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% CO₂ 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 CO₂ compression)
- Less than $20/ton, avoided cost of CO₂ capture (with CO₂ compression)
Chemical Looping Program
Developmental Status

Developmental Equipment

Standard Equipment

Fuel and Limestone Prep
PC/CFB Steam Generator
Gas Clean Up
Power Block ST / GT
Ash Disposal
Switch Yard

Replace:
Chemical Looping
CO₂ Recovery Option
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Chemical Looping Concept

- **Why do it?:** Lowest Cost Option for Capturing $\text{CO}_2$ 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 $\text{O}_2$ in the Oxidizer, leaves $\text{N}_2$ 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 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 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
Chemical Looping
Options and Applications

Applications

- CO₂ Capture - PC/CFB Retrofit
- CO₂ Capture - Ready Power Plant
- Advanced 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
CO2 Capture in Power Plants
Relative Economics

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


Basis:
- Plant size: 400 MWe
- Steam conditions: 3915 psia/1085 degF/1148 degF/2.5in H2o
- Cost basis: 2006, $US
- Coal cost: 1.5 $/MMBtu
- Levelized capital charge: 13.8%
- Capacity factor: 85%

Comparable range of costs for conventional technologies

Chemical Looping cases

2006 $’s

Cost of Electricity cents/Kw-hr

CO2 Allowance Price ($/Ton CO2 Emitted)


Chemical Looping CO2 Avoided Cost: $11-13/ton of CO2
### Significant Volume & Weight Reduction

**Air Fired CFB**

- Building Volume: 220’
- Boiler/Gasifier Weight: 100%

**Chemical Looping Plant**

- Building Volume: 140’
- Boiler/Gasifier Weight: 65%
Chemical Looping Technology

Pulverized Coal 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 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
Cold Flow Model – Flow Stability, Scale-up
Chemical Looping Kinetics

Chemical Looping - Kinetics Summary

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

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
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### Chemical Looping Development

**Phases IV, V, VI**

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**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