ALSTOM
Chemical Looping Combustion Coal Power Technology Development Prototype Phase IVA Kick-off Meeting

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November 18, 2008

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Chemical looping Agenda

- Introduction
- Phase IVA — Herb Andrus
- Safety — Dana Raymond
- DOE Items

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Chemical Looping Development

Overview

- What is the overall Objective?
- What is Chemical Looping?
- Why Chemical Looping? - (Is it worth it?)
- Commercialization Plan, Schedule, Budget
- Chemical Looping background technology – Alstom's PC, CFB and Gasifier experience
- Pilot Plant work - Phases I, II and III successfully completed
- Prototype – Phase IVA
- Future Phase – Demonstration (Phase V)

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Chemical Looping:
a way to Capture CO2 Efficiently, at Low Cost

Objectives:

- **Over 90% CO2 capture from Coal**
- **Less than $20/ton, avoided cost of CO2 capture**
- **Capital cost – 20% lower than Conventional Boiler Island (without CO2 capture)**
- **Beat Steam Power and IGCC performance and economics, world-wide**
- **Medium-Btu gas or Hydrogen without Oxygen Plant**
- **H2 for Hydrogen economy (Future)**

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Chemical Looping Power Plant

What are we trying to do:

•Commercialize a power plant that does everything a power plant is supposed to do and is capable of capturing nearly all of the CO2 that would otherwise be emitted, for about the same cost of electricity and capital cost of today's power plants.

•The aim is to develop a power plant that is significantly less expensive, more efficient, and cleaner than any other type of power plant (current or anticipated) either with or without CO2 capture.

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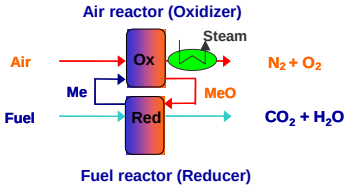
Chemical Looping Concept

- **Why do it?:** Lowest Cost Option for Capturing CO2 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 O2** in the Oxidizer, leaves N2 behind
  - **Carrier Burns** the **Fuel** in the Reducer
  - **Heat** produces **Steam for Power**



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

METAL OXIDE

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

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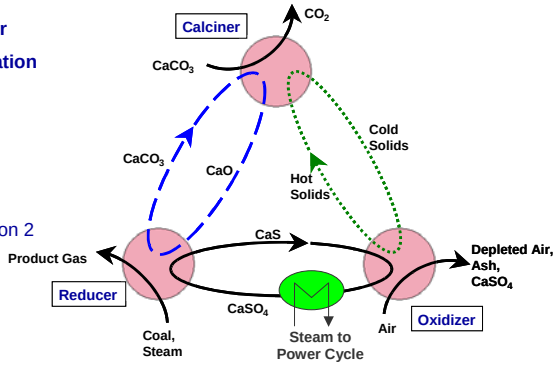
Chemical Looping Concept

- **Chemical Looping Flexibility**
  - Option 1: **Chemical Looping Combustion**
    - Excess Air-to-Fuel
    - Product Gas is **CO2**
    - Heat Produces **Steam for Power**
  - Option 2: **Chemical Looping Gasification**
    - Excess Fuel-to-Air
    - Product gas is **SynGas**
    - No Inherent CO2 Capture
  - Option 3: **Hydrogen Production**
    - Add CaO – CaCO3 Loop to Option 2
    - Add Calciner
    - Product Gas is **Hydrogen**
    - Calciner Off-Gas is **CO2**

Limestone-based



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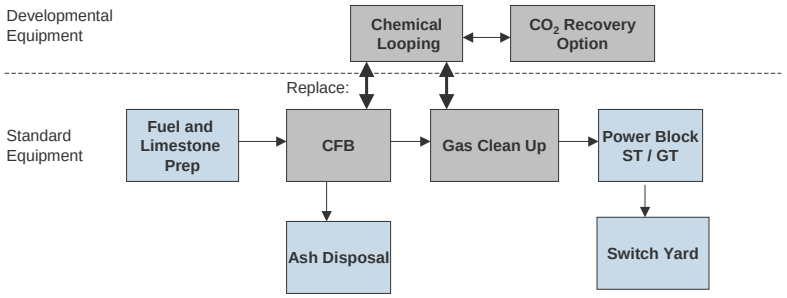
Chemical Looping Program

Equipment Developmental Status



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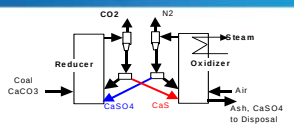
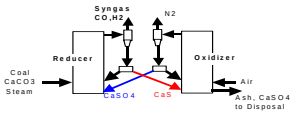
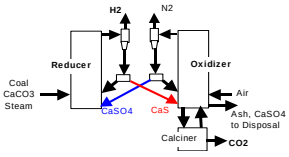
Chemical Looping Flexibility



Option 1 – Combustion with CO2 Capture



Option 2 – Syngas with no CO2 Capture



Option 3 – Hydrogen with CO2 Capture

Applications:

- •CO2 Capture - PC/CFB Retrofit
- •CO2 Capture - Ready Power Plant
- •Ultra Supercritical Steam Cycles

- •IGCC with Downstream CO2 Capture
- •Industrial SynGas
- •Coal-to-Liquid Fuels

- •CO2 Capture - PC/CFB Power Plant
- •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 Development

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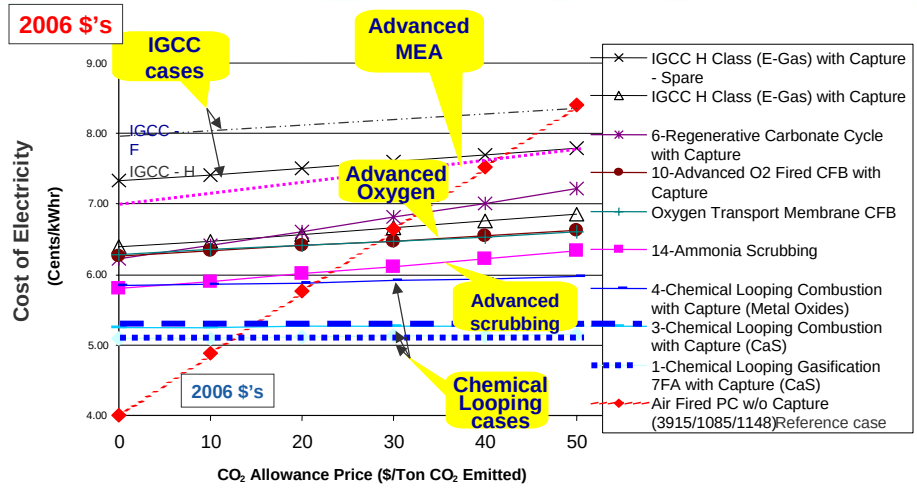
CO2 Capture in Power Plants



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

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Chemical Looping Program

Greenhouse Gas Project Results
Case Descriptions

Case	Description
1	Air Fired CFB without CO2 Capture
2	Oxygen Fired CFB with Moving Bed Heat Exchanger and CO2 Capture
3	Oxygen Fired CFB with CO2 Capture
4	Oxygen Fired Circulating Moving Bed with CO2 Capture
5	Air Fired CMB with CO2 Capture utilizing Regenerative Carbonate Process
6	Oxygen Fired CMB with Oxygen Transport Membrane and CO2 Capture
7	Indirect Combustion of Coal via Chemical Looping and CO2 Capture
8	Built and Operating IGCC Plant without CO2 Capture
9	Built and Operating IGCC with Shift Reactor and CO2 Capture
10	Commercially Offered Future IGCC without CO2 Capture
11	Commercially Offered Future IGCC with Shift Reactor and CO2 Capture
12	Indirect Gasification of Coal via Chemical Looping
13	Indirect Gasification of Coal and CO2 Capture via Chemical Looping

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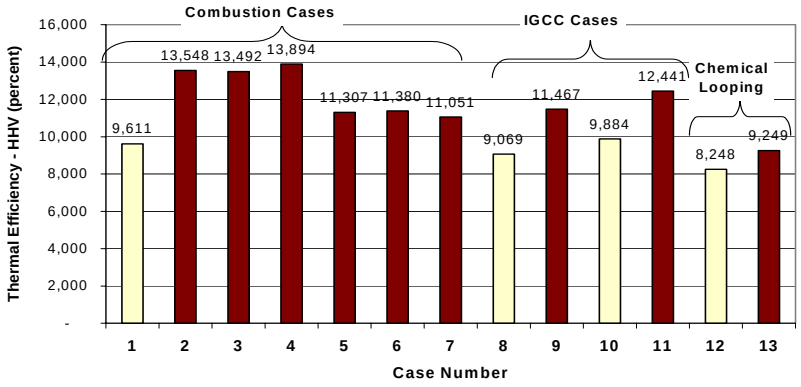
Chemical Looping Program

Greenhouse Gas Project Results - Efficiency



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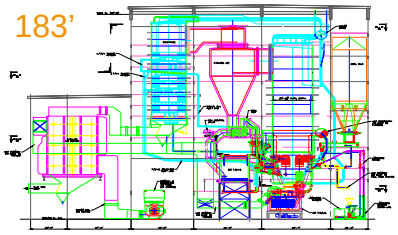
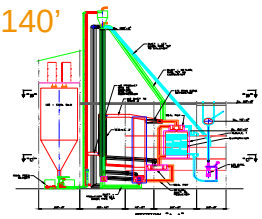
Equipment Comparison

Significant Volume & Weight Reduction

Air Fired CFB	Chemical Looping – Option 3





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

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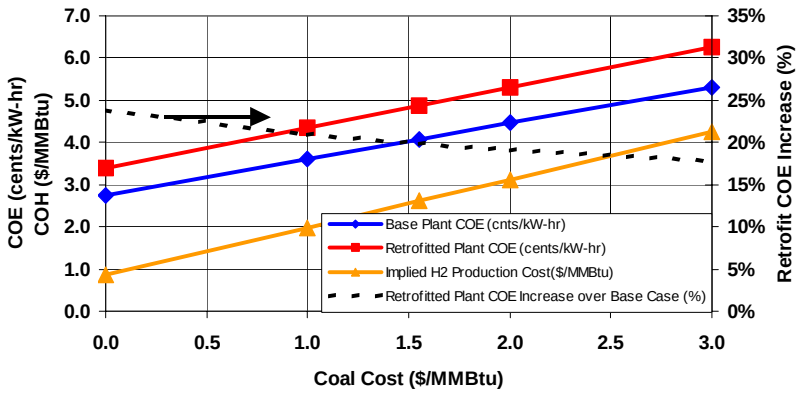
Chemical looping

Retrofit Concept 1 Economics



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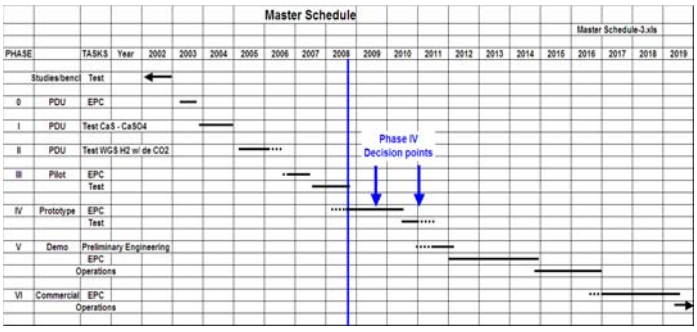
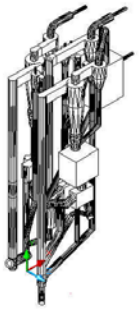
Chemical Looping Development
Phases IV, V, VI



Prototype
(1000 lb/coal/hr)



Decision Points

- Alstom reports project results,
- Alstom re-proposes and re-estimates workscope, budget and schedule for next Budget Period or Phase of work,
- US DOE/Alstom independently decide to proceed.

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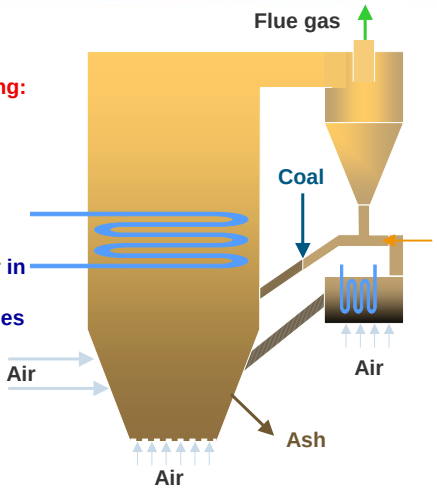
Alstom's Circulating Fluidized Bed (CFB) Boiler

- **CFB Processes are the basis for Alstom's Limestone-based Chemical Looping:**

- Solids transport and control principles
- Limestone sorbent (for sulfur removal)
- Combustion and gasification in lower bed
- Sulfur capture
- Calcination of limestone
- All CaS Chemical Looping reactions occur in Alstom's CFB's
- Same materials and construction techniques



Chemical Looping – Builds on ALSTOM's CFB Technology

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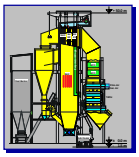
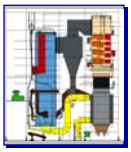
ALSTOM CFB Timeline

Cycle Advancement



CFB
Scott Paper
1x65 MW

CFB
IONE Westwood NEPCO Ultra-Systems
7 Units
15-43 MW

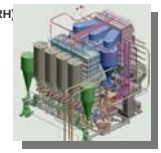


CFB
Thames Shady Point
5X75 MW (RH)

CFB
Texas-New Mexico
2X155 MW (RH)

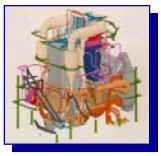
CFB
Warrior Run
1X210 MW (RH)

CFB
Provence, KEPCO
1X250 MW (RH)
1X220 MW (RH)



CFB
Guayama, Red Hills, Seward. E. Kentucky Sulcis
2X250 MW (RH)
2X250 MW (RH)
2X290 MW (RH)
1X260 MW (RH)
1X340 MW (RH)

CFB
Baima, Kaiyuan, Qinhuangdao
1X300 MW (RH)
2X300 MW (RH)
2X300 MW (RH)



Size Scale up

1986 1987 1989 1990 1993 1996 2000 2004

Advancement of Cycle precedes Size scaleup

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Alstom Entrained Gasification Process

120 TPD Process Development Unit 1974 - 1981

- 3.5 Years of Operation
- 140 BTU/SCF Gas (Air-blown)
- Suited to O2-blown
- Equivalent to ~12-15 Mw

Selected by DOE for Two Demo Projects

- 150 MW Gulf States Utilities 1980 -1982
- 65 MW IGCC CWL&P Springfield, Illinois 1990 -1995

Selected for Japanese National Project

- 200 TPD Pilot IGCC 1985 - 1995
- Equivalent to ~20 Mw
- Project Successfully Completed
- 250 MW IGCC Demonstration – In Operation

Technology Ready for Demonstration

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Chemical Looping Development
Key highlights

- Pilot Scale Status
  - Pilot Testing (65 kWth) – Successfully completed (US DOE Phases 1,2,3),
  - Technology Concept Gate Review (TCGR): 19th of June 2008,
  - Prototype (3MWth) Chemical Looping concept approved (TCGR), decision).
- US DOE Award of Phase IVA (Prototype)
  - Phase 4 proposal (3MWth Prototype Installation and Testing)
  - US DOE Contract signed Sept 2008.

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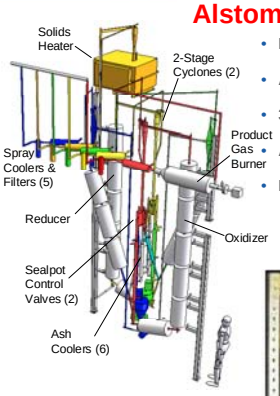
Chemical looping

Alstom's Chemical Looping Pilot Facility



- 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

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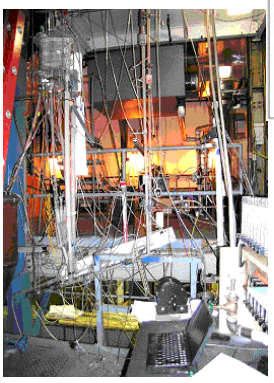
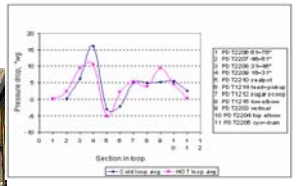
Chemical Looping
Cold Flow Modeling

15 Foot Model





Laser Solids Velocity Probe

40 Foot Model

Cold Flow Model – Flow Stability, Scale-up

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Chemical Looping
Pilot Plant Development

Phase I, II, III - Status

- All Milestones Successfully Completed – On-time, On-budget
- Pilot Testing – Successfully Complete
- 15-foot Cold Flow Model testing completed – Stable Solids Transport achieved
- 40-foot Cold Flow Model – Stability achieved, Scaleup verified
- IGR, SGR, TCGR, Internal and ASME/US DOE Peer Reviews Successfully completed
- Alstom's Phase IV US DOE Prototype Proposal Successful; Contract signed: Sept 2008

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Chemical looping

Chemical Looping 3 MWt Prototype Facility
Preliminary Concept

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

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

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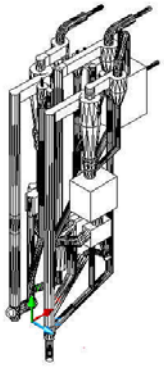
Chemical Looping Prototype
Phase IVA Highlights

- 3MWth Prototype
  - Dedicated planning team has been formed, lead by Dave Towle, PPL Facilities Manager,
  - Support team formed, layout defined, preliminary cost check in works.
  - Steel, Building and Fabricated Process Equipment RFQs at vendors
  - US DOE award, funding in place, 1 Oct 2008 contract start



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Chemical Looping
Phase IV Success Criteria

The success criteria for Phase IVA Budget Period 1 will be:

Substantial progress on engineering, procurement and construction of the Prototype plant,

Validation of the process technical and economic projections, to-date, based on engineering studies and cold flow modeling results.

Decision to proceed after BP1 decision point.

The success criteria for Phase IVA Budget Period 2 will be:

Shakedown testing of the Prototype completed.

Initial testing of non-reactive solids transport (cold flow and perhaps some limited non-reactive hot flow tests) of the Prototype which justifies further testing in a follow-on phase (i.e. Phase IVB).

Data collection of performance information (e.g. flowrates, temperatures, pressures, pressure drops, environmental information) for assessing performance viability.

Update of engineering studies to evaluate commercial options.

Chemical Looping
Task list BP 1

Budget Period 1 – Prototype Engineering

Task 1.0 – Project Management and Reporting

- Environmental Policy Act (NEPA) Information
- Project Management Plan
- Project Reporting.
- Project Continuation Request
- Technical Report
- Subcontractors

Task 2.0 – Prototype Engineering

Task 3.0 – Prototype Procurement and Installation

Task 4.0 – Prototype Operation

Task 5.0 – Solids Transport Testing

Task 6.0 – Engineering Support

Task 7.0 – Analytical Support

Chemical Looping
Task list BP 2

Budget Period 2 – Prototype Procurement, Installation and Operation

Task 1.0 – Project Management and Reporting

- Project Management Plan
- Project Reporting.
- Technical Reports
- Subcontractors

Task 2.0 – Prototype Engineering

Task 3.0 – Prototype Procurement and Installation

Task 4.0 – Prototype Operation

- Prototype Shake-down

Task 5.0 – Solids Transport Testing

Task 6.0 – Engineering Support

Task 7.0 – Analytical Support

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Chemical Looping
Deliverables

1. The Budget Period 1 report and final report
2. Information for NEPA (Budget Period 1)
3. Project Management Plan update (Budget Period 1 and Budget Period 2).
4. Topical report containing results from the prototype plant design and cost estimate (Budget Period 1).
5. Application for Continuation to Budget Period 2 (Budget Period 1).
6. Final / topical report describing results from the prototype testing (Budget Period 2).
7. A technical plan and cost estimate for any future testing .

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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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