Alstom's Calcium Oxide Chemical Looping Combustion Prototype Development

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R&D Meeting
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Pittsburgh PA.

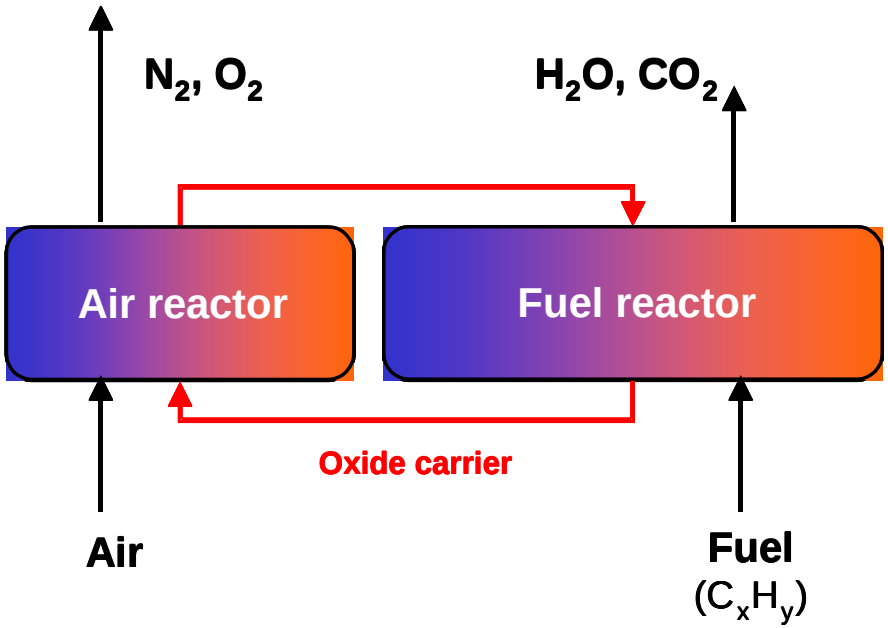
ALSTOM

Alstom Power Inc.
Chemical Looping Development

Over-all Objective:

- **New and Retrofit Application**
- **Over 90% CO2 capture**
- **Less than $20/ton of CO2 avoided**
- **Capital cost – 20% lower than Conventional Boiler Island (without CO2 capture)**
- **Retrofit to Existing Coal-fired Plants with < 20% increase in COE**
- **Medium Btu gas or Hydrogen without Oxygen Plant**

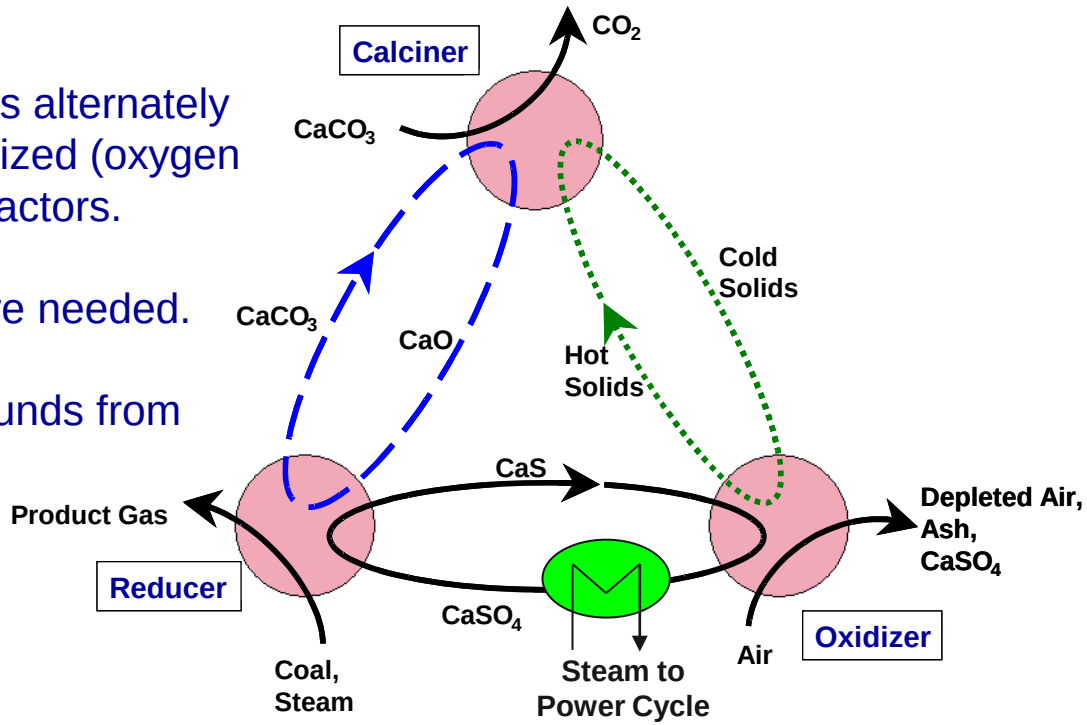
Chemical Looping Principle



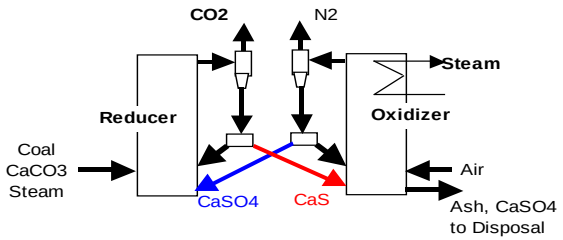
Alstom's Chemical Looping Concept

Why do it? To Capture CO_2, at Lowest COE

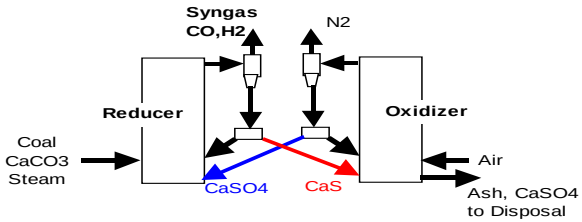
- Coal is indirectly combusted or gasified by hot oxygen carrying reactant.
- The Reactant is not consumed and is alternately reduced (oxygen removed) and oxidized (oxygen replenished) as it cycles between reactors.
- The Reactant also carries heat where needed.
- In Alstom's process, calcium compounds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



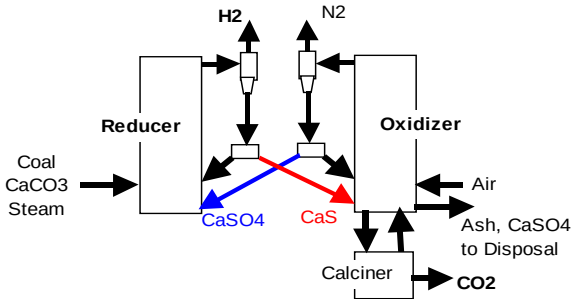
Chemical looping Process: Options and Applications



Option 1 – Combustion with CO2 Capture



Option 2 – Syngas with no CO2 Capture



Option 3 – Hydrogen with CO2 Capture

Applications

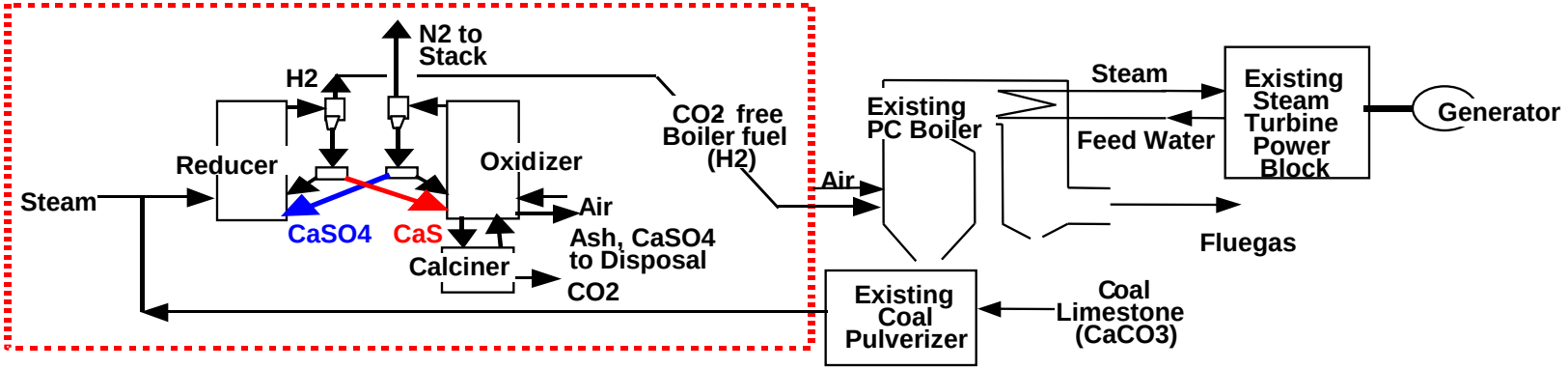
- CO2 Capture – PC Retrofit
- CO2 Capture – CFB Retrofit
- CO2 Capture-Ready Power Plant
- Advanced Steam Cycles

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

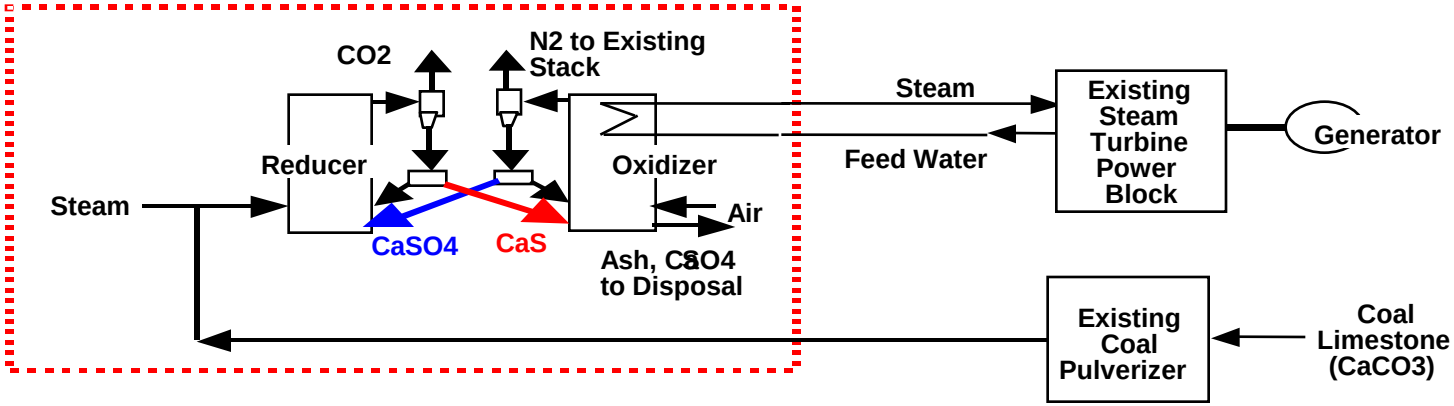
- CO2 Capture – PC Retrofit
- CO2 Capture – CFB Retrofit
- CO2 Capture-Ready PC/CFB Power Plant
- Advanced Steam Cycles
- IGCC with CO2 Capture
- Fuel Cell Cycles
- Industrial Hydrogen, CO2

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

Chemical looping Process:
PC Power Plant - Retrofit Concepts

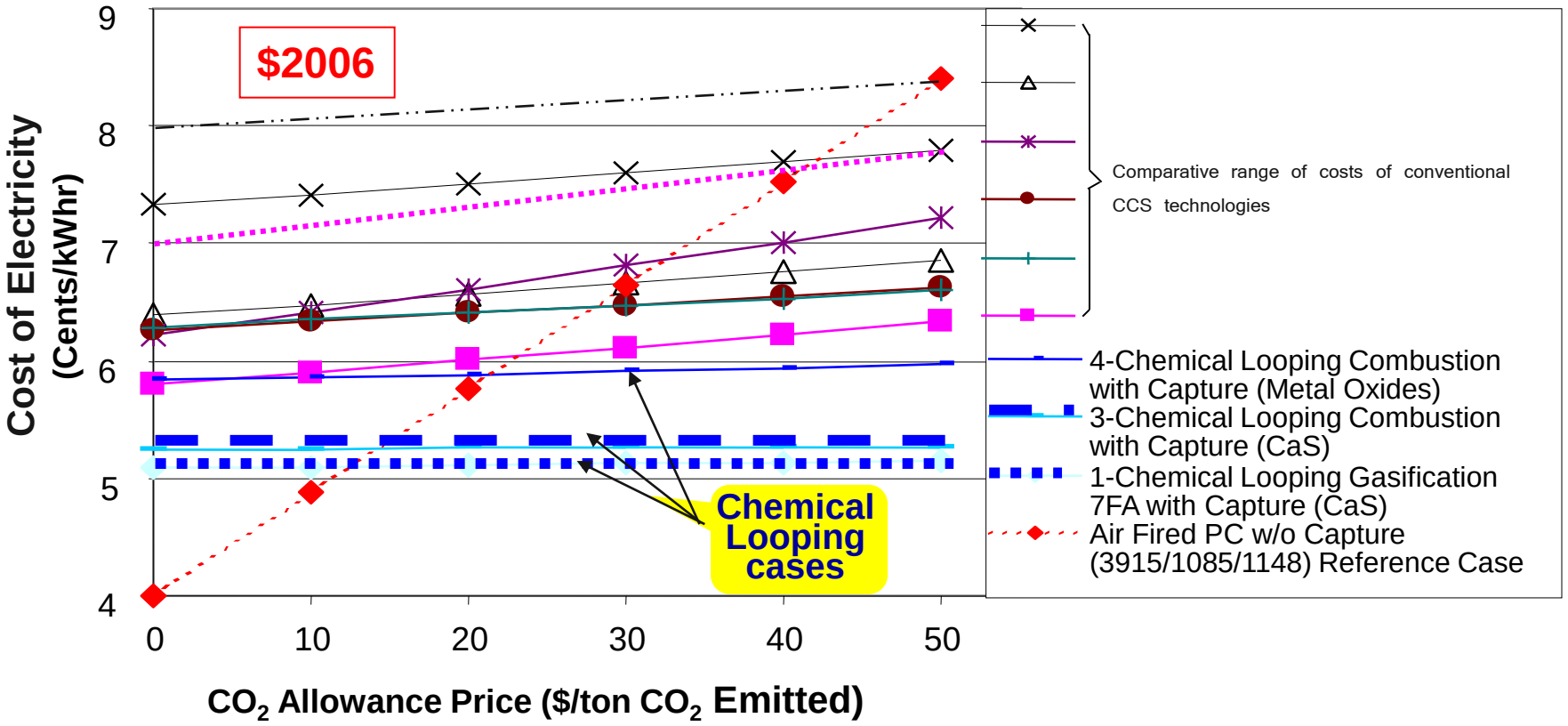


Concept 1 – Chemical Looping – CO2 Free Fuel; Minimum Boiler Modification



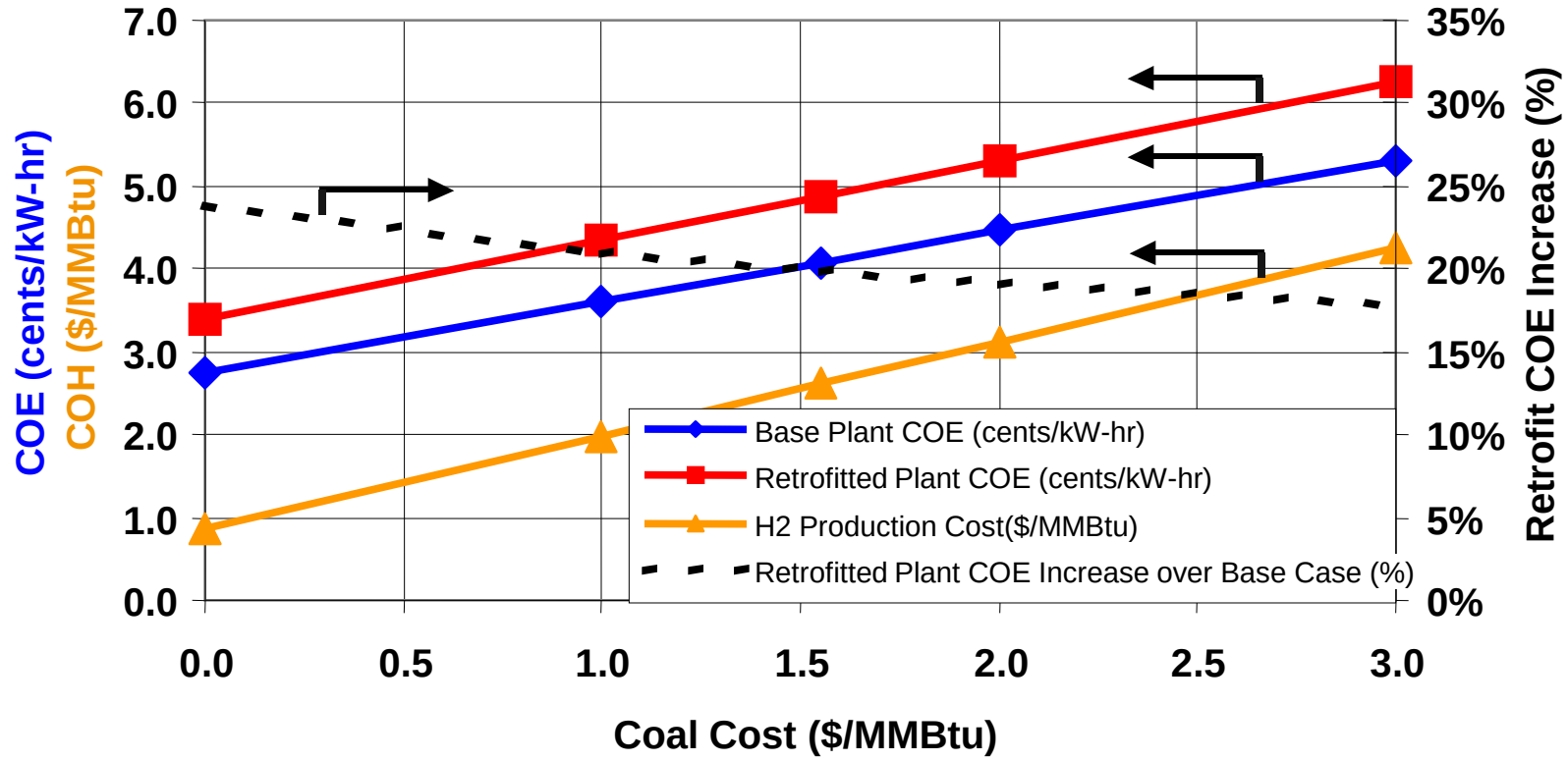
Concept 2 – Chemical Looping Oxidizer Replaces / Modifies Boiler

ALSTOM's Chemical Looping New Capacity Economics



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

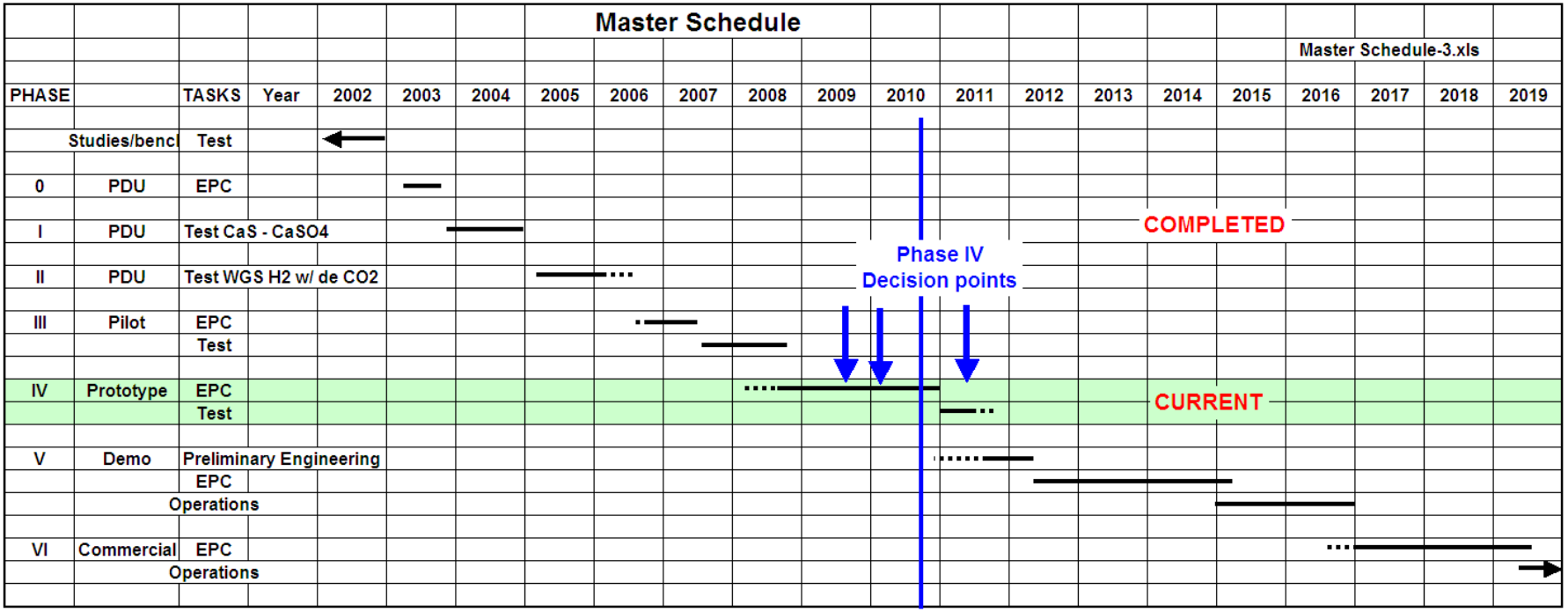
ALSTOM's Chemical Looping Economics for Retrofit Application



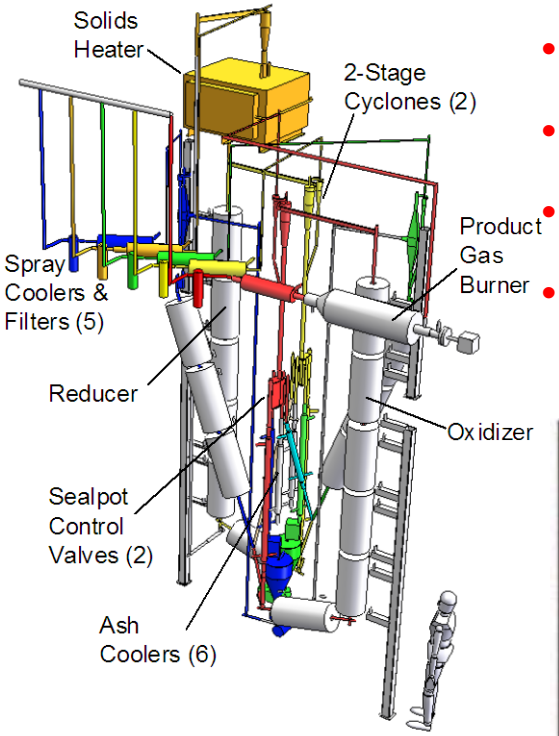
US DOE Goal < 35% COE Increase for CCS

Chemical Looping Development
Phases IV, V and VI

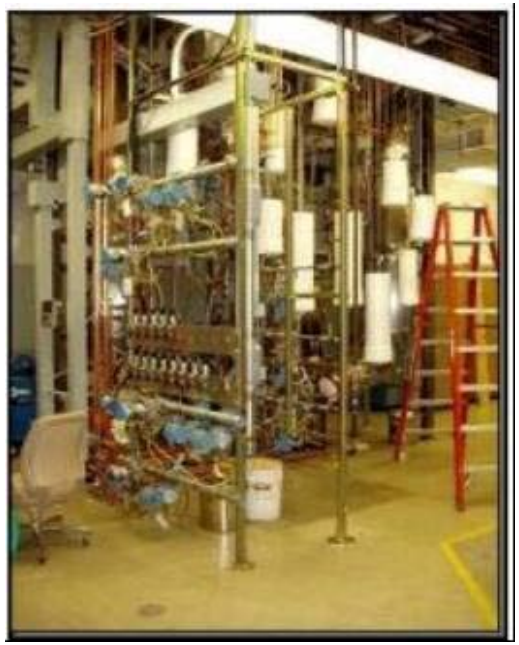
Master Schedule-3.xls
as of 12 Sept 2010



Chemical Looping Pilot Plant 65 kWt

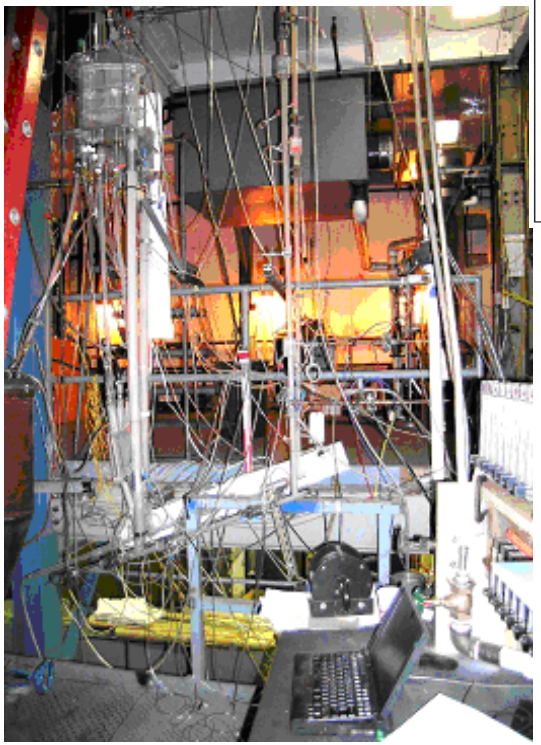


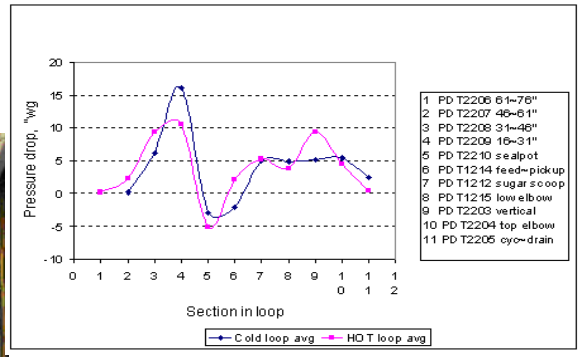
- **Designed and built by Alstom**
- **Allows testing of individual loops and processes**
- **3 year successful test program – Completed**
- **All chemistry / rates verified**
- **Phase 3 - Pilot Plant**
  - **Two exhaust fans / stacks**
  - **Automatic solids transport controls**



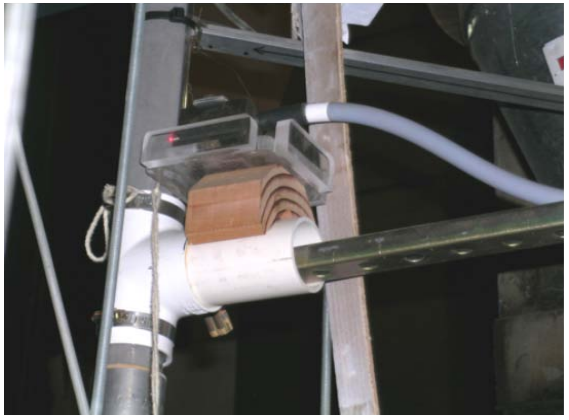
Chemical Looping
Cold Flow Model

15 Foot Model





Laser Solids Velocity Probe



40 Foot Model

Cold Flow Model – Flow Stability, Scale-up

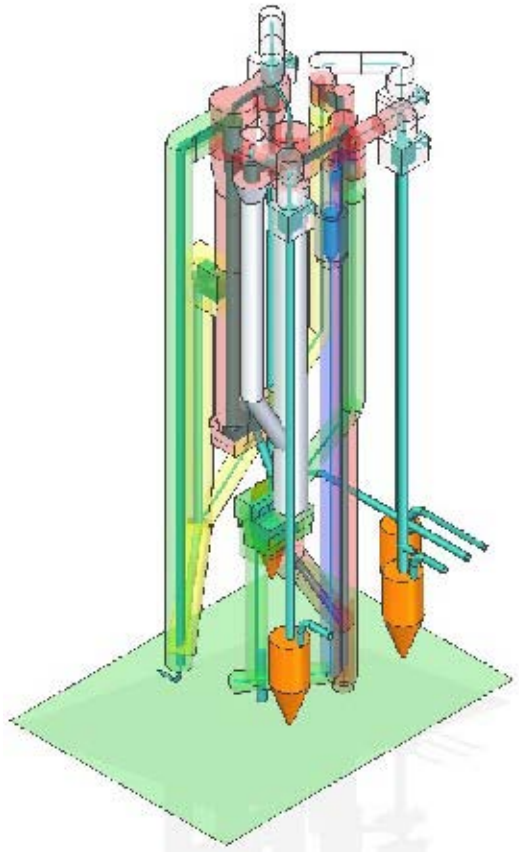
Phase I, II, III - Accomplishments

- 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
- Alstom's Phase IVA - Prototype (3 MWt)
- US DOE Cooperative Agreement – Sept., 2008

Phase I, II, III - Highlights

- Validation of Chemical Looping reactions.
- Simultaneous and smooth operation of four solids transport loops.
- Multi-loop control requirements established.
- Demonstrated start-up, shut-down, and emergency quick shut-down and restart.
- Transport of four different solids types.
- Solids flow scale-up from 3/4” to 4 “ diameter reactor.
- Prototype 3 MWt specification developed.

Chemical Looping Prototype
Phase IVA



Chemical Looping 3 MWt Prototype Facility
Preliminary Concept

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

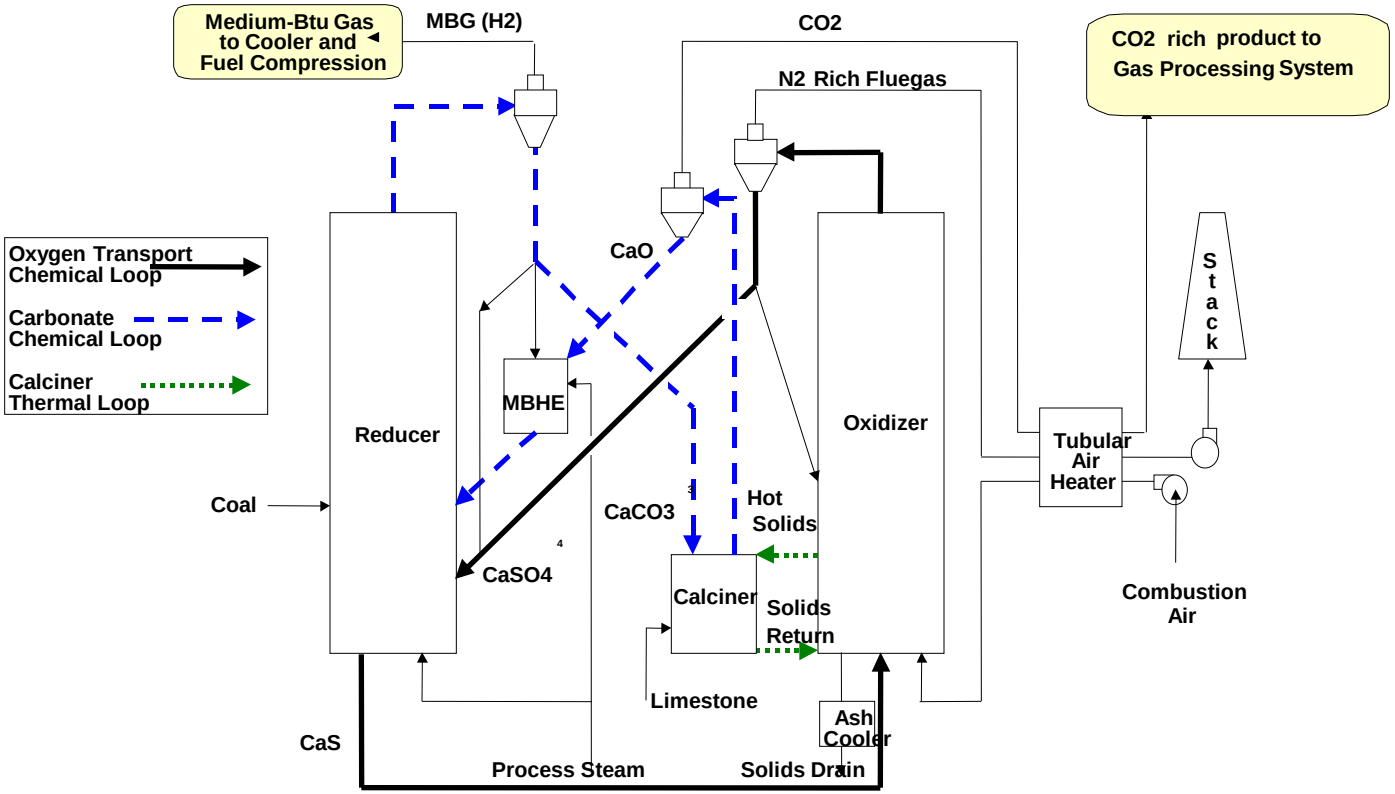
Phase IV Objective:

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

Prototype:

- Location – Alstom Power, Windsor, CT
- All Equipment necessary for viable Demo Design
- Design, construction, operation, maintenance, modification by Alstom

Chemical Looping Prototype
Phase IVA Concept



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

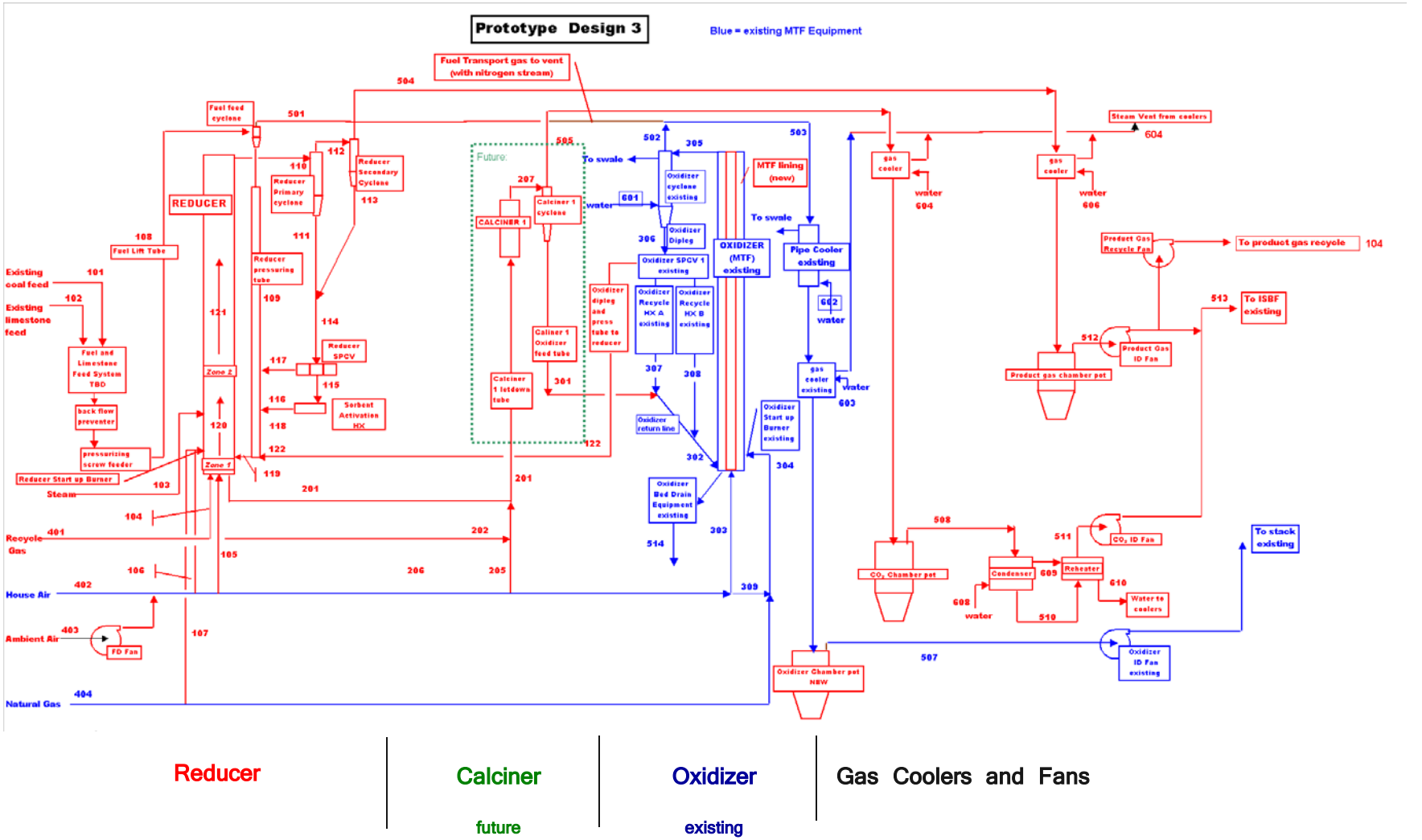
Chemical Looping Development – Phase IVA Design/Build/Test Program

- Small-scale Cold Flow Modeling
  - Vessels scaled from the Prototype plant design
  - Control and distribution of solids/gas flow
  - Startup and Shutdown procedures
  - Identify critical areas (e.g. flow stability, erosion)
  - Prototype operator training
  - Prototype solids transport problem solving
- Design/Test Prototype plant
  - Complete the design tools for the prototype plant
  - Complete the prototype engineering and design for all vessels
  - Prototype Operation/Testing/Modification/Development
  - Update commercial economics analysis and specs recheck

Chemical Looping Development – Phase IVA Work Completed

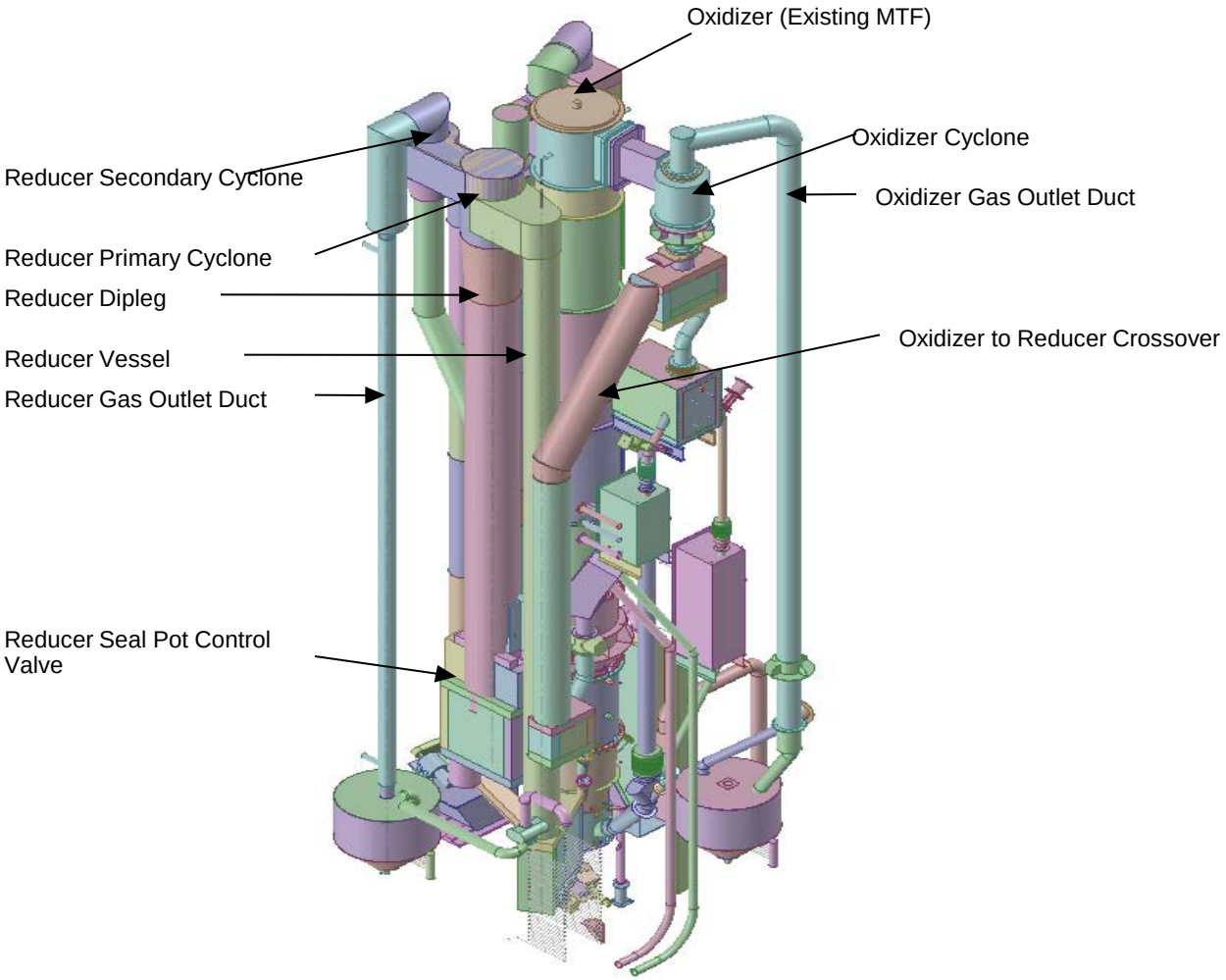
- Preliminary Process Flow Diagram (PFD) and material balance
- Heat loss calculations
- Heat-up rate calculations
- Sizing of critical solids transport control equipment
- Design of the prototype reactors
- Safety requirements
- Control concept
- Concept for startup, shutdown, cold flow testing, hot testing and normal operation
- Piping and Instrumentation Diagram (P&ID)
- Plot plans, equipment and general arrangement drawings
- Specifications for
  - Facilities,
  - Fabricated Equipment,
  - Vendor Equipment,
  - Controls,
  - Gas Analyzer
- Quotes from architect/engineering firms, fabricators and equipment vendors
- A detailed cost estimate

Chemical Looping Prototype
Preliminary PFD

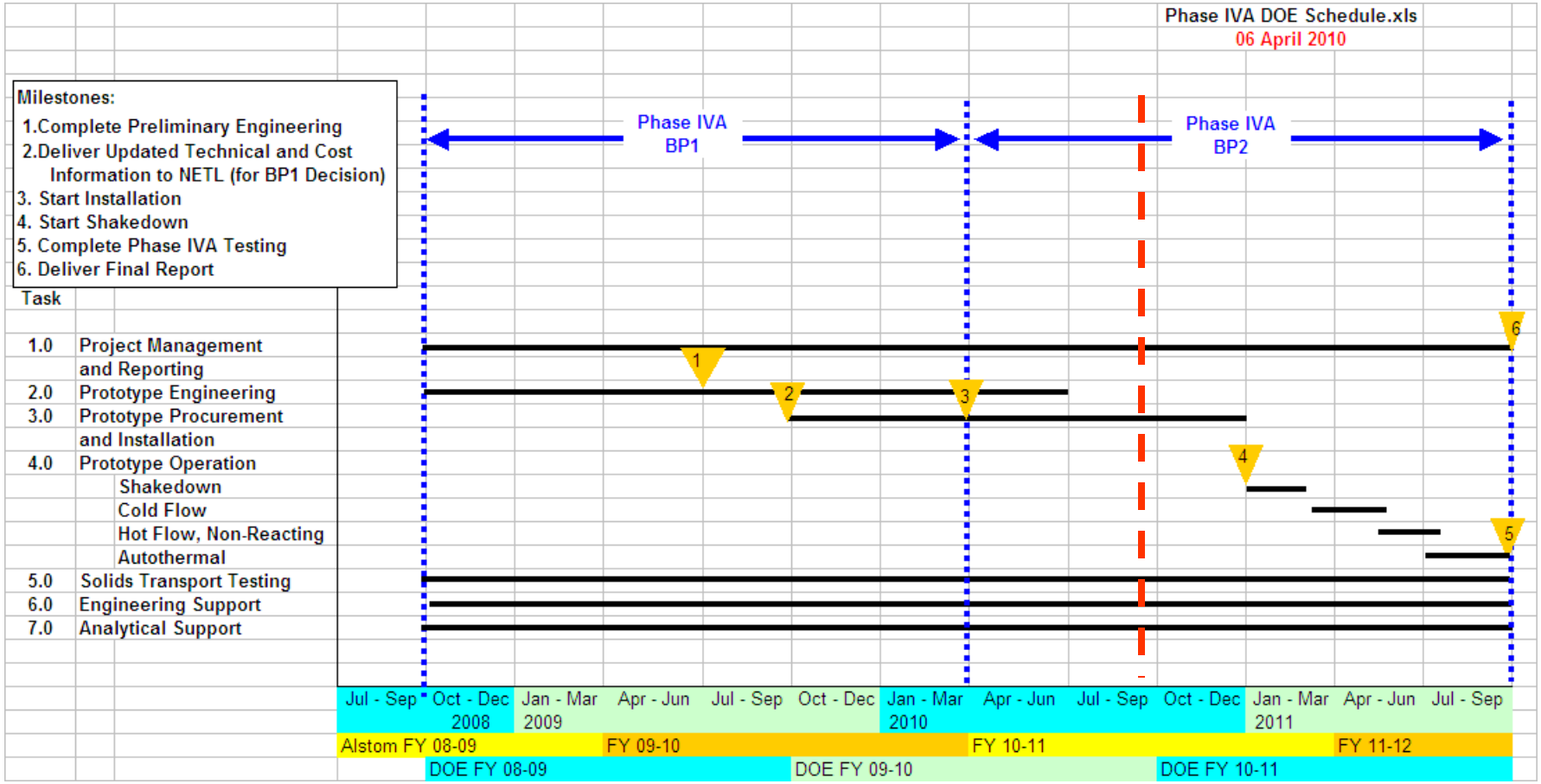


Reducer | Calciner (future) | Oxidizer (existing) | Gas Coolers and Fans

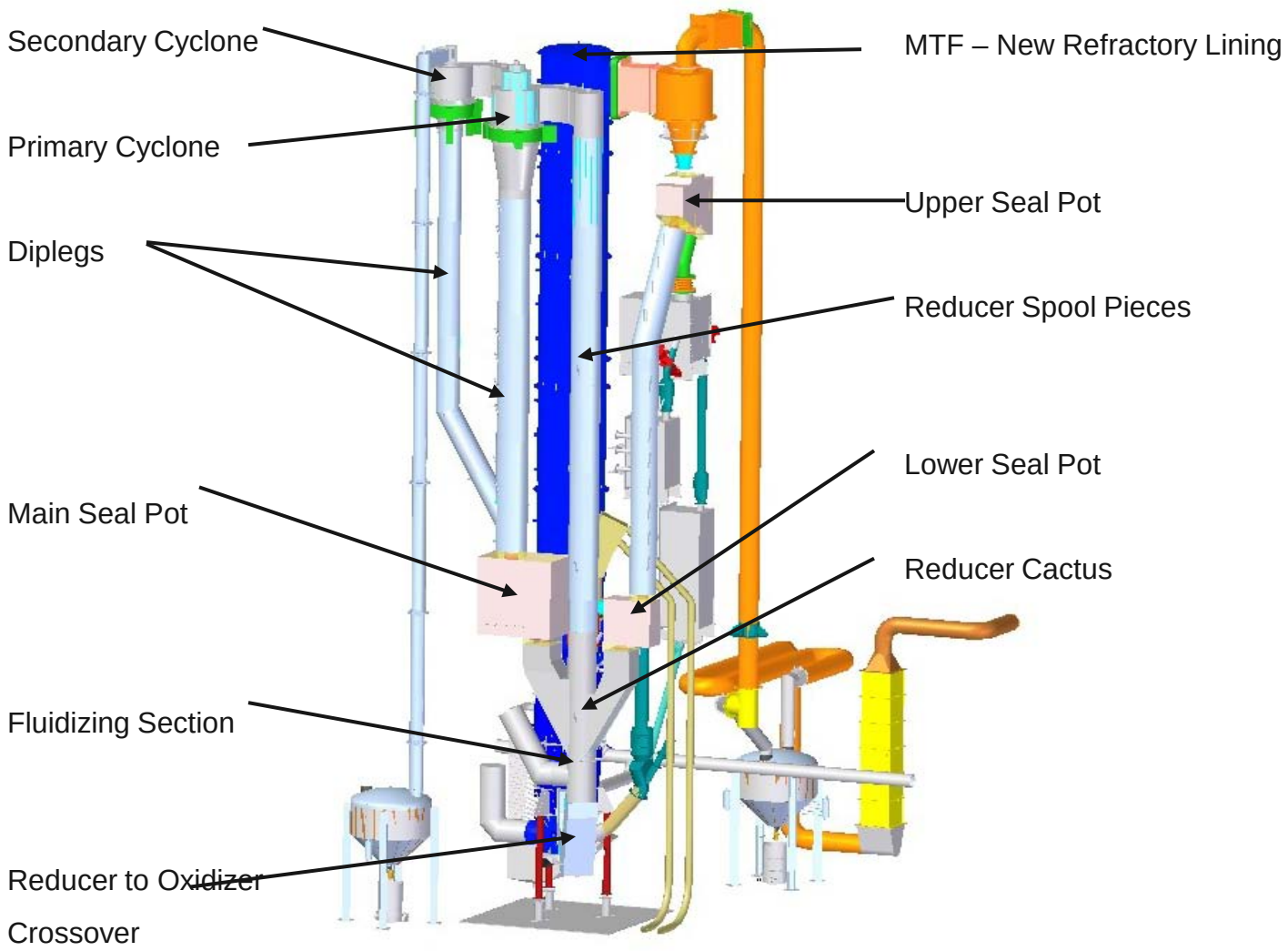
Chemical Looping Prototype
General Arrangement



Chemical Looping Prototype Schedule



Chemical Looping Prototype Component Construction



Chemical Looping Prototype
Cold Flow Model

Cold Flow Model Pieces

Assembling the CFM

Chemical Looping Prototype Component Construction

Cyclones

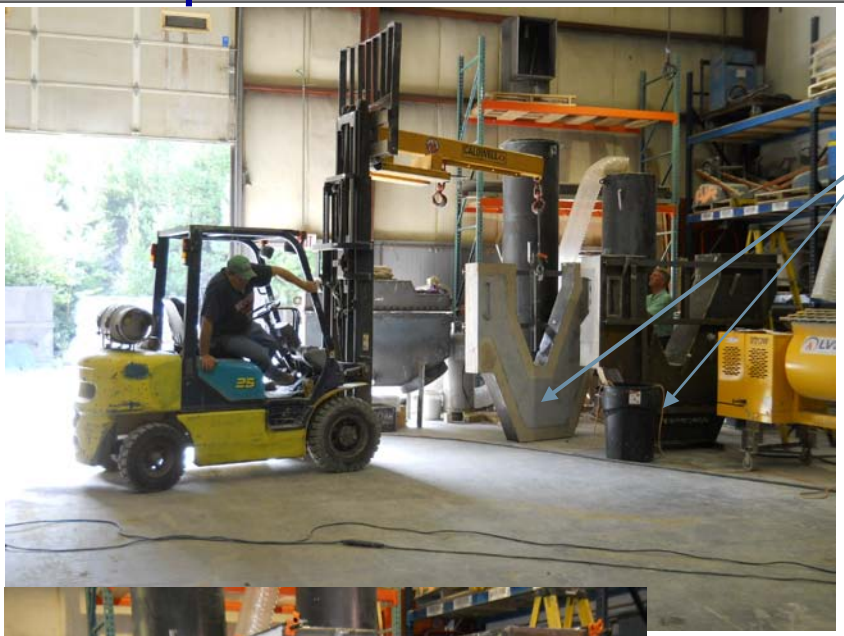
Primary Cyclone Barrel (inverted)

Primary Cyclone cone

Secondary Cyclone Barrel

Secondary Cyclone Cone

Chemical Looping Prototype Component Construction



Reducer to Oxidizer Crossover

(constructed in two halves)

Upper Seal pot

Chemical Looping Prototype Component Construction

Reducer and Dipleg Sections Before Refractory Installation

Chemical Looping Prototype Component Construction

Inside Reducer Section before Refractory Installation

Reducer and Dipleg Sections Lined up for Refractory Installation

Chemical Looping Prototype Component Assembly

'Cactus'
Lifted to
Position
In the Structure

'Cactus' with Fluidizing Section and Seal Pot Connections
Assembled on Ground Level

Chemical Looping Prototype Component Assembly

Main Seal Pot Before lift into Place

Chemical Looping Prototype Component Assembly

Reducer (at top of Cactus)

Chemical Looping Prototype
MTF New Refractory Lining

Top of MTF

Outlet to

Cyclone

Chemical Looping Prototype

Acknowledgement

- US DOE NETL

www.power.alstom.com