Different types of “clean wood”
- Wood waste/Treated wood
- Straw
- Municipal waste

Air emissions from combustion
- Particulates
  - Inorganic HAPs like copper, lead, cadmium, arsenic in fine fraction
- Acid gases
  - SO2, SO3, HCl (Depending on S and Cl content of fuels)
- NOx
- Mercury
- Products of Incomplete Combustion
  - CO
  - Condensable & volatile organics
    - Dioxin/Furans in the presence of organics, chlorine & catalyst like copper

Fuels have differing characteristics

<table>
<thead>
<tr>
<th>Fuel number</th>
<th>l</th>
<th>2</th>
<th>3</th>
<th>l</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>53.3</td>
<td>48.2</td>
<td>33.0</td>
<td>37.1</td>
<td>31.9</td>
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<tr>
<td>Cu</td>
<td>0.13</td>
<td>1.06</td>
<td>0.01</td>
<td>0.03</td>
<td>0.20</td>
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<tr>
<td>Si</td>
<td>460</td>
<td>2.23</td>
<td>0.159</td>
<td>0.143</td>
<td>0.49</td>
<td></td>
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<tr>
<td>K</td>
<td>513</td>
<td>2.30</td>
<td>1.102</td>
<td>1.291</td>
<td>25.8</td>
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<tr>
<td>Ca</td>
<td>279</td>
<td>12.12</td>
<td>0.089</td>
<td>0.772</td>
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</tr>
<tr>
<td>Mg</td>
<td>12.6</td>
<td>1.45</td>
<td>8.37</td>
<td>0.27</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Na</td>
<td>5</td>
<td>92</td>
<td>0.193</td>
<td>0.04</td>
<td>0.01</td>
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<tr>
<td>Cl</td>
<td>271</td>
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<td>0.184</td>
<td>0.33</td>
<td>0.23</td>
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<tr>
<td>S</td>
<td>100</td>
<td>6.16</td>
<td>0.22</td>
<td>0.33</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>SO2</td>
<td>100</td>
<td>6.16</td>
<td>0.22</td>
<td>0.33</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>SO3</td>
<td>100</td>
<td>6.16</td>
<td>0.22</td>
<td>0.33</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>HCl</td>
<td>100</td>
<td>6.16</td>
<td>0.22</td>
<td>0.33</td>
<td>0.01</td>
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</tr>
<tr>
<td>NOx</td>
<td>100</td>
<td>6.16</td>
<td>0.22</td>
<td>0.33</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Mercury</td>
<td>100</td>
<td>6.16</td>
<td>0.22</td>
<td>0.33</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Products of Incomplete Combustion</td>
<td>100</td>
<td>6.16</td>
<td>0.22</td>
<td>0.33</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Condensable &amp; volatile organics</td>
<td>100</td>
<td>6.16</td>
<td>0.22</td>
<td>0.33</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Dioxin/Furans in the presence</td>
<td>100</td>
<td>6.16</td>
<td>0.22</td>
<td>0.33</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>chlorine &amp; catalyst like</td>
<td>100</td>
<td>6.16</td>
<td>0.22</td>
<td>0.33</td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Characterisation of the fuels used

Explanation:
- w: wood chips, d: dry base, m: wet base

- SO2 content: 0.1 - 0.2%
- SO3 content: 0.001 - 0.005%
- HCl content: 0.1 - 0.2%
- NOx content: 0.001 - 0.005%
- Mercury content: 0.1 - 0.2 µg/g fuel
Fuels have differing characteristics

<table>
<thead>
<tr>
<th>Fuel number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content (wt.%)</td>
<td>6.2</td>
<td>7.5</td>
<td>9.7</td>
<td>58.2</td>
<td>26.1</td>
<td></td>
</tr>
<tr>
<td>Ash content (wt.%)</td>
<td>0.95</td>
<td>1.00</td>
<td>0.85</td>
<td>6.85</td>
<td>4.38</td>
<td></td>
</tr>
<tr>
<td>Si (mg/kg)</td>
<td>633</td>
<td>710</td>
<td>165</td>
<td>7.480</td>
<td>6.841</td>
<td></td>
</tr>
<tr>
<td>K (mg/kg)</td>
<td>275</td>
<td>284</td>
<td>1.045</td>
<td>2.460</td>
<td>5.68</td>
<td></td>
</tr>
<tr>
<td>Ca (mg/kg)</td>
<td>1.901</td>
<td>2.102</td>
<td>1.412</td>
<td>14.536</td>
<td>5.51</td>
<td></td>
</tr>
<tr>
<td>Mg (mg/kg)</td>
<td>279</td>
<td>241</td>
<td>294</td>
<td>917</td>
<td>467</td>
<td></td>
</tr>
<tr>
<td>Na (mg/kg)</td>
<td>182</td>
<td>341</td>
<td>10</td>
<td>228</td>
<td>461</td>
<td></td>
</tr>
<tr>
<td>Cl (mg/kg)</td>
<td>200</td>
<td>140</td>
<td>26</td>
<td>228</td>
<td>944</td>
<td></td>
</tr>
<tr>
<td>S (mg/kg)</td>
<td>164</td>
<td>550</td>
<td>112</td>
<td>329</td>
<td>549</td>
<td></td>
</tr>
<tr>
<td>Zn (mg/kg)</td>
<td>164</td>
<td>284</td>
<td>49</td>
<td>92.9</td>
<td>582</td>
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<tr>
<td>Pb (mg/kg)</td>
<td>17.01</td>
<td>4.76</td>
<td>0.51</td>
<td>2.90</td>
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</tr>
<tr>
<td>Cu (mg/kg)</td>
<td>3.11</td>
<td>2.12</td>
<td>3.10</td>
<td>4.90</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Cd (mg/kg)</td>
<td>0.36</td>
<td>0.18</td>
<td>0.05</td>
<td>0.83</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

Flue Gas Fine Particulate Fractions for different fuels

Figure 3: PSD of aerosols formed during the combustion of different biomass fuels in grate fired boilers

Chemical Composition of Aerosols

Dioxin Formation
- Organic precursors are a requisite
- Formation in the presence of chlorine and catalysts like copper
- Sulfur seems to resist dioxin formation in salt-soaked hog combustion testing in BC
- Maximum dioxin formation in the 200 to 350 deg C
  - “De novo” synthesis
Proposed MACT Emission Limits

<table>
<thead>
<tr>
<th>Subcategory</th>
<th>Particulate Matter (lb/MBtu)</th>
<th>Hydrogen Chloride (lb/MBtu)</th>
<th>Mercury (lb/TBtu)</th>
<th>Carbon Monoxide (ppm @3%O2)</th>
<th>Dioxins/Furans (Total TEQ) (ng/dscm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Stoker</td>
<td>E - 0.20, N - 0.0031</td>
<td>E - 0.02, N - 0.000004</td>
<td>E - 3.0, N - 7.0</td>
<td>E - 0.003, N - 0.00033</td>
<td>E - 0.002, N - 0.000003</td>
</tr>
<tr>
<td>Coal Fluidized Bed</td>
<td>E - 0.20, N - 0.0031</td>
<td>E - 0.02, N - 0.000004</td>
<td>E - 3.0, N - 7.0</td>
<td>E - 0.003, N - 0.00033</td>
<td>E - 0.002, N - 0.000003</td>
</tr>
<tr>
<td>Pulverized Coal</td>
<td>E - 0.20, N - 0.0031</td>
<td>E - 0.02, N - 0.000004</td>
<td>E - 3.0, N - 7.0</td>
<td>E - 0.003, N - 0.00033</td>
<td>E - 0.002, N - 0.000003</td>
</tr>
<tr>
<td>Biomass Stoker</td>
<td>E - 0.20, N - 0.0031</td>
<td>E - 0.02, N - 0.000004</td>
<td>E - 3.0, N - 7.0</td>
<td>E - 0.003, N - 0.00033</td>
<td>E - 0.002, N - 0.000003</td>
</tr>
<tr>
<td>Biomass Fluidized Bed</td>
<td>E - 0.20, N - 0.0031</td>
<td>E - 0.02, N - 0.000004</td>
<td>E - 3.0, N - 7.0</td>
<td>E - 0.003, N - 0.00033</td>
<td>E - 0.002, N - 0.000003</td>
</tr>
<tr>
<td>Liquid</td>
<td>E - 0.004, N - 0.00004</td>
<td>E - 0.00003, N - 0.00004</td>
<td>E - 0.0, N - 0.00004</td>
<td>E - 0.004, N - 0.00004</td>
<td>E - 0.002, N - 0.00004</td>
</tr>
<tr>
<td>Gas (Other Process Gases)</td>
<td>E - 0.050, N - 0.00003</td>
<td>E - 0.000003, N - 0.00003</td>
<td>E - 0.000, N - 0.00004</td>
<td>E - 0.000, N - 0.00004</td>
<td>E - 0.000, N - 0.00004</td>
</tr>
</tbody>
</table>

E = Existing Units  
N = New Units

Compliance Strategies - CO

If existing unit is...

- Grate Fired
  - Upgrade air system
  - Convert to vibrating grate
  - Add CO catalyst
  - Add Thermal Oxidizer

- BFB
  - Probably OK – nothing required. CO catalyst is back-up

- Gas Fired
  - Probably OK – nothing required

Compliance Strategies – PM Solid Fuel Fired

If existing unit has...

- Multiclone only: (poor performer on submicron particulates)
  - Add Dry Electrostatic Precipitator (ESP) or Pulse Jet Fabric Filter (PJFF)
- Wet Scrubber (marginal performance on submicron particulates)
  - Add wet ESP downstream of wet scrubber
  - Replace with dry ESP or PJFF
- ESP:
  - Change fuel if difficult ash
  - Enhance ESP performance
    - Add Flue Gas Conditioning
    - Enlarge ESP
  - Replace with PJFF
  - Add Series PJFF or WESP downstream of ESP
Compliance Strategies – HCl Solid Fuel Fired

If existing unit has...

- Multiclone only
  - Change fuel
  - Add Dry Sorbent Injection (DSI)
  - Add Dry ESP or Pulse Jet Fabric Filter
- Wet Scrubber
  - Minor pH control may be needed
- ESP
  - Add DSI
  - ESP Performance may deteriorate
  - Enhance ESP performance/Add Flue
  - Enlarge ESP
  - Replace ESP with PJFF
  - Add wet scrubber/WESP downstream

Compliance Strategies – Hg Solid Fuel Fired

If existing unit has...

- Multiclone only
  - Change to lower Hg fuel
  - Add Powdered Activated Carbon (PAC)
  - Add series PJFF
- Wet Scrubber
  - Change to lower Hg fuel
  - For oxidized Hg fraction
    - Decrease Hg re-emission
  - For elemental Hg fraction
    - Increase Oxidized fraction
- ESP
  - Add PAC
  - Replace ESP with PJFF
  - Add wet scrubber/WESP downstream

AQCS Equipment Options

Dry ESP Upgrades

- Replace worn out, corroded internals
- Gut & stuff; optimize internal collection area, upgrade H.V. electrodes, upgrade T/R sets
- Increase sectionalization
- Raise roof
- Add a field
Dry Electrostatic Precipitators

Wet Electrostatic Precipitator

Pulse Jet Fabric Filters

**Lime preparations system**

**Peak control system**

**Hg and Dioxin removal system**

\[
\begin{align*}
\text{SO}_2 + \text{Ca(OH)}_2 & \rightarrow \text{CaSO}_3 + \text{H}_2\text{O} \\
2\text{HCl} + \text{Ca(OH)}_2 & \rightarrow \text{CaCl}_2 + 2\text{H}_2\text{O} \\
2\text{HF} + \text{Ca(OH)}_2 & \rightarrow \text{CaF}_2 + 2\text{H}_2\text{O}
\end{align*}
\]
Sorbent Injection for HCl, SOx and/or Mercury Control

Option 1 – Sorbent + PJFF
- Sorbent is injected upstream of the PM control device (ESP or FF)
- Collected fly ash and sorbent are mixed

Option 2 – TOXECON™
- Sorbent injection + Secondary baghouse + TOXECON™
- Potential solution to ash reuse problems

Implications of Sorbent Injection with Dry ESPs

- Sodium based sorbent for HCl, SOx control
  - Decrease flyash resistivity
  - Increase ESP Performance / Decrease PM emissions

- Lime for HCl, SOx Control
  - Increase resistivity
  - Decrease ESP Performance / Increase PM Emissions

- PAC for Hg control
  - Most likely will increase PM emissions
  - Flyash sales will be impacted

Sorbent Consumption
- Utilization lower than fabric filter

Implications of Sorbent Injection with Fabric Filters

- Performance (emission) is not sensitive to sorbent
- Higher S fuels possible with alkali sorbent
  - SOx reduction
- Higher sorbent utilization than ESP
  - Acts as fixed bed filter
  - May not work as well with membrane bags
  - PAC (Flyash sales may be impacted)

Search for cleanside SCR solution

- Some Biomass/MWC plants in Northeastern US were considering expansion
- Strict NOx limits were contemplated
  - Thought to be beyond SNCR capability. SCR was the only feasible solution
  - Plans to tap into European SCR experience on MWCs; cleanside location
  - Four catalyst suppliers and their reference plants visited: Shell-CRI, Ceram, Haldor Topsoe, Argillon
Key O&M experience with Cleanside SCR

- Control of dust entering the catalyst is very important. Recommended levels below 5-10 mg/NM3 which are tighter than regulatory limits.
- No catalyst plugging problems till at least 3 to 4 year bag life. Bag failures lead to catalyst plugging and pressure drop creep. A pre-filter was needed.
Key O&M issues with Cleanside SCR, contd.

- Control of SO3 ahead of catalysts is very important
  - Levels below 0.5 ppm are recommended for lower temperature range
  - Avoidance of catalyst plugging by ammonium sulfate fume
  - Higher operating temperatures necessary at higher SO3 levels
Emissions Control at Existing Plants

- There are no universal solutions
- All plants are unique
  - Existing AQCS configuration
  - Available space
  - Age of Equipment
- Other local regulations, i.e. SO₂ & NOₓ
- What are the limits?

QUESTIONS?