AFS program and the Hot Gas Filter Decision Guide

• This sequence of power points will be displayed at 10AM April 29 and will be the background for the discussion

• AFS Program Overview
• Decision Guide, Decision Orchard, AFS, and International Filter News
• Hot Gas Filtration Decision Guide
AFS Program Overview

General

• The 90 minute session will be focused on a slide by slide display of the summary power points.
• As each slide is displayed there is the opportunity for discussion. It would start with the slide author if he so wishes.
• Designated panelists as well as the entire group will be encouraged to ask questions and make observations.
• Panelists and participants are encouraged to submit power points to be included in the summary.
• Anyone is encouraged to submit articles and presentations for inclusion in the Power Plant Decision Orchard.
• The Filtration News article in June will be based on the conclusions reached in the session.
• The summary and the intelligence system will be continually updated.

“Specific

• Provide access to hot gas filter Decision Guide upon registration.
• Provide updated version of HGF Decision Guide prior to the event.
• Provide contact among presenters and attendees before, during and after the event.
• Conduct the program as a series of panels.
• Presenters sit at designated tables during lunch and continue discussions.
• Continuing upgrading of Hot Gas Filter Decision Orchard and articles in IFN.
**Hot Gas Filter Summary is part of a whole system**

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<table>
<thead>
<tr>
<th>IFN article</th>
<th>-- Hot Gas Filter Decision Guide -</th>
</tr>
</thead>
<tbody>
<tr>
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**Power Plant Decision Orchard**

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4As Operating system

- **Alerts**: Weekly Power Alert, fabric filter newsletter
- **Answers**: Orchard Answers with Decision guide locator
- **Analysis**: conference debates, hot topic hours, expert support, white papers and InterWebviews™ in many languages
- **Advancement**: recorded webinars and access to program

---

The Decision Guide is part of a whole system. It is route map to the larger database display (Power Plant Air Quality Decisions) This in turn is part of a complete service for coal fired power plant operators: *Power Plant Systems and Components*. The June Filtration news article will be a compressed version of the revised summary as shaped by the AFS session.
Decision Guide to select hot gas filters and media
## Panelists

<table>
<thead>
<tr>
<th>Company</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEP</td>
<td>Tom Hart</td>
</tr>
<tr>
<td>Babcock &amp; Wilcox</td>
<td>Steve Feeney</td>
</tr>
<tr>
<td>Consultant</td>
<td>Rich Miller</td>
</tr>
<tr>
<td>Donaldson</td>
<td>Eddie Ricketts</td>
</tr>
<tr>
<td>Durr</td>
<td>Martin Shroter</td>
</tr>
<tr>
<td>ETS</td>
<td>John McKenna</td>
</tr>
<tr>
<td>F.L. Smidth</td>
<td>John Johnson</td>
</tr>
<tr>
<td>Filtration Group</td>
<td>John Eleftherakis</td>
</tr>
<tr>
<td>Haldor Topsoe</td>
<td>Nate White</td>
</tr>
<tr>
<td>Purolator</td>
<td>Pavlos Papadopoulos</td>
</tr>
<tr>
<td>SEI</td>
<td>Mick Chambers or Hardik Shah</td>
</tr>
<tr>
<td>Testori</td>
<td>Clint Scoble</td>
</tr>
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</table>
Hot Gas Filtration Decision Guide

A route map and summary of options available and merits of each based on purchasers unique circumstances

*Modified for AFS April 29 Discussion*
Business Factors

Regulatory
• U.S
• EU
• China
• Other

Economic
• Macro
• Micro
  – Plant life
  – Parasitic power cost
# Regulatory, Economic and plant specific impacts on filter choice

<table>
<thead>
<tr>
<th>Subject</th>
<th>Author</th>
<th>Relevant decision</th>
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<tbody>
<tr>
<td>Regulations and Technology</td>
<td>Mcilvaine</td>
<td>Many Different Options created</td>
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<tr>
<td>Emission limits-World</td>
<td>Mcilvaine</td>
<td>New approaches needed to meet new regulations</td>
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<tr>
<td>China limits</td>
<td>Mcilvaine</td>
<td>Will new rules here influence rules for you?</td>
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<tr>
<td>U.S. regulations</td>
<td>Hot topic</td>
<td>Multiple pollution control requires multiple decisions</td>
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<tr>
<td>Cement and other</td>
<td>Mcilvaine</td>
<td>Other industries have the same multiple decisions</td>
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<tr>
<td>PM 2.5 ambient</td>
<td>Troutman-Sanders</td>
<td>Need to evaluate future requirements due to ambient State limits</td>
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<tr>
<td>Condensibles</td>
<td>Hamon</td>
<td>Need to consider small sulfuric acid particle diameter</td>
</tr>
<tr>
<td>Method 5 catch</td>
<td>Hamon</td>
<td>Standard method shows large condensable fraction and may not be valid</td>
</tr>
</tbody>
</table>
Regulations and technology are changing the hot gas filter choices

• China and the U.S. are leading the way with tough particulate emission requirements for power plants.
• Ambient regulations in U.S. states and counties as well as stack regulations for certain cities and provinces in China are much tougher than the national requirements
• The definition of particulate involves size fractions e.g 2.5 microns and physical state (discrete or condensable)
• Requirements involve new and existing installations each with a different set of site specific conditions
• The need to reduce mercury, other toxic metals, HCl, and SO2 changes the particulate reduction decisions.
• Upgrading dry precipitators with new electricals is one option
• One very active retrofit option is replacing the internals of precipitators with fabric bags.
• Wet precipitators are being used in some of the newer U.S. and Chinese installations
• Various dry scrubber/fabric filter combinations are popular
• The ceramic catalytic filter offers potential of small foot print and with DSI can also capture acid gases.
• Metal filters offer an alternative separation at temperatures of 850F and extraction of heat from the clean gas.
• **Many different options based on new regulations and new filter designs**
Emission limits for coal plants around the world in mg/Nm³

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>China</th>
<th>Sinopec Guangzhou</th>
<th>Zhejiang with SCR and WESP</th>
<th>China national</th>
<th>U.S Existing/new</th>
<th>EU Existing/new</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>50</td>
<td>1.4 to 28.5</td>
<td>23,7</td>
<td>200/100</td>
<td>1060-640/117</td>
<td>200/200</td>
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<tr>
<td>SO2</td>
<td>35</td>
<td>2.85 to 7.6</td>
<td>15</td>
<td>200-400/100</td>
<td>350/65</td>
<td>400/200</td>
</tr>
<tr>
<td>PM</td>
<td>5</td>
<td>3.4 to 4.6</td>
<td>3.08</td>
<td>30</td>
<td>45/8</td>
<td>50</td>
</tr>
<tr>
<td>SO3</td>
<td>5</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hg</td>
<td>0.003</td>
<td>0.0004 ug</td>
<td></td>
<td>.03</td>
<td>0.002/0.001</td>
<td></td>
</tr>
</tbody>
</table>

**New approaches needed to meet tough new regulations**
China now has the most stringent particulate limits

- Due to pressure from citizens due to smog, the Chinese government is initiating the toughest air regulations of any country.
- Tough national standards have now been followed by even more stringent standards in a number of cities and even provinces.
- The new national standard of 30 mg/Nm3 for particulate was already tougher than the regulation for existing U.S. coal plants or for plants in the EU.
- The new regulation in Guangzhou and Shanxi limits dust to only 5 mg.
- Existing precipitators will not be able to meet these limits. Zhejiang is meeting the new requirements with a wet precipitator.
- Sinpoec Guangzhou is meeting the standards with a dry scrubber fabric filter system complete with activated carbon injection installed by Longking.
- **Will Chinese rules influence rules elsewhere**
U.S regulations will dictate new hot gas filter approaches

MATS and CSAPR

Mercury and Air Toxics Standards (MATS)
- Limits emissions of toxic air pollutants from coal and oil fired power plants
- Primary pollutants of concern are mercury, hydrogen chloride (HCl) and fine particulates (PM$_{2.5}$)
- FINAL RULE: Compliance by April 2015 with possible extensions of up to 2 years

Cross State Air Pollution Rule (CSAPR)
- Referred to as the “Good Neighbor” rule
- Regulates emissions from one state that may have a negative impact on air quality in a downwind state
- 28 states in the eastern half of the U.S. must limit state-wide emissions of precursors to ozone formation (NOx, SO$_2$ and PM$_{2.5}$)
- FINAL RULE issued August 2011 with first phase to begin in 2012
  - But, the rule did not take effect as scheduled due to litigation
  - August 2012: US Court of Appeals vacated the rule and remanded it to EPA
  - April 2014: US Supreme Court reversed Court of Appeals and reinstated CSAPR
  - November 2014: EPA issued new compliance dates of 2015 to 2017

Together, MATS and CSAPR will require coal plants to install:
- FGD or Dry Sorbent Injection (DSI) to control SO$_2$ and acid gases (HCl)
- SCR or SNCR to control NOx
- Fabric filters or electrostatic precipitators to control particulate matter
- Activated carbon injection units to reduce mercury

Control of multiple pollutants requires multiple decisions
Cement, power and other industries have tight emission standards

• Waste to energy plants have been subjected to tight particulate limits for some time
• Cement plants are finding that precipitators are inadequate to meet regulations in most countries
• The new MACT regulations in the U.S. provide tough requirements for industrial boilers and cement plants
• The MATS regulations in the U.S. provide particulate challenges related to using particulate as a surrogate for toxic metals
• Mining operations, pulp mills and other industries are also facing the necessity of improving particulate capture
• Particulate removal GDPS™ has to take into account the requirements for reduction of other pollutants
MATS PROGRAM STATUS

• Regulates Mercury, Metals HAPS, Acid Gases and Dioxin/Furans

  • Mercury
    • <1.2 lbs Hg/Tbtu (except Pirkey 4.0# Hg/TBbtu)
    • Monitored for reporting with Sorbent Traps on Fleet
    • Most plants will use mercury CEMS of operational indication

  • Acid Gases
    • <0.002 lbs HCl/Mbtu
    • Reporting across fleet:
      • SO$_2$ as a surrogate (<0.2#SO$_2$ /MBtu)
      -or-
      • Quarterly stack testing for HCl

  • Non-Mercury Metal HAPS
    • Quarterly stack particulate monitoring (<0.03 lbs particulate/ Mbtu)

  • Dioxin/Furans
    • Boiler inspections, repairs and tuning (CO, NO$_x$, O$_2$)
    • Annual reporting required.

Supplied by Tom Hart of AEP in the hot gas discussion April 29
<table>
<thead>
<tr>
<th>MERCURY</th>
<th>ACID GASES</th>
<th>Non-Hg Metals</th>
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<tbody>
<tr>
<td>SCR &amp; WFGD</td>
<td>WFGD</td>
<td>ESP – WFGD</td>
</tr>
<tr>
<td>ACI* &amp; Fabric Filter</td>
<td>SBC** &amp; Fabric Filter DFGS &amp; FF</td>
<td>Fabric Filter</td>
</tr>
<tr>
<td>ACI &amp; NID</td>
<td>NID</td>
<td>NID</td>
</tr>
<tr>
<td>ACI &amp; ESP</td>
<td>SBC &amp; ESP</td>
<td>ESP</td>
</tr>
<tr>
<td>ACI &amp; CaBr2 &amp; ESP</td>
<td>WFGD</td>
<td>ESP - WFGD</td>
</tr>
<tr>
<td>WFGD &amp; GMCS</td>
<td>WFGD</td>
<td>ESP - WFGD</td>
</tr>
</tbody>
</table>

*Supplied by Tom Hart of AEP during the AFS hot gas filter session on April 29*
PM 2.5 ambient standards will require reduction

Fine Particulate Matter (PM$_{2.5}$)

- Lowered annual standard to 12 ug/m$^3$ in December 2012
- EPA expects all areas to attain without new control requirements (except CA)
- Vacatur of de minimis levels (SILs and SMCs) could make permitting difficult
  - w/o SMCs, could require onsite monitoring
  - w/o SILs, could make modeling more difficult
- EPA’s implementation rule also vacated
- EPA resets the baseline date; NC objects
Sulfuric acid mist is only 0.3 um in dia.

Particle Sizes

Supplied by Hamon

Choose collector to remove very small particles
PM includes both discrete and condensable aerosols

**What is PM$_{2.5}$?**

**Filterable Particulate**
- <2.5 microns in size
- Exists as solid particulate at temperatures of 250°F or higher
- Collected in “front half” filter of PM test apparatus

**Condensable Particulate**
- <2.5 microns in size
- Vapors that condense
- Primarily SO$_3$ (H$_2$SO$_4$) sulfuric acid
- Toxic metals
- Collected in “back half” impingers in PM test apparatus

50%-75% of PM2.5 is Condensable PM

*Supplied by Hamon*  
*Choice may have to include condensibles*
Condensibles captured in back half of Method 5 train (Hamon)

EPA Method 8 Sampling

Will you have to deal with this uncertain measurement?
# Decision Route – Reasons to address hot gas alternatives

## Recorded Sessions

### HOT TOPIC WEBINARS

<table>
<thead>
<tr>
<th>Date</th>
<th>Title</th>
<th>Duration</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 29, 2015</td>
<td>MATS Compliance Choices</td>
<td>91 minutes</td>
<td></td>
</tr>
<tr>
<td>August 2014</td>
<td>Mercury in Mandarin (available in Mandarin and English by Bobby Chen of CBI)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### INTERWEBVIEWS™ (FREE)

- **Chinese youtube version**
  - [http://youtu.be/ldq33k5UWTs](http://youtu.be/ldq33k5UWTs)
- **Tekran, Karl Wilber** MACT QUESTIONS
- **Sick, Dan Keitzer** MACT CEMS

## Decision Orchard key words

**Free to end users but subscription for others**

<table>
<thead>
<tr>
<th>Generic</th>
<th>Corporation</th>
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<tbody>
<tr>
<td>Mercury</td>
<td>CB&amp;I, Chemtura</td>
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<tr>
<td>CEMS</td>
<td>Thermo Fisher Scientific, SICK Process Automation Tekran Instruments</td>
</tr>
<tr>
<td>Other key words</td>
<td>CSAPR, Industrial Boiler MACT Legislation MATS NAAQS</td>
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</tbody>
</table>

- Tekran, Karl Wilber MACT QUESTIONS
- Sick, Dan Keitzer MACT CEMS
## System and APC impacts on filter choice

<table>
<thead>
<tr>
<th>Subject</th>
<th>Author</th>
<th>Relevant decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Impacts</td>
<td>Mcilvaine</td>
<td>Many process and site specific impacts have to be considered</td>
</tr>
<tr>
<td>Boiler efficiency-APH</td>
<td>Paragon</td>
<td>The air heater outlet temperature is variable and impacts the filter selection</td>
</tr>
<tr>
<td>Mercury Considerations</td>
<td>CBI</td>
<td>The filter decision must be viewed along with the many options to reduce mercury and prevent re-emissions</td>
</tr>
</tbody>
</table>
Plant specific factors

Existing APC
- Particulate
- SO2
- SO3
- Nox
- Mercury
- HCl

Combustion
- Boiler design
- Fuel additives
- Fuel
- Heat recovery

Balance of plant
- Wastewater
- Ash conveying
- Space available
- By product sales
System impacts

- Heat extraction decisions must be made simultaneously with particulate control because of the inter-relationships.
- The precipitator efficiency increases as the inlet temperature is reduced.
- The ability to use lower cost bags is enhanced by reducing both the gas temperature and the acid dew point.
- Reduction of precipitator or baghouse inlet temperature to the acid dew point will cause corrosion and plugging problems.
- Clean hot gas offers a big potential for energy recovery.
- Existing rotary air heaters have inlet air leakage of 10% making the dust collectors larger than need be.
- The SCR increases SO3 which will lead to more condensable particulate.
- Activated carbon for mercury control increases particulate emissions.
- Halogen addition to the coal causes potential corrosion problems.
- Dry scrubbers increase the particulate load and potential emissions and wear on bags.
- Wet scrubbers downstream of a precipitator can improve total particulate capture.
Boiler efficiency is a function of heat transfer in the air heater but limited by the acid dew point.

Function of an Air Heater

- Extracts Waste Heat From Exhaust Gases
- Recycles That Heat to the Incoming Air

- WARMED AIR 620°F
- COOL AIR 100°F
- HOT GAS 700°F
- COOLED GAS 290°F

260°F
320°F
Mercury considerations in many locations

If more than 1.0 lb/TBtu of stack Hg emission is observed, there is Hg reemission across the FGD
Mercury can be removed in the scrubber by adding halogens to the fuel but materials of construction in the filter may have to be considered.
Decision Route – System impacts

## Recorded sessions

<table>
<thead>
<tr>
<th>Hot Topic Webinars</th>
<th>Decision Orchard key words</th>
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<td>January 29, 2015</td>
<td>CORPORATION</td>
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<td><strong>MATS Compliance Choices</strong></td>
<td>Air Preheater</td>
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<tr>
<td></td>
<td>Paragon Airheater Technologies</td>
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<tr>
<td>September 15, 2014</td>
<td><strong>Mercury in Mandarin</strong> (available in Mandarin and English by Bobby Chen of CBI)</td>
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<tr>
<td>August 2014</td>
<td><strong>Nuendorfer, Storm, UDC</strong> analysis of back end upgrades to meet MACT</td>
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<tr>
<td>Chinese youtube version</td>
<td><strong>view it on YouTube,</strong></td>
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</table>

### Decision Orchard key words

- **MATS Compliance Choices**
- 91 minutes
- **Mercury in Mandarin** (available in Mandarin and English by Bobby Chen of CBI)
- **Air Preheater**
- **Paragon Airheater Technologies**
- **Nuendorfer, Storm, UDC** analysis of back end upgrades to meet MACT
- **view it on YouTube,**
Filter Solutions

Precipitator
- Larger dry
- Wet
- Hybrid

Synthetic filter
- Collector
  - Pulse jet
  - Reverse air
  - Medium dP
- Bags
  - Tubular
  - Pleated

Other
- Catalytic
- Ceramic
- Metal
- Venturi
## Precipitator – Scrubber Options -1

<table>
<thead>
<tr>
<th>Subject</th>
<th>Author</th>
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<tbody>
<tr>
<td>All options</td>
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<tr>
<td>Upgrade precipitator</td>
<td>KC Cottrell</td>
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<tr>
<td>Component upgrade</td>
<td>KC Cottrell</td>
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<tr>
<td>Recent SEI designs</td>
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<tr>
<td>Wet precipitators</td>
<td>Mcilvaine</td>
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<td>Wet ESPs</td>
<td>Hamon</td>
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<td>WESP and SO3</td>
<td>Mcilvaine</td>
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<td>Recent installations</td>
<td>Hamon</td>
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## Precipitator – Scrubber Options -2

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<td>Dry scrubber, baghouse</td>
<td>longking</td>
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<td>Dry sorbent injection</td>
<td>Lhoist</td>
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<td>Reagents create PM 2.5</td>
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<tr>
<td>TBD</td>
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</table>
Options to meet tough particulate emission limits

• Upgrade existing precipitator with new more efficient electricals
• Buy a larger precipitator- may have to double size
• Use sorbent injection prior to the air heater to reduce the acid dew point and then make the air heater bigger to reduce the precipitator inlet temperature and improve efficiency
• Install a wet precipitator after the existing precipitator and scrubber
• Replace the precipitator with a fabric filter
• Add precipitator after the fabric filter
• Replace the precipitator with a hybrid fabric filter/ESP
• Combine particulate and scrubbing in one system with a dry scrubber and fabric filter
• Install a catalytic filter or hot gas filter to meet 850 F.
Upgrade ESP to meet MATS

ESP fors for MATS Compliance

- Many existing power stations use ESPs for particulate collection.
- A properly designed ESP can achieve the required MATS limit for PM.
- Existing ESPs designed for previous limits may not need to be replaced.
- A variety of upgrade options can be employed, many in parallel, to improve performance.
- There is no single solution.
Specific upgrade options-KC Cottrell

ESP Upgrade Options

- Improve gas distribution
- Change Internals – collectors, electrodes
- Improve Rapping
- Modern control systems
- Increased power: more T/R sets
- High Frequency T/R sets
- Raise the roof
- Additional inlet/outlet fields
- New parallel ESPs
- Conversion to baghouse
## ESP vs. FF COMPARISON

<table>
<thead>
<tr>
<th>RECENT SEI ESP’s</th>
<th>(filterable)</th>
<th>Outlet</th>
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<tbody>
<tr>
<td></td>
<td>SCA*</td>
<td>lb/mmBtu</td>
</tr>
<tr>
<td>Coffeen #2</td>
<td>***</td>
<td>.0048</td>
</tr>
<tr>
<td>Duck Creek #3</td>
<td>***</td>
<td>.0047</td>
</tr>
<tr>
<td>Tecumseh #9</td>
<td>***</td>
<td>.0038</td>
</tr>
<tr>
<td>Thomas Hill #3</td>
<td>***</td>
<td>.0054</td>
</tr>
<tr>
<td>Cliffside #5</td>
<td>***</td>
<td>.0066</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>313</strong></td>
<td>.0051</td>
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*** Proprietary data

* corrected to 12” plate spacing
## ESP vs. FF COMPARISON

<table>
<thead>
<tr>
<th>PM SIZE</th>
<th>Yi, Hao, Duan, Li &amp; Guo, 2006</th>
<th>Yi, Hao, Duan, Li &amp; Guo, 2006</th>
<th>Duck Creek</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>ESP 99.89</td>
<td>FABRIC FILTER 99.94</td>
<td>ESP 99.91</td>
</tr>
<tr>
<td>PM 10</td>
<td>99.62</td>
<td>99.76</td>
<td>99.73</td>
</tr>
<tr>
<td>PM 5</td>
<td>99.16</td>
<td>99.72</td>
<td>99.63</td>
</tr>
<tr>
<td>PM 2.5</td>
<td>98.59</td>
<td>99.54</td>
<td>99.37</td>
</tr>
</tbody>
</table>

ESP: 0.0047 lb/mbtu
Duck Creek: 0.0027 lb/mbtu
## EXAMPLE #2 (CONT’D)

### SUMMARY – FF RETROFIT

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>$10,230,000</td>
</tr>
<tr>
<td>Demo/Installation</td>
<td>$17,100,000</td>
</tr>
<tr>
<td>New ID Fans (installed)</td>
<td>$ 4,000,000</td>
</tr>
<tr>
<td>Boiler Buckstay Upgrade</td>
<td>$ 6,500,000</td>
</tr>
<tr>
<td>Outage</td>
<td>___56 days</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; Year O&amp;M</td>
<td></td>
</tr>
<tr>
<td>Parasitic Power</td>
<td>$1,600,000</td>
</tr>
<tr>
<td>Routine Maintenance</td>
<td>$1,400,000</td>
</tr>
</tbody>
</table>
## EXAMPLE #2 (CONT’D)

**SUMMARY – ESP REHAB**

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>$10,500,000</td>
</tr>
<tr>
<td>Demo/Installation</td>
<td>$13,700,000</td>
</tr>
<tr>
<td>Outage Duration</td>
<td>56 days</td>
</tr>
<tr>
<td>1\textsuperscript{st} Year O&amp;M</td>
<td></td>
</tr>
<tr>
<td>Parasitic Power Cost</td>
<td>$803,900</td>
</tr>
<tr>
<td>Routine Maintenance</td>
<td>$100,000</td>
</tr>
</tbody>
</table>
Wet precipitators can be part of the most elaborate or simple system

- The ultimate system has an SCR, fabric filter, wet scrubber, and then a final wet electrostatic precipitator.
- Often overlooked is the simple option as follows:
  - A lime wet scrubber captures particulate and SO2
  - A downstream Wet Esp removes the remaining particulate
  - The two can be combined in one tower.
- Advantages:
  - Low cost and easy retrofit
  - Flyash/lime/gypsum encapsulates the mercury and toxic metals
  - Good landfill material
  - High efficiency
# Wet ESP Utility Installations

<table>
<thead>
<tr>
<th>Facility</th>
<th>Size</th>
<th>Fuel</th>
<th>APC</th>
</tr>
</thead>
<tbody>
<tr>
<td>AES- Deepwater</td>
<td>155 MW</td>
<td>Pet Coke</td>
<td>WFGD / WESP</td>
</tr>
<tr>
<td>Dakota Gasification</td>
<td>420 MW</td>
<td>Waste Liquids</td>
<td>WFGD/ WESP</td>
</tr>
<tr>
<td>Dalhousie 1 &amp; 2</td>
<td>315 MW</td>
<td>Orimolsion</td>
<td>WFGD / WESP</td>
</tr>
<tr>
<td>Xcel- Shirco</td>
<td>2 x 750 MW</td>
<td>PRB Coal</td>
<td>WFGD/ WESP</td>
</tr>
<tr>
<td>NBP- Coleson Cove</td>
<td>3 x 350 MW</td>
<td>#6 Oil</td>
<td>WFGD / WESP</td>
</tr>
<tr>
<td>WE- Elm Road</td>
<td>2 x 615 MW</td>
<td>Pittsburgh #8</td>
<td>FF / WFGD / WESP</td>
</tr>
<tr>
<td>CWLP - Dallman</td>
<td>200 MW</td>
<td>Coal Blend</td>
<td>FF / WFGD / WESP</td>
</tr>
<tr>
<td>LGE - Trimble</td>
<td>820 MW</td>
<td>Coal Blend</td>
<td>DESP / FF / WFGD / WESP</td>
</tr>
<tr>
<td>Prairie States</td>
<td>2 x 880 MW</td>
<td>Southern Il. Bit.</td>
<td>DESP / WFGD/ WESP</td>
</tr>
<tr>
<td>EKPC - Spurlock</td>
<td>525</td>
<td>Coal Blend</td>
<td>WFGD/ WESP</td>
</tr>
</tbody>
</table>
Possible Alternative = WFGD + Wet ESP
Wet ESPS for SO3 and fine particulate

• Several WESPS were installed in U.S. to reduce the SO3 plume in the period around 2000
• Subsequently the solution to SO3 was determined to be dry injection
• However, WESPS have been installed on new plants to capture both the SO3 and fine particulate
• Siemens was the major supplier (now Foster Wheeler)
Scrubber capture of fine particulate

- Typical spray tower wet scrubbers do not remove much particulate if there is an efficient precipitator ahead of it.
- A tray tower scrubber is slightly more efficient.
- During an exceedance the scrubber can remove most of the particles.
- At an emission of 0.2 lbs/mm btu from the precipitator, the scrubber will capture more than 0.1 lbs/mm btu.
- Wet scrubbers do not remove much SO3 when it is converted to sub micron hydrochloric acid aerosols.
- With the new mass monitoring requirements particulate must be measured in the wet stack following the scrubber.
- If the scrubber adds to or reduces the particulate it will now be recorded. Previously opacity monitors prior to the scrubber were the basis of determining exceedances.
Scrubber limitations (Hamon)

Limitations on WFGD PM2.5 collection

Will you have to find alternative for H2SO4
## Decision Route – Scrubber, Precipitator

### Webinars Protected

<table>
<thead>
<tr>
<th>Date</th>
<th>Recording tile</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>October 23, 2014</td>
<td><strong>Dry Scrubbing</strong></td>
<td>104 mins</td>
</tr>
<tr>
<td>October 2, 2014</td>
<td><strong>Precipitator Improvements</strong></td>
<td>84 mins</td>
</tr>
</tbody>
</table>

### InterWebViews™) free

<table>
<thead>
<tr>
<th>Date</th>
<th>Subject; company date, language</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>(continuing opportunity for suppliers to provide more comprehensive information)</em></td>
</tr>
</tbody>
</table>
SDA followed by bag filter is one of the routes for hot gas filtration and acid gas removal

B&W has a number of spray dryer absorber units followed by bag filters which meet the new Mats filterable PM limits

<table>
<thead>
<tr>
<th>INSTALLATION</th>
<th>HCI (lb/MBtu)</th>
<th>Mercury (lb/TBtu)</th>
<th>Filterable PM (lb/MBtu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walter Scott 4 (790 MW)</td>
<td>0.000038</td>
<td>0.720</td>
<td>0.0034</td>
</tr>
<tr>
<td>Weston 4 (530 MW)</td>
<td>0.000077</td>
<td>0.893</td>
<td>0.0066</td>
</tr>
<tr>
<td>TS Power Project (220 MW) (Newmont Nevada Energy)</td>
<td>0.000022</td>
<td>0.867</td>
<td>0.0056</td>
</tr>
<tr>
<td>Hawthorn 5A (540 MW)</td>
<td>0.000072</td>
<td>5.30</td>
<td>0.0011</td>
</tr>
<tr>
<td>Spruance Genco 2 (57 MW) (Coal-and tire-firing)</td>
<td>0.000017</td>
<td>0.0026</td>
<td>0.0183</td>
</tr>
<tr>
<td>MATS Limits</td>
<td>0.002</td>
<td>1.2</td>
<td>0.030</td>
</tr>
</tbody>
</table>

**SDA units supplied by B&W are meeting MATS compliance**
Fabric Filters for hot gas filtration

- Fabric filters can be prior to or after the SO2 scrubbing device
- Various cleaning mechanisms impact bag and media selection
- A range of fibers and media is available depending on widely varying site specific conditions
One option is a low pressure long bag design

Recent Trends in Fabric Filters

- Low pressure pulse, long bag design
- Online cleaning
- No bypass on start-up
- Filter as reactor (primary or secondary)
- Increasingly lower emission rates
- Use of PTFE membranes
Bag material considerations-KC Cottrell

Bag Material Considerations

- Operating temperature
- Moisture
- Chemistry
- Abrasion resistance
- Filtering Mechanism
  - Depth vs. Surface Filtration
ENEL has converted ESPs

Fabric Filters running in Enel’s national fleet

<table>
<thead>
<tr>
<th>Plant</th>
<th>Capacity (MWe)</th>
<th>FF type</th>
<th>Installation</th>
<th>Supplier</th>
<th>Year</th>
<th>Bag Lenght [m]</th>
<th>Comp.</th>
<th>Emissions guarantees [mg/Nm3] (*)</th>
<th>Expected FF Emiss. in Operation [mg/Nm3]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fusina 1 &amp; 2</td>
<td>2 x 160</td>
<td>PJ, HP/LV</td>
<td>Conversion</td>
<td>TMK</td>
<td>1999</td>
<td>8.5</td>
<td>2</td>
<td>&lt;30</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Genova 6</td>
<td>160</td>
<td>PJ, HP/LV</td>
<td>Conversion</td>
<td>TMK</td>
<td>2003</td>
<td>9</td>
<td>4</td>
<td>&lt;30</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Sicis 2 (*)</td>
<td>340</td>
<td>PJ, HP/LV</td>
<td>New (**)</td>
<td>Aster</td>
<td>2005</td>
<td>8.5</td>
<td>16</td>
<td>&lt;25</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Torrevald. 1+3</td>
<td>3 x 660</td>
<td>PJ, HP/LV</td>
<td>New (**)</td>
<td>TMK</td>
<td>2005</td>
<td>8</td>
<td>16</td>
<td>&lt;10</td>
<td>&lt;9</td>
</tr>
<tr>
<td>Brindisi S.# 3&amp;4</td>
<td>2 x 660</td>
<td>PJ, HP/LV</td>
<td>Conversion</td>
<td>TMK</td>
<td>2010-12</td>
<td>8</td>
<td>4</td>
<td>&lt;20</td>
<td>&lt;10</td>
</tr>
</tbody>
</table>

(*) Circ.Fla.Bed Boiler (CFB)  (**) Over the existing Electr. Precip. ESP foundations  (*) hourly basis

- Italian references regarding conversions from electrostatic precipitators (ESPs) to fabric filter (FFs) are all “brown field” installations.
- "Conversion" means “transformation” from an electrostatic precipitator to a fabric filter using the previous casing.
- "New" fabric filters to use only the existing foundation of the old previous electrostatic precipitator and to design new filter steel structure and casing.
- There is in addition a small fabric filter installed in a ~ 30 MWe Biomass PP in Calabria (South of Italy)

Acronym: PJ pulse jet; HP/LV high pressure low volume type; ESP Electrostatic Precipitator; TMK Termokimik spa ; Torrevald.: Torrevaldaliga North power plant.
Enel has FF on boilers in Russia, Chile, Spain (Evonik presentation)

Fabric Filters in Enel’s abroad fleet and programs

<table>
<thead>
<tr>
<th>Plant</th>
<th>Country</th>
<th>Capacity (MWe)</th>
<th>FF type</th>
<th>Installation</th>
<th>Supplier</th>
<th>Year</th>
<th>Bag Lenght [m]</th>
<th>Comp.</th>
<th>Emissions guarantees [mg/Nm³]</th>
<th>Expected FF Emiss. in Operation [mg/Nm³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcudia</td>
<td>Spain</td>
<td>2 x 125</td>
<td>PJ, HP/LV</td>
<td>New</td>
<td>Fisia Babcock</td>
<td>n.a.</td>
<td>8</td>
<td>6</td>
<td>&lt;20</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Alcudia</td>
<td>Spain</td>
<td>2 x 130</td>
<td>PJ, IP/IV</td>
<td>New</td>
<td>ABB/BWE</td>
<td>n.a.</td>
<td>7</td>
<td>6</td>
<td>&lt;20</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Tarapacà</td>
<td>Chile</td>
<td>158</td>
<td>PJ, IP/IV</td>
<td>New</td>
<td>ALSTOM</td>
<td>2013</td>
<td>10</td>
<td>8</td>
<td>&lt;10</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Bocamina I</td>
<td>Chile</td>
<td>128</td>
<td>PJ, IP/IV</td>
<td>New</td>
<td>ALSTOM</td>
<td>2007</td>
<td>8</td>
<td>6</td>
<td>&lt;10</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Bocamina II</td>
<td>Chile</td>
<td>350</td>
<td>PJ, HP/LV</td>
<td>New</td>
<td>Slavex</td>
<td>2012</td>
<td>6.5</td>
<td>20</td>
<td>&lt;30</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Reftinskaya 5</td>
<td>Russia</td>
<td>300</td>
<td>PJ, IP/IV</td>
<td>Conversion</td>
<td>ALSTOM</td>
<td>2013</td>
<td>8</td>
<td>4</td>
<td>&lt;50</td>
<td>&lt;20</td>
</tr>
<tr>
<td>Reftinskaya 7</td>
<td>Russia</td>
<td>500</td>
<td>PJ, HP/LV</td>
<td>Conversion</td>
<td>Clyde Bergmann</td>
<td>2014(*)</td>
<td>8.5</td>
<td>16</td>
<td>&lt;50</td>
<td>&lt;20</td>
</tr>
<tr>
<td>Reftinskaya 4</td>
<td>Russia</td>
<td>300</td>
<td>PJ, IP/IV</td>
<td>Conversion</td>
<td>ALSTOM</td>
<td>2015(*)</td>
<td>8</td>
<td>4</td>
<td>&lt;50</td>
<td>&lt;20</td>
</tr>
</tbody>
</table>

(*) Note: expected date / schedule to be confirmed.

- The filters in Russia could be taken as the more challenging in terms of operation and maintenance considering the very high dust content of the coals (up to 40%) and the high NOx inside the flue gas.
- About the remaining units in Russia: #1÷4 and #8÷10 the conversion of the existing electrostatic precipitators ESP to fabric filters FF are today foreseen before the end of this decade.

Other Acronym: HP/LV High Pressure Low Volume type, IP/IV intermediate Pressure - Intermediate Volume, n.a. not available
Eskom will be spending $100 million/yr for bags (Evonik Presentation)

This equates to an average consumption of approx. 350 000 bags per year. Currently all bags are disposed of in a Class H:H Hazardous Waste Dump at Holfontein (350 000 bags = +1 000 000 m² of fabric)
Tubular bags

Tubular bags remain the major choice for higher temperature conditions and heavy dust loadings.

Pleated bags are more expensive and are generally used where space is tight.

The main use of wovens is in glass bags with reverse air cleaning. Most tubular bags are non-woven felts.
Pleated Bags

Pleated bags are being used mostly for retrofit installations where more gas flow is needed or there is a need to reduce pressure drop. Cost is a consideration for new installations as well as ease of cleaning. So issues are

- Space available
- Pressure drop
- Cost
- Cleanability

Key words: Pleated Bags
StarBags in Power Generation

With StarBags, power plants can achieve reduced particulate emissions and lower their usage of activated carbon and lime

- SOLAFT Filtration Solutions, pioneered the development of StarBag™ technology in the early 2000s as developer and patent holder of StarBags™ with the first smelter wide installation at Boyne Smelters in 2004.

- Since then, StarBag™ Solutions have become common in smelters worldwide helping smelters deliver meaningful operational improvements with a strong return on investment (ROI) and relatively short payback period.

- StarBag™ Solutions are installed in filtration systems replacing standard filter bags without any expansion or change to the design of existing bag houses other than a change to the supporting cages.

- With StarBags™ and SOLAFT’s expert support, benefits achieved for smelters can be realized by power generators:
  - Reduced particulate, Hg and SOX emissions
  - Reduced lime and activated carbon usage
  - Increased generation where ID fans are a constraint to air flow
  - Compliance with MATS and operating licenses

- StarBag™ Solutions deliver these benefits by increasing filtration area, thus enabling increased gas volume and particulate load through the bag house while at the same time reducing differential pressure.

- SOLAFT can work closely with power generators around the world to understand their commercial challenges and can configure a StarBag Solution to overcome their challenges and deliver meaningful benefits.
New Developments in Fabric Filtration

We are working closely with power generators, fibre makers, chemists and technologists around the world to bring the most recent thinking and developments to our customers.

<table>
<thead>
<tr>
<th>Emerging Trends</th>
<th>Product Approach</th>
<th>Our solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>High efficiency filtration with stratified fabrics of multi-lobal fibres</td>
<td>PPS inner web with multi-lobal P84 fiber in the face to lower emissions and reduce pressure drop, lowering operating costs and lengthening bag life</td>
<td>PrimaLobe</td>
</tr>
<tr>
<td>Extending life by combating oxygen degradation with new fibres</td>
<td>New fibres with superior resistance to oxidation are being trialled with promising results</td>
<td>PrimaOxyTech</td>
</tr>
<tr>
<td>Fabrics for aggressive acid and non-agglomerating and high velocity dusts</td>
<td>Use of PTFE fiber blended with PPS to resist acid degradation and minimise impact of poor dust cake formation</td>
<td>PrimaGlide</td>
</tr>
<tr>
<td>New software to track bag life, predict bag change-outs and managing bag house operations</td>
<td>Software and product solutions enabling each individual filter bag’s performance to be tracked</td>
<td>FilterFacts</td>
</tr>
<tr>
<td>Extended surface area bags to lower emissions with lower differential pressure and increased flows</td>
<td>Extended surface area bags achieve reduced emissions from reduced pulse frequency</td>
<td>Star Bags</td>
</tr>
</tbody>
</table>
Relative bag costs

Cost Considerations

- Current pricing per bag, 33’ long by 5” diameter:
  - PPS Felt ~ $81-90
  - P-84 Felt ~ $143-158
  - WFG/Membrane ~ $73-81
# Parameters affecting media selection

<table>
<thead>
<tr>
<th>Subject</th>
<th>options</th>
</tr>
</thead>
<tbody>
<tr>
<td>fiber</td>
<td>pps, P84, ptfe, glass, ceramic, acrylic</td>
</tr>
<tr>
<td>media</td>
<td>Non woven, Membrane laminate, woven, sintered</td>
</tr>
<tr>
<td>Plant conditions</td>
<td>Emission limit, Area available, Fan limits</td>
</tr>
<tr>
<td>gas</td>
<td>Flyash load, Sulfuric acid, Sulfates/acids</td>
</tr>
<tr>
<td>Bag shape</td>
<td>Tubular, Pleated, cartridge</td>
</tr>
<tr>
<td>cleaning</td>
<td>Hi vol med Pressure air, High pressure air</td>
</tr>
<tr>
<td></td>
<td>Reverse air, shaker</td>
</tr>
</tbody>
</table>
## Needlefelts: Finishing and Treatments for CFB

<table>
<thead>
<tr>
<th>Description</th>
<th>Fibers</th>
<th>Benefit</th>
</tr>
</thead>
</table>
| **ePTFE MEMBRANE**                                                        | **PAN, PPS, P84, GLASS, PTFE**                                         | - Controlled low emissions  
  - Better efficiency  
  - Cleanability  
  - **Disadvantage**: abrasion, oils, special install, tight fit  
  - Water repellency  
  - Better cake release  
  - Suitable for sticky dust  
  - Water and oil repellency  
  - Very good cake release  
  - Increased bag lifetime  
  - Adds surface area  
  - Suitable for sticky dust  
  - Better filtration efficiency  
  - Very low emissions below 5mg/Nm³ |
| **KLEENTES**                                                              | **PAN**                                                                | - Water repellency  
  - Better cake release  
  - Suitable for sticky dust |
| **MANTES**                                                                | **PAN, PPS, P84, PTFE**                                               | - Water and oil repellency  
  - Very good cake release  
  - Increased bag lifetime  
  - Adds surface area  
  - Suitable for sticky dust |
| **RHYTES**                                                                | **PPS**                                                                | - Better filtration efficiency  
  - Very low emissions below 5mg/Nm³ |
| **SUPERNOVATES**                                                         |                                                                       |                                                                                                                                          |
Membrane laminate has higher efficiency on smaller particles particularly prior to loading.

Efficiency Comparison: 16oz PPS

Conventional Media

Tetratex Laminate (8162)

* Independent test results conducted by LMS Technologies Inc. May 2012

Committed To Solving Your Filtration Challenges
Donaldson cites depth filtration disadvantages

Conventional Filter Media: Depth Filtration

- Efficiency relies on primary cake formation
- Dust cake restricts airflow
- Requires high cleaning energy, which impacts mechanical stresses
- Fine particles migrate into media causing abrasion damage
- Leads to blinding - High pressure drop
## Media selection - Testori

### Selecting Media

The following table outlines a selection chart for filter media, detailing various fiber types, their common brand names, temperature limits, resistance to acids, alkalis, hydrolysis, and oxidation.

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Common Brand Names</th>
<th>Temp Limits* F/C</th>
<th>Resistance to Acids</th>
<th>Resistance to Alkalis</th>
<th>Resistance to Hydrolysis</th>
<th>Resistance to Oxidation</th>
</tr>
</thead>
<tbody>
<tr>
<td>COTTON</td>
<td>NA</td>
<td>180°/85°</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>PVC</td>
<td>Rhovyl, Clevyl</td>
<td>150°/65°</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>POLYPROPYLENE</td>
<td>Herculan</td>
<td>190°/90°</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Poor</td>
</tr>
<tr>
<td>NYLON</td>
<td>Enka, Antron</td>
<td>230°/110°</td>
<td>Poor</td>
<td>Excellent</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>HOMOPOLYMER ACRYLIC</td>
<td>Dolanit, Aksa</td>
<td>257°/125°</td>
<td>Good</td>
<td>Fair</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>POLYESTER</td>
<td>Fortrel, Dacron, et al.</td>
<td>300°/150°</td>
<td>Good</td>
<td>Poor</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>PPS</td>
<td>Torcon, Procon, et al.</td>
<td>375°/190°</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Fair</td>
</tr>
<tr>
<td>ARAMID</td>
<td>Nomex, Conex, et al.</td>
<td>400°/205°</td>
<td>Poor</td>
<td>Excellent</td>
<td>Poor</td>
<td>Fair</td>
</tr>
<tr>
<td>POLYIMIDE</td>
<td>P84</td>
<td>450°/235°</td>
<td>Fair</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>PTFE</td>
<td>Profielen, Toyoflon, et al.</td>
<td>500°/260°</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>FIBERGLASS</td>
<td>NA</td>
<td>550°/285°</td>
<td>Good</td>
<td>Fair</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

*Dry heat only

---

Testori USA, Inc.
www.testori-usa.com
Range of membrane efficiencies

Tetratex® Membrane Products
Particular to the Challenge

Tetratex

Tetratex EXTREME®

Tetratex High Efficiency

Committed To Solving Your Filtration Challenges
### Pleated bags - membranes

**Key words**: Midwesco Pleated Bags

**Particulate and Condensable Removal - Pleated Products by Tom Anderson, TDC Filter**

---

**ASTM 6830-02 Comparison of Media**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Spun Bond Polyester with High efficiency ePTFE Membrane</th>
<th>18-20 Ounce Polyester Felt</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM 2.5 Emissions (g/dscf)</td>
<td>.00000073</td>
<td>.0000073</td>
</tr>
<tr>
<td>Total Mass Emissions:</td>
<td>.0000073</td>
<td>.0000073</td>
</tr>
<tr>
<td>Avg. Residual Pressure Drop (cm w.g.)</td>
<td>1.40</td>
<td>2.67</td>
</tr>
<tr>
<td>Filter Sample Weight Gain (grams)</td>
<td>2.67</td>
<td>8.64</td>
</tr>
<tr>
<td>Avg. Filtration Cycle (secs.)</td>
<td>154</td>
<td>37</td>
</tr>
<tr>
<td>Number of Pulses</td>
<td>142</td>
<td>558</td>
</tr>
</tbody>
</table>
microvel® - Near zero emissions and low dp using fine fibres and Gutsche manufacturing expertise

microvel®- overview of advantages:
• extremely low outlet emissions
• very good regeneration capabilities leading to low dp
• high mechanical stability
• problem free installation with no special tools
• optimal cost-benefit ratio
• excellent case histories and references
optivel® - An optimal combination blending different polymers to achieve the best results

- improved separation efficiency
- optimal cost-benefit ratio
- combination of fibre strengths
- high mechanical stability
- optimal filter cake build-up
- world class reference list
- low dp and emissions
**microvel® & optivel®** - Filter media in filtration mode

Optimal filter cake build-up

- Dust laden raw gas
- Highly porous dust cake
- Compact nedling on filtration side
- Support scrim
- Clean gas side
- Clean gas
## Webinars Protected

<table>
<thead>
<tr>
<th>Date</th>
<th>Recording tile</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>October 23, 2014</td>
<td>Dry Scrubbing <a href="#">MORE</a></td>
<td>104 minutes</td>
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<td>January 8, 2015</td>
<td>Fabric Selection for Hot Gas Applications <a href="#">MORE</a></td>
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## InterWebViews™) free

<table>
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<th>Subject; company date, language</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(continuing opportunity for suppliers to provide more comprehensive information)</td>
</tr>
</tbody>
</table>

### Decision Orchard key words

*access to full data on protected site*
# Ceramic and Metal Filters

<table>
<thead>
<tr>
<th>Subject</th>
<th>Author</th>
<th>Relevant decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catalytic filter with powdered limestone</td>
<td>Durr</td>
<td></td>
</tr>
<tr>
<td>Catalytic filter-ceramic and 3 layer</td>
<td>Haldor Topsoe</td>
<td></td>
</tr>
<tr>
<td>Catalytic filter</td>
<td>Tri-mer</td>
<td></td>
</tr>
<tr>
<td>Metal filters</td>
<td>Purolator</td>
<td></td>
</tr>
</tbody>
</table>
Catalytic filter with embedded catalyst

Filter Element

UltraCat Catalyst Filter: Structure and Size

Nano-bits of NOx, CO, VOC catalyst are embedded into the walls and adhere to the fibers.
## Cleaning & Pressure Drop vs. Competition

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Clear Edge Cerafil</th>
<th>Competition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Porosity</strong></td>
<td>80% (dense outer wall)</td>
<td>90% (open outer wall, dense inner wall, gradient)</td>
</tr>
<tr>
<td><strong>Filtration</strong></td>
<td>Mainly on the conditioned outer surface</td>
<td>First dust penetration and then filtration</td>
</tr>
<tr>
<td><strong>Dust penetration</strong></td>
<td>0.63 mg</td>
<td>5.03 mg</td>
</tr>
<tr>
<td><strong>Pressure drop rise</strong></td>
<td>Gradual</td>
<td>Quick</td>
</tr>
<tr>
<td><strong>Cleaning cycle interval</strong></td>
<td>Long</td>
<td>Short</td>
</tr>
<tr>
<td><strong>Time to 4kPa</strong></td>
<td>6 times longer</td>
<td>1x</td>
</tr>
<tr>
<td><strong>Cleaning interval</strong></td>
<td>Over 5 times longer</td>
<td>1x</td>
</tr>
</tbody>
</table>

VDI 3926/ASTM D6830-02: Testing for cleanable filter media
Cerafil TK-3000 - Long term performance

Glass Furnace

**Application:** Glass furnace exhaust  
**Cerafil TopKat-3000:** 1700 elements  
**Commissioned:** Sep 2009  
**Volumetric flow:** 53,000 scfm (85,000 Nm³/h)  
**Operating temp:** 615°F-660°F (325°C – 350°C)

<table>
<thead>
<tr>
<th>Year</th>
<th>Dust (mg/m³)</th>
<th>*NOₓ (mg/m³)</th>
<th>*SOₓ (mg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>&lt;10</td>
<td>&lt;600 mg/m³</td>
<td>&lt;400 mg/m³</td>
</tr>
<tr>
<td>2013</td>
<td>&lt;10</td>
<td>&lt;600 mg/m³</td>
<td>&lt;400 mg/m³</td>
</tr>
<tr>
<td>2014</td>
<td>&lt;10</td>
<td>&lt;600 mg/m³</td>
<td>&lt;400 mg/m³</td>
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*Permitted limits: NOₓ: 800 mg/m³ and SOₓ: 800 mg/m³*
Existing U.S. Coal-Fired Boilers

Side Stream Application – Example existing ESP

**SO₂ Conversion > 80%**

1.500°C

ClearChemFSI™ micronized CaCO₃

SO₂

CaO

Coal Feed

Convection Sections & economizer

ESP

Dry Ash removal

Boiler feed water

SO₂ < 1%

SO₃ < 1 ppm

160°C

< 60°C

to stack

Ammonia injection

Dürr Catalytic hot gas filter

Dürr 1st stage CHX / HRSG

Dürr 2nd stage CHX / HRSG

CaO

CaSO₄

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

Condensate to other uses or sale
Purolator metal elements

Purolator: technological leadership in turnkey units design
Porofelt® medium ... to ... Poroflow ® HG Elements
Sintered or fiber mesh

Purolator: Filter media technologies

<table>
<thead>
<tr>
<th>Product</th>
<th>Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sintered fibre Porofelt</td>
<td>60 to 85%</td>
</tr>
<tr>
<td>Sintered mesh Poroplate</td>
<td>10 to 45%</td>
</tr>
<tr>
<td>Sintered metal powder</td>
<td>30 to 35%</td>
</tr>
</tbody>
</table>

- Benefit of low pressure drop
  - less blow back gas needed;
  - less usage of blow back valves;
  - lower energy consumption of fans;
  - ... makes it also possible to use higher face velocity
  - less filtration area
  - lower footprint

Purolator Advanced Filtration 2015
Sintered metal fiber advantages over powder

Purolator: Filter media technologies

Sintered Fibre
thin and multilayer

Flow in with dust

Sintered Powder
thick & monolayer

Sintered Metal Fibre

- Less clog: the very few particles passing the fine top layer will not be blocked through coarser support layers
- Superior BB: less energy needed to reach the cake on medium surface
Metallics can achieve high capture but performance on specific applications is more relevant.
High capture rate for 1 micron but what about sub micron fume?
Coal gasification is one successful application for metallic on large units.

Where? ... Applications & industries

- Oil Refinery
  - Fluid Catalytic Cracking
  - Catalytic Reforming
  - Catalytic Dehydrogenation
- Chemical
  - Polyethylene
  - Polypropylene
  - Nitric Acid (Fertilizers)
  - Melamine (PU Resins)
  - Aniline
  - Acrylonitrile
  - Diphenol
  - Hydrogen Cyanide (HCN)
  - Caprolactam
  - Maleic Anhydride / Butadiol
  - PVC (VCM / EDC)
- Natural & Technical Gases
- Gasification
  - Coal Gasification
  - Biomass Gasification
- Ore Smelters dedusting
  - Bauxite (Al)
  - Copper (Cu)
  - Platinum (Pt)
  - Nickel (Ni)
- Other calcination processes
  - Titanium Dioxide (TiO2)
  - Calcium Oxide (CaO)
  - Magnesium Oxide
- Dedusting and Energy Recovery
  - Cement
  - Steel

+ Engineering companies &
+ Filter Industry (System Manufacturer)
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<tr>
<td>Product</td>
<td>Catalytic filter, metal, ceramic</td>
</tr>
<tr>
<td>companies</td>
<td>Durr, Filtration Group, Haldor Topsoe, Purolaor</td>
</tr>
</tbody>
</table>

82
materials

- Resins
- Fibers
- Sorbents
- Coatings
- Substrates
- adhesives
Resins and fibers

- The selection of filter bags is highly influenced by the cost and performance of the resins and fibers used.
- Some suppliers supply both resins and fibers. Others such as Evonik sell fibers but buy the resins (Evonik PPS resin is supplied by Toyobo).
- The price and availability of PPS market is made more uncertain by the huge potential demand for power plant filters e.g. 40,000 tons per year or more.
- The financial problems of Lumena, a large PPS supplier in the Chinese market make the price and availability in this market more volatile.
- New DSI technology allows the temperature and acidity to be controlled. So this cost needs to be weighed against the differences in fiber and media costs.
- The synthetic media/catalytic bag such as the three layer FLS/Haldor Topsoe offers the opportunity for higher temperature fibers e.g. P84 to be used.
TYPICAL FIBERS FOR CFB: CROSS SECTION SHAPES

ROUND
PPS / PTFE

DOG BONE
PAN

TRILOBAL
PPS

MORE SURFACE AREA = INCREASED FILTRATION EFFICIENCY IN SAME BASIS WEIGHT FELT

MULTILOBAL
P84°

HIGHER FILTERING SURFACE
(considering the same titre)

m²/kg

STANDARD SHAPED FIBERS

Fiber shape-Testori
# Dust Collector Fiber Options

## Material Characteristics

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Maximum Operating Temperatures</th>
<th>Chemical Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Degrees F (°C)</td>
<td>Strong Acids</td>
</tr>
<tr>
<td>UHMWPE</td>
<td>176 (80)</td>
<td>****</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>200 (93)</td>
<td>****</td>
</tr>
<tr>
<td>Polyester</td>
<td>275 (135)</td>
<td>***</td>
</tr>
<tr>
<td>Nylon (Polyamide)</td>
<td>250 (121)</td>
<td>*</td>
</tr>
<tr>
<td>PTFE</td>
<td>500 (260)</td>
<td>****</td>
</tr>
<tr>
<td>Glass</td>
<td>500 (260)</td>
<td>****</td>
</tr>
</tbody>
</table>

Hydrophobic versus Hydrophilic
Oleophobic versus Oleophilic
Fiber Blends for coal fired boilers

Main Fiber Blends for Coal Fired Boilers

Testori code

- PAN/P84 (DX)
- PPS/P84 (SX)
- PPS/PTFE (SF)
- P84/PTFE (XF)

Blends are designed to be:
- combination of different fibers in the batt
- combination of batt and scrim made with different polymers
High temperature fiber options

<table>
<thead>
<tr>
<th>Name</th>
<th>Maximum operating temperature</th>
<th>Remarks</th>
<th>Relative cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylic felt (PAN or polyacrylnitrile)</td>
<td>130°C</td>
<td>Lowest maximum operating temperature.</td>
<td>£</td>
</tr>
<tr>
<td>PPS felt (Polyphenylenesulphide)</td>
<td>190°C</td>
<td>Degrades at higher temperatures with &gt;12% oxygen. Resist chemical and thermal attack. Effective when laminated with ePTFE.</td>
<td>££</td>
</tr>
<tr>
<td>Aramid felt</td>
<td>204°C</td>
<td>Not as capable as PPS in chemically active flue gas</td>
<td>£££</td>
</tr>
<tr>
<td>Woven fibreglass</td>
<td>260°C</td>
<td>Fragile, require tight tolerances. Suitable with reverse-air cleaning systems.</td>
<td>£</td>
</tr>
<tr>
<td>P84 felt by Evonik Fibres (polyimide, PI, multi-lobal, tri-lobal)</td>
<td>260°C</td>
<td>Dimensional stability over 204°C but requires oversizing of filter to maintain proper bag to cage fit. Small pore size of 0.5-1 μm (traditional needle felt scrim have a pore size of 15-20 μm).</td>
<td>££</td>
</tr>
<tr>
<td>Pleated elements</td>
<td>Dependant on scim fabric</td>
<td>A/C &lt;3.5:1. Applicable only when additional cloth area is needed to lower A/C ratio and eliminate inlet abrasion.</td>
<td>£££££</td>
</tr>
</tbody>
</table>
P 84 and high performance fibers for ESP retrofits

• A huge market is developing for substituting filter bags for ESP internals
• The low installation cost vs. a new stand alone baghouse justifies higher bag costs
• Existing precipitators are subject to greater temperature variations and other conditions which can be controlled in a new installation
• P84 and other high performance fibers are being embraced for this retrofit application
• Enel and Eskom are two examples