Clean Diesel Technologies, Inc.

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

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 NO\textsubscript{2} 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-DF).”
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</td>
<td>Platinum oxidation catalyst upstream of filter</td>
</tr>
<tr>
<td>Technology</td>
<td></td>
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<tr>
<td>Fuel Borne Catalyst</td>
<td>Platinum catalyst in fuel; engine, exhaust, soot and filter</td>
</tr>
<tr>
<td>with uncatalyzed or lightly</td>
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<tr>
<td>catalyzed DPF</td>
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</table>

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

<table>
<thead>
<tr>
<th>DPF A = Uncatalyzed Fiber Wound Filter</th>
<th>DPF C = Lightly Catalyzed Cordierite</th>
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<tbody>
<tr>
<td>DPF B = Uncatalyzed Cordierite</td>
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<tr>
<td>FBC = Platinum/Cerium Fuel Borne Catalyst</td>
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</table>

<table>
<thead>
<tr>
<th>Engine/Fuel</th>
<th>% Reduction</th>
<th>350 ppm S</th>
<th>450 ppm S</th>
<th>CARB 50 ppm S</th>
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<tbody>
<tr>
<td>88 L-10</td>
<td>98 N-14</td>
<td>96 B+3+EGR</td>
<td>98 Series 60 + EGR</td>
<td>1998 Series 60</td>
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<tr>
<td>DPF A + FBC</td>
<td>DPF A + FBC</td>
<td>DPF A + FBC</td>
<td>DPF A + FBC</td>
<td>DPF A + FBC</td>
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<tr>
<td>0.03</td>
<td>0.02</td>
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DPF Balance Points

<table>
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<tr>
<th>Balance Point Deg C</th>
<th>Cat</th>
<th>Cat</th>
<th>Cat</th>
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<tbody>
<tr>
<td>250</td>
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</tbody>
</table>

Filter      Cordierite | Fiber | SiC | Fiber | SiC | Cat Loader(new)
Engine      B-96 | B-98 | L-10-88 | B-94 | Field | Dyno
Test        Dyno | Field | Dyno | Dyno | LSD | No.2
Fuel        No.2 | No.2 | LSD | No.2 | ULSD |

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

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NO₂ Emissions From FBC/DPF System

<table>
<thead>
<tr>
<th>Exhaust Gas NO₂ (ppm)</th>
<th>0</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
<th>120</th>
<th>140</th>
<th>160</th>
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</thead>
<tbody>
<tr>
<td>Balance Point (Deg.C)</td>
<td>250</td>
<td>270</td>
<td>290</td>
<td>310</td>
<td>330</td>
<td>350</td>
<td>370</td>
<td>390</td>
<td>410</td>
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</table>

0.15/7.5 ppm Pt/Ce Uncatalysed
0.5/15.7 ppm Pt/Ce Uncatalysed
0.05/3.25 ppm Pt/Ce Uncatalysed
0.15/7.5 ppm Pt/Ce at 40-50 ppm S
0.5/15.7 ppm Pt/Ce at 350 ppm S
0.15/7.5 ppm Pt/Ce at 40-50 ppm S
0.05/3.25 ppm Pt/Ce at 350 ppm S
0.05/3.25 ppm Pt/Ce at 40-50 ppm S

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**NO₂ Emissions From FBC/DPF System - Conclusions**

- Pt/Ce FBC does not increase NO₂ emissions with uncatalyzed DPF even at 10 x overtreat
- Further work underway to match low NO₂ with good balance point
- May involve FBC with lightly precatalyzed DPF

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

![Graph showing PM Reduction (%) for various FBC/DOC combinations.]

- Untreated
- 8 ppm or less
- 16 ppm (reference only)
Performance of Bimetallic FBC

On PM Emissions
Versus No.2D

Average Reduction = 23%

% PM Reduction

4 ppm or less
8 ppm
16 ppm

Series 60
N-14
Series 50
Liebherr Gardner EMD
L-10
XUD9

Fuel Economy
Engine Dynamometer Tests

Fuel measurements gravimetric, volumetric or carbon balance

At SwRI
FTP tests
Hot transient tests
13 mode tests

Cummins
B-series
FTP tests

% Improvement

0 5 10

Clean Diesel Technologies, Inc.

02/20/2002
Platinum Plus®
Fuel Economy

Results of 8 Fleets

- Trash Hauling 40 Trucks
- Feed and Livestock 66 Units
- Grocery Distribution 113 Trucks
- Grocery and Fuel Distribution 74 Trucks
- LTL Delivery 2 Units
- Fuel Delivery 22 Units
- Beverage Delivery 73 Vehicles
- Fuel Delivery 26 Units

3% Improvement
4% Improvement
6% Improvement
6% Improvement
7% Improvement
9% Impr.
>10% Impr.
>10% Impr.

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

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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

## Licensed FBC Distributors
- California Fuel Marketers
  - Bulk Treatment
- Direct to Fleet
  - On Site Additization
- On Board Dosing

## Filter Suppliers
- Cordierite, Fiber Wound, Silicon Carbide
  - Clean Air Systems
  - Lubrizol ECS
  - Engelhard
  - Fleetguard
  - Others

## Local Installation And Service
- Engine Distributors or Emission Control Companies
- Cleaire/Cummins West

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