Evaluation of Diesel PM Control Options:  
NYSERDA’s Clean Diesel Technology Field Demonstration Program

Sponsored by:

Lead Contractor:

2007 NYSERDA EMEP Conference - November 16, 2007
Project Team and Partners

**Program funding and management**

**Inventory assistance, PEMS testing**

**National Clean Diesel Campaign Demonstration Assistance Agreement**

Southern Research Institute - *Project Management, Inventory Analysis, Protocol Development, Field Test Planning, PEMS testing*

Environment Canada - *Field Test Planning, Field Testing*

E.H. Pechan - *Inventory Development, Surveys*

Ecopoint - *Control Technology Feasibility Assessment*

Emisstar - *Control Technology Assessment, Field Test Planning*

NYC Dept. of Sanitation - *Host Site, Non-Road Equipment, Technology Installation & Operation*
NYSERDA’s Clean Diesel Technology Field Demonstration Program: Overall Project Goal

- Provide assessments of the *in-use performance* of commercially available *diesel retrofit control technologies* to expand energy-efficient diesel emission control technology options for off-road applications in New York State.
Primary Project Tasks

- Develop a refined non-road equipment and emission inventory for NYS and NYCMA (in-process)
- Identify priority sectors and equipment applications warranting field demonstration
- Assess the technical, economic, and operational feasibility of commercially available retrofit options and select priority controls for demonstrations
- Develop a field testing protocol for in-use evaluations
- Conduct an in-use field demonstration program of control strategies with the participation of equipment owners/operators and emission control technology vendors.
Baseline Non-Road Emission Inventory Results

Contributions to Non-Road PM Emissions Inventory for NYS (L) and NYCMA (R) by Fuel Type
Baseline Inventory Results:
2002 NYS and NYCMA Non-Road Diesel PM Emissions by Equipment Sector

NYCMA = ~64%
2002 Non-Road Diesel PM Emissions by Equipment Type for the NYCMA

- Other: 32%
- Skid Steer Loaders: 9%
- Excavators: 6%
- Rubber Tire Loaders: 8%
- Tractors/Loaders/Backhoes: 10%
- Crawler Tractors/Dozers: 7%
- Commercial Marine Underway Emissions: 7%
- Generator Sets: 7%
- Welders: 4%
- AC/Refrigeration: 5%
- Off-highway Trucks: 5%
- Rubber Tire Loaders: 8%

SOUTHERN RESEARCH
Control Technology Feasibility Analysis

- Evaluate feasibility of various control strategies in non-road applications based on:
  - Emissions Reduction Performance
  - Commercial Availability
  - Durability
  - Costs: Unit Cost; Maintenance & Operation; Installation
  - User Acceptance By Fleets And Equipment Operators
  - Verification Status (ARB or EPA Verified)
# Control Strategies Selected For Evaluation

<table>
<thead>
<tr>
<th>Control Strategy</th>
<th>Typical Emission Reductions</th>
<th>Operating Principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel Oxidation Catalyst (DOC)</td>
<td>PM: Typically 20-30% - depends on fuel, engine, duty. HC: 40-75% CO: 10-50%</td>
<td>![DOC Diagram]</td>
</tr>
<tr>
<td>Diesel Particulate Filters (DPF)</td>
<td>PM: 70-95%+ PM HC: 60-90% (catalyzed) CO: 60-90% (catalyzed)</td>
<td>![DPF Diagram]</td>
</tr>
</tbody>
</table>

Source: Interim Report; [www.Dieselnet.com](http://www.Dieselnet.com); EPA Verified Technologies list
# Control Strategies Selected For Evaluation

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<th>Typical Emission Reductions</th>
<th>Operating Principle</th>
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</table>
| Flow-Through Filters | PM: 40-70%  
HC: 50-90% (catalyzed)  
CO: 50-90% (catalyzed) | ![Flow-Through Filters Diagram] |
| Urea-SCR Catalysts  | NOx: ~90%  
*Typically used in conjunction with DPF, DOC, or FTF to achieve PM, CO, HC reductions* | ![Urea-SCR Catalysts Diagram] |
| Biodiesel            | PM: 0-47%  
HC: 0-67%  
CO: 0-47%  
NOx: -10-0% | ![Biodiesel Diagram] |
Non-Road Equipment Tested

1998 Case 821 Loader, 190 hp
2003 Daewoo Mega 200 Loader, 143 hp
2001 CAT D400 Articulated Dump Truck, 400 hp
2007 Case 445T/M2 Backhoe, 90 hp
2004 Case Skid Steer Loader, 85 hp
2007 Volvo L90F loader, 160 hp
Test Procedures

• In-Use Emissions Evaluations
  – Integrated Sampling Systems: Environment Canada’s DOES2 filter based system
  – PEMS: Horiba’s OBS-2200 real-time sampling (gaseous)

• Generic In-Use Test Protocol for Nonroad Equipment
• ULSD and B5/ULSD
Test Procedures

- **Duty Cycle**
  - Based on in-use observations of typical loader operations
  - Loader worked at salt pile as if loading a salt truck
  - 3 sub-cycles consisting of 5 repetitions of: travel forward (unloaded), fill bucket, travel backward (loaded), stop, travel forward (loaded), dump load, travel backward (unloaded), stop

![In-Use Testing of a Daewoo Loader](image)

![RPM Trace for A Single Duty Cycle](image)
# Control Device Performance

## 1998 Case 821 Loader

<table>
<thead>
<tr>
<th>Sample Location</th>
<th>CO2</th>
<th>NOx</th>
<th>NO2</th>
<th>CO</th>
<th>HC</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. Engine Out</td>
<td>9937</td>
<td>124</td>
<td>43</td>
<td>19.2</td>
<td>1.6</td>
<td>2.5</td>
</tr>
<tr>
<td>PDPF 1 (Cat.)</td>
<td>10000</td>
<td>114</td>
<td>58.9</td>
<td>2.79</td>
<td>1.87</td>
<td>0.041</td>
</tr>
<tr>
<td><strong>PDPF 1 % change</strong></td>
<td>*</td>
<td>*</td>
<td>70.7</td>
<td>-88.3</td>
<td>*</td>
<td><strong>-98.7</strong></td>
</tr>
<tr>
<td>PDPF 2 (Cat.)</td>
<td>9970</td>
<td>112</td>
<td>50.1</td>
<td>0.35</td>
<td>0.324</td>
<td>0.099</td>
</tr>
<tr>
<td><strong>PDPF 2 % change</strong></td>
<td>*</td>
<td>*</td>
<td>14.5</td>
<td>-97.6</td>
<td><strong>-76.5</strong></td>
<td><strong>-95.1</strong></td>
</tr>
<tr>
<td>ADPF 1</td>
<td>9930</td>
<td>148</td>
<td>46.7</td>
<td>16.6</td>
<td>1.31</td>
<td>0.08</td>
</tr>
<tr>
<td><strong>ADPF 1 % change</strong></td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td><strong>-96.4</strong></td>
</tr>
</tbody>
</table>

* No Statistically Significant Change
# Control Device Performance

## 2003 Daewoo Mega 200 Loader

<table>
<thead>
<tr>
<th>Sample Location</th>
<th>CO2</th>
<th>NOx</th>
<th>NO2</th>
<th>CO</th>
<th>HC</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. Engine Out</td>
<td>9965</td>
<td>74</td>
<td>21</td>
<td>38.3</td>
<td>4.3</td>
<td>6.0</td>
</tr>
<tr>
<td>DPF - FTF 1 (Cat.)</td>
<td>10000</td>
<td>68</td>
<td>16.3</td>
<td>2.83</td>
<td>0.412</td>
<td>3.24</td>
</tr>
<tr>
<td>DPF-FTF 1 % change</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>-91.1</td>
<td>-87.6</td>
</tr>
<tr>
<td>DPF - FTF 2 (Cat.)</td>
<td>10000</td>
<td>78.2</td>
<td>32.2</td>
<td>1.61</td>
<td>1.56</td>
<td>4.55</td>
</tr>
<tr>
<td>DPF-FTF 2 % change</td>
<td>*</td>
<td>*</td>
<td>34.2</td>
<td>-96.4</td>
<td>-70.1</td>
<td>-33.2</td>
</tr>
</tbody>
</table>

*No Statistically Significant Change*
## Control Device Performance

### 2001 Cat D400 Articulated Dump

<table>
<thead>
<tr>
<th>Sample Location</th>
<th>Emissions in g/gal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO2</td>
</tr>
<tr>
<td>Avg. Engine Out</td>
<td>9970</td>
</tr>
<tr>
<td>ADPF 1</td>
<td>9950</td>
</tr>
<tr>
<td><strong>ADPF 1 % Change</strong></td>
<td>*</td>
</tr>
<tr>
<td>PDPF 1 (Cat.)</td>
<td>9980</td>
</tr>
<tr>
<td><strong>PDPF1 % Change</strong></td>
<td>*</td>
</tr>
</tbody>
</table>

* No Statistically Significant Change
## Organic and Elemental Carbon Emissions – Engine Out

- **Elemental Carbon vs. Organic Carbon:**
  - Based on filter analysis using NIOSH Method 5040 - Thermal/Optical Transmittance (TOT)
  - Multiple test run filters combined to provide adequate sample

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Engine Out PM (g/min) (OC / EC)</th>
<th>Engine Out PM % (OC / EC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998 Case Loader</td>
<td>0.018 / 0.142</td>
<td>16 / 84</td>
</tr>
<tr>
<td>2003 Daewoo Loader</td>
<td>0.017 / 0.142</td>
<td>13 / 87</td>
</tr>
<tr>
<td>2001 Cat D400</td>
<td>0.024 / 0.152</td>
<td>13 / 87</td>
</tr>
</tbody>
</table>
Control Device Performance – OC/EC & Filter Regeneration

• Emission Control Device Performance

<table>
<thead>
<tr>
<th>Control Type</th>
<th>OC Reduction %</th>
<th>EC Reduction %</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDPF (cat.)</td>
<td>~99%</td>
<td>~93-99%</td>
</tr>
<tr>
<td>ADPF (uncat.)</td>
<td>&gt;95%</td>
<td>~98%</td>
</tr>
<tr>
<td>FTF (cat.)</td>
<td>No Change</td>
<td>18-49%</td>
</tr>
</tbody>
</table>

• Filter Regeneration Emissions:
  • Single triggered regeneration event on ADPFs
  • EC/OC = ADPF 1: 53% / 47%; ADPF 2: 18% / 82%
  • Emission Rate = 0.008 g/min TPM
Control Device Performance – Installation and Economics

• Average Capital Costs for Devices:
  - PDPF - $8,700 – 11,000 (med loader)
  - ADPF - $13,000 (med); $31,000 (large)
  - FTF - $3,200-4,200 (med)
  - DOC - $700-1000 (small-med)

• Installation Requirements
  - direct muffler replacement (2 hrs) to
  - custom design and installation (1 week).

• Maintenance & Operation
  - Most require little maintenance (data monitoring and alarms)
  - ADPFs may require operator to regenerate
  - No failures or issues identified yet (~900 combined hrs accumulated)
    • (to be tracked for 1yr under EPA grant)
Conclusions & Considerations for Diesel Emissions Control

- Non-Road Diesel Equipment is a significant contributor to the NYS and NYCMA PM emissions inventory
- A variety of feasible control options are available
  - May cover wide variety of applications (i.e. low exh. T)
  - Other options viable (alternative fuels, idle reduction, new engines)
- PM reductions ranging from 33% to 99% possible depending on retrofit technology selected
  - Significant reductions of other pollutants (HC, CO) also
  - NO2 could be an issue
- Costs and installation requirements higher than anticipated
  - Few “off-the-shelf” configurations available yet
- Numerous tradeoffs and decisions in selecting diesel controls:
  - Level of control required and cost/benefit
  - Pollutant emissions tradeoffs (i.e. PM vs. NO2)
  - Economics (retrofits vs. new equipment)
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