The Use of Steelmaking Slag in Cement manufacturing

“An Environmental Solution with Commercial Value”
Presentation Objectives:

- Review of Portland Cement Industry Challenges
  - Short-Term Excess Capacity Issues
  - Increasing Environmental Regulations
- Chemical Requirements for Clinker Production
  - Traditional raw material selection
Presentation Objectives:

• Review of Iron & Steel Making Process
• Converting Slag to Cement Clinker
• Commercial Evaluation of Slag as Kiln Feed
  – Cost effective solution for improved productivity
  – Documented Improvement in reducing CO$_2$ & NOx emissions
  – Point of introduction evaluation
• Slag to Clinker Summary
Short-Term Supply / Demand Imbalance

Portland Cement Consumption

- Annual Change, Thousand Tons

- Peak (2006)-to-Trough (2010) Decline:
  41 MMT (Worst in History)

Exhibit 7
## Chemical Oxide Comparison

<table>
<thead>
<tr>
<th></th>
<th>Raw Mix for Clinker (Ignited Basis)</th>
<th>Blast Furnace Slag</th>
<th>Steel Furnace Slag</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>CaO</td>
<td>65-68</td>
<td>42</td>
<td>32-45</td>
</tr>
<tr>
<td>SiO₂</td>
<td>20-23</td>
<td>15</td>
<td>32-42</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>4-6</td>
<td>5</td>
<td>7-16</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>2-4</td>
<td>24</td>
<td>1-1.5</td>
</tr>
<tr>
<td>MgO</td>
<td>1-5</td>
<td>8</td>
<td>5-15</td>
</tr>
<tr>
<td>Mn₂O₃</td>
<td>0.1-3</td>
<td>5</td>
<td>.2-1.0</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.1-1</td>
<td>N/A</td>
<td>.2-2.0</td>
</tr>
<tr>
<td>SO₃</td>
<td>0.1-2</td>
<td>.08</td>
<td>1-2</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.1-1</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.1-0.5</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Cement Plant Schematic
Process Flow
The Calcination Process

Raw Materials Contain $35\% \ \text{CO}_2$

65% of raw material left to clinker form.
Cement Industry Greenhouse Gas Emissions

CO$_2$ Equivalents

1 Ton of Clinker Production $\approx$ 1 ton of CO$_2$ Emissions

- Process - 50%
- Transportation - 5%
- Electricity - 5%
- Fossil Fuel - 40%

Prepared by the Committee on Energy and Commerce staff – October 2007
“As slags have already been calcined and contain trace components that act as mineralizers, they can be converted into the clinker clinker minerals with little or no further energy input into the cement kiln.”

Dr. Michael Clark – Technical Consultant
Steel-Making Process

- **Blast Furnace (BF) Slag**
- **Basic Oxygen Furnace (BOF) Slag**
- **Electric Arc Furnace (EAF) Slag**
Blast Furnace Iron Refining Process
Iron and Slag Making Process Through a Blast Furnace
Air-Cooled Blast Furnace Slag
Granulated Blast Furnace Slag
Slag Making Through A Basic Oxygen Furnace

Iron ore
Coke
Limestone

Gas

400°F
900°F
2400°F
3400°F

Blast of hot air
1400°F - 2100°F

Slag

Blast Furnace

Molten Pig Iron

Scrap
Lime & Dolomitic Flux

Oxygen

Basic Oxygen Furnace
Process of EAF Slag

Lime

Scrap

Electric Furnace
Lime + Iron + 3000°F = Steel Slag

Purifying Steel Produces Slag

Steel Furnace

Calcium Oxide is added to the molten Steel

Lime + Iron + 3000°F = Steel Slag
Portland Cement Compounds

$C_3S$: (Alite) 3 CaO · SiO$_2$ (40-70%)

$C_2S$: (belite) 2 CaO· SiO$_2$ (20-40%)

$C_3A$: 3 CaO· Al$_2$O$_3$ (3-17%)

$C_4AF$: 4 CaO · Al$_2$O$_3$ · Fe$_2$O$_3$ (5-15%)
Converting Slag to Clinker

$\text{C}_2\text{S} \text{ to } \text{C}_3\text{S} \text{ - Exothermic Reaction}$

$\text{C}_2\text{S} + \text{CaO} + \text{Heat} = \text{C}_3\text{S} + \text{Heat}$

- Steel-making Slag
- Lime
- Minimum Heat
- Clinker Plus Heat is Released
Commercial Evaluation of Slag As Kiln Feed

- Incremental Clinker Requirements?
  - Cost of outside clinker purchases
- Is Facility Permitted to Generate Additional Clinker?
- Is Company Motivated to Reduce CO$_2$ and/or NOx emissions?
- Does Facility Have Production Bottlenecks?
  - Raw Grinding
  - Feed System
  - Clinker Cooler
  - Finish Grinding
Commercial Evaluation of Slag As Kiln Feed (continued)

• Compare Existing Raw Mix With Adjusted Raw Mix Utilizing Slag
  - Additional Savings Associated With Purchases, Grinding costs or full requirement of materials

• Prepare Proforma Based Upon Plant Specific Information

• Implement Pilot Test
  - Utilize established protocol for accurate evaluation
Andover Technology Partners
“An Environmental Evaluation of Steelmaking slag in Cement Manufacturing”
TXI Facilities - Three Kiln Technologies

- Mildothian, TX - Long Wet
- Oro Grande, CA - Long Dry
- Hunter, TX - Precalciner
Steel Slag Testing Data: Midlothian Plant Production

10% Increase in Production

Tons per Hour Clinker

Pre-Steel Slag

Steel Slag

Clinker From Raw Fd

Slag TPH
## Raw Materials Impact - Midlothian

<table>
<thead>
<tr>
<th>Material</th>
<th>Pre-Steel Slag</th>
<th>Post Steel Slag</th>
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</thead>
<tbody>
<tr>
<td>Limestone</td>
<td>89%</td>
<td>93%</td>
</tr>
<tr>
<td>Shale</td>
<td>4%</td>
<td>-</td>
</tr>
<tr>
<td>Sand</td>
<td>6%</td>
<td>7%</td>
</tr>
<tr>
<td>Mill Scale</td>
<td>1%</td>
<td>-</td>
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</tbody>
</table>
Steel Slag Historical Data: Hunter Plant Production

Hunter Production: Clinker TPH, 1992-1997

Before Steel Slag

With Steel Slag
Environmental Considerations for CO$_2$ and NO$_x$ Reduction
Steel Slag Testing Data: Midlothian Plant CO$_2$ Emissions

Tons CO2 per ton clinker

~ 7% Reduction in CO$_2$ Emissions
Steel Slag Testing Data: Midlothian Plant NO\textsubscript{x} Emissions

> 40% Reduction in NO\textsubscript{x} Emissions

<table>
<thead>
<tr>
<th></th>
<th>Lbs NO\textsubscript{x} per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Steel Slag</td>
<td>843</td>
</tr>
<tr>
<td>Steel Slag</td>
<td>495</td>
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</tbody>
</table>
Steel Slag  
Test Summary

<table>
<thead>
<tr>
<th>Category</th>
<th>Hunter</th>
<th>Midlothian</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Increase</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Fuel Decrease</td>
<td>2.3%</td>
<td>12%</td>
</tr>
<tr>
<td>CO₂ Decrease</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>NOx Decrease</td>
<td>40%</td>
<td>48%</td>
</tr>
</tbody>
</table>
Steel Slag as a NOx Reduction Technology

“Kiln temperatures while operating with the CemStar process are significantly lower than under normal conditions. Testing showed that, on average, kiln temperature with CemStar is over 200 F lower at the Midlothian plant. The lower kiln temperature with CemStar results in lower NOx generation.”

Andover Technology Partners CemStar Report
Awards For Emissions Reductions

1999 - U.S. EPA’s Climate Protection Award
1999 - U.S. EPA’s Climate Wise Award

“TXI has shown exceptional leadership, personal dedication and outstanding technical achievements in protecting the climate,” said Kathleen Hogan, director of the EPA’s Climate Protection Division.

“We are pleased to recognize their achievements by bestowing this award.”
Summary of Benefits

- 5 - 20% Increased Clinker Production
- Better Fuel Efficiency & Kiln Stability
- Lower Stack Emissions (NOx & CO₂)
- Raw Materials Use and Product Flexibility
- Minimum Implementation and Cost
Methods of Introducing Steel Making Slags Into Portland Cement Kilns
Kiln Feed Introduction

Methods

• Through Raw Milling System
• CemStar Patented Technology
  – After Raw Milling System
  – Directly Fed Into Kiln
Process Diagram - Preheater Plant
“CemStar Technology”
Thank You

RRC National Workshop
March 26, 2009