SO$_3$ GENERATION IN THE FLUE GAS PATH

SO$_2$ + O = SO$_3$ (atomic Oxygen at temp. > 1500F)

SO$_2$ + ½ O$_2$ = SO$_3$ (Catalytic Conversion)

- 0.5 to 1.5% of Flue Gas SO$_2$ is converted to SO$_3$ in Boiler.
- 0.5 to 2% of Flue Gas SO$_2$ is converted to SO$_3$ by the SCR.
INTERACTION OF SO$_3$ & NH$_3$

- Form of visible acid mist / aerosols.
- Formation of Ammonium Bisulphate.
- Formation of Ammonium Sulfate.

$$\text{2 NH}_3 + \text{SO}_3 + \text{H}_2\text{O} = (\text{NH}_4)_2\text{HSO}_4$$
$$\text{NH}_3 + \text{SO}_3 + \text{H}_2\text{O} = \text{NH}_4\text{HSO}_4$$

Ammonium Bisulphate can also formed in the testing train for back half condensable (US EPA method 202).
SO$_3$ CONDENSATION TEMPERATURE (DEW POINT)

Figure 1-1
Sulfuric Acid Dew Point (1004168, March 2004)
SO$_3$ / SULFURIC ACID CONTROL OPTIONS
SO$_3$ / SULFURIC ACID CONTROL OPTIONS

Fuel Additive
- Dolomite
- Magnesite

Furnace Injection
- Micronized Lime
- Aqueous Slurry Magnesium Hydroxide

Alkali Injection into SCR Outlet / AH Inlet
- Magnesium Oxide Powder
- Trona / Sodium Bicarbonate
- Slurry of Sodium Bisulfite/Sulfite (SBS)
- Slurry of Caustic Soda (NaOH)
SO$_3$ / SULFURIC ACID CONTROL OPTIONS

Alkali Injection in at AH Outlet
- Ammonia Injection (Anhydrous or Aqueous)
- Hydrated Lime with or without Humidification

Wet ESP downstream of Limestone WFGD

With SO$_2$ Control Options
- Semi-Dry FGD
- Alkaline (Caustic Soda; Magnesium Hydroxide) WFGD

Note:
1. Combination of SO$_3$ Sorbents can be employed.
2. Multiple Sorbents can provide multi pollutant mitigation (SO$_3$; Hg; HCL; Dioxin; etc.)
Dry Sorbent Injection (DSI) System
— Trona or Sodium Bicarbonate (SBC)

- Trona/SBC
- Silo
- Boiler
- SO₂, SO₃, HCl, HF, NOₓ, Hg
- Economizer
- Air Heater
- ESP/Bag House
- Optional
- Mill
- Air
# DRY SORBENT INJECTION

## DESIGN VARIABLES FOR DRY SORBENT INJECTION

<table>
<thead>
<tr>
<th>Design Variable</th>
<th>Options/Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flue Gas Design Flow</td>
<td>Max / Normal / Low</td>
</tr>
<tr>
<td>Sorbent Characteristics</td>
<td>Particle Size, Milling (Reactivity increases w/surface area), Porosity, Increase reactivity</td>
</tr>
<tr>
<td>Injection Location</td>
<td>Flue Gas Temp., Temperature is critical for increased reactivity, Mixing, Sorbent &amp; Flue Gas Mixing (turndown required), Residence Time, Increased time allows for better improved reaction</td>
</tr>
<tr>
<td>Type of Particulate Collector</td>
<td>Baghouse / ESP, Required NSR</td>
</tr>
<tr>
<td>Computational Fluid Dynamics (CFD)</td>
<td>Mixing, CFD to determine injection locations</td>
</tr>
<tr>
<td>Injection Lance Design</td>
<td>Open or w/Nozzles, Mixing &amp; Flue Gas turndown required</td>
</tr>
<tr>
<td>Sorbent Feed Rate Controls</td>
<td>Fixed Feed Rate, CEM's control not practical (Hg), Adjustable Feed Rate, CEM's controls Feed Rate (SOx)</td>
</tr>
<tr>
<td>Demonstration Testing</td>
<td>Full Scale Testing, Verification and Validation of Design</td>
</tr>
</tbody>
</table>
CALCIUM SORBENT REACTIONS

- $\text{Ca(OH)}_2 + \text{SO}_2 \rightarrow \text{CaSO}_3 + \text{H}_2\text{O}$
- $\text{Ca(OH)}_2 + \text{SO}_3 \rightarrow \text{CaSO}_4 + \text{H}_2\text{O}$
- $\text{Ca(OH)}_2 + 2\text{HCl} \rightarrow \text{CaCl}_2 + 2\text{H}_2\text{O}$
- $\text{Ca(OH)}_2 + 2\text{HF} \rightarrow \text{CaF}_2 + 2\text{H}_2\text{O}$

$\text{CaSO}_3$, $\text{CaSO}_4$, $\text{CaCl}_2$ and $\text{CaF}_2$ are collected in fly ash.
SODIUM BICARBONATE / TRONA REACTIONS

- $2\text{NaHCO}_3 \rightarrow \text{Na}_2\text{CO}_3 + \text{H}_2\text{O} + \text{CO}_2$
- $2(\text{Na}_2\text{CO}_3 . \text{NaHCO}_3 . 2 \text{H}_2\text{O}) \rightarrow 3\text{Na}_2\text{CO}_3 + 5\text{H}_2\text{O} + \text{CO}_2$
- $\text{Na}_2\text{CO}_3 + \text{SO}_2 + 1/2\text{O}_2 \rightarrow \text{Na}_2\text{SO}_4 + \text{CO}_2$
- $\text{Na}_2\text{CO}_3 + \text{SO}_3 \rightarrow \text{Na}_2\text{SO}_4 + \text{CO}_2$
- $\text{Na}_2\text{CO}_3 + 2\text{HCl} \rightarrow 2\text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$
- $\text{Na}_2\text{CO}_3 + 2\text{HF} \rightarrow 2\text{NaF} + \text{H}_2\text{O} + \text{CO}_2$
- $\text{Na}_2\text{CO}_3 + \text{NO}_x \rightarrow \text{NaNO}_3 + \text{CO}_2$

$\text{Na}_2\text{SO}_4$, $\text{NaCl}$, $\text{NaF}$ and $\text{NaNO}_3$ are collected in fly ash.
CALCIUM SORBENT REQUIRED (LBS/ LBS)

<table>
<thead>
<tr>
<th>POLLUTANTS</th>
<th>NSR</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>SO2</td>
<td>1.16</td>
</tr>
<tr>
<td>SO3</td>
<td>0.93</td>
</tr>
<tr>
<td>HCL</td>
<td>1.01</td>
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<tr>
<td>HF</td>
<td>1.85</td>
</tr>
</tbody>
</table>
### Sodium Sorbent Required (LBS/LBS)

#### Trona / SOLVAir Select 200

<table>
<thead>
<tr>
<th>POLLUTANTS</th>
<th>NSR 1.0</th>
<th>NSR 1.5</th>
<th>NSR 2.0</th>
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<tbody>
<tr>
<td>SO2</td>
<td>2.41</td>
<td>3.62</td>
<td>4.82</td>
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<tr>
<td>SO3</td>
<td>1.93</td>
<td>2.90</td>
<td>3.86</td>
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<tr>
<td>HCL</td>
<td>2.11</td>
<td>3.17</td>
<td>4.22</td>
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<tr>
<td>HF</td>
<td>3.86</td>
<td>5.79</td>
<td>7.72</td>
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#### Sodium Bicarbonate

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<th>NSR 1.0</th>
<th>NSR 1.5</th>
<th>NSR 2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO2</td>
<td>2.63</td>
<td>3.95</td>
<td>5.26</td>
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<td>SO3</td>
<td>2.10</td>
<td>3.15</td>
<td>4.20</td>
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<tr>
<td>HCL</td>
<td>2.30</td>
<td>3.45</td>
<td>4.60</td>
</tr>
<tr>
<td>HF</td>
<td>4.20</td>
<td>6.30</td>
<td>8.40</td>
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</table>
PERFORMANCE OF IAC- MULTI MIX SORBENT (IN DEVELOPMENT) – SO₃ & Hg REDUCTION

<table>
<thead>
<tr>
<th>Reading</th>
<th>Time</th>
<th>IAC-MIX Feed Rate (lbs/hr)</th>
<th>Hg (T) (μg/dscm) - Site CEMs</th>
<th>Hg (T) (μg/dscm) - Site CEMs</th>
<th>Stack CO₂ (%vol)</th>
<th>Stack CO₂ (%vol)</th>
<th>Stack Hg (lb/TBtu by Fc) - Plant CO₂ CEMs</th>
<th>Stack Hg (lb/TBtu by Fc) - Plant CO₂ CEMs</th>
<th>SO₂ by Shaw CEMs</th>
<th>Hg (T) Removal Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Base</td>
<td>0</td>
<td>3.30</td>
<td>12.80%</td>
<td>7.1%</td>
<td>0.000</td>
<td>2.69</td>
<td>3.54</td>
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<td>12.10%</td>
<td>7.1%</td>
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<td>3.17</td>
<td>2.82</td>
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<td>52.26%</td>
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<td>3.70</td>
<td>12.20%</td>
<td>7.1%</td>
<td>0.000</td>
<td>3.17</td>
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<td>3.00</td>
<td>12.30%</td>
<td>7.1%</td>
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<td>2.77</td>
<td>2.77</td>
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<td>52.26%</td>
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<tr>
<td></td>
<td>Base Average</td>
<td>0</td>
<td></td>
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<td>7.1%</td>
<td>0.000</td>
<td>3.00</td>
<td>3.00</td>
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<td>52.26%</td>
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<tr>
<td>2</td>
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<td>7.00</td>
<td>1.80</td>
<td>12.40%</td>
<td>7.1%</td>
<td>0.000</td>
<td>1.52</td>
<td>49.45%</td>
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<tr>
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<td>0.40</td>
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<td>12.40%</td>
<td>7.1%</td>
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<td>1.43</td>
<td>52.26%</td>
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<td>9.00</td>
<td>1.00</td>
<td>12.40%</td>
<td>7.1%</td>
<td>0.000</td>
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<td>52.26%</td>
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<td>5</td>
<td>3/22/09 14:49</td>
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<td>12.30%</td>
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<td>52.26%</td>
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<td>6</td>
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<td>16.00</td>
<td>0.70</td>
<td>12.40%</td>
<td>7.1%</td>
<td>0.000</td>
<td>0.59</td>
<td>52.26%</td>
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</tr>
<tr>
<td>7</td>
<td>3/22/09 14:22</td>
<td>16.00</td>
<td>0.70</td>
<td>12.40%</td>
<td>7.1%</td>
<td>0.000</td>
<td>0.59</td>
<td>52.26%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>3/22/09 14:22</td>
<td>21.60</td>
<td>0.20</td>
<td>12.90%</td>
<td>7.1%</td>
<td>0.000</td>
<td>0.16</td>
<td>52.26%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>3/22/09 13:00</td>
<td>2.60</td>
<td>0.20</td>
<td>12.90%</td>
<td>7.1%</td>
<td>0.000</td>
<td>0.16</td>
<td>52.26%</td>
<td></td>
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</tr>
<tr>
<td>10</td>
<td>3/22/09 15:10</td>
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<td>0.10</td>
<td>12.90%</td>
<td>7.1%</td>
<td>0.000</td>
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<td>52.26%</td>
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<td>13.00%</td>
<td>7.0%</td>
<td>0.000</td>
<td>0.08</td>
<td>52.26%</td>
<td></td>
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</tbody>
</table>
PERFORMANCE OF IAC- MULTI MIX FOR MERCURY REDUCTION

MERCURY REDUCTION WITH IAC-MIX

% Hg Removed

IAC Mix Injection Rate (lbs/hr)
TYPICAL SORBENT SILO & INJECTION DESIGN
SI LO WI TH DUAL PANT-LEG HOPPERS
SORBENT SILO WITH THREE DISCHARGE CONES
IAC SORBENT LANCE TIP DESIGN

LANCE TIP DESIGNS

1. Bayonet Tip for even dispersion.
2. Flat end at staggered depths.
3. Flared end for co-current flow.
4. Dispersion “V” tip end.

Note:

1. Lance tip design is based on duct layout and arrangement.
2. Lance diameter based on flow rates and quantity of lances utilized.
3. Multiple Lances for varied depths on same port.
CFD MODELLING FOR LANCE LOCATION
PAC INJECTION FOR MERCURY REMOVAL

SCR / SNCR De-NOx

SCR Converts Hg to oxidized form

Activated Carbon

Oxidizes Elemental Hg and Adsorbs Absorbs Oxidized Hg

PC Fired Boiler

Salable Ash Desired

Fabric Filter

Fabric Filter

SO2 Scrubber

Oxidized Hg
IAC “SUPER-SACK TEST RIG” WITH SCALES

Super-Sack Test Rig w/ Screw Feeder & Weigh Scales
IAC “SILO TEST RIG” WITH SCALES

- CONTROLLED INJECTION RATE WITH FEED BIN ON SCALES
- MULTIPLE INJECTION LANCES FOR EVEN DISTRIBUTION
MERCURY TESTING – SPLITTER & DISTRIBUTOR DESIGN
315 MW PLANT / AIR HEATER OUTLET
# DRY SORBENT INJECTION TEST PLAN

<table>
<thead>
<tr>
<th>Test Objective</th>
<th>Acid Gas Mitigation</th>
<th>% Removal vs Sorbent use. Establish Relationship.</th>
<th>Emission Controls Required - Today &amp; Future.</th>
<th>Establish Co-Benefit Relationship - Nox; Hg Reductions.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorbent(s) to be used</td>
<td>One or Multiple</td>
<td>Trona; Sodium Bicarbonate; Calcium Hydroxide; etc.</td>
<td>Sorbent Particle Size</td>
<td>Milling Requirements (*1)</td>
</tr>
<tr>
<td>CFD Requirement</td>
<td>Injection Location</td>
<td>Evaluate Duct Layout and Design with lance configuration.</td>
<td>CFD Requirement</td>
<td>Injection Location</td>
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<tr>
<td>Injection Location</td>
<td>A/H Inlet</td>
<td>High Temperature Zone ~700 F</td>
<td>A/H Outlet</td>
<td>Low Temperature Zone ~300 F</td>
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<tr>
<td>Real Time Test Data Analysis</td>
<td>CEM’s Data</td>
<td>Ontario Hydro Test</td>
<td>Will require 24 Hrs turnaround</td>
<td></td>
</tr>
<tr>
<td>Test Equipment Design</td>
<td>Sorbent Silo / Bin</td>
<td>Weigh Scales for real time feed rate data</td>
<td>Convey Air Supply</td>
<td>Designed for Lances Flow and Pressure Requirements</td>
</tr>
<tr>
<td>Lances</td>
<td>Sorbent Consumption</td>
<td>With existing APC Equipment</td>
<td>Projection with alternate Particulate Collector</td>
<td></td>
</tr>
<tr>
<td>Results Interpretation</td>
<td>Impact to Particulate Collector</td>
<td>Changes to be implemented (if any).</td>
<td>Impact to installed Boiler Train</td>
<td>Evaluate impacts to SCR; Ash Characteristics &amp; Disposal Impacts (if any).</td>
</tr>
<tr>
<td>(*1) General Guideline:</td>
<td>SO₂ Control</td>
<td>Milling may (not) be required due to low consumption.</td>
<td>SO₂ Control</td>
<td>For removal rates &gt;50%, Milling may reduce sorbent utilization.</td>
</tr>
<tr>
<td>PERMANENT SYSTEM DESIGN BASIS</td>
<td>Demonstrate &amp; Validate</td>
<td>Confirm Capital and Operating Costs</td>
<td>Sorbent Selection</td>
<td>Evaluate Available Sorbents</td>
</tr>
<tr>
<td>Install Permanent System</td>
<td>Design flexibility for today's need and future requirements</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
SILO WITH SCALE CONTROL FOR LIMESTONE ADDITION ON COAL BELT
PEBBLE LI ME ADDI TI ON FOR ARSENI C MI TI GATI ON
# IAC Representative Dry Sorbent Installations

<table>
<thead>
<tr>
<th>No.</th>
<th>Company</th>
<th>Location</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Northern State Power</td>
<td>Red Wing, MN</td>
<td>Boiler – Limestone Injection</td>
</tr>
<tr>
<td>2.</td>
<td>Northern State Power</td>
<td>Red Wing, MN</td>
<td>Boiler – Limestone Injection</td>
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<tr>
<td>3.</td>
<td>Red Trails Ethanol</td>
<td>Richardson, MN</td>
<td>NaHCO3 Injection</td>
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<tr>
<td>4.</td>
<td>Cornings</td>
<td>Harrodsburg, KY</td>
<td>Sodium Bicarbonate Injection</td>
</tr>
<tr>
<td>5.</td>
<td>Wabash Alloys</td>
<td>Dickson, TN</td>
<td>EnviroBlend Injection</td>
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<tr>
<td>6.</td>
<td>Wabash Alloys</td>
<td>Cleveland, OH</td>
<td>EnviroBlend Injection</td>
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<td>7.</td>
<td>Wabash Alloys</td>
<td>Tipton, IN</td>
<td>EnviroBlend Injection</td>
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<tr>
<td>8.</td>
<td>Wabash Alloys</td>
<td>Wabash, IN</td>
<td>EnviroBlend Injection</td>
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<tr>
<td>9.</td>
<td>Lincolnway Energy</td>
<td>Nevada, IA</td>
<td>Sodium Bicarbonate Injection</td>
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<tr>
<td>10.</td>
<td>Heron Lake Bioenergy</td>
<td>Heron Lake, MN</td>
<td>Trona/Sodium Bicarb Injection</td>
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<tr>
<td>11.</td>
<td>Ogden Martin (Covanta)</td>
<td>Kent, MI</td>
<td>Activated Carbon Injection</td>
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<tr>
<td>12.</td>
<td>Constellation Energy</td>
<td>Baltimore, MD</td>
<td>PAC Demo / Wagner Unit 2</td>
</tr>
<tr>
<td>13.</td>
<td>Constellation Energy</td>
<td>Baltimore, MD</td>
<td>PAC Demo / Wagner Unit 3</td>
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<tr>
<td>14.</td>
<td>Constellation Energy</td>
<td>Baltimore, MD</td>
<td>PAC Demo / Crane Unit 1</td>
</tr>
<tr>
<td>15.</td>
<td>Constellation Energy</td>
<td>Baltimore, MD</td>
<td>IAC Mix Testing / Wagner Unit 2</td>
</tr>
<tr>
<td>16.</td>
<td>Constellation Energy</td>
<td>Baltimore, MD</td>
<td>Trona/Sodium Bicarb Wagner Units 1 &amp; 2</td>
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<td>17.</td>
<td>Constellation Energy</td>
<td>Baltimore, MD</td>
<td>Limestone/Crane Wagner Unit 1</td>
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<td>18.</td>
<td>Temple Inland</td>
<td>Waverly, TN</td>
<td>Trona Injection</td>
</tr>
<tr>
<td>19.</td>
<td>Gainesville Regional Utility</td>
<td>Gainesville, FL</td>
<td>Limestone / Arsenic Mitigation</td>
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<tr>
<td>20.</td>
<td>Luminant</td>
<td>Rockdale, TX</td>
<td>MgO Demo / Sandow Unit 4</td>
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</tbody>
</table>
IAC “M” – Intermediate Pressure Pulse Jet Baghouse
6 x 234TB-BHTP-288

Coal Fired Boiler Baghouse
220,000 ACFM @ 420 F
IAC PROCESS BAGHOUSE INSTALLATIONS

- Ashgrove Cement- Springfield, MO  
  Lime Kiln 30,000 ACFM 400F
- Cemex- Louisville, KY  
  Clinker Hot Tank 25,000 ACFM 400F
- IAT Incineration- Richmond, WA  
  Medical/Bio-Waste 5,000 ACFM 500F
- Continental Carbon- Ponca City, OK  
  Carbon Black Reactor 20,000 ACFM 500F
- PPG- Lake Charles, LA  
  Glass Furnace 35,000 ACFM 480F
- Phila Electric- Eddystone, PA  
  Magnesium Oxide 225,000 ACFM 450F
- Carbo Ceramics- Toomsboro, GA  
  Lime Kiln 87,000 ACFM 450F
- Ashgrove Cement- Portland, OR  
  Lime Kiln 20,000 ACFM 425F
- BMH/James Hardie- Nashville, AR  
  Gypsum Dryer 120,000 ACFM 400F
- BMH/Ga Pacific-  
  Gypsum Dryer 80,000 ACFM 400F
- Reynolds Metals- 
  Anode Bake Fce 141,000 ACFM 450F
- Intalco Aluminium- Ferndale, WA  
  Anode Bake Fce 168,000 ACFM 450F
- Cemex- Fairborn, OH  
  Alkali By-Pass 65,000 ACFM 500F
- Lincolnway Energy- Nevada, IA (*)  
  Coal Fired Boiler 220,000 ACFM 400F
- Corn Products- LP Goldfield, IA (*)  
  Coal Fired Boiler 220,000 ACFM 400F
- Red Trail- Richmond, ND (*)  
  Coal Fired Boiler 220,000 ACFM 400F
- Heron Lake Bio Energy, MN (*)  
  Coal Fired Boiler 220,000 ACFM 400F
- Caterpillar- Mapleton, IL (*)  
  Melt Shop Ventilation 240,000 ACFM 250F
- Clow Corp- Oskaloosa, IA  
  Electric Arc Furnace 2x27,500 ACFM 250F
- Nucor Steel-AZ (*)  
  LMF and Meltshop 200,000 ACFM 250F
- Drake Cement, AZ (*)  
  Raw Mill / Kiln 206,000 ACFM 482F
- Drake Cement, AZ (*)  
  Clinker Cooler 98,100 ACFM 392F
- Drake Cement, AZ  
  Coal Mill 20,598 ACFM 194F
- Vienna Correctional Inst.  
  Coal Fired Boiler 2x25,000 ACFM 450F
- Nucor Steel, AL (*) (Engineering)  
  Electric Arc Furnace 1,200,000 ACFM 250F
- Carbo Ceramics- Toomsboro, GA  
  Lime Kiln#1 80,000 ACFM 425F
- Carbo Ceramics- Toomsboro, GA  
  Lime Kiln#2 80,000 ACFM 425F
- Carbo Ceramics- Toomsboro, GA  
  Lime Kiln#3 80,000 ACFM 425F

*Note: (*) IAC “M” Pulse Design with Long Bag, Low Pressure Cleaning Technology.
IAC PROCESS BAGHOUSE INSTALLATIONS

IAC Installations in India

- Dalmia Cement Ltd. (*) Cement Mill 443,200 ACFM 194F
- Krupp Polysius India Ltd. (*) Kiln / Raw Mill 80,046 ACFM 464F
- Birla / Satna Cement (*) ESP Conversion 40,023 ACFM 203F
- Birla / Satna Cement (*) ESP Conversion 22,366 ACFM 203F

Note: (*) IAC “M” Pulse Design with Long Bag, Low Pressure Cleaning Technology.

IAC - Baumco Reverse Air References in the Iron & Steel Industry:

- Krupp Industries GER EAF 1,765,000 ACFM
- Hadeed Ltd. SAU EAF 1,059,000 ACFM
- Great Lakes Steel USA EAF 1,231,000 ACFM
- Ferrowohlen SWI EAF 765,000 ACFM
- Crucible Steel USA EAF 865,000 ACFM
- CF&I USA EAF 540,000 ACFM
- Cascade Steel USA EAF 486,000 ACFM
- Bethlehem Steel USA EAF 874,000 ACFM
- Nucor Steel USA EAF 50,000 ACFM
- Kaiser Steel USA Re-ladling Station 600,000 ACFM
- Wheeling Pittsburgh USA Re-ladling Station 180,000 ACFM
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