

Alstom's Chemical Looping Combustion Coal Power Technology Development Prototype

Iqbal Abdulally - Alstom Power Inc.

Herb Andrus - Alstom Power Inc.

Paul Thibeault – Alstom Power Inc.

John Chiu - Alstom Power Inc.

1st International Chemical Looping Conference
Lyon, France
17-19 March 2010

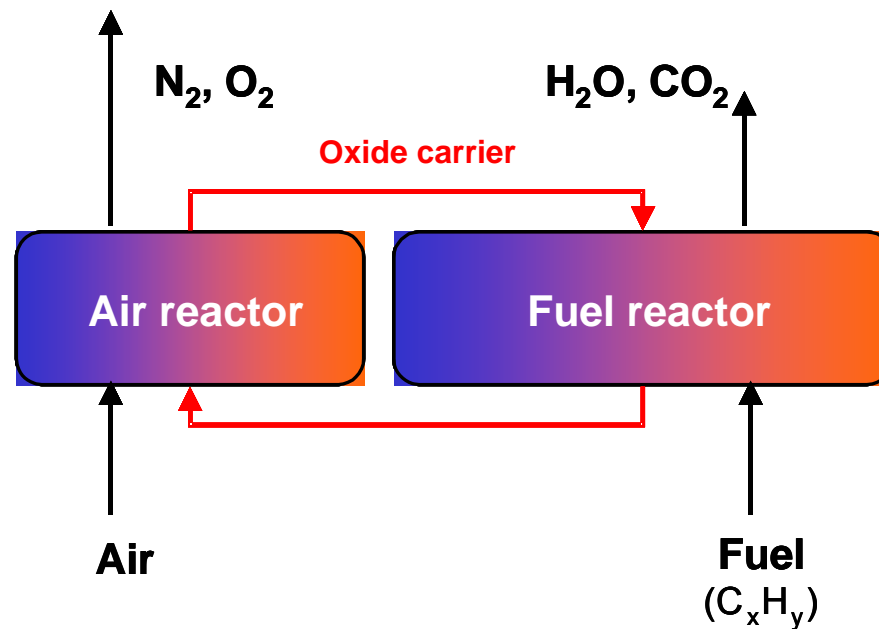
ALSTOM

- CLC Objectives, Options and Concepts
- Economics
- Development and Status
- Current Phase of Development
- Future Road Map

Overall Objective:

- **€15/ton of CO₂ avoided**
- **Over 90% CO₂ capture**
- **10% lower capital cost than a conventional unit (without CO₂ capture)**
- **Less than 35% increase in COE for CCS**

Basic Chemical Looping Principle



No Air Separation Unit (ASU) Required

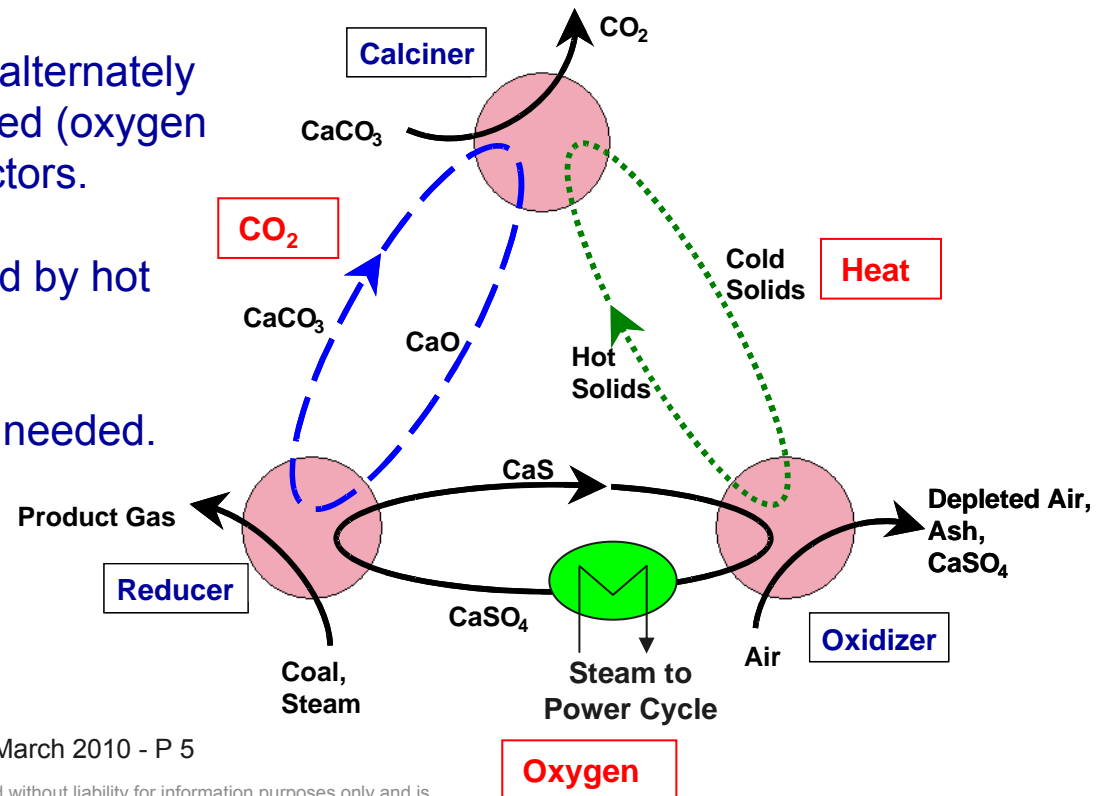
Q. Why Chemical Looping?

A. To Capture CO₂, at Lowest, CAPEX, OPEX and COE

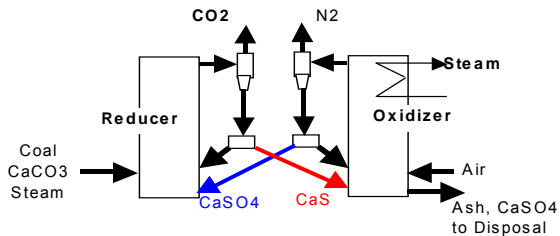
- Alstom's process uses calcium compounds from limestone which become the reactant and carrier solids).
- The Reactant is not consumed and is alternately reduced (oxygen removed) and oxidized (oxygen replenished) as it cycles between reactors.
- Coal is indirectly combusted or gasified by hot oxygen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

Carrier Solids have three functions:

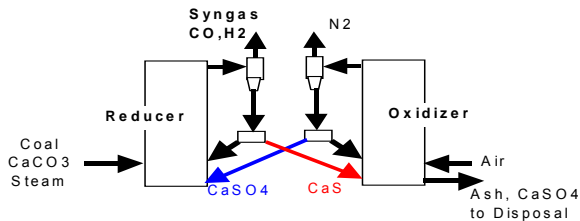
- Oxygen
- Heat
- CO₂



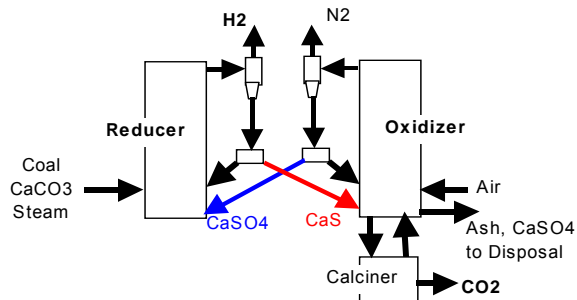
Chemical looping Process: Options and Applications



Option 1 – Combustion with CO2 Capture



Option 2 – Syngas with no CO2 Capture

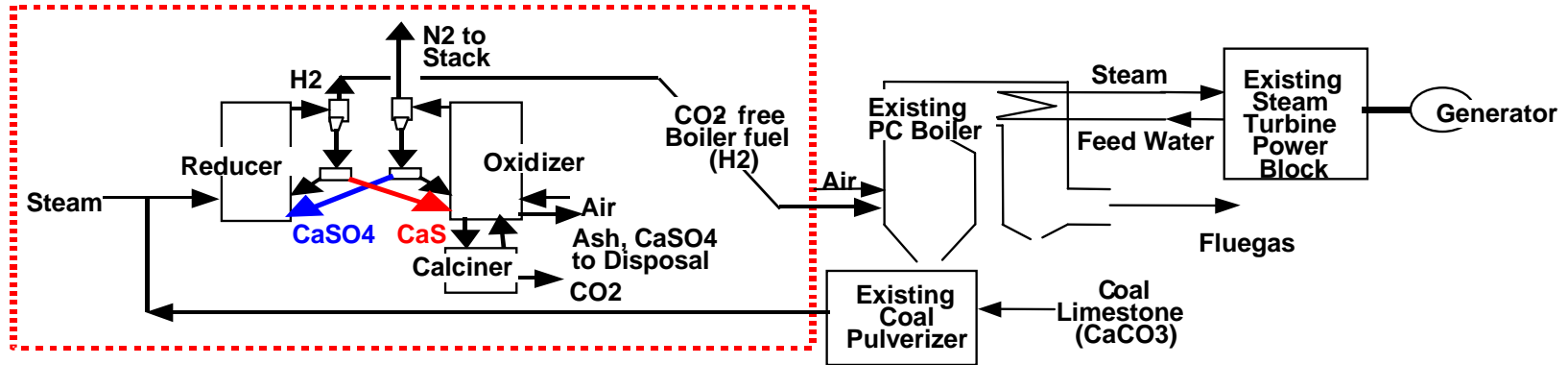


Option 3 – Hydrogen with CO2 Capture

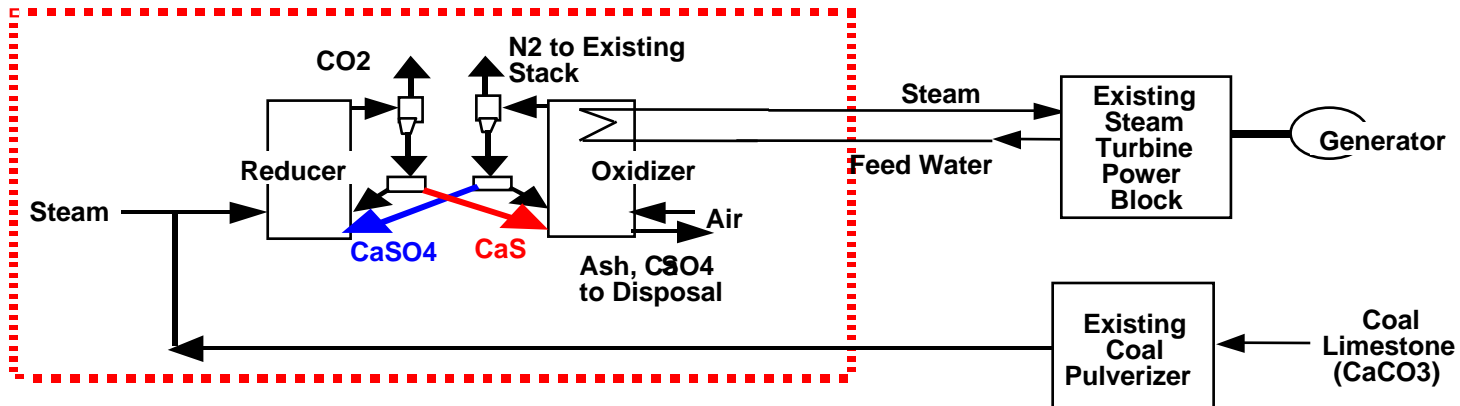
Applications

- 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



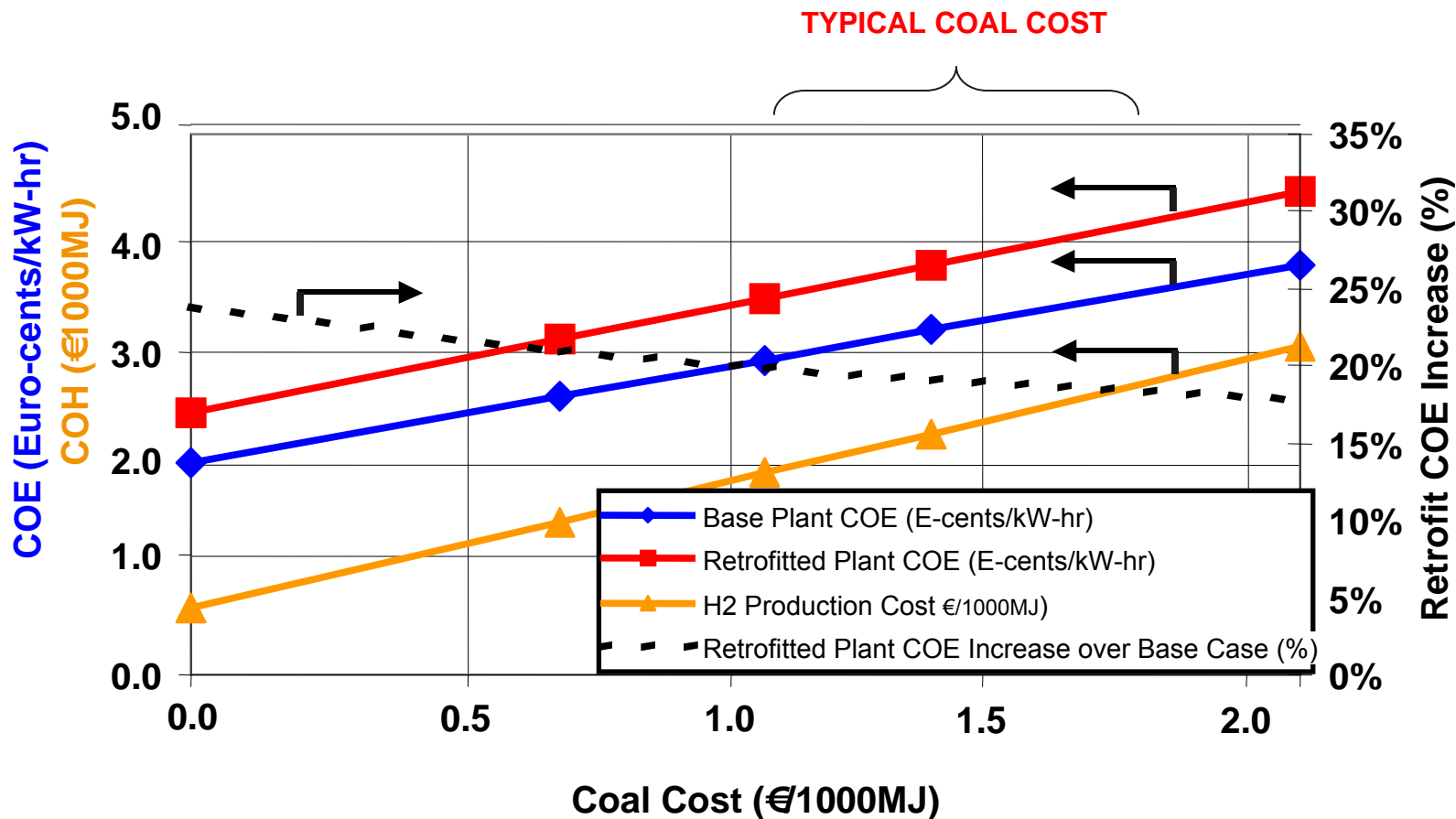
Concept 1 – Chemical Looping – CO_2 Free Fuel; Minimum Boiler Modification



Concept 2 – Chemical Looping Oxidizer Replaces / Modifies Boiler

- CLC Objectives, Options and Concepts
- Economics
- Development and Status
- Current Phase of Development
- Future Road Map

ALSTOM's Chemical Looping Economics for Retrofit Application



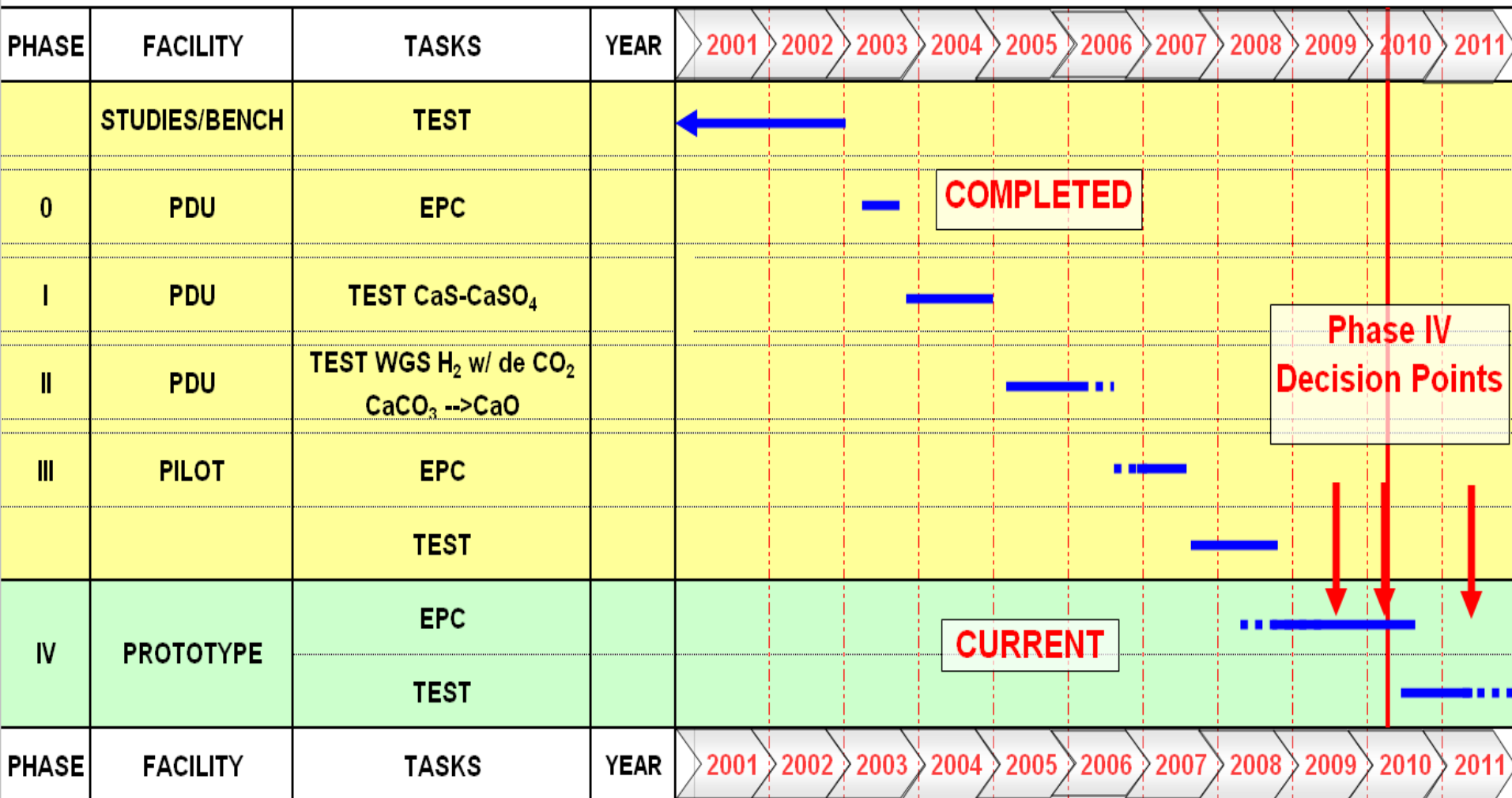
US DOE Goal < 35% COE Increase for CCS

- CLC Objectives, Options and Concepts
- Economics
- Development and Status
- Next Phase of Development
- Future Road Map

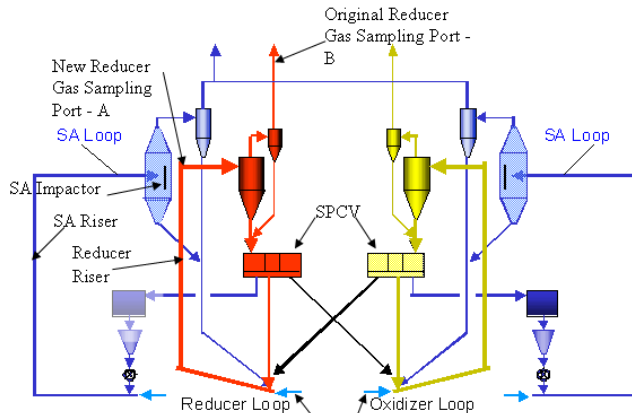
Chemical Looping Development Phases I,II,III & IV



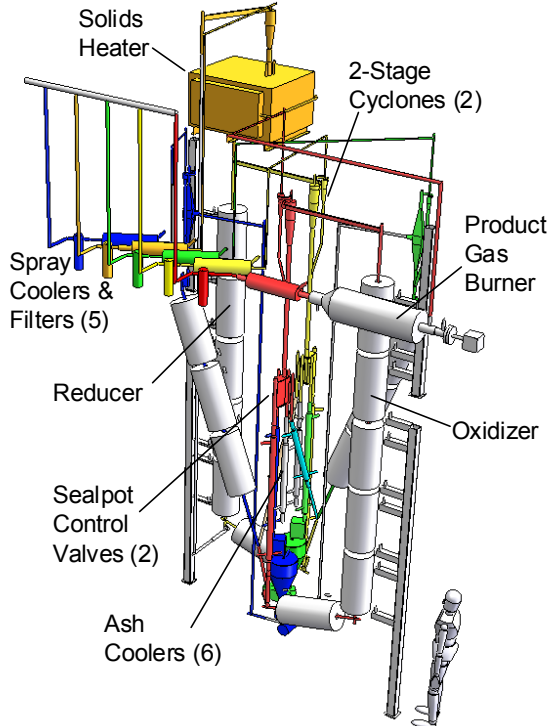
MASTER SCHEDULE



Chemical Looping Pilot Plant 65 kWt



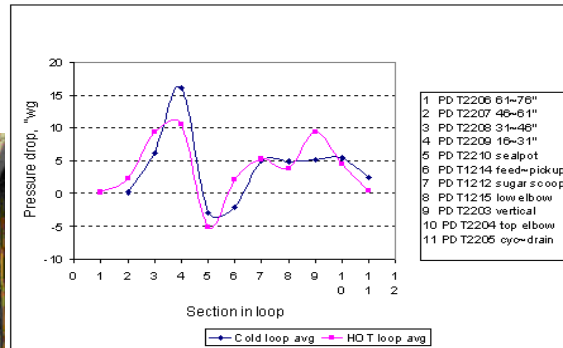
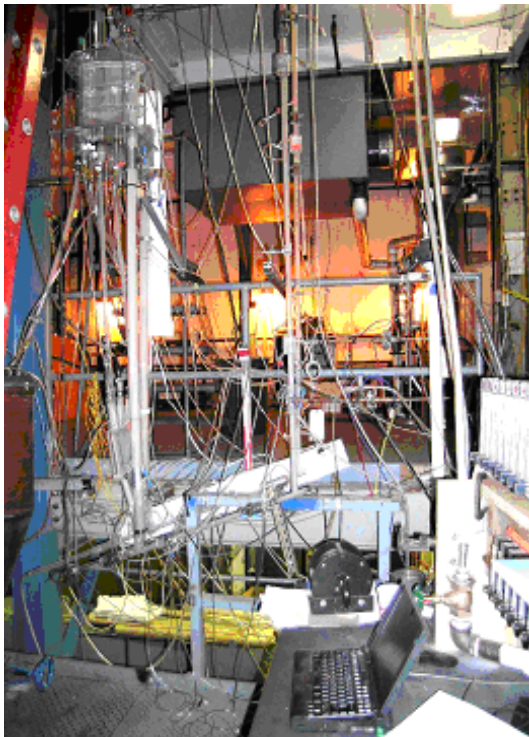
- **Designed and built by Alstom**
- **Allows testing of individual loops and processes**
- **3 year successful test program – Completed**
- **All chemistry / rates verified**
- **Phase III - Pilot Plant**
 - **Two exhaust fans / stacks**
 - **Automatic solids transport controls**



Alstom's Chemical Looping Prototype Development - 17-19th March 2010 - P 12

Chemical Looping Cold Flow Model

4.6 m Model



12.2 m Model



Laser Solids Velocity Probe



Cold Flow Model – Flow Stability, Scale-up

Phase I, II, III - Accomplishments

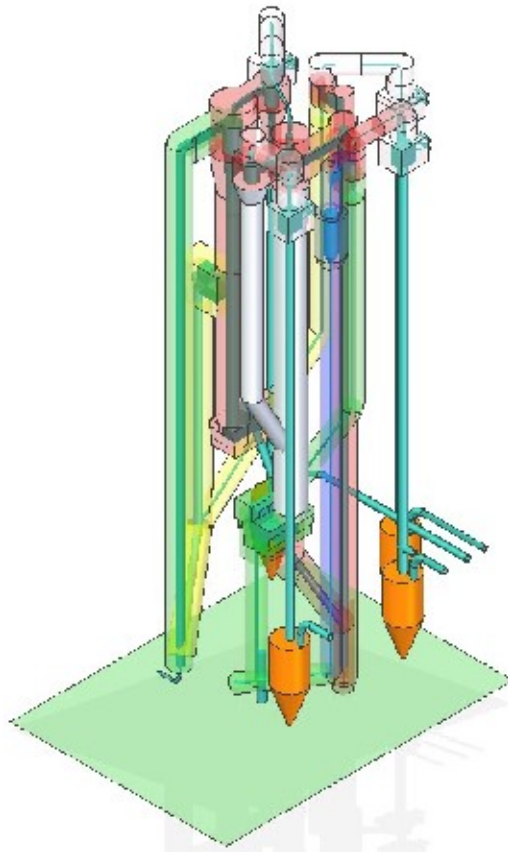
- All Milestones successfully completed – On-time, On-budget
- Pilot Testing (65 kW_{th}) – Successfully completed
- 4.6 m Cold Flow Model testing completed – Stable solids transport achieved
- 12.2 m Cold Flow Model – Stability achieved, Scale-up verified
- Alstom's Phase IVA - 3 MW_{th} Prototype Release.
- US DOE Cooperative Agreement – Sept., 2008

Phase I, II, III - Highlights

- Reactions Validation
- Simultaneous and smooth operation of 4 solids transport loops.
- Multi-loop control requirements established.
- Start-up, shut-down, and emergency quick shut-down and restart demonstrated.
- Scale-up of Solids flow from 4.6 m tall X 19 mm diameter to 12.2 m tall X 100 mm diameter reactor.
- 3 MW_{th} Prototype specification developed.

- CLC Objectives, Options and Concepts
- Economics
- Development and Status
- Current Phase of Development
- Future Road Map

Chemical Looping 3 MWt Prototype Facility Preliminary Concept



- 455 kg/hr coal flow
- 1st Integrated Operation
- 1st Auto-thermal Operation

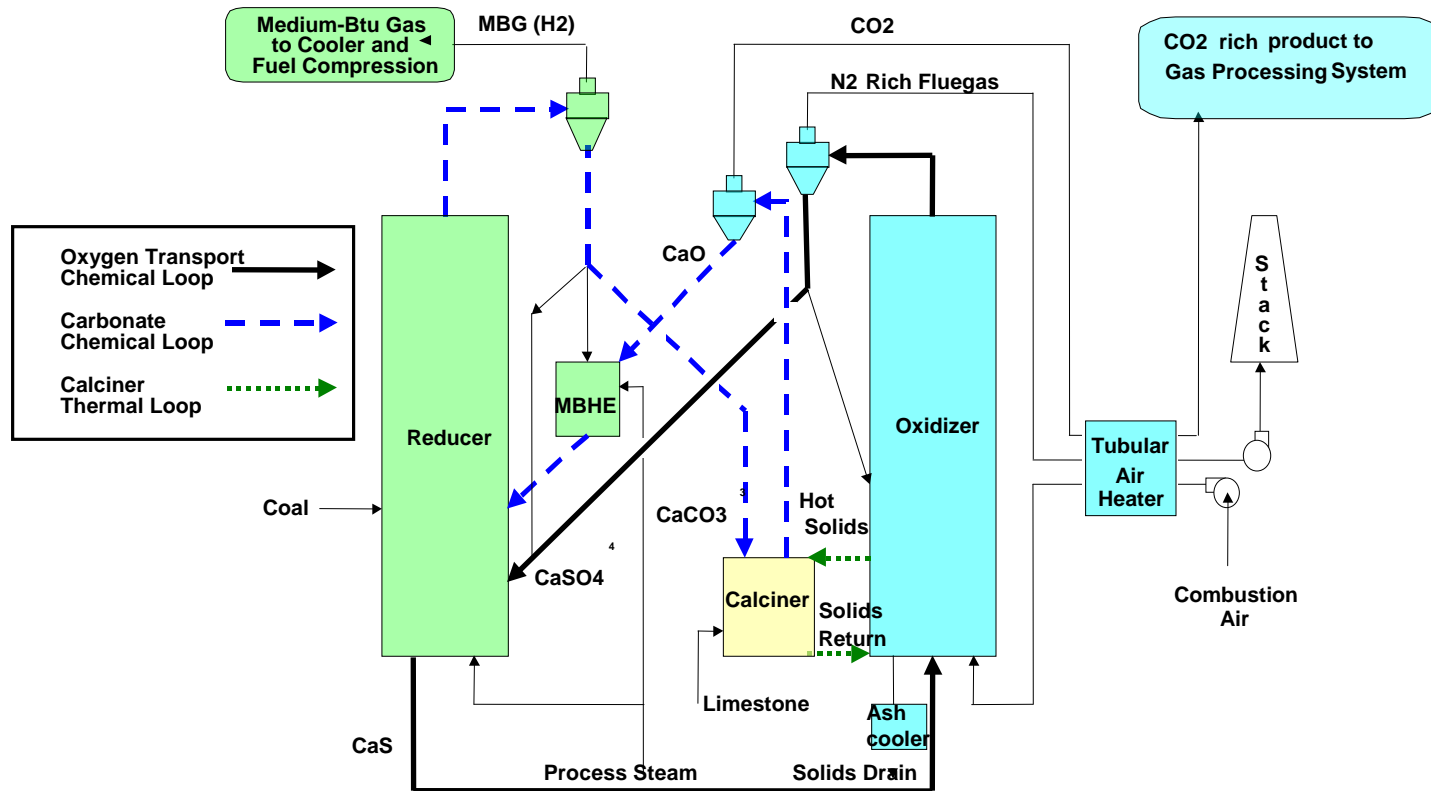
Phase IV Objective:

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



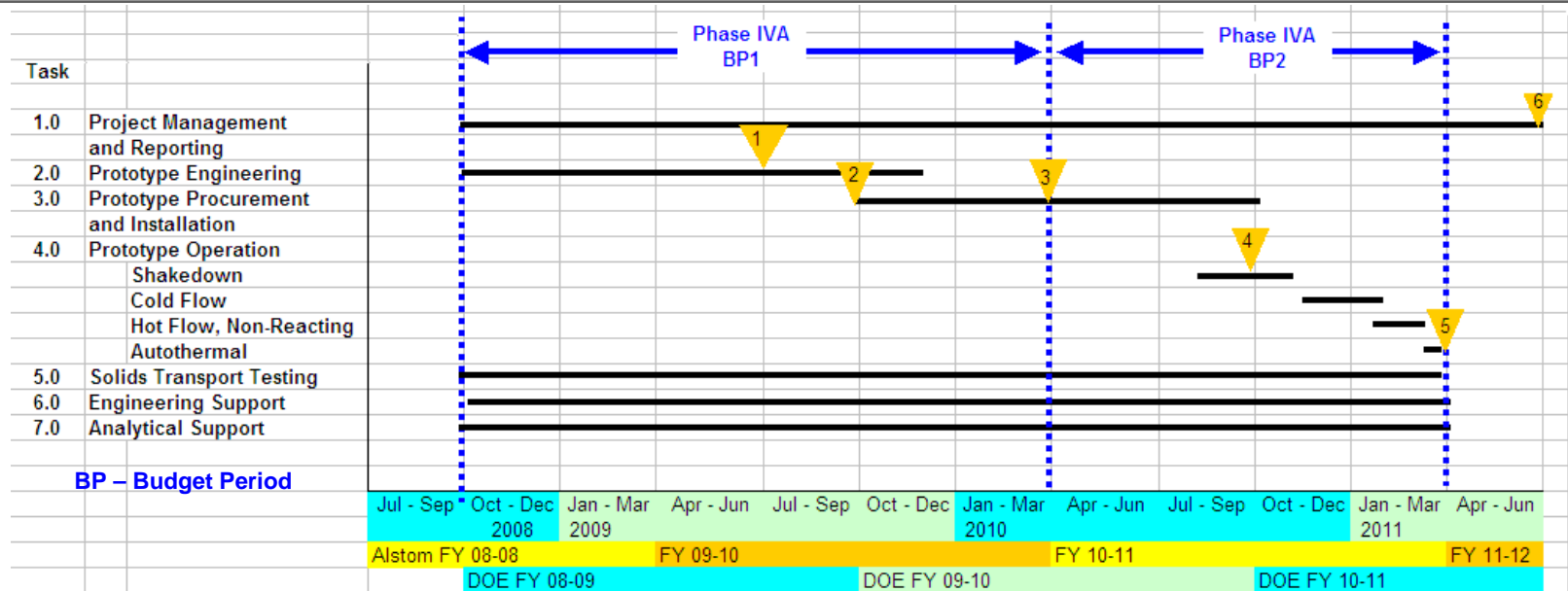
1. Solids Transport Testing

- Prototype as Cold Flow Model (CFM)
- High Solids Load Tests in 12.2 m CFM

2. Design/Build/Test Program -

- Modified Small-scale Cold Flow Modeling
- Design/Test Prototype plant

Chemical Looping Prototype Current Schedule

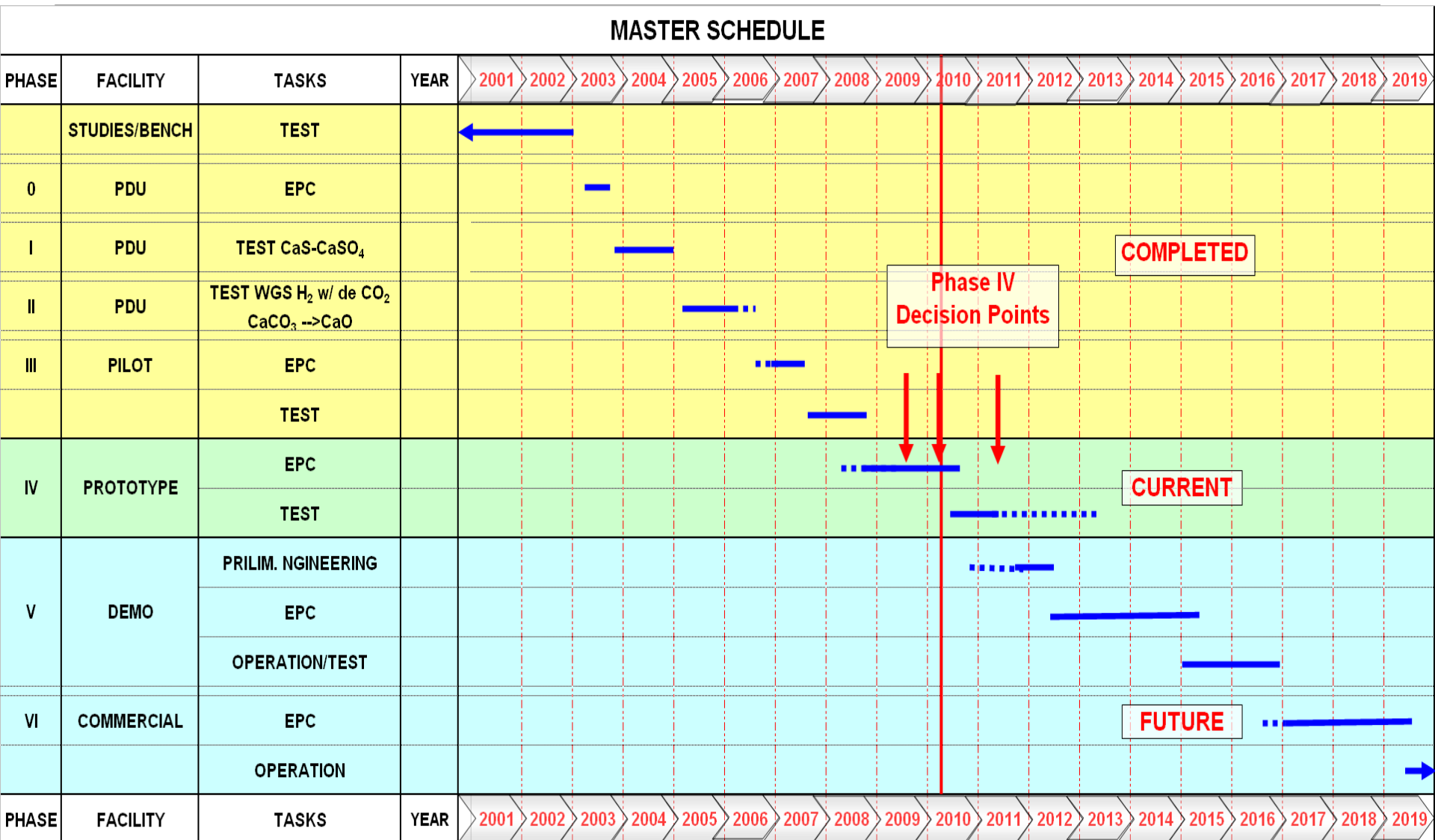


Milestones:

1. Preliminary Engineering – Completed
2. Submit Updated Cost to DOE-NETL –Completed
3. Start Installation
4. Start Shakedown
5. Complete Phase IVA Testing
6. Deliver Final Report

- CLC Objectives, Options and Concepts
- Economics
- Development and Status
- Current Phase of Development
- Future Road Map

Chemical Looping Development Proposed Phases V and VI Schedule



Alstoms Chemical Looping Prototype Development - 17-19th March 2010 - P 22

Acknowledgements

- US DOE NETL
- Dr. Fred Zenz (PEMM Corp)
- Dr. Jim Lim and Dr. John Grace (UBC)

www.power.alstom.com

ALSTOM