FSI + CATALYTIC FILTRATION + CONDENSING HEAT EXCHANGERS (CHX)

HOW TO MAKE POLLUTION CONTROL PROFITABLE

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James E. Smith - Co-author, CEO Chemsmith, LLC
Shuman Moore - Co-author, CEO ClearChem Development, LLC

McIlvaine webinar, March 2015
Operator Environment

- Regulatory Pressures
  - A majority of existing Utility & Industrial solid fuel, coke oven gas or oil firing major source boilers or heaters are affected by increasingly tighter current & expected environmental legislation

- Typical Solutions Used or Considered
  - Current BAT options are a mix of several processes, designed to treat a single emissions challenge and configured in many different ways in the flue gas duct
  - Fuel switch, retirement or conversion to gas options also are in play, with all their material technical & commercial impacts
  - Finding the optimum CAPEX and OPEX solution for the specific operation conditions of an affected boiler is elusive

<table>
<thead>
<tr>
<th>Regulation</th>
<th>Pollutant targeted</th>
<th>Partial List Compliance options¹</th>
<th>Expected date of compliance</th>
<th>IMPACT ON FUEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATS MACT</td>
<td>HAPs (mercury, acid gases, PM)</td>
<td>ACI, CHX baghouse FGD/DSI/FSI</td>
<td>2015/16</td>
<td>Coal (strong)</td>
</tr>
<tr>
<td>GHG Standards for existing plants</td>
<td>GHG</td>
<td>Unknown, CHX, improved heat rate, coal drying &amp; enzyme use, trading allowances</td>
<td>Uncertain ~2020</td>
<td>Coal (strong) Gas (moderate)</td>
</tr>
<tr>
<td>316(b)</td>
<td>Cooling water intake</td>
<td>Mesh screens, cooling towers</td>
<td>Uncertain ~2018</td>
<td>Coal (moderate) Gas (moderate)</td>
</tr>
<tr>
<td>Combustion by-products (ash)</td>
<td>Ash, control equipment, waste</td>
<td>Bottom ash dewatering, dry fly ash silos, double-blind landfills</td>
<td>Uncertain ~2020</td>
<td>Coal (moderate)</td>
</tr>
<tr>
<td>Regional Haze</td>
<td>NOx, SO₂, PM</td>
<td>SCR/SNCR, FGD/DSI/FSI, baghouse/ESP, combustion controls, CHX</td>
<td>Uncertain ~2019</td>
<td>Coal (strong)</td>
</tr>
<tr>
<td>CSAPR</td>
<td>NOx, SO₂</td>
<td>SCR/SNCR, FGD/DSI/FSI/CCF, CHX, fuel switch, trading allowances</td>
<td>Uncertain</td>
<td>Coal (moderate)</td>
</tr>
</tbody>
</table>


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### CAPEX - Individual Compliance Technologies Est. Costs

<table>
<thead>
<tr>
<th>Process type</th>
<th>Dust removal</th>
<th>NOx removal</th>
<th>Hg removal</th>
<th>Acid gas removal</th>
<th>Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>USD/kW&lt;sup&gt;6&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bag house</td>
<td>200 – 500</td>
<td>55 – 100</td>
<td>175 – 450&lt;sup&gt;3&lt;/sup&gt;</td>
<td>50 – 140</td>
<td></td>
</tr>
<tr>
<td>ESP</td>
<td>270 – 340</td>
<td>450&lt;sup&gt;3&lt;/sup&gt;</td>
<td>120 – 470</td>
<td>450 – 900</td>
<td>40 – 270&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>Dürr CCF&lt;sup&gt;2&lt;/sup&gt;</td>
<td>50 – 140</td>
<td>120 – 470</td>
<td>450 – 900</td>
<td>40 – 270&lt;sup&gt;3&lt;/sup&gt;</td>
<td>10</td>
</tr>
<tr>
<td>SCR</td>
<td>55 – 100</td>
<td>175 – 450&lt;sup&gt;3&lt;/sup&gt;</td>
<td>450&lt;sup&gt;3&lt;/sup&gt;</td>
<td>450 – 900</td>
<td>40 – 270&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>SNCR&lt;sup&gt;3&lt;/sup&gt;</td>
<td>50 – 140</td>
<td>120 – 470</td>
<td>450 – 900</td>
<td>40 – 270&lt;sup&gt;3&lt;/sup&gt;</td>
<td>10</td>
</tr>
<tr>
<td>ACI&lt;sup&gt;1,3&lt;/sup&gt;</td>
<td>450 – 900</td>
<td>40 – 270&lt;sup&gt;3&lt;/sup&gt;</td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>FGD</td>
<td>50 – 140</td>
<td>450 – 900</td>
<td>40 – 270&lt;sup&gt;3&lt;/sup&gt;</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>DSI</td>
<td>50 – 140</td>
<td>450 – 900</td>
<td>40 – 270&lt;sup&gt;3&lt;/sup&gt;</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>ClearChem FSI&lt;sup&gt;7&lt;/sup&gt;</td>
<td>50&lt;sup&gt;5&lt;/sup&gt; – 100&lt;sup&gt;++4&lt;/sup&gt;</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switch to NG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- CAPEX sum up for individual compliance technologies while following regulatory demand
- **Conclusion:**
  - Optimizing CAPEX by exploiting synergies

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<sup>1</sup> incl. fabric filter

<sup>2</sup> estimate for a unit size of 15 MW and 30 MW

<sup>3</sup> Coal Capacity on risk for retirement in PJM 2011 (PJM Interconnection is the largest U.S. Regional Transmission Organization with 830 members from generators and transmitters)

<sup>4</sup> Jeff Broderik, Peerless, McIlvaine webinar on MATS timing and technology options, Aug. 2014 – (pure conversion costs, with infrastructure closer to 350 USD/kW)

<sup>5</sup> Babcock & Wilcox, Natural Gas Conversions of Existing Coal Fired Boilers (not including NG price volatility risk or drop in output due to NG moisture content)

<sup>6</sup> EEI, Potential Impacts of Environmental Regulation on the U.S. Generation Fleet, January 2011 & EPA IPM 4.10 Basecase assumptions (CAPEX decreases with increasing boiler size

<sup>7</sup> ClearChem FSI's by-products preserve existing ash sales and avoid necessity for ash ponds
ClearChemFSI™

CHALLENGE – STRUCTURING CAPEX
SOLUTION – Utilize Synergies by Combination of Technologies

<table>
<thead>
<tr>
<th>Process type</th>
<th>Dust removal</th>
<th>NOx removal</th>
<th>Hg removal</th>
<th>Acid gas removal</th>
<th>CAPEX¹, USD/kWhr</th>
<th>Switch to NG USD/kWhr</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPEX Structuring</td>
<td>Dürr CCF</td>
<td>ACI (By others)</td>
<td>ClearChemFSI</td>
<td>0.0069 – 0.0142</td>
<td>0.0009 – 0.0018 (0.0069)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bag house</td>
<td>SNCR</td>
<td>ACI</td>
<td>DSI</td>
<td>0.0071 – 0.024</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ESP</td>
<td>SCR</td>
<td>FGD</td>
<td></td>
<td>0.0118 – 0.0243</td>
<td></td>
</tr>
</tbody>
</table>

✓ Conclusion:

- CAPEX of combined ClearChem / Dürr technologies is on the low side of compliance options
- CAPEX for switch to natural gas (NG) is lower than for other technologies

¹ Based on 15 year depreciation and 5 % annual interest rate (generic CAPEX without soft/finance costs)
ClearChemFSI™

CHALLENGE – STRUCTURING CAPEX

SOLUTION – Taking Advantage of OPEX

<table>
<thead>
<tr>
<th>Process type</th>
<th>Dust removal</th>
<th>NOx removal</th>
<th>Hg removal</th>
<th>Acid gas removal</th>
<th>Heat recovery</th>
<th>Switch to NG</th>
<th>(Savings) / Cost</th>
<th>TCO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>Dürr CCF</td>
<td>ACI (By others)</td>
<td>ClearChem FSI</td>
<td>Dürr CHX (By others)</td>
<td>-</td>
<td>-</td>
<td>(0.00101)</td>
<td>0.0068 – 0.01495</td>
</tr>
<tr>
<td>Cost1, USD/kWhr</td>
<td>0.00468 – 0.0059</td>
<td>0.00208 – 0.00815</td>
<td>0.00018</td>
<td>0.00087 – 0.00173</td>
<td>-</td>
<td>0.0009 – 0.0069</td>
<td>0.00337 – 0.00841</td>
<td>0.0043 – 0.00916</td>
</tr>
</tbody>
</table>

✓ Considering calorific value of the fuel

- Cost for larger systems start falling below cost of switching to Nat. Gas
- No Nat. Gas price volatility exposure with ClearChem & Dürr package
- Note: ClearChemFSI & Dürr technologies in combination have the ability to lower Hg with high surface reagent and longer residence time, but more data needed

1 Based on 15 year depreciation and 5 % annual interest rate (generic CAPEX without soft/finance costs)
2 Source: Babcock Power, Challenges When Converting Coal-Fired Boilers to Natural Gas - expected decreased boiler efficiency between 2-5% (→ http://www.babcockpower.com/pdf/RPI-TP-0232.pdf)
3 Published work by Consol and Lehigh indicate cooling helps capture of Hg in existing systems suggesting that the FSI + CHX combination might eliminate the ACI bringing potential savings to 0.00309 to 0.00916 USD/kWhr.
ClearChemFSI™
APC PROFIT CREATION
APC Adding Value to Plant Economics

SO₂ Conversion > 80%

1.500°C

550°C

Air preheater

SO₂ < 1%
SO₃ < 1 ppm

160°C

< 60°C

to stack

Boiler feed water

Ammonia injection

Coal Feed

ClearChemFSI micronized CaCO₃

SO₂

CaO

CaO

CaSO₄

Dry Ash removal with possible future heat recovery - No need for ash pond

Condensate to other uses or sale

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Coal-fired capacity (308 GW) represents about 1/3rd of the total generation capacity

- Majority of coal capacity (233 GW) is owned by regulated companies (IOUs, munis/coops, etc.), and the rest (75 GW) is owned by merchant companies

Majority (93%) of the coal capacity lacks at least one major equipment (scrubber, SCR and baghouse) to control air emissions

Metin Celebi, Coal Plant Retirements and Market Impacts, The Brattle Group, Wartsila Flexible Power Symposium, February 2014
ClearChemFSI™
EXISTING U.S. COAL-FIRED BOILERS

Side Stream Application – Example existing ESP

SO₂ Conversion > 80%

1.500°C

Convection Sections & economizer

550°C

Ammonia injection

Air preheater

400°C

ClearChemFSI micronized CaCO₃

SO₂

CaO

Coal Feed

Dürr Catalytic hot gas filter

Dürr 1st stage CHX / HRSG

160°C

< 60°C

Dürr 2nd stage CHX / HRSG

Dry Ash removal

Boiler feed water

Dry Ash removal with possible future heat recovery - No need for ash pond

Condensate to other uses or sale

to stack

SO₂ < 1%
SO₃ < 1 ppm

CaO

CaSO₄/3

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EXISTING U.S. COAL-FIRED BOILERS
Side Stream CAPEX

✓ Side stream is combined with existing APC equipment
  o FSI, DSI, ESP, SNCR, SCR or FGD

✓ Side stream is a perfect choice to add new APC functionality while enhancing reduction of existing equipment for
  o SO₂, NOx, NH₃, PM and SO₃

✓ CAPEX for side stream installation will be reduced according to the flow distribution

✓ Additional savings result from partial load operation mode of existing equipment
# CONCLUSION – KEEP IT SIMPLE

<table>
<thead>
<tr>
<th>Process type</th>
<th>Dust removal</th>
<th>NOx removal</th>
<th>Hg removal</th>
<th>Acid gas removal</th>
<th>Heat recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Plant</td>
<td>Dürr CCF</td>
<td>ACI, FSI, &amp; CHX</td>
<td>ClearChemFSI</td>
<td>Dürr CHX</td>
<td></td>
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<tr>
<td>Existing Plant</td>
<td>side stream</td>
<td>existing</td>
<td>ClearChem FSI</td>
<td>Dürr CHX</td>
<td></td>
</tr>
<tr>
<td></td>
<td>existing</td>
<td>existing</td>
<td>ClearChemFSI</td>
<td>Dürr CHX</td>
<td></td>
</tr>
</tbody>
</table>

- Exploit synergies
- Create profit by releasing latent energy
- Utilize existing equipment
- Preserve existing sales channels
- Avoid additional OPEX

**Conclusion is valuable enough having filed for patent**
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