

Washington State University Extension Energy Program

New Engine Technologies

Diesel Engines

Beginning with the 2007 model year, new heavy-duty engines must meet a particulate matter (PM) emission standard of 0.01 grams per brake horsepower hour (g/bhp-hr). The highway diesel program also establishes standards for nitrous oxide (NO_x) and non-methane hydrocarbons (NMHC) of 0.20 g/bhp-hr and 0.14 g/bhp-hr, respectively. The NO_x and NMHC standards are phased in over three years, while the PM standard requires 100 percent compliance starting with model year (MY) 2007.

Future off-road diesel engine standards are considerably less stringent than the 2007 on-road standards. However, they will require significant emissions improvements over existing off-road engines. The new off-road PM standards are specific to model year and engine size, but in general, are about 20-60 percent lower than current Tier 1 standards. For off-road engines above 175 horsepower, PM standards will drop from 0.4 g/bhp-hr to 0.15 g/bhp-hr. For the most part, these standards will be phased in through 2005.

Diesel engine emissions are currently controlled through improvements to the basic engine, rather than through the use of after-treatment technologies (the exception being diesel oxidation catalysts). With these control changes, there is usually a tradeoff between NO_x improvements and PM improvements. To control NO_x emissions, lower combustion temperatures are desirable, while PM emission improvements generally result from higher combustion temperatures.

Currently, diesel emissions are reduced by turbo-charging, after-cooling, high pressure fuel injection, retarding injection timing and optimizing combustion chamber design. (See Ref.1) Turbochargers reduce both NO_x and PM emissions by approximately 33 percent when compared to naturally aspirated engines. (See Ref.1.) After-cooling with turbo-charging provides even larger NO_x and PM reductions by decreasing the temperature of the charged air after it is heated by the turbocharger. Retarding injection timing reduces the peak flame temperature, which improves NO_x emission but typically results in higher PM emissions. Combustion chamber improvements and air-fuel injection advancements are ongoing in the industry and result in improved fuel economy and emission reductions.

As diesel engine improvements reach their limit, NO_x and PM emission control will most likely require after-treatment devices to achieve new, stringent emission standards. Diesel oxidation catalysts have been used in some engines since the 1990s to reduce PM emissions. These devices have proven effective at reducing PM emissions by 25 percent or more. They are robust and require little or no maintenance.

Diesel oxidation catalysts will not allow engine manufacturers to meet the 2007 emission standards, however. (Ref. 2) The catalyzed diesel particulate filter and the continuously regenerating diesel particulate filter have demonstrated their effectiveness in reducing particulate emissions to 2007 standards. When coupled with ultra-low sulfur diesel, DPFs have achieved PM reductions of greater than 95 percent and have engine out PM emission levels of 0.008 g/bhp-hr. In its review of diesel engine technology developments necessary to meet 2007 standards, the U.S. Environmental Protection Agency identified diesel particulate filters (when coupled with ultra-low sulfur diesel) as the leading technology for PM compliance.(Ref. 2) While meeting NO_x standards is proving problematic, all of the engine manufactures surveyed by EPA indicated that they could meet 2007 PM standards. (Ref. 2) In fact, one engine manufacturer was identified as already selling vehicles with catalyzed diesel particulate filters (DPFs) that met 2007 PM standards.

Although EPA reports that catalyst based emission control technologies represent the most viable path for reducing PM and NO_x emission to levels below the 2004 standards, they also suggested that emerging in-cylinder emission control technologies may provide valuable synergistic benefits for compliance with 2007 standards. (Ref. 2) Both Toyota and Nissan have been developing new combustion technologies that break the traditional NO_x versus PM tradeoff and produce very low emissions of both. Nissan utilizes two distinct combustion modes. When engine torque is greater than 40 percent, the engine operates using conventional diesel combustion. At lower operating loads, the engine is operated with a low-temperature

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premixed combustion approach. Using this latter approach, engine PM and NO_x emissions are reduced by more than 90 percent. Toyota is also developing a low temperature combustion technology that gives very low engine out NO_x and PM emissions.

Natural gas

Natural gas is a gaseous fuel composed mostly of methane, with smaller amounts of propane, ethane, helium, carbon dioxide and water. While natural gas is considered an effective alternative to diesel fuel, it is not as convenient to use as a liquid fuel. Natural gas must either be compressed to 3,000-3,600 pounds per square inch (psi), or liquefied through super cooling to -327.2 degrees F. In either case, refrigeration or compression equipment is required for refueling purposes.

Compression is the most common method for delivering natural gas for vehicle use. Currently, there are over 1,200 compressed natural gas (CNG) stations in the United States. Because of its lower fuel density, CNG is not considered a practical fuel for long distance, heavy-duty truck applications such as Class 7 and 8 trucks. CNG is being used successfully in shorter range, heavy duty applications such as street sweepers and refuse trucks, and has a long history of use in many medium-duty applications such as school bus and transit fleets. For longer range applications, liquid natural gas (LNG) is the preferred fuel. While LNG infrastructure is fairly limited at present, it is slowly being developed, primarily in Southern California, and Arizona. Even still, it takes about 1.7 times the volume of LNG to provide an amount of energy equivalent to a gallon of diesel.

Because natural gas has a very high octane rating, it does not readily ignite in diesel engines. As a result, most heavy duty natural gas engines use a spark-ignition, four-stroke cycle to achieve combustion. However, original equipment manufacturers are developing natural gas engines that employ the more efficient, diesel combustion cycle. Cummins Westport Inc., of Vancouver, British Columbia, is currently developing a 15 liter, 400 horsepower, high-pressure, direct-injection (HPDI) engine called the ISX-G. (Ref. 3) This engine compresses air, unmixed with fuel, like a conventional diesel engine. The system then injects a small amount of diesel pilot fuel, followed by natural gas, which is stored onboard as LNG. Unlike other *dual-fuel* engines, the ISX-G technology is unique in that it preserves the diesel cycle's high compression ratio and apparently produces diesel-like torque and fuel efficiency. Cummins Westport Inc. expects that this technology will be able to meet future emission standards.

Emissions

Natural gas engines are typically considered cleaner than petroleum fueled engines. However, all engines are becoming cleaner as engine manufacturers are required to meet stricter emission standards. Therefore, when comparing diesel versus natural gas emissions, it is important to make sure that like technologies are considered.

A case in point is a recent study conducted by the California Air Resources Board. In the spring of 2002, CARB released the results of a study on transit bus emissions. (Ref.4) The study compared the emissions of a state-of-the-art diesel bus running on ultra-low sulfur diesel and equipped with particulate trap technology, to an older, natural gas bus that employed no after-treatment controls. Preliminary results indicated the natural gas buses were found to discharge more mutagenic emissions, particulate mass, hydrocarbons and carbon monoxide.

Natural gas industry advocates argued that the results were unfairly comparing state-of-the-art diesel technology with older natural gas technology. As a result, CARB completed a follow-up study that investigated the emissions of currently manufactured natural gas buses equipped with oxidation catalysts. (Ref. 5) The CARB study found that the oxidation catalyst equipped CNG buses produced very low toxic emissions. Further, in terms of total PM mass, the study showed that CNG, with or without oxidation catalysts, is "significantly superior" to the current and "conventional" diesel bus, including the catalyst-equipped bus fueled with ultra-low sulfur diesel. (Ref. 5)

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In August 2002, the U.S. Department of Energy (DOE) published the results of a multiple year study of United Parcel Service (UPS) trucks operating on CNG. (Ref. 6) Although most of the CNG technology used by UPS is early production equipment, emission testing indicated that the CNG trucks had much lower emissions than diesel trucks of a similar age. Chassis dynamometer tests revealed that the CNG trucks had 95 percent lower particulate emissions, 75 percent lower emissions for carbon monoxide and 49 percent lower NOx emissions.

North Thurston Public Schools, located in Lacey, Washington, is currently purchasing four new CNG powered buses. Each bus is powered by a Cummins 230 horsepower, 5.9G natural gas engine with catalyst. The engine was certified for PM emissions of 0.02 g/bhp-hr. The equivalent ISB diesel engine manufactured by Cummins has a PM certification of 0.09 g/bhp-hr, an increase of about 78 percent. It should be noted that PM emissions from the diesel engine would be reduced significantly if retrofitted with a catalyzed diesel particulate filter.

Cost

Natural gas powered buses and trucks cost more than conventional diesel powered vehicles. The North Thurston Public School CNG powered school buses manufactured by BlueBird have a price premium of approximately \$23,000. The Port of Seattle is paying approximately \$40,000 more for a CNG option on a New Flyer of America, 40 foot, low-floor coach powered by an 8.3 L Cummins natural gas engine. The Port of Seattle purchase of a natural gas powered street sweeper manufactured by Elgin under the model name Crosswind J will cost about \$46,000 more than an equivalent diesel model.

Natural gas powered fleets may also be required to install refueling equipment due to the limited availability of natural gas fueling stations. A time-fill compressed natural gas refueling network appropriate for a school bus fleet could cost \$100,000 or more. A commercial sized CNG station capable of fast filling vehicles is estimated to cost upwards of \$300,000, while the State of New York identified a cost of \$5 million for a fuel station capable of refueling 30 buses per hour. Maintenance shops and garages may also require costly safety modifications such as the addition of spark arrestors and methane detection equipment.

Hybrid electric

An emerging alternative to conventional diesel engines is the electric hybrid system. Hybrid buses typically utilize an electric drive coupled in series or operating in parallel with a combustion engine and traction battery.

Hybrid technology allows the use of a smaller internal combustion engine which is designed to operate near its optimum efficiency, thereby minimizing engine emissions and maximizing fuel economy. Typically, a hybrid system also employs regenerative braking which transforms kinetic energy into electric energy, again improving fuel economy. To a fleet operator, hybrid technology is attractive because it does not require the development of new refueling infrastructure or modifications to existing maintenance areas.

Emissions

New York City Transit (NYCT) operates a small, but growing fleet of diesel/hybrid buses. Emissions testing on NYCT's original fleet of 10, 1998 Orion VI hybrid buses was conducted by West Virginia University using a mobile chassis dynamometer.(8) On the Commercial Business Test cycle, the hybrid buses produced 50% lower PM emissions and 36% lower NOx emissions as compared to the NovaBUS RTS diesel buses operated by NYCT. Additional emission testing was completed on the new Orion VII diesel hybrid buses and the conventional Orion V diesel buses, with and without catalyzed diesel particulate filters. The new hybrid bus had 49% lower NOx and 93% lower PM than the Orion V diesel bus without the particulate filter. The new hybrid bus had 49% lower NOx, and 60% lower PM than the Orion V bus equipped with a diesel particulate filter.

Cost

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The 1998 NYCT hybrid buses cost an average of \$465,000 each.(8) A NYCT diesel bus cost about \$290,000, or \$175,000 less. The next generation Orion VII hybrid buses purchased by NYCT cost \$385,000 per bus, or about \$95,000 more than the average NYCT diesel bus.

References

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- 6) *UPS CNG Truck Fleet-Final Report*, USDOE/NREL, August, 2002.
- 7) *NYCT Diesel Hybrid-Electric Buses: Final Results*, USDOE/NREL, July, 2002.