ALSTOM’s Chemical Looping Combustion Prototype for CO$_2$ Capture from Existing Pulverized Coal Fired Power Plants

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Paul Thibeault - Alstom Power
Bruce Lani US DOE/NETL

2012 CO$_2$ Capture Technology Meeting, July 9 – 12, 2012
### Agenda

<table>
<thead>
<tr>
<th>1st topic</th>
<th>General Project &amp; Technology Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd topic</td>
<td>Phase 0 to III Activities</td>
</tr>
<tr>
<td>3rd topic</td>
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</tr>
<tr>
<td>4th topic</td>
<td>Next Steps</td>
</tr>
</tbody>
</table>
The Alstom Group: a Worldwide Leader in Power Generation

Over 41 GW under execution

- Nuclear
- Hydro
- Steam
- Gas

Chemical Looping Technology Development

Full Power Systems Portfolio

N 1 in air quality control systems
N 1 in services for electric utilities
N 1 in hydro power
N 1 in conventional nuclear power island
N 1 in integrated power plants
Recent acquisitions of solar & wind power

2012 CO2 Capture Technology Meeting - July 9 – 12, 2012
Project Overview
Project Goals and Objectives

• Chemical Looping Program:

  ➢ Develop and commercialize chemical looping process to meet the goals for new or existing coal-fired power plants.

• Prototype Project:

  ➢ Design (BP1), build, and test (BP2) a 3 MWth Prototype to demonstrate Chemical Looping
    □ Systematic Testing
    □ Extended auto-thermal operation
  ➢ Obtain engineering and operating information necessary to design and build a reliable follow-on demonstration plant.
Alstom’s Chemical Looping Development Targets:

- Over 90% CO₂ capture from coal
- Less than $20/ton avoided cost of CO₂ capture
- Capital cost 20% < conventional steam plant (w/o CO₂ capture)
- Applicable to retrofit and new coal-fired power plants
- Retrofit < 20% increase in COE
- Beat steam power and IGCC performance and economics, world-wide
- Medium-Btu syngas or hydrogen without oxygen plant
- Economical H₂ production at low cost
# Chemical Looping Prototype Schedule

## As Planned

### Phase IVA DOE Schedule

Milestones:
1. Complete Preliminary Engineering
2. Deliver Updated Technical and Cost Information to NETL (for BP1 Decision)
3. Start Installation
4. Start Shakedown
5. Complete Phase IVA Testing
6. Deliver Interim Report
7. Deliver Final Report

<table>
<thead>
<tr>
<th>Task</th>
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</thead>
<tbody>
<tr>
<td>1.0 Project Management and Reporting</td>
<td>2.0 Prototype Engineering</td>
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<tr>
<td>3.0 Prototype Procurement and Installation</td>
<td>4.0 Prototype Operation</td>
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<tr>
<td>Shakedown</td>
<td>Cold Flow</td>
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<td>Hot Flow, Non-Reacting</td>
<td>Hot Flow, Reacting</td>
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<td>5.0 Solids Transport Testing</td>
<td>6.0 Engineering Support</td>
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<td>7.0 Analytical Support</td>
<td>8.0 Testing:</td>
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<tr>
<td>- Systematic</td>
<td>- Autothermal Optimization</td>
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<td>5. Complete Phase IVA Testing</td>
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<td>6. Deliver Interim Report</td>
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<tr>
<td>7. End of Phase IVA Program</td>
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</tbody>
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### Phase IVA is on Schedule

2012 CO₂ Capture Technology Meeting: July 9 – 12, 2012 P 6

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### Project Overview – Phase IV

#### Funding

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<th>Description</th>
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</thead>
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<td>October 2008 to September 2011</td>
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<td>Alstom Funding</td>
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<td><strong>Total Budget 2008 to Present</strong></td>
<td><strong>$10,744,530</strong></td>
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#### Participants:

[Logos of participating organizations]
Alstom’s Limestone Based Chemical Looping (LCL™) Concept & Process Options

Option 1 – Chemical looping combustion
Excess air (CaSO₄) to fuel
Product gas is CO₂
Heat produces steam for power

Option 2 – Chemical looping gasification
Excess fuel to air (CaSO₄)
Product gas is Syngas
No inherent CO₂ capture

Option 3 – Hydrogen production
Add CaO-CaCO₃ to Option 2
Add calciner
Product gas is H₂
Calciner off-gas is CO₂

Main Reactions:

Air Reactor (Oxidizer)

CaS + 2O₂ -> CaSO₄ + Heat

Fuel Reactor (Reducer)

2 C_fuel + CaSO₄ + Heat -> CaS + 2 CO₂
8 H_fuel + CaSO₄ + Heat -> CaS + 4H₂O

Alstom’s LCL™ process is suited to coal
Chemical Looping Process: Options and Applications

**Option 1 – Combustion with CO2 Capture**
- Coal
- CaCO3
- Steam
- Reducer
- CaSO4
- CaS
- Oxidizer
- Air
- Ash, CaSO4 to Disposal
- CO2
- N2
- Steam
- Syngas
- CO, H2

**Option 2 – Syngas with no CO2 Capture**
- Coal
- CaCO3
- Steam
- Reducer
- CaSO4
- CaS
- Oxidizer
- Air
- Ash, CaSO4 to Disposal
- H2
- N2

**Option 3 – Hydrogen with CO2 Capture**
- Coal
- CaCO3
- Steam
- Reducer
- CaSO4
- CaS
- Oxidizer
- Air
- Ash, CaSO4 to Disposal
- CO2

**Applications – LCL™**
- CO2 Capture – PC Retrofit
- CO2 Capture – CFB Retrofit
- CO2 Capture-Ready Power Plant
- Advanced Steam Cycles with CO2 capture

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

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

Flexible technology with low cost
Chemical Looping Overview
Retrofit Options

Concept 1 – Chemical Looping CO₂ Free Fuel; Minimum Boiler Modifications (Option 3)

Concept 2 – Chemical Looping Oxidizer Replaces/Modifies Boiler (Option 1)

Retrofit Options at < 20% Increase in CO₂ Capture
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<thead>
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<th>1st topic</th>
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</tr>
</thead>
<tbody>
<tr>
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<tr>
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Limestone CLC Development Timeline

- Earlier Program:
  ✓ Process and Sorbent Investigation
  ✓ Economic Evaluation
  ✓ Lead to Chemical Looping Program

- Chemical Looping Development
  ✓ Phase 0 (2001) - Alstom's Internal Development Project, Construction of the Process Development Unit (PDU)
  ✓ Phase II (2005) - Verified Gasification Chemistry and Process Control Strategy
  ✓ Phase III (2006) - Developed Automatic Control System
  ✓ Phase IVA (2008) - Built 3 MW Prototype, Shakedown and Initial testing
Agenda

1st topic  General Project & Technology Background

2nd topic  Phase 0 to III Activities

3rd topic  Phase IV Activities and Status

4th topic  Next Steps
• Main objectives:
  - Design, engineering, construction, commissioning and operation of a 3 MWth CaS prototype,
  - Autothermal operation of Limestone-based prototype,
  - Proof of concept – deliver data required to scale up to Demo and commercial size
• 50 month program
  - Shakedown completed
  - First coal fire completed June 2011
  - Autothermal operation Scheduled for August/Sept. 2012
• Total approved budget: 9.25 M$, cost share by US-DOE and Alstom
• Partners: US-DOE/NETL & Alstom
Chemical Looping Prototype Component Construction

The Prototype was integrated into the existing Multi-use Test Facility (MTF)

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Prototype Validation: Computational Fluid Dynamics

Study and improve:
- Fluidization
- Solids transport
- Mixing in “Cactus”
- Residence times
- Fixed carbon retention in reducer

Improving LCL™ Process
Prototype Validation: Cold Flow Model Testing

Stable coupled operation with smooth solids transport
Prototype Testing Status

Main Milestones:
- June 2011 - First coupled run with Pitts #8 Coal
- Sept. – Oct. 2011 - Series of short runs with Pitts #8 coal
- May 2012 - Reducer tests decoupled, nitrogen blown runs with Adaro coal and charcoal – All reducer reactions observed
- June 2012 – Extended reducer tests with Adaro Coal – All reducer reactions observed

Major Achievements:
- Controlled solids recirculation in CFM & prototype.
- Coal firing at low reactor temps with low tar formation.
- Coal firing at design temperature with no evidence of tar formation.
- SAHE operation.
- Hot restart after main fuel trip.
- Production of CO₂ (Option 1) and Syngas (Option 2).
- Combustion reactions with chemical looping reactions.

Hot Coupled Loop Operation Achieved with Coal & Charcoal
Prototype Validation: “Decoupled” Tests Towards Autothermal

Decoupled Reducer Test

- Reducer data produced:
  - Coal and CaSO4 conversions
  - Solids recycle rate per coal flow
  - Reducer solids loading

Reducer Reaction:
CaSO4 + Coal ↔ CaS + CO2
(endothemic)

Decoupled Oxidizer Test

- Oxidizer data produced:
  - CaS ↔ CaSO4 conversions
  - Solids recycle rate per CaS conversion
  - Sulfur retention data
  - Oxidizer solids loading

Reducer Reaction:
CaSO4 + Coal ↔ CaS + CO2
(endothemic)

Integrate Autothermal Test

- Autothermal test data produced:
  - Sustained operation without nat gas
  - Coal conversion rate
  - CaS ↔ CaSO4 conversions
  - Carbon carry-over to Oxidizer
  - Sulfur release data
  - Solids recycle rate per CaS conversion
  - Reducer and Oxidizer solids loading

Reducer Reaction:
CaSO4 + Coal ↔ CaS + CO2
(to produce CaS for Oxidizer)

Oxidizer Reaction:
CaS + Air ↔ CaSO4 + heat
(to produce heat & CaSO4 for Reducer)

Air burns CaS from reducer for heat to drive Reducer reactions.
Significant Observations:
- All LCL™ reactions realized
- High carbon burnup efficiency > 98%
- Negligible carbon carryover to oxidizer
- Oxygen demand - 15 to 20%
- SO₂ release can be minimized by varying excess air (CaSO₄) to fuel ratio
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Limestone Based Chemical Looping
Path Forward

• Oxidizer Testing: July – August 2012
• Coupled Autothermal Operation: August -September 2012

Decoupled Reducer Test

Reduced data produced:
- Coal and CaSO4 conversions
- Solids recycle rate per coal flow
- Reducer solids loading

Decoupled Oxidizer Test

Reduced data produced:
- CaSO4 + Coal ⇌ CaS + CO2
- Reducer solids loading

Integrating Autothermal Test

Autothermal test data produced:
- Sustained operation without net gas
- Coal conversion rate
- CaS ⇌ CaSO4 conversions
- Carbon carry-over to Oxidizer
- Sulfur retention data
- Solids recycle rate per CaSO4 conversion
- Reducer and Oxidizer solids loading

Air burns CaS from reducer
for heat to drive Reducer reactions.
LCL™ Process Development Steps
Managed Development and Scale-up

Reference Design Studies

Scale-Up

2000-2004

1996

Bench Tests

Drop-Tube/TGA

Pilot Plant

10-100 kWth

1-3 MWth

Prototype

Commercial Scale

>100 MWe

2020-2025

2008-2012

Demonstration

10-50 MWe

2015-2020

CFD Modeling, Controls and Tool Development

Small & Large Cold-Flow-Model

Reference Design Studies

Managed Development and Scale-up

Pilot Plant

Prototype

Commercial Scale

Demonstration
Acknowledgments

• Funding Partners:
  – US-DOE/NETL, Alstom

• Key Team Members:
  – Herbert E. Andrus, John Chiu, Jr., Paul Thibeault, Carl Edberg, Jim Kenney, Michael Clark
Thank You!
Any Questions?
www.alstom.com