Evaluation of Diesel PM Control Options:

NYSERDA's Clean Diesel Technology Field Demonstration Program

Sponsored by:

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Lead Contractor:

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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*

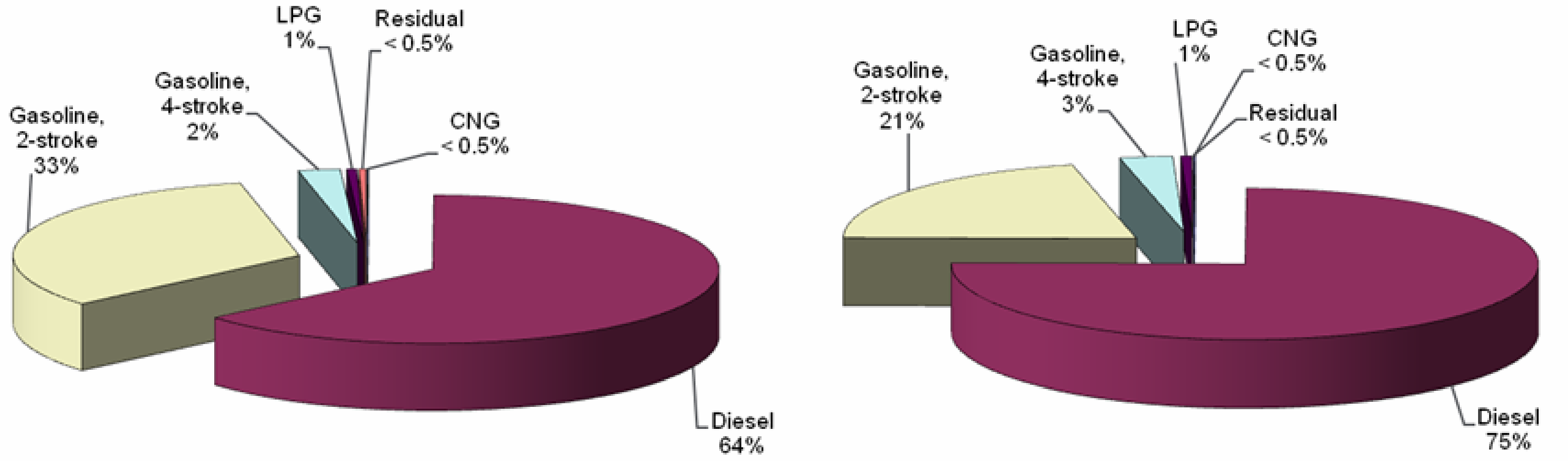
NYSERDA's Clean Diesel Technology Field Demonstration Program: Overall Project Goal

- 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.

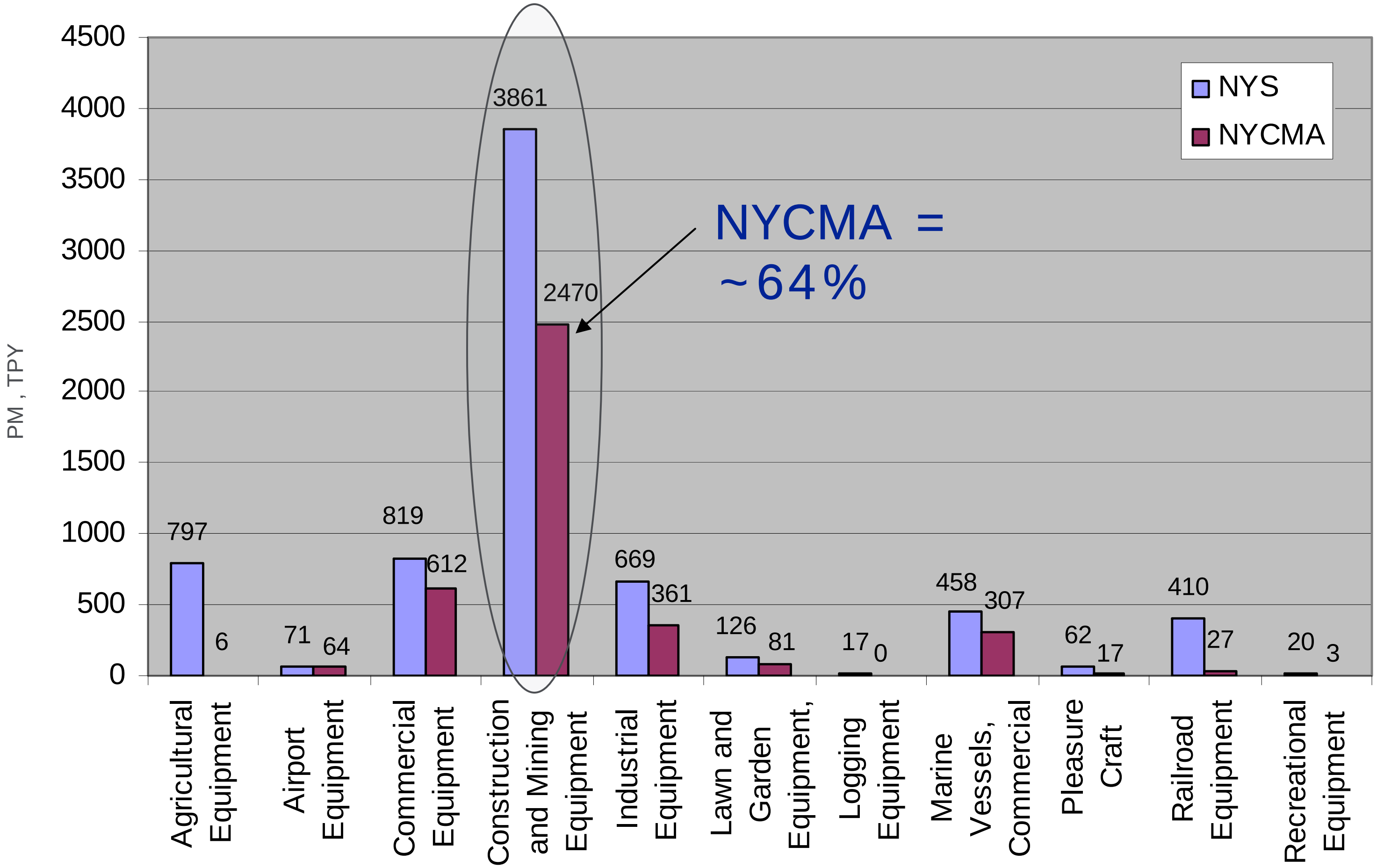
Baseline Non-Road Emission Inventory Results



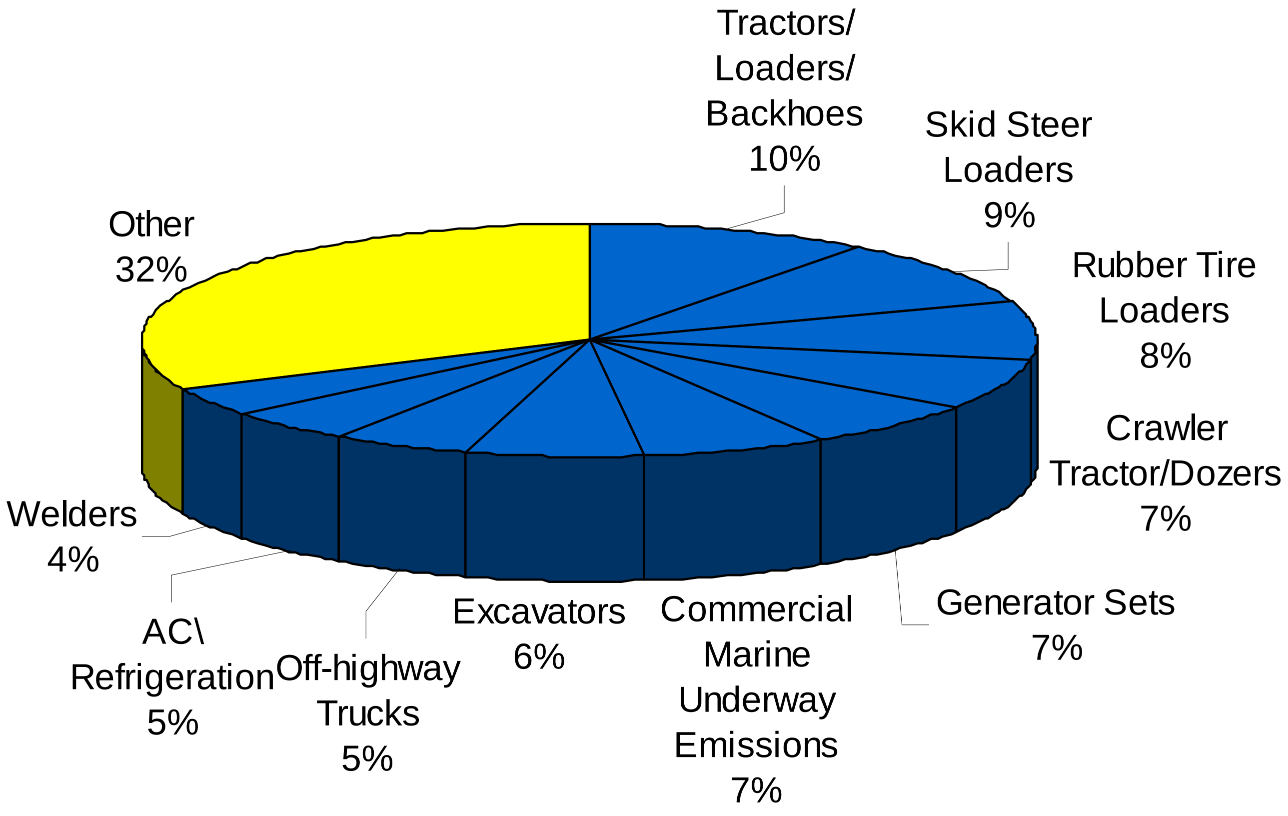
Contributions to Non-Road PM Emissions Inventory for NYS (L) and NYCMA (R) by Fuel Type

Baseline Inventory Results:

2002 NYS and NYCMA Non-Road Diesel PM Emissions by Equipment Sector



2002 Non-Road Diesel PM Emissions by Equipment Type for the NYCMA



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)

An example of an oxidation catalyst which can reduce particulate matter by 20 - 50 percent.
Photo Courtesy of Johnson Matthey

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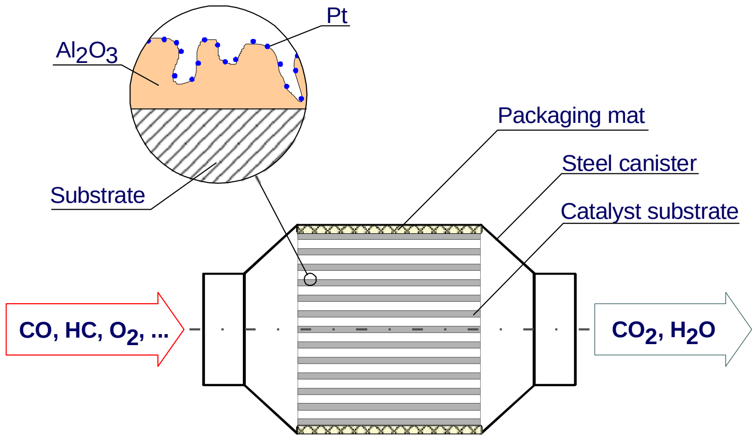
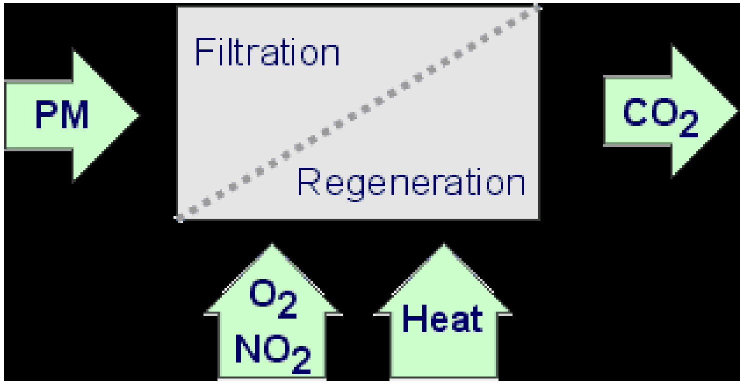
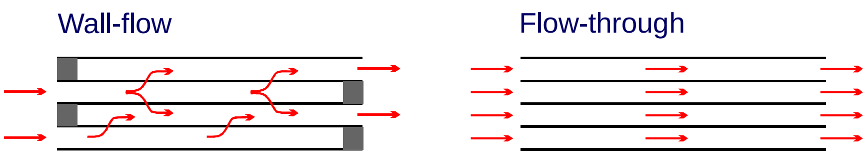
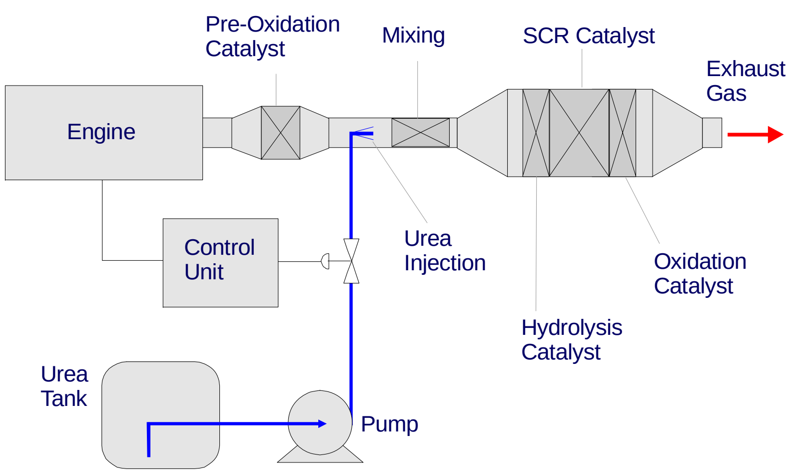
Control Strategies Selected For Evaluation

Control Strategy	Typical Emission Reductions	Operating Principle
Diesel Oxidation Catalyst (DOC)	PM: Typically 20-30% - depends on fuel, engine, duty. HC: 40-75% CO: 10-50%	
Diesel Particulate Filters (DPF)	PM: 70-95%+ PM HC: 60-90% (catalyzed) CO: 60-90% (catalyzed)	

Source: Interim Report; www.Dieselnet.com; EPA Verified Technologies list

Control Strategies Selected For Evaluation

<table>
<tr><th>Control Strategy</th><th>Typical Emission Reductions</th><th>Operating Principle</th></tr>
<tr><td>Flow-Through Filters</td><td>PM: 40-70%
HC: 50-90% (catalyzed)
CO: 50-90% (catalyzed)</td><td>
</td></tr>
<tr><td>Urea-SCR Catalysts</td><td>NOx: ~90%

Typically used in conjunction with DPF, DOC, or FTF to achieve PM, CO, HC reductions</td><td>
</td></tr>
<tr><td>Biodiesel</td><td colspan="2">PM: 0-47%   HC: 0-67%   CO: 0-47%   NOx: -10-0%</td></tr>
</table>

Non-Road Equipment Tested

1998 Case 821 Loader, 190 hp

2003 Daewoo Mega 200 Loader, 143 hp

2007 Case 445T/M2 Backhoe, 90 hp

2001 CAT D400 Articulated Dump Truck, 400 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)

Environment Canada's DOES2

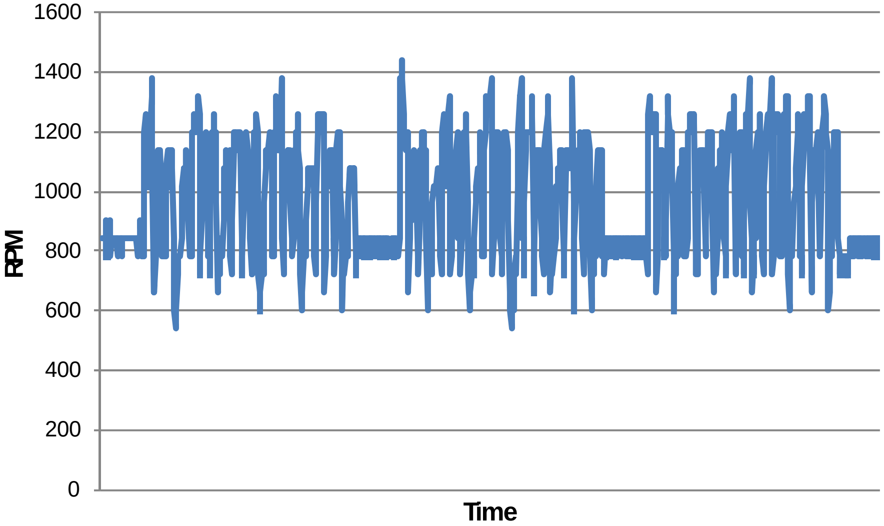
Horiba OBS-2200 PEMS

- 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



RPM Trace for A Single Duty Cycle

Control Device Performance

1998 Case 821 Loader

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

****** No Statistically Significant Change***

Control Device Performance

2003 Daewoo Mega 200 Loader

	Emissions in g/gal					
Sample Location	**CO2**	**NOx**	**NO2**	**CO**	**HC**	**PM**
Avg. Engine Out	9965	74	21	38.3	4.3	6.0
DPF - FTF 1 (Cat.)	10000	68	16.3	2.83	0.412	3.24
DPF-FTF 1 % change	*	*	*	***-91.1***	***-87.6***	***-37.6***
DPF - FTF 2 (Cat.)	10000	78.2	32.2	1.61	1.56	4.55
DPF-FTF 2 % change	*	*	***34.2***	***-96.4***	***-70.1***	***-33.2***

***** No Statistically Significant Change*

Control Device Performance

2001 Cat D400 Articulated Dump

	Emissions in g/gal					
Sample Location	**CO2**	**NOx**	**NO2**	**CO**	**HC**	**PM**
Avg. Engine Out	9970	139	46	26.8	2.1	1.4
ADPF 1	9950	142	43.1	29.9	3.12	0.11
ADPF 1 % Change	*	*	***-11.8***	***12***	***58***	***-91.7***
PDPF 1 (Cat.)	9980	115	62.8	3.05	1.96	0.071
PDPF1 % Change	*	*	***45.5***	***-88.6***	***-11.2***	***-95.1***

****** 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

Equipment Type	Engine Out PM (g/min) (OC / EC)	Engine Out PM % (OC / EC)
1998 Case Loader	0.018 / 0.142	16 / 84
2003 Daewoo Loader	0.017 / 0.142	13 / 87
2001 Cat D400	0.024 / 0.152	13 / 87

Control Device Performance – OC/EC & Filter Regeneration

- **Emission Control Device Performance**

Control Type	OC Reduction %	EC Reduction %
PDPF (cat.)	~99%	~93-99%
ADPF (uncat.)	>95%	~98%
FTF (cat.)	No Change	18-49%

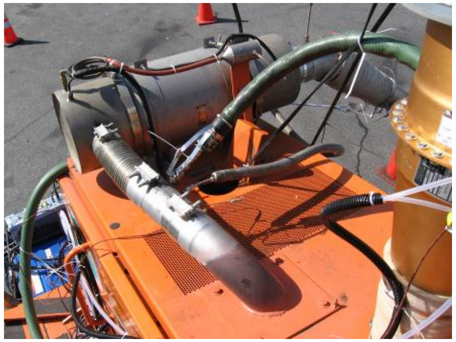
- **Filter Regeneration Emissions:**
  - Single triggered regeneration event on ADPFs
    - EC/OC = ADPF 1: 53% / 47%; ADPF2: 18% / 82%
    - Emission Rate = 0.008 g/min TPM

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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