Retrofitting America’s Diesel Engines
A GUIDE TO CLEANER AIR THROUGH CLEANER DIESEL

November 2006
The Diesel Technology Forum is the nation’s leading information resource on and promoter of clean diesel technology, its value, economic importance, environmental progress and promise for the future. The Forum promotes clean diesel solutions for new diesel engines (on/off road), conducts technology demonstrations and works with stakeholders to modernize and upgrade existing diesel engines. Members include leaders in diesel engine, vehicle and component manufacturing, fuel refining, and emissions treatment systems.
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I. EXECUTIVE SUMMARY

America needs diesel engines and cleaner air; advanced clean diesel technology offers both. Diesel power drives the economy by building our nation’s infrastructure of roads and bridges, taking crops from the fields to food on the table, and providing vital transportation of people and goods in the most efficient and cost effective manner possible. No other technology can match diesel’s unique combination of energy efficiency, sheer power, reliability and durability across so many sectors of the economy. In all applications, diesel technology has experienced continuous improvement with increasing performance, lower fuel consumption and lower emissions, making today’s technology much cleaner and more efficient than what was available even a few years ago.

The future looks even cleaner. Industry’s continued improvements are leading to a new generation of clean diesel vehicles and equipment that will virtually eliminate regulated emissions in both on- and off-road applications. This new clean diesel technology will not only be available in new vehicles and equipment, but can be applied to existing engines, thereby multiplying its benefits. The nation’s goals for accelerated improvements in air quality have led regulators to identify the modernizing and upgrading of existing diesel engines as one of the most cost-effective options for achieving emissions reductions.

The arrival of clean diesel technology. The year 2007 will mark the beginning of a new era in clean diesel technology. The clean diesel system includes three fundamental components: cleaner diesel fuel; lower-emitting diesel engines; and new emissions control technology. Together, this new system will fulfill the promise of clean diesel technology across many applications.

Fuel. Although ultra low sulfur diesel (ULSD) fuel has been used for many years, its availability has been limited, requiring users to truck it in for specific projects. However, as of October 15, 2006, ultra low sulfur diesel fuel (defined as 15 parts per million or ppm of sulfur) has become nationally available at the retail level and is required for use in all new 2007 and later on-highway vehicles. Fuel with 500 ppm sulfur will still be allowed for off-road vehicles, however in response to EPA standards adopted in 2004, diesel engines in all applications (on-road, off-road, locomotive and marine, without exception) will be required to use ULSD by 2014.

Engines. ULSD’s arrival not only helps reduce emissions from existing or “legacy” diesel engines up to 10 percent, but enables diesel engine manufacturers to develop significantly cleaner and more advanced engines. Advancements in engine technology such as high pressure fuel injection, variable geometry turbochargers and refinements in the combustion process are enabling heavy duty diesel trucks and buses to meet new, lower EPA emissions standards requiring an additional 90 percent reduction in emissions. Engines for off-road applications such as construction equip-
ment and non-highway transport will also be required to meet tighter standards over a period of years, with the final regulations for rail and marine engines due from EPA in 2006.

**Emissions Control Technology.** The third element of the clean diesel system is the use of advanced emissions control technology, including oxidation catalysts and particulate filters. The modernization and upgrading of older diesel vehicles through one of retrofit’s “five R’s” can help achieve significant, cost-effective reductions of PM (particulate matter) and NOx (oxides of nitrogen) emissions, which contribute to better air quality. Each of the “five R’s” – rebuild, refuel, retrofit, repower and replace – has advantages and strengths that can be tapped to tailor an emissions reduction program to specific air quality improvement goals, budgets and equipment owners’ needs.

Whichever approach is identified, the greatest chance of success occurs when the operating characteristics of the candidate vehicles or equipment for upgrading are accurately matched with an approved emissions reduction solution.

**Financial resources.** While the air quality benefits of diesel retrofit are strong, the economic benefits are less clear. Large operators may capture the good will and economic value of good corporate citizenship more readily than small operators that face few direct economic or market pressures related to their environmental performance.

Thanks to new federal funding opportunities

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**Figure 1.2 Comparison of Typical CMAQ Funded Projects**

<table>
<thead>
<tr>
<th>Project</th>
<th>Cost Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repower Lumber Loader</td>
<td>$3,169</td>
</tr>
<tr>
<td>Repower Transit Buses</td>
<td>$5,000</td>
</tr>
<tr>
<td>Repower Off-Road Engines</td>
<td>$5,331</td>
</tr>
<tr>
<td>Repower Construction Equipment</td>
<td>$5,331</td>
</tr>
<tr>
<td>Replace Older Trucks</td>
<td>$7,200</td>
</tr>
<tr>
<td>Vehicle Inspection and Maintenance Programs</td>
<td>$1,900</td>
</tr>
<tr>
<td>Speed Limit Enforcement</td>
<td>$4,747</td>
</tr>
<tr>
<td>Vanpool Programs</td>
<td>$10,500</td>
</tr>
<tr>
<td>Taxi Replacement with CNG</td>
<td>$14,300</td>
</tr>
<tr>
<td>Bike Racks on Transit Buses</td>
<td>$19,500</td>
</tr>
<tr>
<td>Employer Encouraged Ride-Sharing</td>
<td>$22,700</td>
</tr>
<tr>
<td>Volunteer Parking Cash-Out Subsidy</td>
<td>$23,255</td>
</tr>
<tr>
<td>Bus Replacement with CNG</td>
<td>$46,900</td>
</tr>
<tr>
<td>New Transit Investments</td>
<td>$66,400</td>
</tr>
<tr>
<td>Traffic Signal Optimization</td>
<td>$66,700</td>
</tr>
<tr>
<td>Bicycle/Pedestrian Facilities</td>
<td>$46,100</td>
</tr>
<tr>
<td>Alternative Fuelled Buses</td>
<td>$126,400</td>
</tr>
</tbody>
</table>

Source: www.dieselforum.org/retrofit-tool-kit-homepage/cost-effectiveness-comparisons/
through the Environmental Protection Agency, the Department of Transportation and the Department of Agriculture, the potential for greatly expanded retrofit programs is now significant. Some states are already matching these funds while others are adopting new programs to qualify for Federal assistance.

**Experience in the field.** Considerable experience in modernizing and upgrading diesel engines has been gained over the last 8 to 10 years in several key sectors of equipment. High profile diesel emissions reductions projects, such as the retrofit of construction equipment at Connecticut’s Q-Bridge Construction Project and Massachusetts’ Big Dig, have encouraged efforts in other states. Several large-scale diesel engine emissions reduction demonstration programs currently being
completed are proving the effectiveness of these emissions control mechanisms.

This Diesel Technology Forum (DTF) paper provides a primer on potential strategies for upgrading existing diesel engines in both on- and off-road equipment. It does so by focusing on four fundamental factors that affect the rate and extent of our national diesel fleet transformation:

1) the emissions benefits realized with new diesel technology;

2) methods for upgrading emissions performance – rebuilding, refueling, repowering, retrofitting and replacing;

3) elements of successful projects, including cost-effectiveness; and

4) availability of financial assistance for diesel retrofits at the federal and state level.

Since DTF published its first report on retrofit technologies in 2003, the industry’s principal focus has shifted from general awareness of retrofit technologies to adoption and implementation of emissions reduction strategies. For this reason, DTF has chosen to focus this report on the growing opportunities for widespread application of retrofit technology.
Diesel engines constitute the primary source of power used in heavy-duty applications throughout the nation. Two thirds of all farm and construction equipment, over 90 percent of all commercial trucks and virtually 100 percent of all rail and marine engines are powered by diesel engines. The inherent performance advantages of diesel technology – powerful output, excellent fuel efficiency, better safety, low operating temperatures and superior durability – make them critical to the transportation, agriculture, mining, retail and emergency preparedness industries, just to name a few.

Less recognized are the inherent environmental advantages of diesel engines. Compared to gasoline engines, diesels emit less carbon monoxide (CO), hydrocarbon (HC) and carbon dioxide (CO₂). The outdated perception of the diesel engine as “dirty” is based on the comparatively higher levels of particulate matter (PM) and nitrogen oxides (NOₓ) emitted by older diesel engines.

Yet over the last 25 years significant progress has been made in diesel engine design to lessen the production of regulated emissions from the combustion process. The fruits of this investment will be available in 2007 when diesel engine manufacturers begin selling on-road diesel engines that meet EPA’s reduced emissions levels. Engines meeting similarly strict emissions levels will be sold in off-road applications by 2011. Because of this commitment, diesel vehicles and equipment will be significantly cleaner than even a few years ago, so much so that by 2010, diesel buses will certify to the same emissions standards as those fueled by natural gas.

Engine technology investments have been significant, but cannot fully account for the emissions reductions inherent in the newest vehicles. Today’s clean diesel system is made up of three components – the fuel, engine and emissions control device – all of which work interdependently to make diesel power both efficient and clean.

In order to fully appreciate the opportunities for cleaning up the entire fleet of legacy vehicles and equipment used across the country, it is necessary to understand how each of these component parts contributes to reducing diesel emissions.

**The Clean Diesel System – Three Interdependent Components**

As noted above, diesel engines have changed significantly over the years as emissions regulations have grown more stringent. Yet after a series of improvements, engine manufacturers were limited in the emissions reductions they could achieve through engine modifications. High sulfur levels in on-road diesel fuel restricted further improvements in the combustion process and prevented the use of many emissions control devices to clean up exhaust gases. As a result, EPA looked beyond the engines and adopted a more systematic approach. With new regulations on the sulfur levels within diesel fuel, engine manufacturers not only were able to improve their efficiency, but also able to use more effective filters and emissions control devices without fear of clogging. In other words, lowering the fuel sulfur levels has enabled technology to achieve the new standards. This new approach has led to today’s clean diesel system, with each of the components working together interdependently.

**Even if no engine or emissions control device changes are made, ULSD use alone is capable of reducing engine-out PM emissions by up to 10 percent.**

**The Fuel – Ultra Low Sulfur Diesel**

Prior to 2007, diesel fuel for trucks, buses and other on-road vehicles could have up to 500 parts per million (ppm) of sulfur. In parts of the country, lower sulfur diesel fuel (less than 50 ppm) has been available, but it was generally limited to urban areas where it was brought in by truck to fuel particular centralized fleets. Since October 15, 2006, most retail diesel fueling stations offer Ultra Low Sulfur Diesel Fuel (ULSD), defined as having a maximum sulfur level of 15 ppm.

ULSD is a petroleum distillate product that undergoes hydro-desulphurization to eliminate more than 99 percent of the sulfur content. Sul-
fur, a component of all petroleum-based feedstocks and grades, serves primarily as an engine lubricant, although undesirably so because it creates corrosive combustion byproducts, releases sulfur oxides into the environment, and increases deposits on fuel injectors and combustion components. This removal of sulfur from diesel is analogous to the removal of lead from gasoline, enabling the effective use of advanced catalysts and emissions filters.

Even if no engine or emissions control device changes are made, ULSD use alone is capable of reducing engine-out PM emissions by up to 10 percent, depending on engine design, manufacturer, and operating duty-cycle.1 Just as most on-road diesel fuel switched to ULSD in October 2006 (since engines manufactured in 2007 or later require it), fuel for off-road engines will be reduced to 500 ppm of sulfur in 2007 and then down to the ULSD level of 15 ppm in 2010 (see Table 2.1).

**The Engines**

In response to EPA regulations, diesel engine manufacturers have made significant investments in developing technologies to greatly reduce PM and NOx emissions from new diesel engines. Combustion chambers have been redesigned to maximize air and fuel mixture, common rail fuel injection systems have brought higher injection pressures, variable geometry turbochargers have been added to boost energy, and computer technology has been incorporated to monitor and control engine processes to maximize efficiency. Diesel engines manufactured in 2006 emit 83 percent less particulate matter and 63 percent less NOx than they did in 1990. These emissions will be reduced even further beginning in model year 2007, when new regulations require reduction of both PM and NOx emissions by 98 percent from their 1988 levels – virtually eliminating these emissions by 2010 when the standards are fully phased in. Figure 2.1 shows the significant progress made over the years in reducing PM and NOx emissions from new on-highway heavy-duty diesel engines.

Significant emissions reductions for off-road en-

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**Table 2.1 Non-Road Diesel Fuel Standards**

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Refiners &amp; Importers</td>
<td>NON-ROAD</td>
<td>500+ ppm</td>
<td>500 ppm</td>
<td>500 ppm</td>
<td>500 ppm</td>
<td>15 ppm</td>
<td>15 ppm</td>
<td>15 ppm</td>
<td>15 ppm</td>
</tr>
<tr>
<td>Large Refiners &amp; Importers</td>
<td>LOCOMOTIVE &amp; MARINE</td>
<td>500+ ppm</td>
<td>500 ppm</td>
<td>500 ppm</td>
<td>500 ppm</td>
<td>500 ppm</td>
<td>15 ppm</td>
<td>15 ppm</td>
<td>15 ppm</td>
</tr>
<tr>
<td>Small Refiners and other exceptions</td>
<td>NON-ROAD, LOCOMOTIVE AND MARINE</td>
<td>500+ ppm</td>
<td>500+ ppm</td>
<td>500+ ppm</td>
<td>500+ ppm</td>
<td>500 ppm</td>
<td>500 ppm</td>
<td>500 ppm</td>
<td>15 ppm</td>
</tr>
</tbody>
</table>

Except in California, compliance dates for Non-Road, Locomotive and Marine fuels are: June 1 for refiners and importers, August 1 downstream from refineries through fuel terminals, October 1 for retail outlets, and December 1 for in-use

In California, all diesel fuel will transition in 2006. Compliance dates for Non-Road fuels are: June 1 for refiners and importers, July 15 downstream from refineries through fuel terminals, and September 1 for retail outlets. Locomotive and Marine diesel fuels must transition to 15 ppm ULSD by January 1, 2007

Source: Clean Diesel Fuel Alliance

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**Figure 2.1 Diesel Emissions Reductions 1988-2010**

Source: U.S. EPA On-Highway Heavy Duty Diesel Emissions
Engines and machines – such as farm tractors, construction and mining equipment – were finalized in 2004, setting in motion a progressive reduction of diesel emissions that parallels the progress made in the highway sector. These reductions will be phased in between 2008 – 2014 based on engine size and power output. Engine and fuel solutions are likely to be adequate for the 2008 – 2010 timeframe with emissions control devices becoming necessary in 2011.

Taken together, these new emissions roadmaps will guide both on-road and off-road new diesel engines and vehicles into the future as very low emissions technology – competitive with alternative fuels in many cases.

**Emissions Control Technology**

The third component of the clean diesel system is the use of emissions control devices to reduce emissions, usually particulate matter or nitrogen oxides, from the exhaust stream. Since there has generally been stronger interest in PM reduction technologies, their market availability is greater than those for NOx, although EPA and/or CARB verification of additional NOx reduction technology is on the horizon. While the number of technology options and their effectiveness continue to improve, the most common emissions control devices in use today are diesel oxidation catalysts and diesel particulate filters.

Due to their low cost, ease of use and installation, lack of monitoring or maintenance requirements, and compatibility with a wide variety of fuels, diesel oxidation catalysts (DOCs) have been used for more than 30 years and are perhaps the most proven emissions control option. DOCs, similar to mufflers that reduce tailpipe emissions, have been installed on an estimated 750,000 heavy-duty applications and are the most common retrofit option for on- and off-road vehicles and equipment in use today. A typical DOC consists of a stainless steel canister containing a honeycomb structure called a substrate. The interior surfaces of the substrate are coated with catalytic precious metals such as platinum or palladium. As exhaust flows over the precious metals, a chemical reaction occurs, which removes the soluble organic carbon fraction of the particulate matter (oxidizing it into water vapor and other gases), usually resulting in a PM reduction of 20 percent to 50 percent. Since no additional heat or energy source is required to achieve this PM reduction, DOCs are referred to as passive devices. DOCs have been installed on new urban buses and new diesel pick-up trucks, are required in many mining operations, and have been deployed on a large number of school buses nationwide.

Unlike the DOC, diesel particulate filters (DPFs) physically trap the PM as the exhaust gas flows through the substrate. In order to prevent filter clogging with soot that can shut down the engine, DPFs are engineered to oxidize these solid trapped particulates at exhaust temperatures typical to diesel engines to form gaseous products and ash through a process called regeneration. DPFs are typically coated with a catalyst such as platinum, that promotes regeneration which oxidizes the PM, resulting in total PM reductions of 80 percent to 95 percent.

2 "Retrofitting Emission Controls on Diesel Powered Vehicles,” MECA, April 2006, pg. 2.

### Table 2.2 Final Off-Road Emissions Standards

<table>
<thead>
<tr>
<th>Rated Power</th>
<th>First Year that Standards Apply</th>
<th>PM †</th>
<th>NOx ‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>hp &lt; 25</td>
<td>2008</td>
<td>0.30</td>
<td>—</td>
</tr>
<tr>
<td>25 ≤ hp &lt; 75</td>
<td>2013</td>
<td>0.02</td>
<td>3.5*</td>
</tr>
<tr>
<td>75 ≤ hp &lt; 175</td>
<td>2012-2013</td>
<td>0.01</td>
<td>0.30</td>
</tr>
<tr>
<td>175 ≤ hp &lt; 750</td>
<td>2011-2013</td>
<td>0.01</td>
<td>0.30</td>
</tr>
<tr>
<td>hp ≥ 750</td>
<td>2011-2014</td>
<td>0.075</td>
<td>2.6 / 0.50</td>
</tr>
<tr>
<td></td>
<td>2015</td>
<td>0.02/0.03</td>
<td>0.50</td>
</tr>
</tbody>
</table>

* Source: www.epa.gov/cleandiesel/documents/aaac-apr06.pdf
  * The 3.5 g.hp-hr standard includes both NOx and non-methane hydrocarbons
  † in grams per horsepower-hour (g/hp-hr)
DPFs are generally designed as a direct replacement for the original muffler, but are larger and heavier, requiring extra mounting brackets to be properly installed on the vehicle. Since passive DPF regeneration requires specific exhaust temperatures, it may not be a suitable retrofit option for vehicles or off-road equipment that operate at low exhaust temperatures or have other operating conditions (i.e. short runs, stop and go, vacillating between high duty cycles and idling). Due to this need for specific exhaust temperatures, the devices must be evaluated in a worst case duty cycle application in order to determine if the filter will work effectively, with requirements varying by manufacturer. DPFs also require the use of ULSD in order to operate properly, a condition that has hindered their widespread adoption but is ameliorated with the national availability of ULSD in October 2006.

Active diesel particulate filters are also available which take the form of a bare filter substrate that regenerates either electronically or through hydrocarbon injection. The former needs to be plugged in requiring some vehicle/machine “down time,” although it is less sensitive to fuel type or duty cycle. The latter is done through use of fuel from the fuel tank. This causes a slight fuel economy loss and requires ULSD but also allows for a greater range of duty cycle applications. All diesel particulate filters require periodic cleaning to remove the ash that builds up in them. This ash results from the lubricating oil used in typical engine operations. Thus all DPFs require a monitor to measure backpressure to ensure that the ash does not build up past manufacturers’ guidelines.

DOCs and DPFs represent the majority of retrofits installed to date, however, a number of other technologies are also available, including closed crankcase ventilation (CCV), selective catalytic reduction (SCR), lean NOx catalysts (LNC) and exhaust gas recirculation (EGR). A summary of these technologies are provided in Table 2.3, however more detailed info can also be found at www.dieselforum.org/meet-clean-diesel/road-to-2007/2007-technology-gallery/.

Technology Verification

As these and other technologies are developed, manufacturers usually submit them to EPA or the California Air Resources Board (CARB) for independent verification of their effectiveness. These verification programs serve two primary purposes. First, they quantify the reduction of EPA-regulated emissions – particulate matter (PM), oxides of nitrogen (NOx), hydrocarbons (HC) and carbon monoxide (CO) – through a comprehensive testing requirement. Second, they provide certainty that the control technologies will provide emissions reductions over a long period of time, through a long-term durability evaluation.

While certain differences exist between the two programs, they serve similar purposes, and both are recognized as important tools in determining the effectiveness of emissions control technologies both when new and after many hours of operation. In the summer of 2004, CARB and EPA signed a Memorandum of Agreement (MOA) providing reciprocity for most emissions control technologies (ECT) that already have been recognized as “verified technologies” regardless of the verification program selected. For most major diesel retrofit projects, including those funded by federal, state and regional governments, verified technology is a prerequisite to financial support, making verification a key component in the technology development process. An updated list of each program’s verified technologies can be found on its website: www.arb.ca.gov/diesel/verdev/verdev.htm and www.epa.gov/otaq/retrofit/retroverifiedlist.htm.
Table 2.3 Summary of Available Options for Reducing Diesel Emissions

<table>
<thead>
<tr>
<th>Emissions Control Technology</th>
<th>Description</th>
<th>Percent Emissions Reduction*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel Particulate Filter (DPF)</td>
<td>DPFs are honeycomb or mesh devices that filter, or trap PM from the exhaust. Exhaust temperature, duty cycle, and fuel type are critical elements to evaluate prior to selecting a DPF.</td>
<td>Up to 90+ — 60-90 60-90</td>
</tr>
<tr>
<td>Diesel Oxidation Catalyst (DOC)</td>
<td>DOCs reduce harmful pollutants by catalytically converting pollutants to water and carbon dioxide (CO2). Inside the canister is a honeycomb substrate that is coated with a small amount of precious metals where the reaction occurs.</td>
<td>20-50 — 60-90 60-90</td>
</tr>
<tr>
<td>Lean NOx Catalyst (with a DPF)</td>
<td>LNCs are catalysts that promote the reduction of NOx by using hydrocarbons as a reducing agent. Often an LNC is combined with a DPF.</td>
<td>Up to 90+ 25 60-90 60-90</td>
</tr>
<tr>
<td>Exhaust Gas Recirculation (with a DPF)</td>
<td>EGR technology recirculates a portion of engine exhaust back into the engine. This recirculation cools peak combustion temperatures and dilutes the oxygen content of the fuel-air mixture, thus reducing NOx. EGR can be coupled with a DPF to reduce even more PM.</td>
<td>Up to 90+ Up to 50 (60-90 with DPF) 60-90 60-90</td>
</tr>
<tr>
<td>Selective Catalytic Reduction</td>
<td>SCR technology injects urea (or some form of ammonia) into the exhaust stream which reacts over a catalyst to reduce NOx emissions.</td>
<td>30-50 Up to 90+ 50-90 50-90</td>
</tr>
<tr>
<td>Closed Crankcase Ventilation systems</td>
<td>CCV systems are designed to return crankcase blow-by gases to the engine intake for subsequent combustion during the engine combustion process.</td>
<td>10-15 — 30-40 30-35</td>
</tr>
<tr>
<td>Ultra-Low Sulfur Diesel</td>
<td>ULSD fuel has a sulfur content of 15 parts per million (PPM) or less.</td>
<td>5-10 — — —</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>Renewable fuel (meeting ASTM spec 6751) that can be manufactured from vegetable oils or animal fats.</td>
<td>varies varies varies varies</td>
</tr>
<tr>
<td>Additives</td>
<td>Chemicals added to the fuel in very small amounts to improve one or more properties of the base fuel.</td>
<td>— Up to 5 — —</td>
</tr>
<tr>
<td>Emulsions</td>
<td>Water and additives mixed with fuel to lower combustion temperatures.</td>
<td>varies varies</td>
</tr>
<tr>
<td>Repowering</td>
<td>Replacing an older engine with a newer, cleaner engine or replacing a diesel engine with one that can use alternative fuels.</td>
<td>varies varies varies varies</td>
</tr>
<tr>
<td>Replacement</td>
<td>Replacing older vehicles and equipment with ones that are newer and cleaner.</td>
<td>varies varies varies varies</td>
</tr>
</tbody>
</table>

*Percent emissions reduction of the following pollutants: PM - Particulate Matter, NOx - Nitrogen Oxides, CO - Carbon Monoxide

Source: EPA Progress Report 2005
The adoption of this three-part clean diesel system will significantly improve air quality as new diesel vehicles and equipment enter the marketplace across the United States in the years to come. According to EPA, its 2007 heavy-duty highway engine rule and its off-road diesel rule will result in annual reductions of 4,000,000 tons of NOx and 250,000 tons of PM combined by 2030 when fully implemented. While these reductions are substantial, EPA lacks the statutory authority to retroactively strengthen standards for the estimated 11 million diesel engines in operation today, resulting in the creation of its “voluntary” retrofit program. Given the fact that diesel’s inherent durability allows well-maintained diesel engines to operate for 20 to 30 years and power vehicles for more than 1 million miles in many applications, engines manufactured prior to 2007 could potentially still be operating until 2036. Congress limited the Agency’s authority in this regard, because it could cause extreme hardship to require either vehicle owners/operators or engine manufacturers to conduct engine enhancements on millions of in-use vehicles across the nation – not to mention the huge logistical burdens that would result from attempting to enforce such a retroactive requirement. In some cases, such changes would not even be technologically feasible.

Nevertheless, different aspects of the latest clean diesel technology can be applied to many of these older diesel engines, resulting in lower emissions of PM and NOx. These changes can in some cases bring the emissions profile of existing engines significantly closer to those clean diesel engines under development to meet the new 2007 clean engine standards. The cost of diesel engine retrofits is highly variable based on many factors including an engine’s particular operating characteristics, the age of the equipment or vehicle, and the nature of the proposed technology solution. Emissions filters and catalysts typically range from several hundred dollars to tens of thousands of dollars. As a result, many fleet owners cannot undertake these projects without some type of outside financial assistance or benefits such as partial financial awards, tax credits, emissions credit trading programs or improved stakeholder relations. Some state and local governments have adopted local ordinances or laws that mandate emissions reductions, and in some cases have applied contract requirements that incentivize or require the retrofitting of existing diesel engines and equipment to bid on public contracts. These conditions are discussed in further detail later in this paper.

The Five R’s of Retrofit

The concept of “retrofit” has typically been defined broadly. While the term is frequently used as a label describing various exhaust emissions control devices such as the DOCs and particulate filters previously outlined, it can also encompass a broader range of options to reduce emissions, including re-powering, rebuilding and in some instances replacing existing equipment, as detailed below:

- **Rebuild.** After 3 or 4 years, rebuilding some core engine components to manufacturers’ original specifications can return emissions performance to the original design levels. Some manufacturers also have options to improve emissions beyond the original performance levels.

- **Refuel.** Use of Ultra-low Sulfur Diesel (ULSD) can lower emissions, as can some other renewable fuels and fuel products such as biodiesel and emulsifiers.

- **Retrofit.** The installation of exhaust emissions control technologies such as particulate filters, oxidation catalysts, exhaust gas recirculation (EGR), selective catalytic reduction (SCR) devices, and lean NOx catalysts (LNCs).

- **Repower.** Replacing the older engine in diesel-powered equipment with a new or newer diesel engine can dramatically reduce emissions.

- **Replace.** Replacing entire vehicles or equipment may be the best option for some of the oldest, heaviest emitting vehicles or equipment due to technological feasibility and cost considerations.

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Cost Effectiveness

Since the adoption of the Clean Air Act in 1970, public, private and non-profit stakeholders have been searching for ways to improve air quality. This effort has been particularly intense in areas of the country where counties are found to be in violation of EPA’s National Ambient Air Quality Status (NAAQS) for key pollutants.

If one accepts the proposition that efforts should be made to improve air quality since clean air improves the quality of life, it is logical to assume that the lowest cost methods of doing so would be preferred. Over the years, several studies have been undertaken to determine the cost effectiveness of various air quality improvement methods.

The Diesel Technology Forum compiled the data presented in Figure 3.1 to exemplify the cost effectiveness of various air quality improvement methods. This data was collected by the Metropolitan Washington (DC) Council of Governments and the Transportation Research Board from specific diesel retrofit projects. As shown in the graphic, diesel retrofit projects demonstrate significant cost-effective advantages as compared to other eligible CMAQ projects.

Similar figures were found by the National Research Council (NRC) in its assessment of the CMAQ program with the finding that “when compared on the sole criterion of emissions reduced per dollar spent, approaches aimed directly at emissions reductions…..have been more successful than most CMAQ strategies relying on changes in travel behavior.”

Recognition of diesel retrofits’ cost effectiveness led Congress to direct the Federal Highway Administration to give diesel retrofit projects priority for CMAQ funding in its 2005 reauthorization of the federal highway bill. In her introduction of the amendment that established this priority, Senator Hillary Clinton explicitly linked the development of the amendment to the findings of the NRC report and several members of Congress specifically cited the cost-effectiveness of diesel retrofit in reducing emissions as cause for their support of the amendment.

Source: www.dieselforum.org/retrofit-tool-kit-homepage/cost-effectiveness-comparisons/

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Figure 3.1 Comparison of Typical CMAQ Funded Projects

<table>
<thead>
<tr>
<th>Diesel Retrofits: Cost-Effective Solutions</th>
<th>Other Typical CMAQ Projects</th>
</tr>
</thead>
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<tr>
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Source: www.dieselforum.org/retrofit-tool-kit-homepage/cost-effectiveness-comparisons/
IV. IMPLEMENTATION CRITERIA

A successful retrofit project begins with careful selection of engine candidates. Some engines and vehicle applications make much better retrofit candidates than others, and certain engines and vehicles may simply be inappropriate for investment in an upgrade. Once a particular fleet has been selected, the next step in the retrofit process is to identify the most appropriate retrofit strategy. Proper technology matching helps ensure that emissions performance meets a project’s air quality improvement goals, while vehicle reliability is not negatively impacted and the project’s overall effectiveness is not undermined. For example, use of cleaner fuels that are not available at retail outlets is a poor match for on-road, line-haul trucking fleets that rely on retail fuel purchase, but are a good match for fleets that are centrally fueled, such as municipal refuse vehicles or off-road construction equipment. Some technologies, such as DPFs and catalyzed wire mesh filters (CWMFs), are significantly heavier than the original equipment mufflers they are designed to replace and require additional mounting brackets for stability as well as thermal blankets to help sustain specific exhaust temperatures for regeneration. Both approaches may also require some engineering and fabrication to aid in installation as well as assuring that safety is not impaired by blocking sight lines or exposing personnel to hot surfaces.

Certain technologies, while appearing attractive on paper, require specific operating profiles to be effective. As noted earlier, passive DPFs require specific minimum threshold engine exhaust temperatures to ensure effective regeneration of accumulated soot. As a result, their application may be limited and verification requires the installation of on-board backpressure monitors to warn operators during day-to-day operation of an impending need for maintenance i.e. to indicate when ash removal is necessary.

Many of the most effective diesel emissions reduction devices require some level of periodic maintenance to operate effectively and safely. DPFs require periodic disassembly to clean out ash deposits. Closed Crankcase Ventilation (CCV) systems require periodic filter replacement much like an engine oil filter (and frequently at the same intervals). Sophisticated NOx-reduction technologies, such as SCR, require periodic refilling of on-board urea reductant tanks. Failure to follow these and other prescribed procedures could compromise the effectiveness of the technology, render the vehicle inoperative, or even damage the engine. On the other hand, none of these or other precautionary and maintenance procedures are particularly onerous, and with adequate training, are easy to perform and adhere to over the life of the vehicle.

In some retrofit decisions, technical issues may be less important than economic considerations. Diesel engines are used in a variety of industry sectors: school bus, freight, construction, ports and agriculture. Each is characterized by a unique operating environment and business model that must be considered in order to balance emissions benefits with business profitability. For example, what works for terminal operators at ports may be completely inappropriate, or even disadvantageous for line-haul truck operators, construction contractors, or school bus operators. What follows is a brief look at some of these sector specific considerations.

School Buses
Approximately 400,000 full-size school buses are currently in operation, the majority of which are diesel powered. Of these, roughly one-third were built before 1991, emitting six times more PM and twice the NOx of a 2005 diesel bus. These vehicles are obvious candidates for retrofit projects, and yet EPA estimates that only 7.5 percent of them – due to a number of considerations – have been involved in a clean school bus proj-
ect. One of the biggest impediments to school bus retrofits is the lack of funding. Approximately 70 percent of school buses are owned, operated and maintained by school districts, which are locally funded and often cash strapped due to competing demands on municipal budgets. EPA’s Clean School Bus USA program has tried to fill this gap, however other challenges such as the limited capacity of individuals within the district or the lack of public partners to apply and manage grants create additional challenges, even if sufficient federal funds were available to cover the need.

From a technical perspective, DPFs have been verified with critical temperature specifications based on engine load and speed, thereby making some inappropriate for school bus applications that tend to operate under minimal load. They also require the use of ULSD, which before October 2006, has generally been unavailable outside of major metropolitan areas. As a result, a majority of the retrofits to date have been performed with DOCs, which are less expensive and could run on readily available diesel fuel.

**Freight**

Ground freight transportation, comprising on-road trucks and rail, accounts for 82 percent of all goods movement in the U.S. Together these modes account for 40 percent and 30 percent of transportation-related NOX and PM emissions, respectively. Truck and rail transport of goods will continue to grow in the years ahead. Although significant emissions reductions will be realized through the nationwide introduction of ULSD fuel and cleaner heavy-duty engines in 2007, additional progress can be realized through a variety of retrofit options, including anti-idling devices, fleet modernization, engine upgrades and exhaust emissions control devices.

In the rail industry, technological barriers with emissions control devices make widespread retrofit a longer term proposition. One alternative is to rebuild or repower older locomotive engines with those that result in lower emissions levels while simultaneously improving overall performance. Another option is to install auxiliary power units (APUs) as an anti-idling technology. APUs allow the locomotive engine to be shut down while maintaining constant power to the train. By using significantly less fuel and emitting fewer emissions than the locomotive engine, APUs can help improve air quality while providing a fuel-saving alternative for the railroad.

Like the rail industry, trucks spend a significant amount of time idling, primarily to keep drivers cool and comfortable while not on the road. As a result, APUs and advanced truck stop electrification also can help supply truck drivers with electricity to meet their needs while the engine is turned off. In both cases, economic benefits complement the emissions reductions through fuel conservation and less engine wear and tear.

Nevertheless, unlike locomotives, trucks can benefit from the application of exhaust emissions control devices. In 2003, EPA created its SmartWay program to help reduce emissions and energy consumption from the ground freight industry. This voluntary collaborative serves to reduce environmental footprints by helping carriers reduce their emissions and encouraging shippers to use only participating SmartWay carriers.

In order to help make emissions reduction and fuel efficiency technologies more accessible,

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6 Ibid., pg. 31.
SmartWay has developed upgrade kits that combine the two so that fuel efficiency cost savings can pay for the emissions reduction improvements. SmartWay helps carriers identify national and state loan programs to help finance the initial cost of the upgrade kits. More information on the program is available at: www.epa.gov/smartway.

Ports

There are over 180 seaports along the U.S. contiguous coasts, islands and internal waterways, most of which are controlled by state or local public governmental agencies. Many of these also lie in or border NAAQS non-attainment areas and have become a particular concern for regulators and adjacent communities. Unlike other sectors, ports are an amalgam of five different sub-sectors operating within the same geographical area, all of which operate under different business models and operating conditions. As a result, diesel emissions reduction strategies will differ depending upon their unique technological challenges, the complexity of their business operations and the influence of public port authorities.

Ocean-going ships typically present the greatest challenge due to their very large compression ignition engines, complex worldwide operations and limited port involvement other than temporary docking. For this sub-sector, emissions reduction programs have focused on fuel quality through Sulfur Emission Control Areas because fuel used in ocean-going ships is known as bunker oil, a more energy-dense, less-refined, higher sulfur fuel. Of the four other subsectors: harborcraft, drayage trucks that transport goods into and out of the port, rail service and dockside equipment used for cargo handling, the latter has been given most attention.

Terminal operators rely on smooth, continuous operation of their loading equipment to maximize efficiency and profitability. As a result, replacing or repowering older equipment followed by refueling with lower sulfur fuels have been among the most preferred emissions reduction strategies at ports. The former provides better performance together with air quality improvements, making it an attractive option. The benefits of refueling include easy implementation and little if any intrusion on terminal operations since there is no downtime required for installation. Retrofit emissions control technologies are generally regarded as less attractive owing to concerns about operating performance in harsh environmental conditions, fear about equipment downtime for maintenance and operator sight obstruction issues.

In addition to these technical considerations, port-related retrofits can be hampered by the competition for funds which may also be needed to meet national security mandates and the complexity of working with multiple jurisdictions.

Construction

Despite the construction industry’s size and importance to the U.S. economy, the majority of companies are quite small, with 92 percent of the industry’s 700,000 firms having fewer than 20
employees. They tend to be low-margin businesses with much of their business value accumulated in their capital equipment. Because of this, construction companies resist modifications that will restrict their equipment’s operability. Retrofit technology offers few economic benefits and poses potential risks for owners due to the downtime associated with installation and possible additional maintenance and training costs. Yet increasingly, failure to invest in these equipment upgrades can prevent them from competing for projects with contracting requirements for cleaner equipment.

Currently 2.1 million units of off-road construction equipment are believed to be in use, 31 percent of which are so old that they have no emissions controls. Emissions reductions from off-road diesel engines have lagged behind their on-road counterparts, making the potential for air quality improvements through retrofit of these vehicles more cost-effective. This is particularly true in urban areas where the majority of construction sites, population centers and non-attainment areas are located.

The construction industry poses several unique challenges in retrofit decisions including extended idles and/or low-speed operation periods, vibration, high levels of dust, space limitations and operator visibility. Repowering has been a strong retrofit option for construction equipment since upgraded engines pose less performance risk and can improve equipment performance and longevity. Another option is to use Upgrade Kits as part of a rebuild solution. Refueling and emissions control devices offer other possibilities, with the latter somewhat limited by their NOx/PM emissions ratio, age, varying duty cycles and the limited number of verified technologies. Unfortunately, the specificity of construction equipment applications has hindered the speed at which new technologies have been developed, tested and verified.

Although significant emissions reductions will be realized through the nationwide introduction of ULSD fuel and cleaner heavy-duty engines in 2007, additional progress can be realized through a variety of retrofit options.

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7 Ibid., pg. 48-9.
8 Ibid., pg. 49.
Federal, state, and local governments have used a variety of strategies to incentivize fleet owners/operators to undertake diesel engine emissions reduction projects. Before turning to the specifics of such strategies, however, it is helpful to understand how these programs can fit into the context of state government obligations under the Clean Air Act.

Diesel engine emissions reduction strategies may be used by state and local governments to help meet their obligations under the Clean Air Act. Specifically, the EPA has set National Ambient Air Quality Standards (NAAQS) for several common pollutants – including PM, and ozone – but individual states are tasked with developing and implementing strategies to meet these standards. EPA reviews these standards every five years.

Counties that do not meet a standard are deemed to be in “non-attainment” and must submit a State Implementation Plan (SIP) that provides for the implementation and enforcement of control measures to attain and maintain the standard. If the SIP does not provide for sufficient emissions reductions, the EPA can step into the state’s role and impose its own wide-ranging restrictions on sources within the state. Moreover, if the state does not attain the air quality standards within a specified time period, it risks becoming ineligible for millions of dollars in federal highway funds.

EPA designated non-attainment areas for the 8-hour ozone NAAQS with an effective date of June 15, 2004, with SIP submissions due by June 2007. Non-attainment area designations for the 1997 PM 2.5 NAAQS became effective on April 5, 2005 with SIPs due on April 5, 2008. The latest 2.5 standards announced by the EPA in 2006 will lead to subsequent SIP submissions in 2013. A map of all non-attainment areas can be found at: www.epa.gov/air/data/reports.htm.

There are many different emissions reduction strategies that EPA will accept in a state’s SIP, and each of the strategies a state selects is assigned a specific “SIP Credit” that is applied toward meeting the state’s air quality obligations. EPA policy allows 3 percent of the total emissions reductions needed by a state to come from a category of clean air programs known as voluntary mobile source emissions reduction programs. In certain situations, states may work with their Regional EPA Office to obtain credit for such programs to account for even more than 3 percent of the required reductions. In any case, voluntary mobile source programs can be an important aspect of a state’s overall air quality strategy. Such programs include diesel emissions performance enhancements, which the EPA specifically encourages through its Voluntary Diesel Retrofit Program and its general Guidance on Innovative and Voluntary Air Pollution & Control Strategies.

Federal Funding Sources

Despite the recognized cost-effectiveness of diesel retrofit as an air quality improvement measure, growing and competing priorities have significantly limited the amount of funds available for voluntary diesel retrofit projects.

**Diesel Emissions Reduction Program**

In 2000, EPA announced a new voluntary initiative called the Diesel Retrofit Program to clean up older diesel engines in trucks, buses and construction equipment. This was followed by the creation of the Clean School Bus USA Partnership in 2003 with $5 million in funding. In 2004 EPA launched the National Clean Diesel Campaign and provided both school bus and other demonstration retrofit grants, reaching a total appropriation of $12 million in 2006.

Beginning in FY2007, EPA’s diesel retrofit funds will be administered under the Diesel Emissions Reduction Program (DERP) which was created through the Energy Policy Act of 2005. Under this program, EPA will establish a competitive grant and low-cost revolving loan program. Seventy percent of appropriated funds will be available for the national program administered by EPA and the other 30 percent will be available for similar programs operated by states. More

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10 www.epa.gov/oms/stateresources/policy/pag_guidance.htm
details about the program can be found at: www.dieselforum.org/policy-insider/diesel-emissions-reduction-act/.

The funding of EPA’s DERP program was authorized for up to $200 million annually for five years or a total of $1 billion. However, each year’s funding level will be determined by Congress during the annual appropriations process, with input from the President’s annual budget request for EPA. These annual funding levels may vary from year to year as Congress responds to various budget pressures and priorities.

Distribution of these funds by EPA is likely to be through a combination of national and regional awards with states handling funds given to them by EPA independently. Over the last several years EPA has launched several regional “diesel collaboratives,” in an effort to bring business, government and non-profit interests together to promote local solutions to reduce diesel emissions. Following from the initial success of the West Coast Diesel Collaborative, several more were launched throughout 2005 and 2006. Through this structure, EPA hopes to promote partnerships and greater awareness about grant opportunities while addressing a combination of national, regional and sector specific priorities. For more information about EPA funding and the regional diesel collaboratives, visit www.epa.gov/diesel/.

U.S. Department of Transportation

Congestion Mitigation and Air Quality Program

The other primary federal source of funding for diesel retrofit comes from the Federal Highway Administration (FHWA). In 1991, a year after Congress amended the Clean Air Act to accelerate efforts to achieve the National Ambient Air Quality Standards, the Congestion Mitigation and Air Quality program (CMAQ) was created as part of the Intermodal Surface Transportation Efficiency Act (ISTEA) to fund transportation projects that reduce emissions in non-attainment and maintenance areas. CMAQ funds require a 20 percent state or local match and must be distributed through a public sector partner. They are generally apportioned to state departments of transportation according to a formula based on air quality and population.

Although the Federal Highway Administration and the Federal Transportation Authority must approve all CMAQ-funded projects, there is no one system for identifying and approving projects at the state level. Metropolitan planning organizations (MPOs) have varying levels of authority over project selection, but are responsible for ensuring that projects are included in transportation improvement programs (TIP). Coordination between transportation and air quality officials at state and local planning agencies is critical to ensuring that TIPs conform with State Implementation Plans for obtaining NAAQS attainment, otherwise federal highway dollars could be jeopardized.

Diesel retrofit projects have previously been eligible for funding under the CMAQ program, but have traditionally represented a miniscule percentage of overall program expenditures, with transit and traffic flow improvement projects accounting for two-thirds to three-quarters of all program funds. This is expected to change as a result of the transportation authorization bill passed by Congress in 2005.

Under SAFETEA-LU, the Safe, Accountable,

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*Authorizations shown here will be augmented by a portion of the Equity Bonus program funds
Source: Federal Highway Administration

11 This percentage has been reduced in a few select states through various legislative or administrative actions.
Flexible, Efficient Transportation Equity Act: A Legacy for Users, more than $8.6 billion was authorized for the CMAQ program for FY 2005–2009. The bill placed added emphasis on the cost-effectiveness criteria in the selection of projects, with language giving particular priority to diesel retrofits, including off-road applications. However, the savings clause states this retrofit prioritization “is not intended to disturb the existing authorities and roles of governmental agencies in making final project selections.”

Some states have been reluctant to fund diesel retrofit projects, preferring instead to support more traditional transportation system improvements. On the other hand, there are several states that recognize the value of diesel retrofits for improving air quality and view CMAQ as a valuable resource. California, Connecticut, Georgia, Idaho, North Carolina, Tennessee, and Texas are just some of the states that have used CMAQ funds for diesel retrofit projects. A summary of three particular state examples is provided below. A more complete list of CMAQ-funded retrofit projects can be found at: www.dieselforum.org/retrofit-tool-kit-homepage.

**Tennessee: A statewide priority for diesel retrofit**

With 18 counties designated as non-attainment for ozone and/or PM 2.5, the Tennessee Department of Transportation (TDOT) created a Clean Transportation Initiative to reduce on- and off-road mobile source emissions. TDOT dedicated $4.8 million in CMAQ funds over three years to a Clean Transportation Innovations Incentives Fund for reducing emissions from heavy-duty diesel through the use of retrofit control equipment and idling reduction technology.

The Innovations Incentive Fund is managed by TDOT and will fund public/private partnerships focusing on emissions control solutions, replacement, repowering, and rebuilding as well as encouraging idling reduction and cleaner fuels. Select pilot projects will begin in late 2006 focusing on construction equipment, public fleets and idling reduction options for switchyard locomotives. This will be followed by a competitive program in FY2007.

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Historically, TDOT has allocated approximately two-thirds of its CMAQ funds to MPOs, giving them wide authority for project selection. Because of increases in the state’s overall CMAQ budget, this percentage will likely fall closer to one-half beginning in 2007. TDOT is also dedicating more resources to new, multi-region and statewide concerns, and MPOs have developed new project selection criteria that emphasize emissions reduction benefits.

Like the national apportionment formula, TDOT does not account for PM 2.5 nonattainment status in its CMAQ distribution to MPOs. However TDOT is providing resources to address PM 2.5 issues by creating a statewide fund for PM 2.5 CMAQ projects. Currently $4.3 million has been earmarked from the FY05 – FY06 CMAQ budget for this fund. Because diesel retrofits are one of the most cost-effective PM 2.5 reductions, these funds are likely to support additional retrofit projects in the state with the first request for projects expected before the end of 2006. These two dedicated funds together with additional resources that may be dedicated for diesel retrofits by MPOs will help Tennessee achieve cleaner air. More information about the Tennessee Department of Transportation’s Environmental Policy office can be found at www.tdot.state.tn.us/environment/policy.

Idaho: Supporting clean school buses
Unlike many states on the east coast, Idaho is fortunate not to have any NAAQS non-attainment or maintenance counties. As a result, Idaho is one of a few states that receives the minimal apportionment of funds under the CMAQ program averaging between $2 million to 4 million annually.

In Idaho, CMAQ funds are administered by the Idaho Department of Transportation in a statewide competitive program. Projects must show cost-effectiveness, provide significant air quality benefits and be directed toward solving a transportation-related air quality program. Although most states require a local 20 percent funding match, Idaho DOT has reduced the required match to 7.34 percent in order to increase the availability of funds throughout the state.

To date IDOT has committed CMAQ funds in support of two school bus retrofit projects. The projects, both sponsored by Idaho Department of Environmental Quality, provide for the installation of diesel oxidation catalysts and CCVs on school buses in Idaho Falls, Meridian and Idaho City. All three towns have publicly-owned school bus fleets and have committed to provide the local match. The first program, beginning in the fall of 2007 has a total cost of $500,000 and has been further supplemented with a $250,000 EPA Clean School Bus USA grant. The second program for FY09 has a total cost of $320,315. Idaho’s experience proves that cleaner air for children is a nationally recognized priority with benefits that can be realized in all communities regardless of their attainment status. More information about Idaho’s CMAQ program is available at: itd.idaho.gov/planning/reports/cmaq/cmaq.html.

North Carolina: A second state funding source
In 2004, the North Carolina Department of Transportation (NCDOT) announced changes in its CMAQ program guidelines, for the first time giving MPOs the authority to determine project priorities. North Carolina receives approximately $20 million in CMAQ funds annually. Roughly 20% of this amount is retained for statewide projects with the rest being divided among North Carolina’s 21 nonattainment counties. Both statewide and MPO programmed CMAQ dollars included diesel retrofit projects during North Carolina’s most recent approval of new CMAQ projects.
In Mecklenburg County, the Charlotte Area Transit System (CATS) had been the beneficiary of a locally funded pilot project which retrofitted three buses with diesel particulate filters and provided ULSD for their operation. The success of this pilot led CATS to pursue CMAQ funding through the local Mecklenburg-Union Metropolitan Planning Organization for additional retrofits. CATS’ application was strong due to its previous experience with the technology and the availability of funds from a local sales tax supporting public transportation for the 20% local match. As a result, the Mecklenburg Union MPO was able to recommend the program which was ultimately allocated $640,000 in FY06 CMAQ funds to install particulate filters on an additional 90 buses. 

With regards to statewide projects, the North Carolina DOT also awarded $1.6 million over three years to the North Carolina Solar Center at North Carolina State University to establish a three-year Clean Fuel Advanced Technology Program (CFATP). A 20% match was provided by the North Carolina Division of Air Quality and the State Energy Office, bringing the total program funds up to $2 million. This program complements the effort of individual MPOs by providing sub award grants dedicated to mobile related emissions reduction projects.

Under the CFATP, public and private entities in ozone or PM nonattainment and maintenance areas can apply for funding of on-road and off-road diesel retrofits, in addition to idle reduction technologies, truck stop electrification and the incremental cost of alternative fuel vehicles and their refueling infrastructure. First time technology users and/or applications are being targeted in an effort to encourage greater access to these

The Charlotte Area Transit System (CATS) benefited from a pilot project that retrofitted three buses with diesel particulate filters. The program’s success led CATS to pursue CMAQ funding to install filters on an additional 90 buses.
funds. With greater outreach and recognition for exemplary projects through a new, statewide Mobile Clean Air/Renewable Energy award as part of the program, North Carolina is proving that its state agencies are committed to working together to promote diesel emissions reduction projects.

Environmental Quality Incentives Program
Another federal, though more restricted source of funds can be acquired through the Department of Agriculture’s Environmental Quality Incentives Program (EQIP). EQIP was initiated in 1997 and reauthorized in the 2002 Farm Bill as a voluntary assistance program that seeks to promote agricultural production and environmental quality as compatible goals, optimize environmental benefits, and help farmers and ranchers meet Federal, state, tribal, and local environmental requirements.

Program priorities include a range of environmental challenges such as threats to soil, water and air. The program allows farmers and ranchers to obtain up to 75 percent of the cost of conservation efforts, with some exceptions allowing up to 90 percent. Funds are available in every state and are administered through the Natural Resources Conservation Service (NRCS). Applications are accepted on a rolling basis and can be obtained at local USDA Service Centers. More information about the program is available at: www.nrcs.usda.gov/programs/equip.

National priorities are used by NRCS to allocate available EQIP funds to State Conservationists. The State Conservationist, with advice from the State Technical Committee, decides how funds will be allocated and what practices will be offered. In California, the NRCS has established a diesel engine replacement program which will provide up to 50% of the actual cost of new diesel engines used for pumping irrigation water. $724,000 was obligated to the program in 2004, followed by $467,000 in 2005 and $486,000 in 2006. Counties eligible for the EQIP Diesel Engine Replacement Initiative are defined as severe or extreme non-attainment areas for ozone by EPA. While California is the only state with this specific diesel engine replacement program targeting air quality concerns, other states may be willing to consider similar projects. Additional information about California’s Diesel Engine Replacement program is available at www.ca.nrcs.usda.gov/programs/airquality.html.

Supplemental Environmental Projects
Supplemental Environmental Projects (SEPs) are frequently included in enforcement agreements reached between the federal government and businesses or individuals who have violated environmental laws. As part of a settlement, an alleged violator may voluntarily agree to undertake an environmentally beneficial project related to the violation in exchange for mitigation of the penalty to be paid. Diesel retrofits have been the focus of several Supplemental Environmental Projects in recent years. A summary of significant cases and settlements can be found on EPA’s website at: www.epa.gov/compliance/civil/seps/index.html.

Since the late 1990s, individual states started taking additional responsibility for improving their air quality problems through the creation of state-funded emissions reduction programs.

State Funding Sources
Since the late 1990s, individual states started taking additional responsibility for improving their air quality problems through the creation of state-funded emissions reduction programs. Although California and Texas have some of the oldest, largest and most established programs, many other states, including North Carolina, New Jersey, and Ohio have undertaken efforts to designate state funds to support emissions reductions through diesel retrofit. The following is a summary of the aforementioned state programs, however, continuously updated information on these and other
programs can be found at [www.dieselforum.org](http://www.dieselforum.org).

**California’s Carl Moyer Program**

The Carl Moyer Memorial Air Quality Standards Attainment Program is a voluntary incentive-based grant program to reduce emissions from trucks, off-road equipment, marine vessels, locomotives, and currently unregulated engines through diesel retrofits as defined under broad definition of retrofit (the five R’s). While the program was originally created in 1998 to reduce NOx emissions, projects that reduce PM and reactive organic gas emissions (ROG) are also eligible for funding.

The program is currently funded at approximately $140 million per year through state general revenues, vehicle registration fees, tire fees and other sources. The California Air Resources Board (ARB) establishes the program’s rules and guidelines, while the state’s regional air quality management districts (AQMDs) administer the program in their area and distribute the funds. While each regional AQMD can establish additional funding requirements to meet specific priorities, all are required to use a “cost-effectiveness formula” to rank projects. This formula includes PM, NOx, and ROG emissions reductions.

The majority of projects that have been successfully funded and implemented through the Carl Moyer program include the installation of emissions control retrofit devices on government-owned fleets of on-highway vehicles, including trucks and buses. Additional projects include repowering of agriculture pumps, construction equipment and marine vessels, as well as subsidizing the purchase of natural gas vehicles. During its first six years, the Moyer Program provided $154 million to reduce emissions from approximately 7,000 diesel engines. A total of 18 tons per day reduction of NOx was achieved during this period at an impressive cost-effectiveness of $3,000 per ton. 14

**The Texas Emissions Reduction Plan (TERP)**

The Texas Emissions Reduction Plan was created by the Texas Legislature in 2001 to support emissions reductions of diesel engines that are difficult or impossible to regulate through mandated programs. Approximately 70 percent of the funding for the program comes from vehicle title application fees (cars and trucks), while the remainder comes from surcharges on the sale of trucks and heavy duty diesel equipment in the state, as well as fees for truck inspections.

TERP was originally structured very similarly to California’s Carl Moyer program but has subsequently embraced a number of differences. Most importantly, TERP is solely focused on NOx emissions and does not consider PM or ROG in its cost effectiveness evaluations. Administratively, TERP funds are distributed at the state level by the Texas Council for Environmental Quality (TECQ) as opposed to California, where funds are disbursed by individual air districts. It also includes a small business program that targets heavy duty truck and equipment owners who own fewer than two heavy duty units.

**The TERP program has awarded more than $336 million in grants since its inception.**

The TERP program has awarded more than $336 million in grants, funding approximately 888 projects, for a projected reduction of more than 75,500 total tons of NOx since its inception. The program’s overall cost effectiveness level is projected to be less than $4,400 per ton. 15

To date, the largest portion of TERP funding has been awarded to off-road sector projects. By 2009, the TERP program is expected to provide more than $670 million in funds for diesel

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14. 2005 Carl Moyer Program Guidelines, pg. 3.
emissions reduction projects. The program is currently due to end in 2010, but is anticipated to be extended to 2013.

In 2005 the Texas Legislature added a school bus emissions reduction program to TERP but did not appropriate any funds for its implementation. This school bus program, if funded, would provide grants primarily for PM reduction projects. Additionally, in an effort to simplify and shorten the TERP Grant Program application process, legislation was passed in 2005 requiring the Texas Commission on Environmental Quality (TCEQ) to establish a standardized ongoing rebate program. The rebate program would allow applicants to receive a set amount of funding for pre-determined emissions reductions activities, similar to an appliance rebate program. More information on these and other aspects of the TERP program can be found at: www.tceq.state.tx.us/implementation/air/terp.

In September 2005, New Jersey enacted a new Diesel Risk Reduction Law, which sets the framework for a program to control particulate matter from diesel-powered mobile sources.

**North Carolina Mobile Source Emissions Reduction Grant Program**
North Carolina’s emissions reduction program, created in 1995, actually predates both the Carl Moyer and TERP programs, and was established to achieve reductions in on- and off-road mobile source related emissions primarily for ozone and carbon monoxide. Grants are awarded by the Department of Environment and Natural Resources and are funded through a gasoline tax equal to 1/64 of a cent for each gallon of gasoline sold.

During the first five years of the program, the vast majority of awards were for the conversion to or purchase of natural gas vehicles. In 2001 and 2002 the program was cancelled due to a statewide budget crisis. Since its restoration in 2003, annual distributions have averaged between $600,000 – $800,000 with most awards supporting the retrofitting of buses with Diesel Oxidation Catalysts as well as idle reduction or biodiesel related equipment. More information on the program is available at: www.ncair.org/motor/ms_grants.

**New Jersey Diesel Risk Reduction Program**
In September 2005, New Jersey enacted a new Diesel Risk Reduction Law, which sets the framework for a program to control particulate matter from diesel-powered mobile sources. According to this law, garbage trucks (publicly owned or used in a public contract), transit buses, and other publicly owned on-road and off-road vehicles will be required to install exhaust emissions control devices. In addition, all school buses (publicly and privately owned), will be required to install closed crankcase controls.

New Jersey municipalities are currently developing inventories and compliance plans that will likely be due in 2008. Retrofit technology and installation costs will be reimbursed by the State of New Jersey through the Corporate Business Tax as approved through a constitutional amendment in November 2005. Retrofit requirements will be phased in over 10 years based on the availability of funding. Annual funding levels are anticipated to be in the range of $14 million.

Other provisions of the law require the use of ULSD by all on- and off-road diesel vehicles by January 2007 and extend authority to local police to enforce existing idling regulations. New Jersey Department of Environmental Protection will provide further guidance on how to comply with the law, with more information to be made available at: www.nj.gov/dep/airworkgroups/diesel_workgroup.htm.

**Ohio**
In 2006 a Clean School Bus Fund was created in a state budget bill to provide funding for diesel retrofits in the state of Ohio. During its first year the program is expected to provide $1 million funded from polluter penalties collected from Ohio EPA’s enforcement actions. Funds can be used to retrofit public school district buses or those owned by commercial companies that are contracted to provide district transportation.
services. Grant awards can range from $5,000 to $100,000, but must be have a 5 percent local match. Priority is given to districts in non-attainment areas.

The first nine awards, totaling approximately $425,000, were announced in June 2006. Additional applications will be accepted in September 2006 and March 2007. More information on this program is available at: www.epa.state.oh.us/oeef/html/schoolbus.htm.

In addition to the school bus program, the Ohio General Assembly passed a bill in the fall of 2006, which was subsequently signed by the Governor, creating a statewide Diesel Emissions Reduction Program.

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In addition to the school bus program, the Ohio General Assembly passed a bill in the fall of 2006, which was subsequently signed by the Governor, creating a statewide Diesel Emissions Reduction Program. The program is consistent with section 793 of the Diesel Emissions Reduction Program in the Energy Policy Act of 2005 and includes two funds in the state treasury: the Diesel Emissions Grant Fund and the Diesel Emissions Reduction Revolving Loan Fund. Both funds consist of money appropriated to them by the General Assembly, grants obtained from the federal government under section 793, and other grants, gifts, or contributions. As of this writing, no state funds have been appropriated for the program, but in light of Ohio’s serious air quality challenges, there is likely to be pressure on appropriators to do so in the next legislative session.

State Infrastructure Banks
A State Infrastructure Bank (SIB) is a revolving fund that allows funds from federal surface transportation funding programs to be loaned to eligible federal-aid projects. The state then receives repayments over time that can be directed towards other transportation projects. A SIB, much like a private bank, can offer a range of loans and credit assistance enhancement products to public and private sponsors but may first need to be authorized by the State Legislature. SIBs require a 25 percent non-Federal match in cash to all Federal funding put in the account – although if a State has a sliding scale ratio, it may be applied. States also have the opportunity to contribute additional state or local funds beyond the required nonfederal match.

Thirty-two states currently have SIBs which are generally used to finance surface transportation projects such as highway and road construction. However, these funds are also eligible to be used to finance diesel retrofits or other emissions reduction programs if a state DOT chooses to commit funds to such a program. Oregon is one of the first states to look at this possibility, announcing in June 2006 that it would commit $3 million from its SIB and $2 million from the state Department of Energy to capitalize an initiative to help finance the purchase of EPA Smartway Upgrade Kits for trucks traveling along the I-5 corridor. Monthly fuel savings from the kit can exceed monthly loan payments, thereby increasing profits from the first day companies acquire the kits. More information on this program and Cascade Sierra Solutions, a non-profit which is distributing the kits is available at: www.cascadesierrasolutions.org. For more information on SIBs, please refer to the FHWA website at: www.fhwa.dot.gov/innovativefinance/sib.htm.

Contracting Requirements
Another alternative used by some state and municipal governments to promote diesel retrofits has been the adoption of contracting requirements for equipment used on public works projects. With Massachusetts’ Big Dig project and Connecticut’s Q-Bridge project as visible examples, more and more government entities are considering such contract provisions. In New York, retrofit requirements were included in the

World Trade Center recovery and rebuilding project and are now required in all New York City construction projects as a result of New York City’s Local Law 77. This commitment was expanded to the state level in August 2006 when the Governor signed into law legislation which requires the use of ULSD and best available retrofit technology in all state-owned heavy duty diesel vehicles or heavy duty diesel vehicles under contract with the state (with exceptions for agricultural equipment, emergency vehicles and other select cases). 18

While such measures have received strong support from environmental groups, they pose challenges for the construction community since they give a competitive advantage to firms that have already retrofitted their equipment and larger firms, which can better afford capital equipment investments. One way to ameliorate this potential competitive disadvantage is to provide a contract allowance that partially or fully offsets the cost of the emissions reduction investment as part of the final contract. Examples of these allowances have been found in Georgia and Texas, with other localities just beginning to adopt such measures. The Associated General Contractors of America (AGC) has been particularly interested in the impact of such provisions on their members. More information impact of contract requirements on the construction industry is available at the AGC website at: www.agc.com.

**Tax Incentives**

Another possible, though infrequently used, incentive to promote investment in diesel emissions reduction equipment has been the creation of state tax incentives. They can take the form of exemptions, deductions or credits. In 2000, the state of Oregon created a tax credit to help compensate for the cost of installing pollution control devices on EPA’s verified technology list. The provision provides a maximum 35 percent credit against Oregon income taxes (rates may be less for equipment not used exclusively in Oregon). The credit is intended to cover expenditures for the cost of the retrofit, including the equipment and installation costs. In the state of Georgia, income tax credits can be taken for up to 10 percent of the cost of emissions control technology upgrades.

Tax incentives are not contingent upon funding levels; therefore firms do not face the same degree of competition as they do when applying for limited amounts of grant funding. Nevertheless, they are often insufficient to meet the incremental cost of installing emissions control technology and can be of limited value to companies that make little profit and thus have little tax liability.

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18 The legislative text for this law is available at http://assembly.state.ny.us/leg/?bn=S08185&sh=t
VI. EXPERIENCE IN THE FIELD: SAMPLE RETROFIT PROJECTS

Thanks to continuing technological advances, and the verification of these technologies, the number of retrofit projects undertaken in the United States has grown significantly over the last 5 years. EPA launched its National Clean Diesel Campaign with the goal of retrofitting 11 million engines. While a large percentage of early projects were limited to a very few technologies and sectors, the case history has increased significantly. This has led to greater recognition of the role of diesel retrofit in air quality improvements and greater efforts by legislators and administrators to increase funding for this purpose.

What follows is a series of brief project summaries of successful diesel retrofit projects. They were chosen to provide a broad overview of the type of projects being undertaken and the challenges encountered during implementation.

Freight Trucks: ARCO/BP & Ralph’s Grocery

ARCO, a BP company, completed a one-year EC-Diesel® Technology Validation Program in 2001 to analyze the performance of heavy-duty diesel vehicles fueled with ARCO’s ultra-low sulfur Emissions Control Diesel (ECD® or EC-Diesel®) and retrofitted with passively regenerating particulate filters. The purpose of the program was to analyze emissions reductions from retrofitted vehicles using EC-Diesel® while also studying any effects on fuel economy and maintenance requirements. A wide variety of diesel fleets were included in the program; however, this case will highlight the experience with large freight trucks due to their similarities with many other trucks across the country and ARCO’s extensive testing of this subcategory.

Figure 6.1 Freight Truck Average Emissions (City-Suburban Heavy Vehicle Route Cycle)

Source: Society of Automotive Engineers
The trucks were divided into four groups as outlined in Figure 6.1. The filters and assemblies from two different manufacturers were custom-designed for the fleet, taking into account the engine model, power rating and duty cycle. Excluding installation labor, the cost of each retrofit device was about $6,000 – and would have been substantially lower if a large number of the units had been ordered. The average installation time was about three hours for one manufacturer’s filters, and about six hours for the other one. In addition to replacing the original muffler with the filter units, insulation wrap was added to a portion of the exhaust pipe to reduce heat rejection, and special consideration was given to mounting bracket design and clearance issues in order to accommodate the heavier and somewhat larger filter units.

After the retrofit, the trucks returned to normal operation for a one-year period. During this time, ARCO conducted two rounds of emissions testing, which not only enabled comparisons between testing groups, but also allowed for an analysis of each group’s emissions performance over time. The first round of emissions testing occurred just a few weeks after the trucks had been retrofitted. The second round occurred after the one-year demonstration period. To better account for vehicle-to-vehicle variability, all 20 of the Ralph’s Grocery demonstration vehicles were emissions tested.

Over the entire 12-month period – during which each truck accumulated over 100,000 miles – the filter units experienced no failures, and no truck required roadside assistance related in any way to the ECD® fuel or particulate filters.

From a fuel economy perspective, the data showed a 2 percent to 3 percent decrease in miles per gallon for all three test groups fueled with ECD®, attributable to the somewhat lower energy content of this fuel. There was essentially no difference in fuel economy between the retrofitted and non-retrofitted trucks fueled with ECD®, demonstrating that despite causing some increased back-pressure, the particulate filters caused no measurable fuel economy penalty.

With regard to emissions, results showed that neither device experienced significant deterioration after 100,000 miles. Compared to the control vehicles fueled with CARB Diesel, the retrofitted vehicles fueled with ECD® reduced PM emissions by 98 percent to 99 percent in both rounds, reduced CO emissions by 96 percent to 98 percent in the first round and 62 percent to 89 percent in the second round, and practically eliminated HC emissions to undetectable levels (shown as “0” on the HC graph in Figure 6.1) during both rounds of testing. Consistent with NYCT’s testing of the filters, ARCO found that NOx emissions were basically unaffected by the ULSD/retrofit. Although there was a small decrease in NOx emissions between CARB Diesel and the ECD®-fueled test groups in the first round of emissions testing, this decrease was not statistically significant.

Overall, ARCO’s testing showed that large tractor/trailers retrofitted with either manufacturer’s catalytic particulate filter and fueled with ECD® ultra-low sulfur diesel fuel will achieve dramatic reductions in PM, HC and CO emissions. ARCO’s second generation ECD®-1 has been commercially available throughout California at ARCO retail sites across the state since 2002. (For additional information, see the DTF website at: www.dieselforum.org/retrofit/tech_casesudy.html).

**Construction Sector Case Study:**

**Connecticut “Q-Bridge” Retrofit Project**

Dubbed the “Q-Bridge” Project for the replacement of the Pearl Harbor Memorial Bridge over Connecticut’s Quinnipiac River near New Haven, the I-95 New Haven Harbor Crossing Corridor Improvement Program is in reality, a multi-faceted construction project that requires road widening, bridge replacement and exchange rebuilding near areas that are in non-attainment for NOx and PM. Based on the success of the Big Dig, the retrofit requirements for the Q-Bridge projects were incorporated as part of the
The Q-Bridge project started in 2002 and will continue for approximately 12 years, with completion slated for 2014. To date, over 105 pieces of off-road construction equipment used over the 7.2-mile site have been retrofitted with DOCs, with no reported operational or warranty problems.

Initial contract bid specification. In this “contract-based” type of project, the retrofit component is included in the overall bid price provided by all prospective contractors in order to create a “level playing field” and eliminate discrimination against any specific contractor. Contractors such as small-, minority-, or women-owned businesses were provided diesel emissions reduction technical and administrative assistance to facilitate their participation in the bidding process.

Initially, the project participants wanted to deploy a combination of emissions control devices, such as DPFs and DOCs, in conjunction with cleaner fuels. As the diesel emissions component evolved, it became clear that cost and logistical issues favored use of DOCs or clean fuels, and in the end, the contract specification was written to reflect this sentiment.

The Q-Bridge project started in 2002 and will continue for approximately 12 years, with completion slated for 2014. To date, over 105 pieces of off-road construction equipment used over the 7.2-mile site have been retrofitted with DOCs, with no reported operational or warranty problems. Similarly, a robust enforcement program, administered by CT DOT for the off-road equipment and CT DMV for an on-highway smoke opacity testing program, has ensured adherence to contract requirements. Estimates for reduced emissions during the I-95 NHHC Corridor Improvement Program are 20 tons/year for carbon monoxide and 2 tons/year for fine particulate matter (with clean fuels or oxidation catalysts) and 8 tons/year for hydrocarbons (with oxidation catalysts only). While the Q-Bridge project will not benefit from more effective DPF technologies, the successes with widespread, quantifiable DOC retrofits for a long-term, large-scale construction project is noteworthy for similar future projects.

School Bus Sector Case Study: New Haven School Bus Retrofit Program

The State of Connecticut, along with the Connecticut Department of Environmental Protection (CT DEP), has long been concerned about the effect of diesel emissions from school buses on children. In Connecticut, 387,000 children ride more than 6,000 school buses statewide each day, with nearly all the buses operating on diesel fuel. Studies show Connecticut children spend between 20 minutes to several hours each day traveling on these predominantly diesel-powered buses, leading CT DEP to embark on a campaign to ultimately retrofit all of Connecticut’s school buses. A significant landmark of the plan was the completion of the Norwich, Connecticut School Bus Retrofit Project in 2004. This was followed by the New Haven School Bus Project, which took advantage of local SEP funding that was specifically earmarked to pursue school bus retrofits in the City of New Haven.

Initially, the project participants were eager to install passive diesel particulate filters (DPFs) because of their high PM-removal performance. Early in the control technology selection process however, it was decided to switch to a simultaneous deployment of diesel oxidation catalysts (DOCs) and closed crankcase ventilations (CCVs) due to the lack of sustainable high temperatures for PM regeneration, the desire to focus specifically on emissions reductions in the bus, and the higher cost of DPFs, which would have limited the number of buses to be retrofitted. By equipping the entire fleet with CCVs and DOCs, all the buses and their pupils benefit from reduced emissions. Furthermore, the amount of
PM reduced with the combination of CCVs and DOCs was the same as if DPFs had been installed on one-half the buses (approximately 1/5 ton of PM emissions per year).

Installation of the control technologies began in 2004 and was completed in 2006. Altogether 181 buses were retrofitted with CCVs and DOCs and have performed flawlessly, providing critical emissions reductions for both the community at large and for the students riding the buses. The retrofit program has been augmented with a strictly enforced anti-idling program, as well as extensive community outreach and education highlighting the success of the program. Two other school bus retrofit programs in the Connecticut cities of Hartford and Bridgeport are planned, using $1 million total SEP funding from another source.

**Ports Sector Case Study: Push Boat Engine Repowers in Texas**

The eight counties around Houston, Texas are affected by significant air quality problems, most notably those exceeding federal ozone standards. This area is also a major shipping hub where many push boats service the ports and travel through the inland waterway. Most of the engines propelling these vessels and providing auxiliary power are old since the capital cost and installation complexities of newer, cleaner engines often prevent fleet owners from upgrading their engines.

In order to take advantage of Texas’ TERP program, Megafleet hired a consultant in 1995 to interpret the rules associated with the TERP grant program and help prepare the grant application. The consultant also analyzed the emissions levels of their propulsion and auxiliary engines and assisted with the identification of new, cleaner engines eligible for funding under the TERP grant program. While this may seem like a simple task, technical requirements and program limitations had to be assessed and quantified to determine the feasibility and cost of installing new, cleaner engines. In the end, this assistance proved valuable in helping Megafleet win an award for almost $1 million to purchase and install several propulsion and auxiliary engines on their fleet of push boats.

The propulsion engines approved for funding under this program range from 300 horsepower to 500 horsepower while the new auxiliary engines are at 61 horsepower. Over a 10-year lifespan, both the propulsion and auxiliary repowered engines are projected to reduce NOx emissions by 385 tons and PM by a significant amount, although the TERP program does not quantify the PM reductions. While Megafleet will have other costs associated with its engine repowering, the benefits of the new engines, along with the TERP funding, exceed these costs, making these repowers both economically valuable to Megafleet and environmentally valuable to the citizens of Texas.
VII. CONCLUSION

C lean diesel is here. Thanks to billions of dollars of investment to improve diesel fuel and equipment, many of yesterday’s diesel engines can now be replaced or upgraded to make them significantly cleaner. All Americans will reap the returns from this investment as our nation’s air quality improves. Diesel engines are fundamental to the U.S. economy and now, as a result of clean diesel technology, they are an equally important contributor to improved air quality.

Diesel retrofit is highly cost-effective, but one size does not fit all. As noted earlier, several studies have proven that diesel retrofits are extremely cost effective. Some equipment may not be candidates for emissions control devices, but could potentially have emissions reduced through repowering with a newer, cleaner diesel engine. In other cases, engines may be only a few years old and already have some emissions control technology, but can have emissions reduced through selective use of ULSD. Each retrofit case is unique in terms of its business and its technological environment, but in most cases, a retrofit, broadly defined as one of the 5 R’s, can reduce diesel emissions for virtually all diesel vehicles and equipment purchased before 2007.

Financial incentives can accelerate these benefits. Without efforts to retrofit currently operating diesel vehicles and equipment, diesel’s durability, a traditional strength, could prolong the full realization of clean diesel technology’s emissions benefits. Retrofit technology can help counties come into attainment for PM and ozone standards and expedite infrastructure improvements through conformity determinations, however public support is necessary if these improvements are to be attained and the air quality benefits are to be realized. Over the last two years, federal funding in support of retrofit projects has been increased, but much more can be done. As awareness about the cost effectiveness of diesel retrofits grows, it is hoped that this report and others will encourage legislators, planners and administrators to see retrofit programs as a secure investment with multiple dividends as they’re faced with growing budgetary constraints.

Well designed state retrofit programs will have multiple beneficiaries. States can enhance federal retrofit programs with additional funds to promote projects which maximize cost effectiveness and address regional priorities. One way of doing this is to dedicate a percentage of apportioned CMAQ funds for diesel retrofit projects. Alternatively, states can create their own program funded from state and local sources. As this paper has shown, several states have already taken the lead and evidence has already proven these programs’ success. Whether it is CMAQ funds, gas taxes, corporate business taxes, vehicle registration fees or some other previously untapped source, states have proven that a small investment of funds can bring substantial emissions reduction payoffs.

As state officials consider new program options, the Diesel Technology Forum believes the most successful programs will:

- Be voluntary and incentive based;
- Embrace a broad definition of retrofit which enhances user acceptance;
- Give priority for verified technology (EPA or CARB certified) and overall cost-effectiveness criteria, while providing some incentives for new, innovative technologies; and
- Provide sustainable, long-term funding that does not fall on the users who undertake retrofit projects.

Voluntary emissions reduction programs at both the federal and state level have been extremely successful and should continue to be administered in order to minimize administrative burden, until the cleanest possible diesel technology is embraced in all major sectors of the economy.