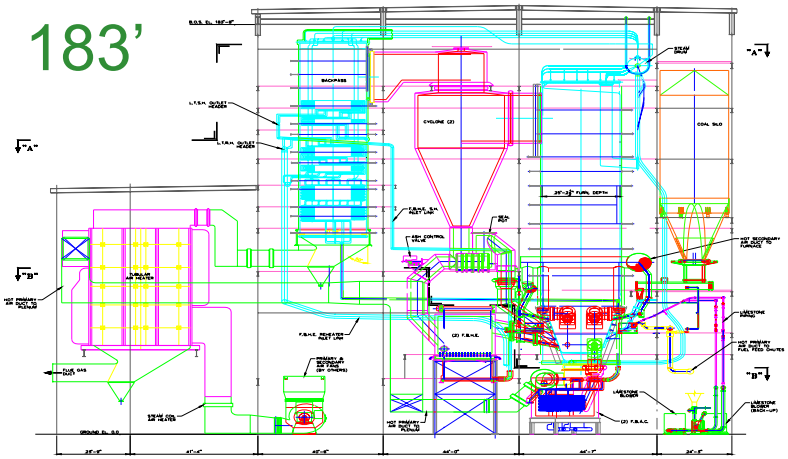
**Reference: DOE GHG Phase I, Bozzuto, et.al, Alstom Power, 2003**

**Chemical Looping CO2 Avoided Cost: $11-13/ton of CO2**

# Significant Volume & Weight Reduction

## Air Fired CFB

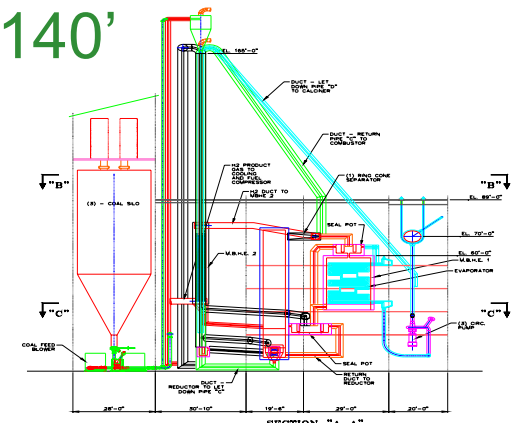
183’



220’

## Chemical Looping Plant

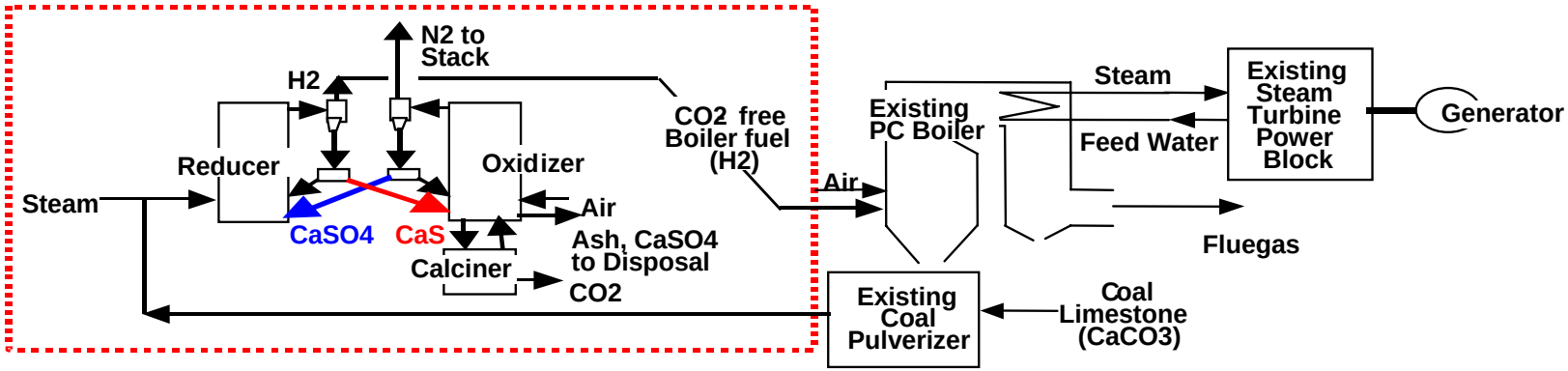
140’



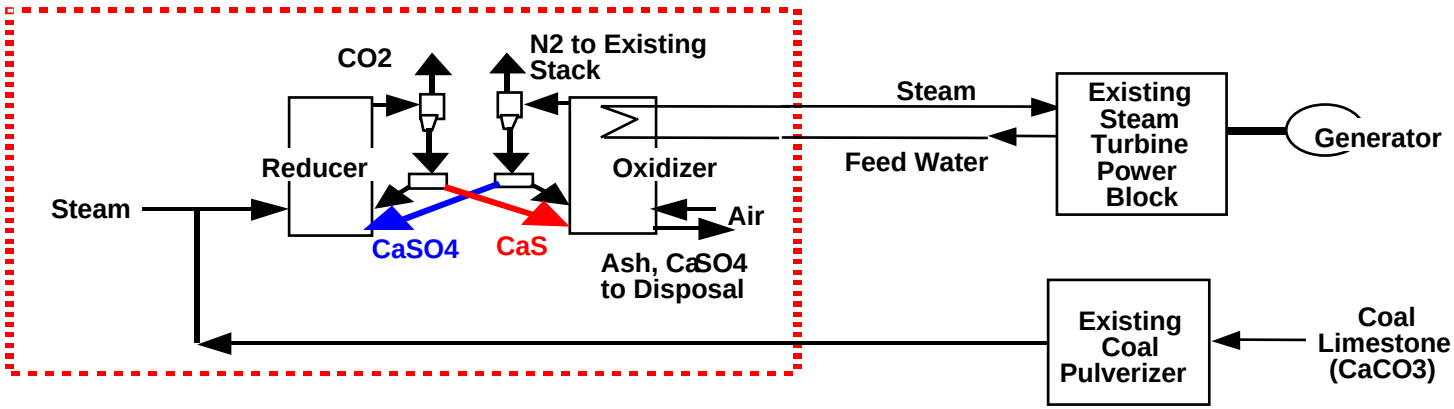
127’

| | | |
|---|---|---|
| Building Volume | 100% | 48% |
| Boiler/Gasifier Weight | 100% | 65% |

## Pulverized Coal Power Plant - Retrofit Concepts



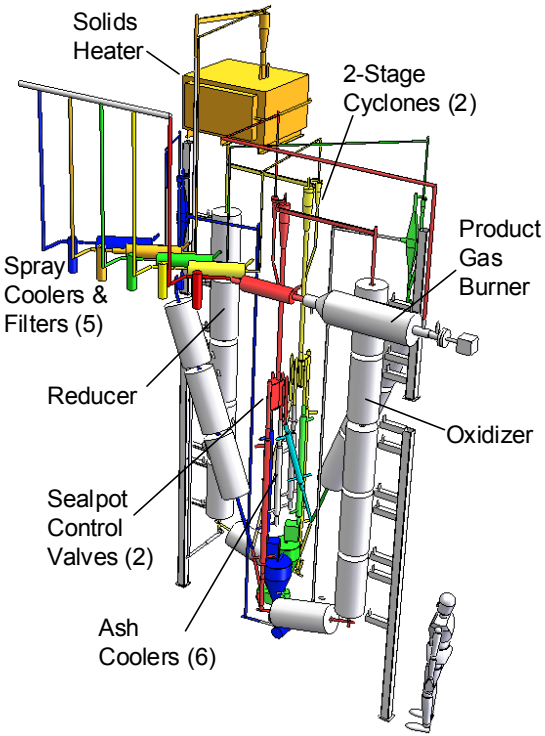

**Concept 1 – Chemical Looping – $CO_2$ Free Fuel; Minimum Boiler Modification**



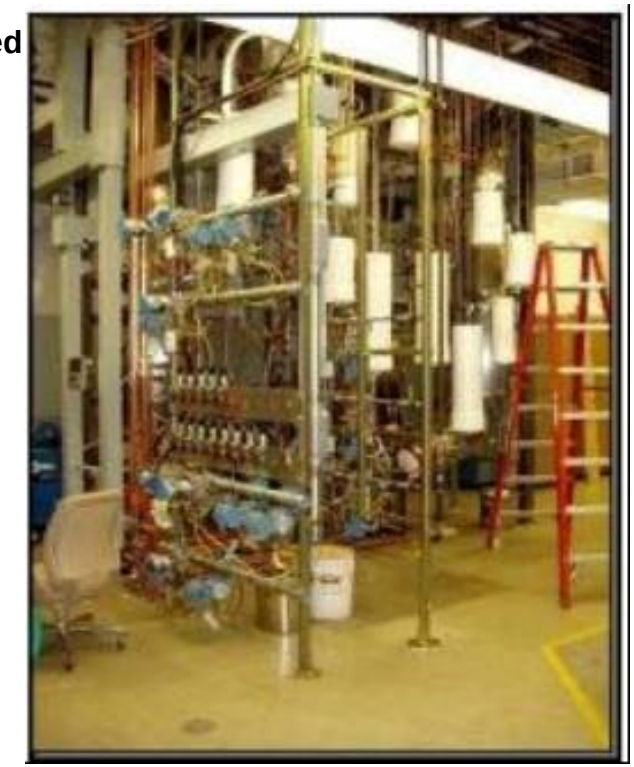

**Concept 2 – Chemical Looping Oxidizer Replaces / Modifies Boiler**

# Chemical Looping Pilot Plant

## Alstom's Chemical Looping Pilot Facility (65 kWt)

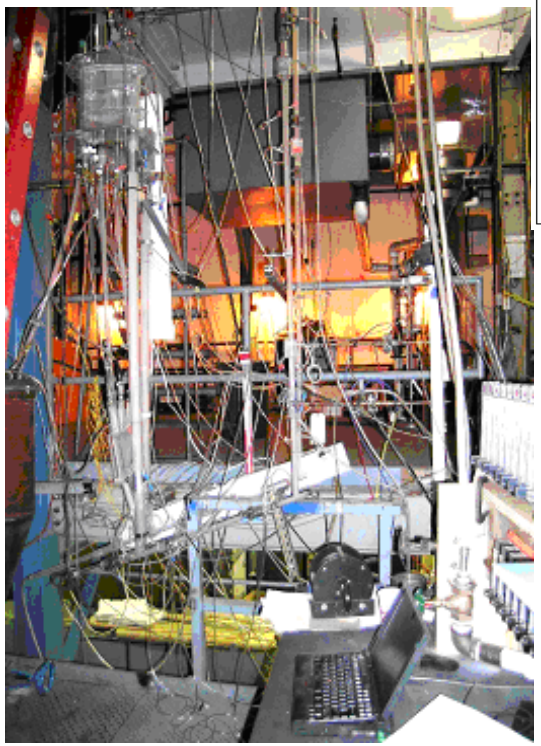


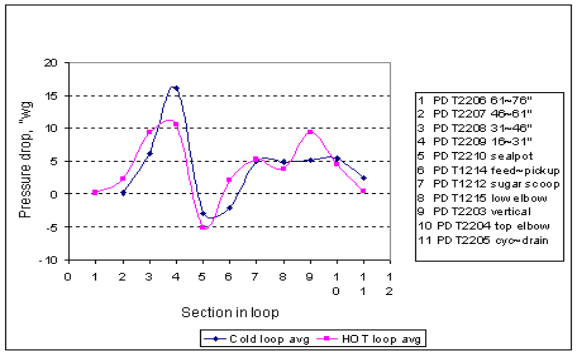

- **Designed and Built by Alstom**
- **Allows Testing of Individual Loops and Processes**
- **3 Year Successful Test Program – Completed**
- **All Chemistry/Rates Verified**
- **Phase 3 - Pilot Plant**
  - **Two Exhaust Fans/Stacks**
  - **Automatic Solids Transport Controls**



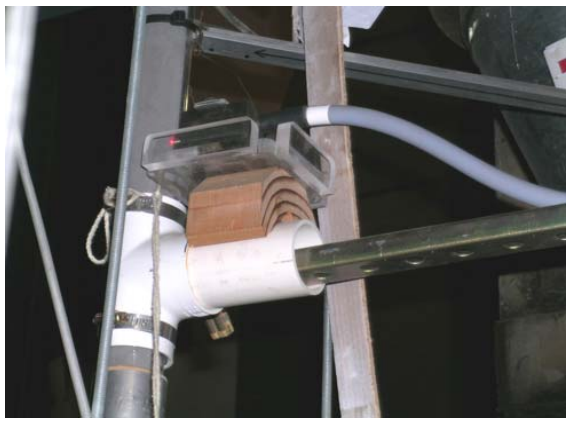
# Chemical Looping
## Cold Flow Model

### 15 Foot Model





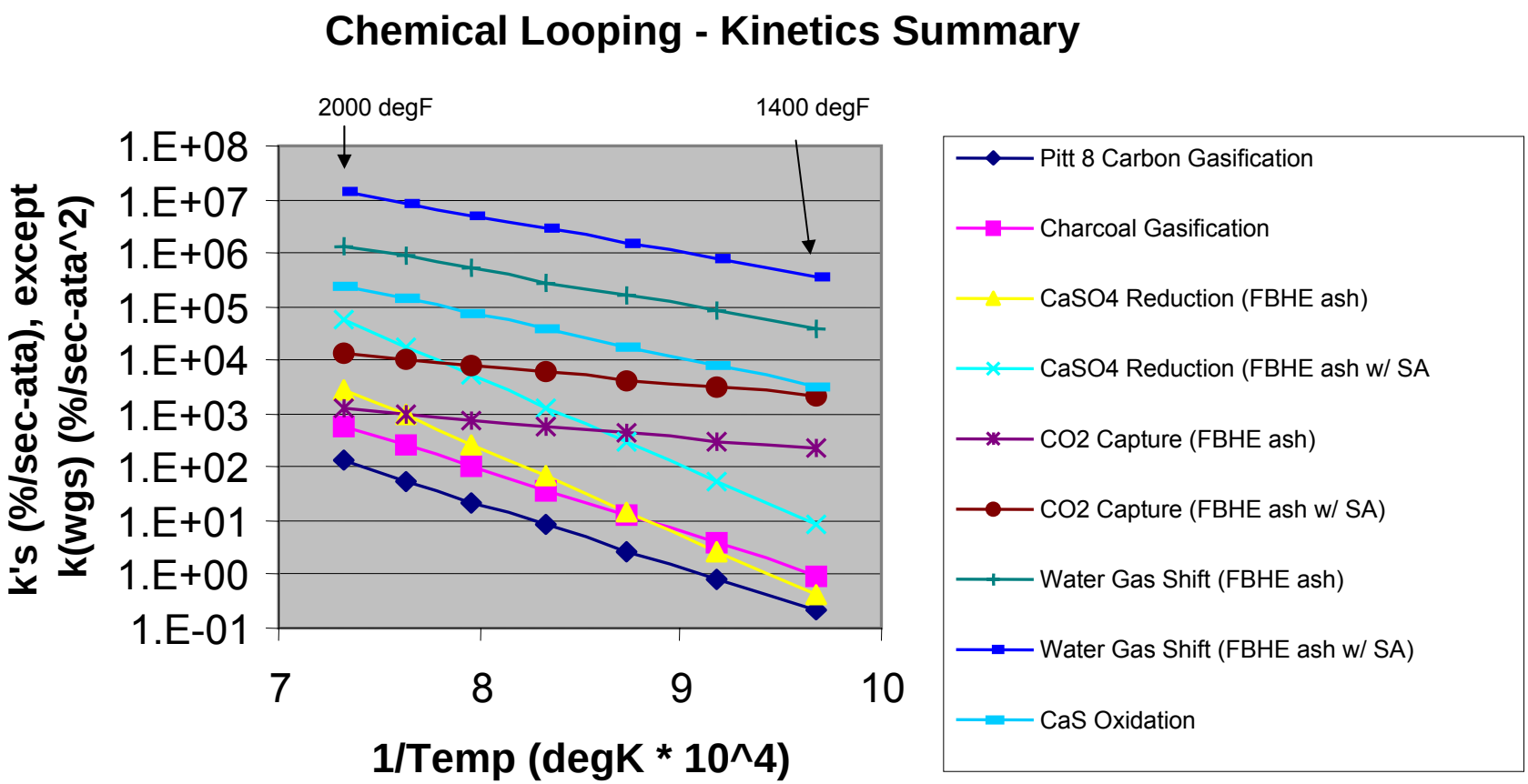

### Laser Solids Velocity Probe



### 40 Foot Model

## Cold Flow Model – Flow Stability, Scale-up

# Chemical Looping Kinetics




**Kinetic Rates exceed Design Requirements**

# US DOE Phase I, II, III - Accomplishments

- All Milestones Successfully Completed – On-time, On-budget
- Pilot Testing (65 kWt) – Successfully Complete
- 15-foot Cold Flow Model testing completed – Stable Solids Transport achieved
- 40-foot Cold Flow Model – Stability achieved, Scaleup verified
- Internal and ASME/US DOE Peer Reviews Successfully completed
- Alstom's Phase IVA - Prototype (3 MWt):
  US DOE Cooperative Agreement - Sept, 2008

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# Chemical Looping Prototype
## Phase IVA

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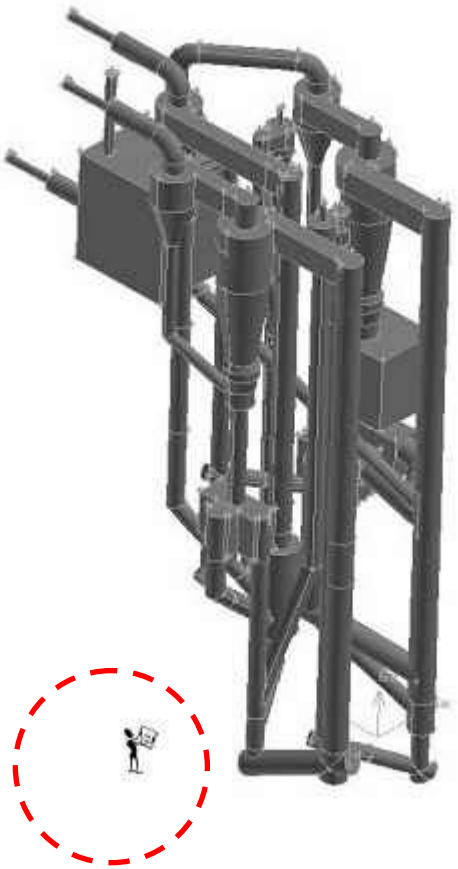
## Chemical Looping 3 MWt Prototype Facility
## Preliminary Concept



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

### Phase IV Objective:

**Obtain the engineering and operating information required to build and operate a reliable, commercial-size demonstration plant.**

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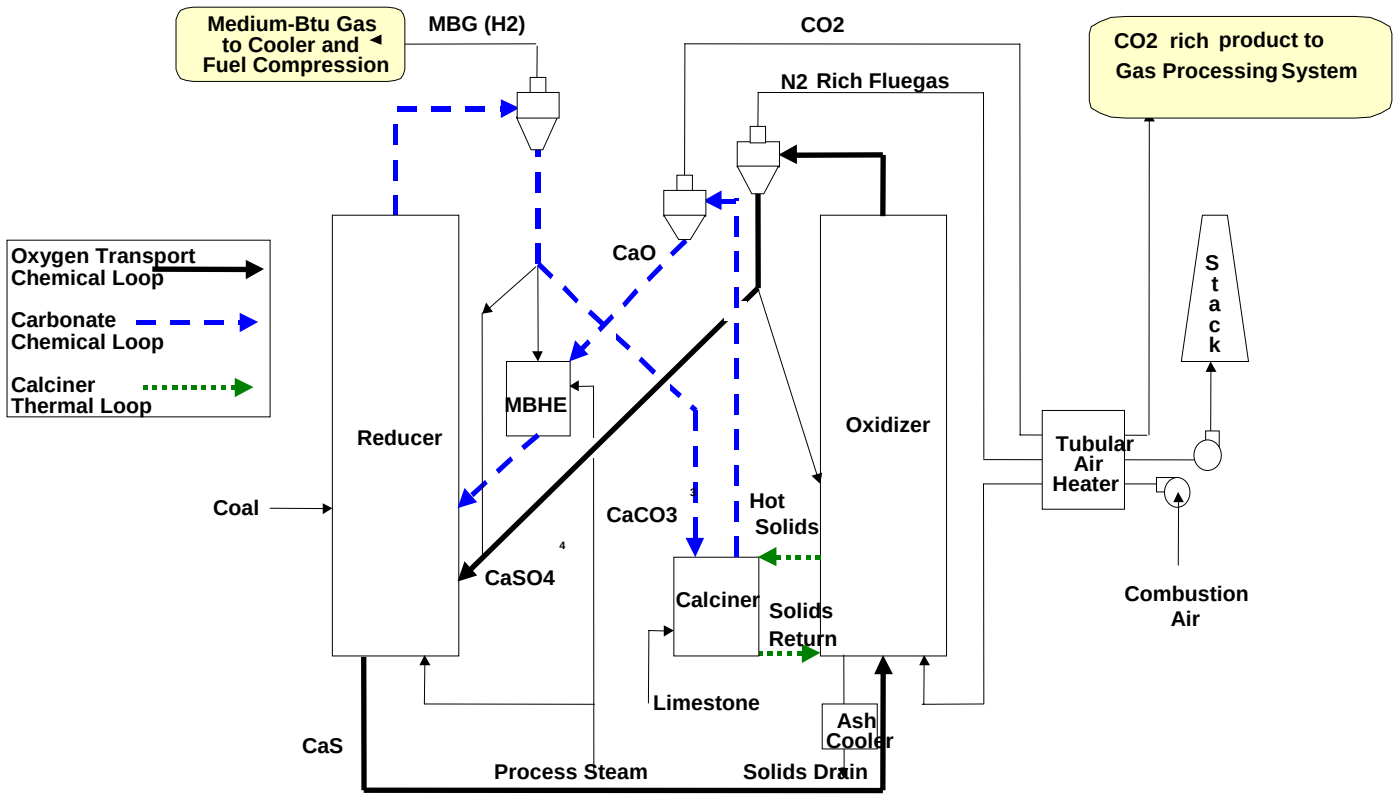
# Phase IVA – Prototype Concept

- **Prototype Location – Alstom Power, Windsor, CT.**
  - **All Equipment Necessary for Viable Demo Design**
  - **1000 lb coal / hr – Combustion, Syngas, Hydrogen**
  - **Design, Construction, Operation, Maintenance, Modification by Alstom**



# Chemical Looping Development - Phase IVA

## Solids Transport Testing

- Prototype Cold Flow Model (CFM)
  - Startup and operating methods
  - Identify/Solve critical technical aspects
  - Improve plant arrangement
  - Assist cost study
- High Solids Load Tests in 40-ft CFM
  - Solids/gas Transport design tool
  - Quantify the key parameters in this region

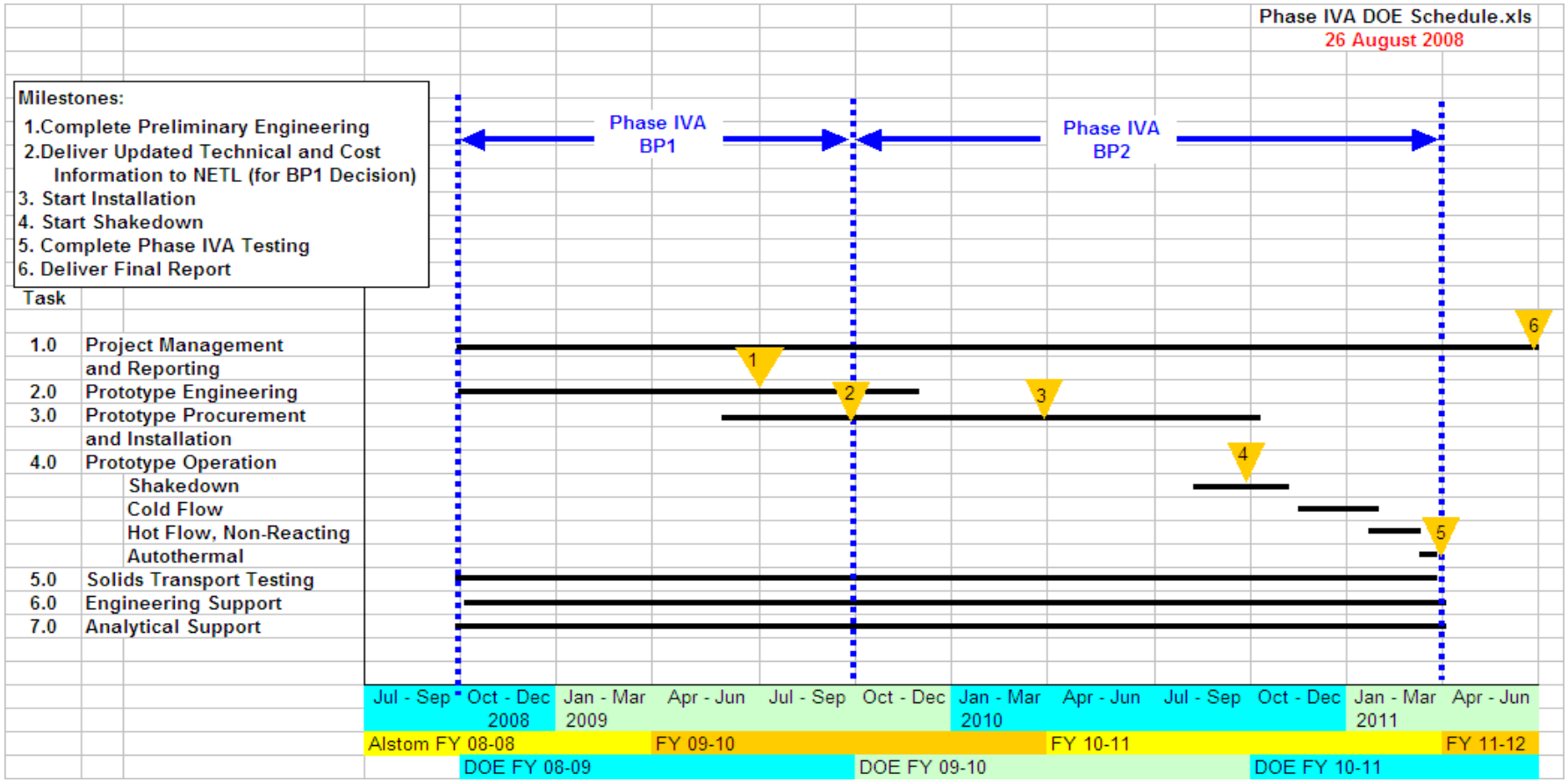
# Chemical Looping Development – Phase IVA

## Design/Build/Test Program

- Small-scale Cold Flow Modeling
  - Vessels scaled from the Prototype plant design
  - Control and distribution of solids/gas flow
  - Startup procedures
  - Identify critical areas (*e.g*. erosion, control) for the prototype plant design
  - Prototype operator training
  - Prototype solids transport problem solving

- Design/Test Prototype plant
  - Complete the design tools for the prototype plant
  - Complete the prototype sizing and selections for all vessels
  - Prototype Operation/Testing/Modification/Development
  - Update commercial economics analysis and specs recheck

# Prototype Schedule



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# Chemical Looping Development

## Phases IV, V, VI

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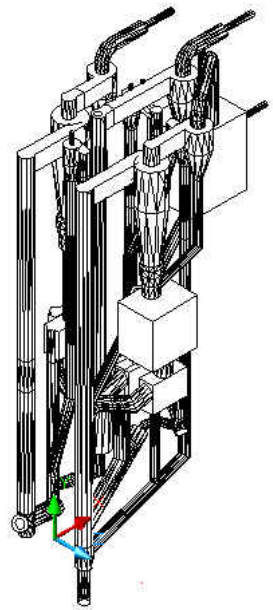
**Master Schedule**

Master Schedule-3.xls

| PHASE | | TASKS | Year | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Studies/benc | Test | | ← | | | | | | | | | | | | | | | | | |
| 0 | PDU | EPC | | | — | | | | | | | | | | | | | | | | |
| I | PDU | Test CaS - CaSO4 | | | | — | — | | | | | | | | | | | | | | |
| II | PDU | Test WGS H2 w/ de CO2 | | | | | — | ··· | | | | | | | | | | | | | |
| III | Pilot | EPC | | | | | | · — | | | | | | | | | | | | | |
| | | Test | | | | | | | — | — | | | | | | | | | | | |
| IV | Prototype | EPC | | | | | | | | ···— | — | | | | | | | | | | |
| | | Test | | | | | | | | | | —··· | | | | | | | | | |
| V | Demo | Preliminary Engineering | | | | | | | | | | | ···— | | | | | | | | |
| | | EPC | | | | | | | | | | | | — | — | — | | | | | |
| | | Operations | | | | | | | | | | | | | | — | — | — | | | |
| VI | Commercial | EPC | | | | | | | | | | | | | | | | ···— | — | — | |
| | | Operations | | | | | | | | | | | | | | | | | | | → |

Phase IV
Decision points

## Prototype
(1000 lb/coal/hr)



# Chemical Looping Development Plan

- Demonstration Plant – Phase V:
  - Objective: Demonstrate Reliability and Performance
  - Electric Utility Sponsor/Existing site – locate during Phase IV
  - 50 to 100 MWe

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