I. INTRODUCTION

A. Purpose of and Topics Covered in the Guidance Document

The purpose of the WRAP Offroad Guidance Document is to:

1. Provide guidance to WRAP members and stakeholders on the major elements needed to develop a well-structured retrofit program and program options for offroad engines.

2. Introduce a basic description of retrofit technologies and identify the factors to consider in evaluating and selecting retrofit strategies.

3. Provide insights based on current program experience involving the application of retrofit technologies on offroad engines.

Volume 1 addresses the elements of structuring a retrofit program and is designed to assist those WRAP members and others involved in air quality program development. Volume 2 contains a detailed description of retrofit technologies and experience. That volume is designed to provide background information on retrofit strategies for air quality professionals and provides product users with a basic introduction on retrofit technologies, as well as the current knowledge base on their use.

The Guidance Document is posted on the WRAP Mobile Sources Forum website at www.wrapair.org/forums/msf/index.html, then click on the link to the Offroad Retrofit Guidance Document. Periodic updates will be provided as new information becomes available. Topics to be updated are expected to be mostly related to Volume 2 and the appendices. Updated sections will contain the date of the most recent revisions.

B. Overview of WRAP Offroad Retrofit Program Elements

The Western Regional Air Partnership (WRAP) is a voluntary organization of western states, tribes, federal agencies, and private sector partners. It was formed in 1997 as the successor to the Grand Canyon Visibility Transport Commission that made over 70 recommendations in June 1996 for improving visibility in 16 national parks and wilderness areas on the Colorado Plateau. The WRAP promotes, supports, and monitors the implementation of those recommendations throughout the West. The WRAP is also implementing regional planning processes to improve visibility in all Western Class I areas by providing the technical and policy tools needed by the states and tribes to implement the federal regional haze rule.

The WRAP Mobile Sources Forum (MSF) is responsible for investigating and recommending mobile source emission control measures to its member states and tribes, particularly in the context of regional haze. Because of the growing portion of emissions due to offroad sources and the slow replacement rates of diesel engines, the MSF has chosen to focus on emissions from existing offroad engines and vehicles. The objective of the Offroad Retrofit Program is to promote emission reductions from existing offroad engines by providing WRAP members and equipment owners with a wide variety of professional services, including: 1) written guidance, 2) technical support, 3) outreach services, 4) identification of incentives, public policy options, and examples of successful efforts and reduction opportunities. The term "retrofit" is designed to encompass the full range of available strategies to reduce emissions from existing offroad diesel engines including technology-, fuel-, and operations-based approaches.

C. Offroad Sectors and Retrofit Application Opportunities

DIESEL OFFROAD ENGINE APPLICATIONS

Offroad engines are a significant and growing source of diesel emissions. Approximately 6,000,000 diesel offroad engines are in use today in the U.S. A wide variety of offroad engines are used in numerous applications as summarized in Table 1-1.

Table 1-1, List of Offroad Diesel-Powered Equipment Types

Recreational Equipment Specialty Vehicles (e.g., snow groomers, utility and personnel carriers) **Construction Equipment** Pavers Rollers Scrapers Paving Equipment Surfacing Equipment Trenchers Bore/Drill Rigs Excavators Cranes Graders Off-highway Trucks Crushing/Pro. Equipment Rubber Tire Loaders Rubber Tire Dozers Tractors/Loaders/backhoes Tampers/Rammers Crawler Tractors Skid Steer Loaders Dumpers/Tenders Other Construct. Equip. **Industrial/Commercial Equipment** Aerial Lifts Forklifts Sweepers/Scrubbers Terminal Tractors Generators Compressors Airport Ground Support Equipment	**Agricultural Equipment** 2-Wheel Tractors 4-Wheel Tractors Agricultural Tractors Combines Balers Agricultural Mowers Swathers (crop cutters) Hydro Power Units Irrigation Sets **Commercial Equipment** Generator Sets (Primary Power) **Logging Equipment** Fellers/Bunchers/Skidders **Mining/Oil Field Equipment** Airport Support Equipment Surface Mining Equipment Underground Mining Equipment Oil Field Equipment **Marine Equipment and Vessels** Recreational Marine Engines Coastal Marine Vessels Ocean-going Vessels Marine Port Equipment **Locomotives & Railway Maintenance Equipment** Passenger/Freight Locomotives Switcher Locomotives Diesel Railway Maintenance Equipment

Offroad engines range from under 50 hp (e.g., lawn and garden equipment, portable generators) to over 750 hp (e.g., large earthmoving equipment) and to as large as 67,000 hp for large oceangoing container ships. Some applications have very transient operation while others operate largely in a steady state mode (e.g., agriculture irrigation pumps, locomotives, marine vessels). Also, some applications operate at high-load while others operate at low load or spend substantial time at idle (e.g. switcher locomotives).

RETROFIT STRATEGIES

A large and growing list of strategies are available for reducing emissions from existing offroad diesel engines. These strategies addressed in this Guidance Document include technology-, fuel-, and operations-based approaches and are listed in Table 1-2 below.

Table 1-2, Strategies for Reducing Emissions from Offroad Diesel Engines

Technology-Based Strategies	**Fuel-Based Strategies**
Diesel Oxidation Catalyst (DOC)	Ultra-low Sulfur Diesel (ULSD) Fuel
Diesel Particulate Filter (DPF)	Biodiesel
Lean NO_x Catalyst (LNC)	Diesel Fuel Emulsions
Selective Catalytic Reduction (SCR)	Diesel Fuel Additives
Selective Non-catalytic Reduction (SNCR)	
Low Pressure Exhaust Gas Recirculation (EGR)	**Operations-Based Strategies**
Closed Crankcase Ventilation (CCV) systems	Idle Reduction
Engine Electronic Control Module (ECM) Reprogram	Engine Repower
	Early Retirement of Equipment
	Engine Rebuild
	Engine Maintenance and Repair

Table 1-3 contains a summary of available information on emission reduction potential, costs, breadth of application, and experience for both on-road and offroad retrofit strategies described in Table 1-2.

FACTORS AFFECTING APPLICATION OF RETROFIT STRATEGIES TO OFFROAD ENGINES

Overview

A number of technology-based, fuel-based and operation-based strategies are being applied to existing diesel offroad engines to reduce diesel exhaust emissions. For example, over 250,000 DOCs and 20,000 DPFs worldwide have been equipped on offroad engines to reduce particulate matter (PM), unburned hydrocarbon (HC), and carbon monoxide (CO) emissions. Also, technologies like SCR and LNC/DPF systems have been retrofitted on offroad engines for control of oxides of nitrogen (NO_x). ULSD, biodiesel, diesel emulsions and alternative fuels have been used to fuel offroad engines to reduce emissions. Finally, operational changes like reduced idling policies and auxiliary power units have employed.

Table 1-3, Summary of Retrofit Technologies for Reducing Diesel Emissions

Emission Control Technology	Percent Emission Reduction				Product Cost (175-300 hp)	Other Cost Items	Breadth of Application	Estimated Number of Retrofits	EPA or CARB Verified
	PM	NO_X	HC	CO					
[1]DPF	Up to 90+	--	60-90	60-90	$5500-$8000	4-8 hrs. for install. DPF cleaning.	Application-specific	>200,000 (Worldwide)	Yes
[2]DOC	20-50	--	30-90	30-90	<$1000-$2000+	1-4 hrs. for Install.	Nearly universal	>350,000 (Worldwide)	Yes
[3]LNC/DPF	Up to 90+	25	60-90	60-90	$15,000+	Up to 16 hrs. for install. Slight FE loss.	Application-specific	>3,000 (Worldwide)	Yes
[4]EGR/DPF	Up to 90+	Up to 50	60-90	60-90	$15,000+	Up to 16 hrs. for install. DPF cleaning.	Application-specific	>3,000 (Worldwide)	Yes
[5]SCR	30-50	Up to 90+	50-90	50-90	$15,000+	Up to 8 hrs for install. Urea supply equiv. to up to 4% FE penalty.	Application-specific	>2,000 (Worldwide)	Yes
[6]CCV Systems	10-25	--	30-40	30-35	$450-$600	Replace filter 25,000 miles or annually. Filter cost $20-$50.	Nearly universal	>3,000 (U.S.)	Yes
[7]ECM Reprogram	--	Up to 25	--	--	No cost, unless a DOC or DPF is included as a system.		Application-specific	>50,000 (U.S.)	
[8]Emulsions	16-60	10-25	[8]V	[8]V	[11]$0.15-$0.25/gal	--	Nearly universal	Use in >[12]200 vehicles (U.S.)	Yes
[9]Additives	--	Up to 5	--	--	[11]$0.05-$0.15/gal	--	Nearly universal	Use in >[12]2,000 vehicles (U.S.)	Some In Process
[10]Biodiesel	[10]V	[10]V	[10]V	[10]V	[10]V	--	Nearly universal	>1.2 Million gal/yr (U.S.)	Yes
ULSD	3-18	--	--	--	[11]$0.05-$0.30/gal	--	Nearly universal	>[13]137 million gal/yr (U.S.)	Yes

Notes:

1) Information based on a catalyst-based, passive DPF. Other DPF technologies are available such a DPF+FBC systems and a variety of active systems. The hardware and other costs will vary among DPF systems.
2) Information based on performance of DOC alone. DOC technology can be combined with FBC, SCR, and LNC technology as well.
3) Information based on performance of LNC/DPF system because this is the system that is verified.
4) Information based on performance of an EGR/DPF system because the low pressure EGR technology verified for retrofit applications requires the use of a DPF to function effectively.
5) Information based on performance of SCR technology alone. SCR technology can be combined with SNCR, DOC, and DPF technology.
6) Information based on closed crankcase ventilation system technology alone. However, closed crankcase ventilation emission control technology has only been verified as a combined system with DOC technology.
7) Information from CARB.
8) HC and CO results vary (V) and yield emission reductions or increases, depending on several engine and operating factors.
9) Not including FBC additives.
10) Emission reductions and cost vary (V) with concentration of biodiesel in diesel fuel blend.
11) Typical range of cost differential compared to No. 2 conventional on-road low sulfur diesel fuel.
12) U.S. DOE-EIA data for ULSD production in 2004.

Challenges to Applying Retrofit Strategies to Offroad Engines

While retrofit strategies have been successfully applied to offroad engines, the offroad diesel engine sector presents certain challenges for retrofit strategies (particularly technology-based) beyond those experienced in retrofitting on-road vehicles. The additional challenges include:

- Since emissions standards were first applied to on-road vehicles and subsequently adopted for offroad engines, offroad diesel engines have less sophisticated engine/emission control systems than comparable model year on-road engines.

- The number of engine models, operating modes, and manufacturers, as well as the number of equipment types, models, applications, and manufacturers is far greater than the numbers found in the on-road sector and virtually all will require an engineered emission solution.

- The horsepower rating of offroad engines covers a much broader range (less than 25 hp to over 750 horsepower) than the range for on-road vehicles (typically175 hp to 450 hp).

- A limited number of verified retrofit products are available for offroad applications.

- The sulfur level for diesel fuel used in land-based offroad engines (up to 3,000 ppm sulfur) and marine engines (up to 20,000 ppm sulfur; for example, bunker fuels in Europe currently have an average sulfur level of 27,000 ppm) is much higher than the sulfur level in conventional on-road diesel fuel (less than 500 ppm sulfur).

- Offroad equipment frequently is used in rigorous operating environments, in enclosed areas, or in areas where risk of explosions exist.

Vast Number of Different Engine, Equipment, Application and Manufacturers - Given the large number of different engines, equipment, applications and manufacturers, the challenge of tailoring a strategy, particularly technology retrofits, is greatly increased as compared to on-road applications. This is because each application may require a slightly different design adding to the resources needed to identify the appropriate approach, as well as adding to the costs of technology.

Broad Horsepower Range – Applying retrofit technologies from on-road applications to offroad applications is somewhat easier where the on-road and offroad engines have comparable horsepower ratings. However, offroad engines are often much smaller (e.g. less than 175 hp) or much larger (over 450 hp). While retrofit technology has been successfully applied to both very small engines (e.g., forklifts) and very large equipment (mining equipment, locomotives and marine vessels), extra care must be taken in the design and application of these technologies.

Variations in Hours Operated - Some offroad equipment is operated for only a few hours annually. For example, some construction equipment is used for less than 350 hours per year.

Limited Verified Technologies – A limited number of technologies, (e.g., SCR, emulsions, DOC/emulsions, DOC/CCVs, and DPFs), have been verified for a limited number of offroad engine models. This fact makes it more challenging in selecting retrofit technologies for offroad applications because only a few have been evaluated and approved. Also, little or no opportunity exists for gaining State Implementation Plan (SIP) credits if an unverified technology is used. Increasing the number of different verified retrofit products and the applications for products in the offroad sector is absolutely essential to making significant progress in reducing emissions from existing offroad engines.

High Sulfur Level of Offroad Diesel Fuel – May limit or preclude the use of certain retrofit technologies such as DPFs, LNCs, and EGR/DPFs.

Challenging Operating Environments – Offroad equipment often operate in rigorous environments where retrofit technologies can be exposed to high vibration, dust and/or moisture. Where proper attention to design has been taken, retrofit technologies have been successfully applied to engines operating in such environments. Similarly, where engines operate in enclosed areas or in areas with a risk of explosions, care must be taken in the design and application of retrofit technologies. But again, where the proper design and technology selection is made, retrofit technologies have achieved significant emission reductions without jeopardizing worker safety.

Factors Facilitating Application of Retrofit Strategies to Offroad Engines

Applying retrofit strategies to offroad diesel engines does offer several advantages not always present with on-road applications. First, many offroad applications operate for defined time periods (shifts) with regularly scheduled down times. This fact, for example, allows the utilization of DPFs that are cleaned by external heating equipment at the end of a daily shift. DPFs, using external filter cleaning, have a boarder application than catalyst-DPFs, which require ULSD and need minimum exhaust temperatures to operate. Secondly, offroad equipment often has an on-site or dedicated fueling structure that creates the opportunity to use ULSD, biodiesel, and diesel emulsions. Finally, many offroad engine applications (e.g., locomotives, marine vessel) operate primarily in a steady-state mode that facilitates the use of technologies such as SCR, which typically achieve greater NO_x reduction during steady-state engine operation.

SECTOR SPECIFIC FACTORS TO CONSIDER WHEN SELECTING A RETROFIT STRATEGY

Each offroad application is unique in terms of horsepower ranges, operating cycles, affected industries, and the flexibility to participate in a program without disrupting commercial operations. These and other factors are discussed below for each of the major offroad sectors.

Construction Equipment

Overview -- Construction equipment is used for residential, commercial, and industrial building construction and for transportation infrastructure (e.g. roads, highways, and bridges) construction and maintenance. The construction sector has the broadest range of equipment types and uses, as well as engines that represent a considerable horsepower range (less than 25 hp to over 750 hp). A significant sector of construction equipment has a long operational life, in some cases up to 25 to 30 years or more. Over 90% of the new construction equipment purchased is privately owned. Construction equipment is owned, leased or rented.

Considerable experience exists with retrofit strategy application in the construction sector. DPF, flow-through filters, SCR, DOCs, biodiesel, ULSD, and fuel emulsions have been used in this sector. For example, over 10,000 pieces of construction equipment worldwide have been retrofitted with DPFs.

Several successful mandatory programs have been implemented involving construction equipment including: 1) the Switzerland construction retrofit program, 2) the I-95 New Haven Crossing Corridor Improvement Project (Q Bridge), 3) the Massachusetts Central Artery/Tunnel Project (the Big Dig), and New York City's Local Law #77. A number of voluntary programs in the U.S. are focusing on construction equipment in Texas, New York, Massachusetts and elsewhere.

Funding for retrofit programs involving construction equipment have come from state programs like the Texas Emissions Reduction Program (TERP) and the Carl Moyer Program in California, as well as, from the U.S. EPA. The construction industry at the national and state levels has been actively engaged in helping to develop and promote effective programs to reduce emissions from existing diesel-powered construction equipment.

Sector Specific Considerations in Developing Retrofit Strategies for Construction Equipment – A number of considerations should be kept in mind when evaluating and developing a retrofit strategy for construction equipment. These considerations include:

- *Different engine, equipment, and operating cycles* – In developing a retrofit strategy for a construction project, the particular inventory of equipment and operating cycles must be considered.

- *Diesel Fuel Sulfur Levels* – The level of sulfur in the available fuel is a factor in selecting the appropriate strategies. Since construction equipment is typically fueled from a central fueling facility, the possibility of using ULSD, biodiesel, emulsions and alternative fuels exists.

- *Rigorous Operating Environment* – The strategy selected must be capable of withstanding the rigorous operating environment of construction equipment.

- *Movement of Equipment from Site to Site* – Construction equipment sometimes is moved from site to site at fairly regular intervals. This fact must be considered for fuel-based strategies or for technologies that require ULSD (fuel availability at all sites). Also, if public funds are involved in underwriting the cost of technology to improve air quality around a particular site, limitations for removing that equipment from the site should be established.

- *What Happens to Retrofit Equipment Once the Project is Completed?* – A related issue is that once the construction project is completed, does the retrofit technology remain on the equipment or is it removed? If it is removed, provisions for removal, reusing or retiring the technology must be made.

- *Operating Shifts* – Since construction equipment is often operated in shifts, an opportunity exists to utilize technology that needs maintenance on a regular basis. The best example is a DPF that uses external heat sources to clean the filter and may require daily cleaning. This maintenance can be performed between shifts and thus avoid any downtime.

Industrial/Commercial Equipment

Overview -- The primary use of industrial and commercial equipment is materials handling (e.g. warehouse forklifts or airport ground support equipment). This equipment is typically powered by engines less than 175 hp, but in some cases larger engines are used. This category also includes utility vehicles like sweepers/scrubbers, as well as, generators and compressors. Generators range from less than 50 hp to over 2,900 hp.

Technology- and fuel-based retrofit strategies have been applied extensively to industrial and commercial equipment. For example, over 40,000 DPFs and over 200,000 DOCs have been installed on materials handling equipment (primarily forklifts). Disposable filters have also been used in this application. Alternative fuels, such as propane, have been use to fuel material handling and other commercial equipment. Pilot programs are underway at several airports evaluating a switch to CNG-powered airport ground support equipment (GSE) and retrofitting equipment with emission control technology on GSE. The U.S. Federal Aviation Administration has funding available to help pay for the cost of GSE retrofits.

Sector Specific Considerations in Developing Retrofit Strategies for Industrial and Commercial Equipment -- Some of the key factors to consider when evaluating a retrofit strategy for this section include:

- *Proven Retrofit Strategies Available* – This sector has substantial experience with a variety of retrofit strategies, including DOCs, DPFs and alternative fuels.

- *Different Engine, Equipment, and Operating Cycles* – While the range of equipment types is narrower than the construction sector, the type of equipment and use must be considered, nonetheless, in developing a retrofit strategy for a particular application,.

- *Enclosed Operating Environments* - Some industrial/commercial equipment is operated indoors. Special care must be taken to insure that workers and others are not exposed to increased levels of regulated or unregulated pollutants from the use of emission control strategies (e.g., potential increase in NO_2 emissions from catalyst-based DPFs or DOCs).

- *Diesel Fuel Sulfur Levels* – The level of sulfur in the available fuel is a factor in selecting the appropriate strategies. Since industrial/commercial equipment is typically fueled from a central fueling facility, the possibility of using ULSD, biodiesel, emulsions and alternative fuels exists.

- *Movement of Equipment* – Equipment used in commercial and industrial applications generally do not move from site to site as frequently as construction equipment. Nevertheless, the possibility of equipment being moved needs to be considered.

- *Operating Shifts* – Since commercial and industrial equipment are often operated in shifts, an opportunity exists to utilize technologies that need maintenance on a regular basis. This maintenance can be performed between shifts and thus avoid any downtime.

Agricultural Equipment

Overview -- Most agriculture equipment falls in the 100 to 200 hp range (e.g., tractors), but some equipment is larger. Irrigation pumps fall into two general categories. The first category is mobile pumps (in the range of 25 hp), which are portable and are moved from site to site (staying in one place an average of six months). Most are built with spark ignition engines, but some use compression ignition (diesel) engines. The second category is stationary pumps, which are maintained permanently at one site or moved infrequently. These pumps use engines that are typically in the 50 to 2,000 hp range. In the agriculture sector, the greatest retrofit activity has been with irrigation pumps. For example, the Carl Moyer program in California has funded engine repowers and/or engine replacements with new alternative fuels engines on irrigation pumps. Retrofit technologies such as DOCs have also been applied to pumps and generators used in the agriculture sector.

Sector Specific Considerations in Developing Retrofit Strategies for Agricultural Equipment -- Applying retrofit strategies involves consideration of several factors including:

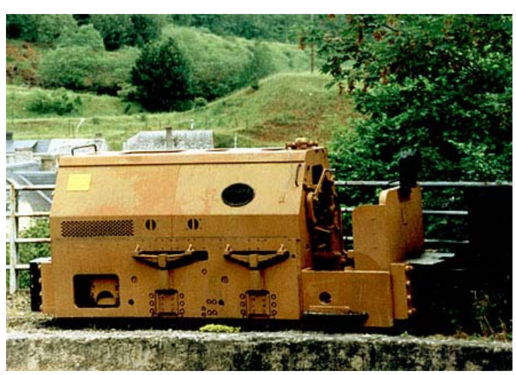
- *Size of the Farm* – The size and ownership of farms can vary greatly from small family farms to large agricultural combines owned by large corporations. In evaluating strategies, this fact should be considered. Agricultural equipment used on small, family-owned farms may not be a good candidate for technology retrofits, but fuel-based strategies, for example biodiesel, may be a good possibility. For larger agricultural operations, the full range of strategies may be appropriate.

- *Remote, Unmanned Locations* – Some agricultural pumps are used in remote, unmanned areas that may make maintaining retrofit technology a challenge.

- *Diesel Fuel Sulfur Levels* – The level of sulfur in the available fuel is a factor in selecting the appropriate strategies. Agricultural equipment is centrally fueled, but getting a supply of ULSD to the farms, particularly those located in more rural areas, may not be possible without paying a high price differential.

Mining/Oil Field Equipment

Overview – Retrofit technologies, such as DPFs and DOCs have been utilized in mines in North America and in Europe. Both catalyst-based DPFs and DPFs employing external heat to clean the filter have been used. Mining and oil field equipment typically falls within the same horsepower range as construction equipment, but some mining equipment uses engines ranging up to 750 hp or greater.



Sector Specific Considerations in Developing Retrofit Strategies for Mining/Oil Field Equipment – A number of considerations should be kept in mind when evaluating and developing a retrofit strategy for mining and oil field equipment. These considerations include:

- *Rigorous Operating Environment* – The strategy selected must be capable of withstanding the rigorous operating environment of mining equipment.
- *Operating in Enclosed Areas* – In the case of underground mining, retrofit technologies must be designed to operate safely in environments where explosions may be a risk and not increase any pollutants that may pose a heath risk to workers in such enclosed areas (e.g., NO_2).
- *Different Engine, Equipment, and Operating Cycles* – The number of different types of mining equipment is considerably less than the case with construction equipment. Nevertheless, the different engine operating conditions and applications need to be considered in selecting retrofit strategies
- *Oil Field Equipment Steady-State Operation* – Oil field equipment such as pumps and generators typically operate at steady-state. This situation enables the use of technologies such as DPFs, SCR, DOCs that have been applied to similar engines in other offroad and/or stationary engine applications.
- *Remote, Unmanned Location of Oil Field Equipment* – Oil field equipment can be located in very remote areas where personnel may not be present on a daily basis. Technologies requiring frequent maintenance may not be good candidates for those applications.
- *Diesel Fuel Sulfur Levels* – The level of sulfur in the available fuel is a factor in selecting the appropriate strategies. Since mining equipment and oil field equipment are typically fueled from a central fueling facility, the use of ULSD, as well as alternative fuels such as biodiesel may be a possibility. However, for equipment located in remote areas, the option of using a fuel other than conventional diesel may be difficult.
- *Operating Shifts* – Since mining equipment is often operated in shifts, an opportunity exists to utilize technology that needs maintenance on a regular basis. This maintenance can be performed between shifts and thus avoid any downtime.

Marine Equipment and Vessels

Overview -- Marine vessels fall within three general categories – 1) recreational vessels (e.g. in-boards), 2) commercial costal vessels (tugs, ferries, fishing boats), and 3) ocean-going vessels. Commercial marine vessels can range from less than 500 hp (e.g. small fishing boats) to over 100,000 hp for large, ocean-going vessels. Marine port equipment is similar to the types of equipment found in the commercial/industrial equipment sector, although some port equipment such as cargo container lifts cranes can be quite large. Also, on-road vehicles such as trucks operate at ports (e.g., transporting freight to and from the port).

Recreational vessels may not be good candidates for technology-based strategies because of the more challenging operating environment of these marine vessels (i.e. the technology must be protected from exposure to water) and the fact that such vessels are privately owned. However, since these vessels are fueled at marinas, there is the possibility of using ULSD or biodiesel for example.

A number of strategies to reduce emissions from commercial coastal vessels have been employed around the world. For example, DPFs have been installed on sightseeing boats in Switzerland, DOCs have been installed on ferries in Hong Kong, and SCR technology has been installed on ferries, tugboats, and smaller cargo vessels in Europe. Several projects are underway in the U.S. evaluating the use of ULSD, fuel emulsions, and biodiesel on ferries.

Controlling emissions from existing large, ocean-going vessels is a challenge for several reasons, including: 1) the large size of the engines and the available space to install technology, 2) the fact that these vessels visit many ports, and 3) regulation of such vessel is by international convention. One very promising strategy is to employ shore-power when these vessels are docked at ports. Several projects are in operation or getting underway including ports in Long Beach, Seattle, and Juneau.

A number of initiatives are getting underway in the U.S. to reduce emissions from equipment and vehicles used at marine ports. For example, approximately 500 yard hustlers at ports on the west coast are being retrofitted with DOC/CCV systems. Also, ULSD, biodiesel, alternative fuels and diesel emulsions are being used at ports. Developing port-wide strategies requires a holistic approach due to the variety of vehicles, equipment and vessels involved.

Sector Specific Considerations in Developing Retrofit Strategies for Marine Vessels and Marine Port Commercial Equipment **--** Some of the key factors to consider when evaluating and developing a retrofit strategy for this sector include:

Marine Vessels

- *Retrofit Strategies Are Emerging* – Depending on the type of vessel, technology-based, fuel-based and operation-based strategies exist and are emerging.

- *Broad Ranges of Engine Size and Applications* – Marine engines range from less than 50 hp to over 100,000 hp and the applications vary from recreational boating to ocean-going cargo and passenger vessels. As noted above, care must be taken in matching the appropriate strategies with the specific applications.

- *Need for Power Source for Vessels Docked at Ports* – When vessels dock at ports, they typically use their diesel engines to provide auxiliary power. An opportunity exists to use less polluting, more efficient shore power.

Marine Port Equipment

- *Different Engine, Equipment, and Operating Cycles* – While the range of equipment types is narrower than the construction sector, the type of equipment and use must be considered, nonetheless, in developing a retrofit strategy.

- *Diesel Fuel Sulfur Levels* – The level of sulfur in the available fuel is a factor in selecting the appropriate strategies. Since port equipment is typically fueled from a central fueling facility, the possibility of using ULSD, biodiesel, emulsions and alternative fuels exists.

- *Movement of Equipment* – Equipment used in port applications generally does not move from site to site as frequently as construction equipment. Nevertheless, the possibility that port equipment could be moved needs to be considered.

- *Operating Shifts* – Since port equipment is often operated in shifts, an opportunity exists to utilize technologies that need maintenance on a regular basis. This maintenance can be performed between shifts and thus avoid any downtime.
- *Public Owned/Operated* – Since many large ports are publicly-owned, it may be easier to initiate a retrofit program with this kind of entity than a large privately-owned operations like a farm or farm coop.

Locomotives and Railway Maintenance Equipment

***Overview* –** The locomotive sector consists of engines used to power switcher locomotives, passenger and freight locomotives (line-haul), and railway maintenance equipment. There are over 20,000 locomotives operating in the U.S. Locomotives engines operate for decades and many are powered by high-emitting two-stroke engines. Locomotive engines are very large, ranging from 1,500 to 4,000 hp.

The locomotive sector is a challenging one for implementing retrofit strategies. Nevertheless, technologies have been retrofitted on locomotives. For example, over 100 locomotives in Europe have been equipped with DPFs that typically employ active filter regeneration strategies such as fuel burners or electrical resistance heaters. Some of these systems have been operating effectively (up to 85% PM control efficiency) for over 390,000 miles. SCR systems also have been employed on locomotives in Europe. In 1998, the U.S. EPA established a requirement that locomotive engines (both switcher and line-haul) originally manufactured from 1973 to 2001 must be rebuilt to meet specified emissions standards at the time of rebuild. Reduced idling strategies are an effective approach, particularly with switcher locomotives that operate at extended periods at idle. For example, a pilot reduced idling program in California for switcher yard locomotives is underway. Lower emitting alternative fuel switcher engines and battery/engine hybrid powertrain systems have also been employed.

Rail maintenance equipment consists of ground-based and rail-based. The ground-based equipment is similar to construction or industrial sector equipment. The rail-based equipment (maintenance-of-way equipment) utilizes a smaller locomotive type, or highway trucks that have been fitted with rail car wheels to allow them to operate on tracks.

Sector Specific Considerations in Developing Retrofit Strategies for Railway Construction Equipment and Locomotive Engines **–** The factors to consider in developing strategies for ground-based railway maintenance equipment are similar to those that should be considered in applying strategies to construction and industrial/commercial applications (discussed above). A number of considerations should be kept in mind when evaluating a retrofit strategy for locomotive engines. These considerations include:

- *Older Engines* – Locomotive engines typically operate for decades between rebuilds and some are very high PM-emitting two-stroke engines. Retrofitting engines with technologies such as DPFs or DOCs is extremely challenging. Successful application of retrofit technologies such as DPFs and SCR on locomotive engines have typically focused on new model year engines. If retrofit technologies are used on locomotive engines, backpressure and other operating conditions should be monitored.

- *Available Space* – Locomotive engines are quite large and designing a retrofit technology to adequately control emissions within the available space on the locomotive engine is very challenging.
- *Steady-State Engine Operation* – Locomotive engines primarily operate in a steady-state mode. The lack of transient modes facilitates application of technologies such as SCR that are most effective during steady-state engine operation (assuming the other challenges noted above can be addressed).

- *Central Fueling Infrastructure* – Switcher locomotives are typically fueled at the rail yard, providing an opportunity to employ a fuel-based strategy such as biodiesel, ULSD, and LNG. For example, BNSF Railroad has operated several LNG-fueled switcher locomotives in Los Angeles for a number of years.

- *Movement of Line-Haul Locomotives from State to State* – Fuel-based strategies for line-haul locomotive engines is more challenging because these engines literally travel from coast to coast. Setting up a fueling infrastructure for interstate routes is difficult.

- *Rigorous Operating Environment* – The strategy selected must be capable of withstanding the rigorous operating environment (high vibration) of locomotive engines.

- *Operating Shifts* – Since switcher locomotives often operate in shifts, an opportunity exists to utilize technology that needs maintenance on a regular basis. This maintenance can be performed between shifts and thus avoid any downtime.

- *Extended Idling Periods* – Some locomotives (e.g. switcher locomotives) operate for long periods. An opportunity exists to employ reduced idling practices and technology.

D. Overview of Visibility Impacts and Health Effects of Diesel Exhaust

VISIBILTY IMPACTS

One of the most basic forms of air pollution is haze. Haze is a result of the interaction of sunlight and visibility reducing (pollution) fine particles in the air. Some of the sunlight is absorbed by the pollution particles while other portions of sunlight are scattered prior reaching an onlooker. Increasing the number of pollution particles in the air increases the absorbing and scattering effect, therefore reducing the clarity and color of what an observer would see. Over the years, fine particles have significantly reduced the range an observer can see. For example, in the West, the visibility range has decreased from 140 miles to 35-90 miles. In the East, the visibility range has decreased from 90 miles to 15-25 miles.

Haze-causing pollutants (mostly PM) consists of very small liquid and solid particles in the air. PM particles vary greatly in size, shape, composition, and material. Particles small enough to be inhaled into the deepest parts of the lungs are 10 microns or less in diameter and are referred to as “respirable particulate matter” or PM_{10}. This also includes fine particles 2.5 microns or less in diameter known as $PM_{2.5}$. PM_{10} and $PM_{2.5}$ can be directly emitted into the air through a number of ways that include natural (dust, soot from fires) and manmade (electric power generation, motor vehicles, manufacturing processes) activities. Other types of PM are formed when NO_x and sulfur dioxide (SO_2) emitted into the air form visibility reducing particles and are carried several miles from their source. In addition to significantly contributing to haze, PM has also been linked to serious health effects which will be discussed in the section below.

Because of the visibility reducing aspects of PM, in addition to the harmful human health effects, damages to crops, forests and other plants, the U.S. EPA and California Air Resources Board (CARB) have adopted ambient air quality standards. Under the 1990 amendments to the Clean Air Act, Congress required EPA to take regulatory action on regional haze within 18 months of receiving the Western States Commission report on visibility in Grand Canyon National Park, which was delivered in 1996. In 1997, EPA proposed regional haze regulations in addition to issuing new National Ambient Air Quality Standards (NAAQS) for PM. Currently, these standards are violated in several parts of the western United States. Table 1-4 lists the federal ambient air quality standards for PM:

Table 1-4, National Ambient Air Quality Standards for PM

Averaging Time	PM_{10}	$PM_{2.5}$
Annual	50 $\mu g/m^3$	15 $\mu g/m^3$
24 hours	150 $\mu g/m^3$	65 $\mu g/m^3$

In 1999, EPA announced the Regional Haze Rule to improve air quality and reduce emissions in 156 national parks (over 6,000 acres), wilderness areas (over 5,000 acres) and national memorial parks (over 5,000 acres), known as “Class I” areas. Since it is known that PM can travel great distances, sometimes hundreds of miles, all 50 states are required to participate in the Regional Have Rule, even those that do not have a Class I area. One principle element of the Clean Air Act is the establishment of Best Available Retrofit Technology (BART) for certain existing sources placed into operation between 1962 and 1977. The Regional Haze Rule also provides an option for states to comply by implementing a coordinated approach.

Five regional planning organizations (RPOs) were formed as a result of the Grand Canyon Visibility Transport Commission and are comprised of states, tribes and federal agencies. These RPOs are:

- Mid-Atlantic and Northeast States Visibility Union (MANE-VU)
- Central States Regional Air Partnership (CENRAP)
- Midwest Regional Planning Organization
- Visibility Improvement State and Tribal Association of the Southeast (VISTAS)
- Western Regional Air Partnership (WRAP)

In addition to the RPOs, organizations acting under the auspices of the RPOs provide states and tribes with technical, outreach and regulatory support for RPOs submitting Regional Haze Rule SIPs. For example, MANE-VU is supported by the Northeast States for Coordinated Air Use Management (NESCAUM), Ozone Transport Commission (OTC) and the Mid-Atlantic Regional Air Management Association (MARAMA).

HEALTH EFFECTS SUMMARY

Diesel engines have the potential to cause humans adverse health effects. Exhaust emissions from diesel engines contain PM, which is readily respirable, and contain suspected carcinogens that cause respiratory problems and even premature death. Gaseous chemicals found in diesel exhaust are haze-forming NO_x and SO_2 that form fine particles, which fall back to earth in the form of acid rain. There are also a few probable or definite cancer-causing compounds that are associated with diesel exhaust: benzene, formaldehyde, soot from diesel buses and trucks, and 1,3-butadiene. These compounds fall into a category called toxic air pollutants and are not among the six criteria pollutants regulated by EPA. The toxic air pollutants are regulated under the National Emissions Standards Hazardous Air Pollutants (NESHAPS) rather than under the NAAQS. This toxic mix of chemicals in diesel exhaust is thought to pose a cancer risk greater than that of any other air pollutant. However, diesel engines are not the only emitter, such as power generation plants, of harmful PM and gaseous air pollutants. That is why it is difficult to distinguish the health risks attributed to diesel exhaust emissions as opposed to those attributed to other air pollutants.

Exposure to diesel emissions is difficult to assess due to the fact that diesel exhaust is comprised of a complex mixture of constituents, which is only a small part of a broad array of other air pollutants. For example, the combustion of tobacco produces the same chemical components as those found in diesel emissions and furthermore, both natural and manmade activities are responsible for sources of respirable PM. The EPA estimated in 1996 that offroad land-based diesel engines, locomotive engines, and marine engines produced approximately 40% of the total mobile-source inventory of $PM_{2.5}$ and 25% of the NO_x inventory. As of 2000, EPA estimated that heavy-duty trucks and buses accounted for approximately one-third of the NO_x emissions and one-quarter of the PM emissions from mobile sources. However, proportional contributions of the NO_x and PM emissions in some urban areas are significantly higher than the national average. The Health Effects Institute indicates that there are several factors to consider when estimating exposure to diesel emissions:

- Improvements in diesel engine design, aftertreatment technology, and use of reformulated, emulsified, biodiesel, and low sulfur fuels will change future exposure levels from past and current levels.
- Chemical and physical characteristics of diesel emissions change as new technologies and fuels are implemented.
- Diesel emissions undergo atmospheric transformation processes that may alter the toxic and carcinogenic properties, which may make the new constituents more or less hazardous.

In addition to the improvements in diesel engine design, aftertreatment technology, and alternatives to on-road diesel fuel in reducing diesel engine emissions, EPA's current standards regulating on-road and offroad diesel engines will also reduce the amount of diesel emissions. By 2030, national inventories of $PM_{2.5}$ and NO_x will be approximately 80% lower than the emissions in 2000. However, EPA also estimates that that more than half of the benefit of these reductions will not be realized until after 2015. The biggest factor for the delay in achieving emission reduction benefits is the fact that diesel engines are the workhorse of the United States and have the potential to be in service for extended periods of time, especially offroad diesel engines. EPA estimates that offroad diesel engines operating at typical loads can last between 9 to 20 years.

For the remainder of this section, currently available information on the potential health effects of exposure to diesel exhaust (DE) are described, based on findings from recent, extensive studies performed by the U.S. EPA and CARB. Both the EPA and CARB studies yielded results that were, for the most part, very similar. Much of the same basic information on human and animal exposure studies was used in both reports. The main difference between the studies is related to the conclusions about the suitability of using analyses of railroad workers and truck drivers for deriving cancer risks. EPA concluded that the data, although it is the best available, is still too uncertain to serve as the basis for any quantitative conclusions on the relationship between DE and cancer risk. CARB cites the very same studies and has determined that there is a risk of cancer formation due to exposure. The CARB study also concludes that there is a cancer risk to humans exposed to DE, based on data from tests on rats, while EPA concludes that there is insufficient evidence.

Health Effect Characterization of Diesel Exhaust

While the EPA and CARB studies assessed the effects of DE as a whole, rather than characterizing each individual component, it is useful to understand the characteristics and general health effects of each of the pollutants of concern, even though no one really knows how all of the individual pollutants in DE react with each other. For example, particles of many types and sizes are known to be irritants, therefore it is not surprising to see that DE has some properties that may cause irritation to many parts of the body. On the other hand, two pollutants may combine together in a way that the combined effect is greater than the sum of the parts, or could cause health effects that are not at all related to the individual pollutants. It is also important to understand that the individual pollutants contained in DE can come from many other sources besides DE.

***Particulate Matter (PM)* -** PM is made up of carbon, adsorbed organic compounds, hydrocarbons, and hydrocarbon derivatives. PM have a range in size, which is based on the mean particle diameter. The size of the particle directly relates to where the particle will be deposited in the human body. Particles that are larger than 2.5 microns are usually deposited in the upper respiratory tract. Particles that have a diameter that is less than 2.5 microns can be deposited almost anywhere, but they are usually found in the lower part of the respiratory tract, which includes the deep part of the lung that produce aggravation of respiratory and cardiovascular diseases and certain allergic sensitivities . The risk of these health effects is greatest in the elderly and children. PM is also associated with premature death as well as increased hospital admissions, emergency room visits, school absences, work days lost, and restricted activity days. The NAACQS for PM defines the maximum amount of particles that can be present in outdoor air without threatening the public's health, as listed in Table 1-4.

***Ozone* -** Ozone, the main component of smog, is a highly reactive gas formed by complex reactions with volatile organic compounds (VOCs) and NO_x in the presence of heat and sunlight. VOCs are a multitude of fuel-based compounds that result from a very small portion of the incomplete combustion of fuel in an engine. Some specific types of VOCs, such as benzene (which is found more predominantly in the unburned fuel portion of gasoline engine exhaust), are considered toxic air pollutants. Toxic air pollutants are noted for their cancer causing properties. In addition to causing cancer, benzene is also suspected of causing birth defects, as well as respiratory and reproductive effects. VOCs from diesel engines also contribute to secondary PM formation. Secondary processes mean that the particles are formed after they are released into the atmosphere as opposed to particles that have already formed in the engine and are directly emitted from the exhaust.

A photochemical oxidant, ozone can kill living cells on contact in the same manner as household bleach. Ozone forms readily in the lower atmosphere on hot, sunny days. Evidence has shown that short-term exposure to ozone results in harmful respiratory effects including chest pain, coughing, and shortness of breath. Inhalation causes acute respiratory problems such as worsening of asthma symptoms. Prolonged exposure and repeated exposure to ozone can reduce the volume of air that the lugs breathe while increasing the permeability. In addition, ozone adversely affects crop yields, damages National Parks, and increases the susceptibility of plants to pests. People who work outdoors, children, and adolescents are at the greatest risk for ozone exposure. Table 1-5 lists the current NAAQS for the maximum amount of ozone that can be present in outdoor air without being harmful to human health:

Table 1-5, National Ambient Air Quality Standards for Ozone

Exposure Standard	Ozone Level
1-hour Average	0.12 ppm
8-hour Average	0.08 ppm

Oxides of Nitrogen (NO_x) - The oxides of nitrogen are chemical compounds that form when the nitrogen and oxygen found in air combine during combustion. Nitrogen dioxide (NO_2) has been linked with increased susceptibility to respiratory infection, increased airway resistance in asthmatics, and decreased pulmonary function. The inhalation of NO_2 can aggravate preexisting lung disease, constrict the bronchial tubes, and cause one to be more vulnerable to respiratory infections. In high enough concentrations, it can cause adverse health effects in sensitive populations. NO_2 appears as a gas with a light brownish tint, and in the presence of sunlight, forms ozone and smog in urban areas. The NAAQS for NO_x is shown in Table 1-6.

Table 1-6, National Ambient Air Quality Standards for NO_x

Averaging Time	NO_x
Annual	0.053 ppm

Sulfur Dioxide (SO_2) - Sulfur dioxide is a gaseous compound of sulfur and oxygen and primarily comes from the burning of coal and other industrial processes such as smelters, paper mills, and chemical plants that use sulfur-containing fuel. The formation of SO_2 in diesel exhaust depends on the amount of sulfur in the fuel that is being used. SO_2 mainly affects the respiratory system, especially the respiratory systems of asthmatics. Other health effects that are associated with the inhalation of SO_2 are much the same as the health effects associated with the inhalation of NO_x: bronchial tube constriction and the aggravation of preexisting respiratory ailments.

Children, the elderly, and people with asthma, cardiovascular disease or chronic lung disease are most susceptible.

Carbon Monoxide (CO) - Carbon monoxide is a colorless, odorless gas that is a product of the fuel combustion process. High concentrations can cause dizziness, headaches and fatigue. Very high concentrations in closed areas such as would occur by operating a vehicle in a closed garage can lead to death. Once carbon monoxide is inhaled, it interferes with the delivery of oxygen to the body's tissues, affecting the cardiovascular and nervous system. Carbon monoxide can also impair manual dexterity, learning ability, visual perception, and the performance of complex tasks for healthy individuals. Sensitive populations include the elderly, young infants, anyone with severe diseases, and people with chronic bronchitis or emphysema. Individuals with certain types of heart disease are especially sensitive to carbon monoxide; they may experience chest pain if they are exposed to carbon monoxide while they are exercising.

Summary of Diesel Exhaust Pollutants and Their Health Effects

Table 1-7 contains a summary of diesel exhaust pollutants and their related health effects.

Table 1-7, Summary of Diesel Exhaust Pollutant Sources and Health

POLLUTANT	PRIMARY SOURCES	HEALTH EFFECTS
CARBON MONOXIDE (CO) Colorless, odorless gas that forms from the incomplete combustion of fuels.	Two-thirds of CO emissions come from transportation sources, mainly highway motor vehicles. Other sources are related to industrial processes.	If CO is inhaled, it enters the blood stream and interferes with the delivery of oxygen to vital tissues, affecting the cardiovascular and nervous systems. Impairments can occur in: manual dexterity, learning ability, visual perception, and performance of complex tasks by healthy individuals. High concentrations can cause dizziness, headaches and fatigue. People with certain types of heart disease are especially sensitive.
VOLATILE ORGANIC COMPOUNDS (VOCs) Form from the incomplete combustion of fuel. React with NOx and sunlight to form ozone.	Gasoline engines are the largest source of VOC emissions. Other sources include diesel engines, industrial facilities, and consumer products such as charcoal lighter fluid, paint thinners and hairspray.	React with NOx and sunlight to form ground-level ozone, a severe irritant that damages cells and lung tissues and reduces the ability of the lungs to fight infection. Certain types of VOCs, such as benzene (which most frequently comes from gasoline engines), can cause cancer, and are suspected of causing reproductive effects, birth defects and respiratory problems.
OXIDES of NITROGEN (NO_x) Form from the combustion of fuel with the nitrogen and oxygen found in the air. A light brown gas in low concentrations and a component of the brown colored haze (smog) in urban areas.	Diesel and gasoline engines, electric utility plants, and industrial combustion processes, are the main sources of NO_x emissions.	Inhalation can aggravate pre-existing lung diseases and constrict the bronchial tubes. NO_x can increase respiratory illnesses in children and make breathing more difficult for asthmatics. Indirect adverse affects are created by harming vegetation. Certain types of NO_x compounds (called Nitro-PAHs) can cause cancer and possibly contribute to birth defects.
PARTICULATE MATTER (PM) Solid particles from smoke, dust and ash, as well as condensing vapors in the form of very fine liquid droplets which form during the combustion of fuels. PM can remain suspended in the air for long periods of time.	Diesel engines, gasoline engines, industrial facilities such as smelters, and the combustion of fuels for industrial and electric utility applications are the main sources of PM. Other significant sources include road dust, smoke from fireplaces and wood stoves and groundbreaking that occurs during construction and farming processes.	PM in general increases respiratory and lung disease, and possibly premature death. Sensitive populations such as children, the elderly, and people with heart or lung disease are particularly at risk. PM also damages paint, soils clothing and reduces visibility.
DIESEL EXHAUST (DE) A complex mixture of over 100 gaseous and particle constituents. The particulate matter in DE is mostly fine and ultrafine in size.	DE results from the combustion of diesel fuel in diesel engines used in on-road and non-road vehicle and equipment applications.	At high concentrations and prolonged exposure, DE can cause respiratory system irritation, lightheadedness, vomiting, nausea and tingling in the extremities. Possible effects include increases in allergic sensitivity, and neurological, behavioral, and liver damage. Long term exposure to DE is a possible respiratory hazard and is considered to have the potential to cause cancer.