A specialty chemical company supplying fuel additives and systems technology that reduce harmful emissions from internal combustion engines while improving fuel economy

CARB - International Diesel Retrofit Advisory Committee
Part I - Performance of FBC Based Systems
February, 2002

Commercial Product Groups

Platinum Plus® Platinum/ Cerium Fuel Catalysts
- Performance (Fuel Economy)
- Emissions (No.2D, Jet/Kero, ULSD or Emulsions)
- Aftertreatment (Used With Oxidizers And Filters)

ARIS™ 2000 Urea Injection System For Selective Catalytic Reduction Of NOx
- Packaged Stationary Systems (Commercial)
- Mobile Systems (Prototypes In Field)
- LOE-NOx™ 3200 Urea Based Reagent
**What is a Fuel Borne Catalyst? (FBC)**

- Organo metallic fuel soluble catalyst
- Typically platinum and/or cerium or iron
- In-use dose rates of 4 - 60 ppm metal in fuel
- Dose rates above 15 ppm can lead to increase in ultrafine metal oxides
- Can reduce engine out soot emissions
- Can reduce soot oxidation temperatures in DPF’s by 100-250°C
- USA requires EPA Registration of FBC’s for on-highway use
  - Minimum Tier 1 – 1000 hr. engine test
  - Regulated emissions test plus 200 unregulated species
  - Additive emissions, speciation, literature review and risk assessment
- Europe requires VERT, VSET for FBC/DPF
- Several thousand commercial applications worldwide

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**Platinum/Cerium (FBC)**

- Patented bimetallic platinum/cerium kerosene based solution used at 4-8 ppm metal in fuel
  - Non toxic, non mutagenic, non water soluble
- Reduces engine out PM, HC, CO and improves fuel economy
- Synergistic with DOC
- Improves regeneration performance of uncatalyzed or lightly DPF’s
  - Regeneration @ 300 - 350 °C
  - No NO₂ increase
  - Minimum ash
  - Softer regeneration
- No harmful metal emissions, ultrafines, or secondary emissions
- Over 1,000 vehicles in service
- Registered with U.S. EPA for use in on-highway fuel (December 1999)
- Approved under VERT and VSET protocols for use with filters (2000)
- BUWAL approved for filters (2001)
- Submitted to EPA under Voluntary Retrofit
- Planned submittal to CARB (1st Qtr. 2002)
DPF APPROACHES

“Catalyst-based DPFs use catalyst materials to reduce the temperature at which collected diesel PM oxidizes. The catalyst material can either be directly incorporated into the filter system, or can be added to the fuel as a fuel borne catalyst (FBC-DFP).”
CARB-Risk Reduction Plan, October 2000

<table>
<thead>
<tr>
<th>Technology</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precatalyzed DPF</td>
<td>Platinum catalyst on filter surface</td>
</tr>
<tr>
<td>Continuously Regenerating Technology</td>
<td>Platinum oxidation catalyst upstream of filter</td>
</tr>
<tr>
<td>Fuel Borne Catalyst</td>
<td>Platinum catalyst in fuel; engine, exhaust, soot and filter</td>
</tr>
</tbody>
</table>

Particulate Reduction For FBC/DPF Combinations on Various Engines/Fuels

- **DPF A** = Uncatalyzed Fiber Wound Filter
- **DPF B** = Uncatalyzed Cordierite
- **DPF C** = Lightly Catalyzed Cordierite
- **FBC** = Platinum/Cerium Fuel Borne Catalyst

<table>
<thead>
<tr>
<th>Engine/Fuel</th>
<th>Particulate Reduction %</th>
<th>350 ppm S</th>
<th>450 ppm S</th>
<th>CARB 50 ppm S</th>
</tr>
</thead>
<tbody>
<tr>
<td>88 Series 60 + EGR</td>
<td>DPFB + FBC</td>
<td>79%</td>
<td>75%</td>
<td>52%</td>
</tr>
<tr>
<td>98 Series 60 + EGR</td>
<td>DPFA + FBC</td>
<td>83%</td>
<td>41%</td>
<td>51%</td>
</tr>
<tr>
<td>98 Series 60 + EGR</td>
<td>DPFB + FBC</td>
<td>81%</td>
<td>39%</td>
<td>51%</td>
</tr>
<tr>
<td>1998 Series 60</td>
<td>DPFA + FBC</td>
<td>83%</td>
<td>39%</td>
<td>51%</td>
</tr>
<tr>
<td>1998 Series 60</td>
<td>DPPA + FBC</td>
<td>83%</td>
<td>39%</td>
<td>51%</td>
</tr>
<tr>
<td>1998 Series 60</td>
<td>DPFC + FBC</td>
<td>83%</td>
<td>39%</td>
<td>51%</td>
</tr>
</tbody>
</table>

Clean Diesel Technologies, Inc.
DPF Balance Points

<table>
<thead>
<tr>
<th>Balance Point Deg C</th>
<th>Filter</th>
<th>Fiber</th>
<th>Test</th>
<th>Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat</td>
<td>Cordierite</td>
<td>B-96</td>
<td>Dyno</td>
<td>No.2</td>
</tr>
<tr>
<td>Cat</td>
<td>B-98</td>
<td>Field</td>
<td>LSD</td>
<td>No.2</td>
</tr>
<tr>
<td>Cat</td>
<td>B-98</td>
<td>Dyno</td>
<td>Dyno</td>
<td>Field</td>
</tr>
<tr>
<td>Cat</td>
<td>L-10-88</td>
<td>Field</td>
<td>LSD</td>
<td>No.2</td>
</tr>
<tr>
<td>Cat</td>
<td>B-94</td>
<td>Field</td>
<td>ULSD</td>
<td></td>
</tr>
</tbody>
</table>

Cat = Catalyzed DPF  UnCat = Uncatalyzed DPF  FBC = Fuel Borne Catalyst (Pt/Ce)

NO₂ Emissions From FBC/DPF System

Exhaust Gas NO₂ (ppm) vs Balance Point (Deg.C)

- All Catalysed Filters
- Uncatalysed 10ppm S
- 0.25/3/20ppm Pt/Ce
- 0.15/7.5ppm Pt/Ce at 350ppm S
- 0.15/7.5ppm at 40-50ppm S
- 0.5/7.5ppm at 40-50ppm S
- 0.5/7.5ppm Pt/Ce at 350ppm S
NO\textsubscript{2} Emissions From FBC/DPF System - Conclusions

- Pt/Ce FBC does not increase NO\textsubscript{2} emissions with uncatalyzed DPF even at 10 x overtreat
- Further work underway to match low NO\textsubscript{2} with good balance point
- May involve FBC with lightly precatalyzed DPF

Performance of FBC/DOC Combinations on PM Emissions (Versus No.2D)
**Performance of Bimetallic FBC**

On PM Emissions
Versus No.2D

Average Reduction = 23%

![Graph showing % PM Reduction for different applications and series numbers.]

**Fuel Economy Engine Dynamometer Tests**

Fuel measurements gravimetric, volumetric or carbon balance

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTP tests</td>
<td>4.3</td>
</tr>
<tr>
<td>Hot transient tests</td>
<td>5.5</td>
</tr>
<tr>
<td>13 mode tests</td>
<td>7</td>
</tr>
<tr>
<td>FTP tests</td>
<td>7</td>
</tr>
</tbody>
</table>

Clean Diesel Technologies, Inc.
Platinum Plus® Fuel Economy
Results of 8 Fleets

- Trash Hauling 40 Trucks 3% Improvement
- Feed and Livestock 66 Units 4% Improvement
- Grocery Distribution 113 Trucks 6% Improvement
- Grocery and Fuel Distribution 74 Trucks 6% Improvement
- LTL Delivery 2 Units 7% Improvement
- Fuel Delivery 22 Units >10% Impr.
- Beverage Delivery 73 Vehicles >10% Impr.
- Fuel Delivery 26 Units

FBC Dosing Alternatives

- Manual addition to vehicle tank or fleet/field bulk tank
- Bulk fuel pretreatment by licensed fuel suppliers
- Automatic dosing at fuel pump or vehicle on-board dosing
- In use verification procedures
  - Fuel sample analysis for catalyst
  - Dosing system audits
Benefits of Bimetallic FBC/DPF System

- Ultra-low dose rate (4 to 8 ppm)
- Significant reductions in PM, HC, CO, PAH’s and ultra-fines
- Combined with EGR or timing changes for 20-40% NOx reduction
- Uses lower cost uncatalyzed or lightly catalyzed filters
- Continuous regeneration at 280°C-320 °C
- MPG improvement helps offset FBC cost
- Fuel flexibility (15-350ppm S)
- Commercially available
- Planned submittal to CARB (1st quarter 2002)
## CDT's FBC/DPF California Commercialization Strategy

<table>
<thead>
<tr>
<th>Licensed FBC Distributors</th>
<th>Filter Suppliers (Cordierite, Fiber Wound, Silicon Carbide)</th>
<th>Local Installation And Service</th>
</tr>
</thead>
</table>
| - California Fuel Marketers  
  - Bulk Treatment  
  - Direct to Fleet  
  - On Site Additization  
  - On Board Dosing | - Clean Air Systems  
  - Lubrizol ECS  
  - Engelhard  
  - Fleetguard  
  - Others | - Engine Distributors or Emission Control Companies  
  - Cleaire/Cummins West |

Clean Diesel Technologies, Inc.