Reno, Nevada
NOISE-CON 2007
2007 October 22-24

A comparison of green and conventional diesel bus noise levels

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ABSTRACT

The growing use of green buses has been fueled by the need for reducing noise emissions as well as airborne particulates. Hybrid diesel-electric, electric trolleybus and compressed natural gas (CNG) buses are all promoted to have lower noise levels than conventional diesel buses. This paper provides a general comparison of the noise levels from these vehicle types under idling, acceleration and constant-speed pass by operations.

1. INTRODUCTION

In one project for the Maryland Mass Transit Administration (MTA) in which alternative vehicle types were considered, buses with purely electric propulsion systems were found to have noise impacts extending only about one-third the distance as those for conventional diesel buses.[i] Diesel-electric hybrid buses are widely believed—and promoted—to be significantly quieter than conventional buses: "Utilizing hybrid electric technology, theses buses will dramatically reduce both engine noise and emissions."[ii]

Bus transit is virtually universal in population centers. Bus rapid transit (BRT), which incorporates features of light rail transit systems, is generating widespread interest. Choices are available today that may permit bus operations with significantly less noise impact. Currently, many transit agencies are beginning to use or demonstrate diesel-electric hybrid buses due to the interest in more environmentally friendly bus systems and sustainability.[iii] Available data documenting the potential benefit in reduced sound levels from technologies, especially diesel-electric hybrids, are rather limited. This paper presents a general description of these bus technologies, a comparison of *available* noise emission levels of some of the more common bus technologies being used by North American transit agencies and a comparative overview of the noise emission results.

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2. BUS VEHICLE TECHNOLOGIES

The most common bus vehicle types can be differentiated as:

a. Diesel
b. Compressed natural gas
c. Diesel-electric hybrid
d. Electric trolleybus (with overhead catenary)

Conventional diesel buses are the most prevalent bus technology in use (80% of total North American fleet), followed by compressed natural gas (CNG) and liquefied natural gas (15% of total fleet). As of 2006, only four transit agencies utilize electric trolleybus vehicles comprising only a small percentage of the total fleet.[iv]

Diesel buses with compression ignition engines use diesel fuel for propulsion and electric power for auxiliary equipment. Unlike gasoline engines that require a spark for ignition, diesel engines compress the fuel-air mix and raise its temperature high enough to cause ignition. Noise sources from diesel buses are generally caused by the exhaust system, radiation of the engine block, the cooling system (especially fans), air intake components and tire/pavement-interaction noise.

CNG buses utilize a reciprocating internal-combustion engine similar to conventional diesel buses except that in lieu of diesel fuel they use a methane mixture in a spark-ignition engine for propulsion. CNG buses emit fewer EPA-regulated air emissions than diesel buses. The predominant noise sources are similar to that of diesel buses. Different fuel as well as different operating conditions and efficiencies allow CNG buses to potentially have different noise emissions than diesel buses.

Diesel-electric hybrid buses use an on-board diesel engine to produce electric power that charges batteries. The batteries in turn provide electric power to run the electric propulsion motors. The two main types of diesel-electric hybrid propulsion systems are series and parallel drive trains. Series drive train systems only utilize the electric motors for propulsion and the diesel engine is simply a generator for producing power. Parallel drive trains will engage the diesel engine for propulsion under certain conditions where additional power is needed such as accelerating or climbing hills. Noise sources for diesel-electric hybrid buses include the electric propulsion motors in addition to those of conventional diesel buses. The expected benefits of this technology in regard to noise is the ability for the diesel engine to run at a constant speed and at its highest efficiency since it is only needed to power storage batteries.

Electric trolleybus technology has been in use for many years and is best suited for lower speed (40-mph top speed), urban operations. The vehicles tend to have long service lives, but require an overhead-wire infrastructure similar to light rail systems. Electric trolleybuses use electricity from catenary wire systems to power electric motors and auxiliary equipment. Noise sources from electric trolleybuses include the interaction between the catenary wire and the pantograph or trolley poles, electric motors, auxiliary equipment such as cooling fans and air conditioning and the tire/pavement interaction. Although not part of the trolleybus vehicle, substations required for supplying power to the catenary wire system are another source of noise with these systems.

3. BUS NOISE LEVELS

Data presented were evaluated as part of noise studies for the Maryland MTA, Houston Metro, Los Angeles Metro and Neoplan USA. [v, vi, vii]

To assess bus noise impacts for the Maryland MTA Baltimore Red Line Project—and especially to quantify potential benefits of hybrid buses, sound level data measured at the Altoona Bus Research and Testing Center were analyzed. Performance tests included exterior noise measurements 50 ft from the travel lane centerline in accordance with Society of Automotive Engineers (SAE) test procedure J366b, *Exterior Sound Level for Heavy Trucks and Buse*s, in three conditions:

- Full-throttle acceleration from constant speed ≤35 MPH, just prior to transmission upshift.
- Full-throttle acceleration from standstill.
- Stationary, with the engine at low idle, high idle, and wide-open throttle.

Sound level data were available for six conventional (including one CNG-fueled) and five hybrid buses (including one CNG-fueled) of various makes and models, and one gas-turbine-electric hybrid (the 24,500-lb AVS). The test buses ranged 22–60 ft in length and up to 66,000 lb in weight. These data will be presented in this paper as streetside-curbside energy average sound levels.

CNG bus noise emissions of Neoplan USA 40-foot and 60-foot articulated buses were measured. These measurements were conducted in support of efforts by Nelson Muffler to design a retrofit muffler for the Neoplan CNG buses to minimize noise emissions particularly under idling conditions. Measurements were conducted of idling noise and acceleration tests in general accordance with SAE standard J366b for full-throttle acceleration from standstill.

Measurements of Irisbus Civis diesel-electric hybrid buses operating for the Southern Nevada RTC were conducted in conjunction with the Houston Metro North Hardy Corridor and Southeast-Universities Corridor Environmental Impact Statements (see figure 3). These measurements include maximum constant-speed pass-by noise levels at 50 feet. The bus is manufactured by a joint venture of Renault and Fiat’s industrial vehicle company, Iveco. The Civis is 61 feet in length with an articulation and three axles. Propulsion is provided by individual electric motors on four of the wheels.

In a study for Los Angeles Metro, maximum constant-speed pass-by noise levels were measured of electric trolleybuses operating in revenue service for Seattle Metro. Seatttle Metro electric trolleybuses include both 40-foot and 60-foot buses.

A. Idling Noise Levels

The Maryland MTA data are summarized in Table 1. The hybrid buses showed benefits in the stationary tests—about 2 dBA quieter in idling measurements and about 7 dBA quieter for the wide-open-throttle condition compared to conventional diesel buses. In this comparison, the hybrid buses are slightly, but not significantly, quieter than the conventional buses in the low-idle and high-idle conditions. However, although based upon limited data, the hybrids are significantly quieter in stationary, wide-open-throttle operation.

Table 1. Conventional v. Hybrid Idling Sound Levels
(averages are rounded to nearest whole decibel, air conditioning off, excluding AVS bus)

		EX. STATIONARY SL (dBA)		
PARAMETER	POWERTRAIN	Low Idle	Hi Idle	WOT
Average*	ALL	65	68	75
	conven.	65	69	77
	hybrid	64	67	70
	CON – HYB	**2**	**2**	**7**
Standard Deviation	ALL	2.5	2.9	3.6
	conven.	3.1	3.1	1.7
	hybrid	1.3	2.6	0.5
Count	ALL	11	8	7
	conven.	6	5	5
	hybrid	5	3	2

Measurements of Neoplan 40-foot and 60-foot articulated buses were conducted including several muffler designs intended to reduce low frequency tones (35 Hz). Streetside-curbside averages of idle noise levels of the 40-foot CNG buses with air-conditioning off were 64 dBA under low-idle conditions and the 60-foot CNG bus were 65 dBA for the best muffler design. These data show that idling noise levels of the CNG buses are very comparable to conventional diesel buses.

Idling noise levels were measured of the electric trolleybuses operated by the Massachusetts Bay Transportation Authority (see figure 4). Idling noise levels of the electric trolleybuses are controlled by the specific auxiliary equipment that is running. With the air-conditioning on, low-idle noise levels were 60 dBA at 50 feet. Although data are limited under idling conditions, electric bus technology clearly has a significant benefit in reduced idling noise levels compared to diesel, CNG or diesel-electric hybrid buses. This factor can be of significant benefit to reducing noise impact for communities—especially since this technology is typically utilized in more urbanized areas where bus idling noise can be a common annoyance and source of complaints.

B. Acceleration Noise Levels

The Maryland MTA data are summarized in Table 2. Maximum pass-by sound levels are plotted versus gross vehicle weight in Figure 1. Hybrid buses were slightly quieter than the conventional buses in the wide-open-throttle acceleration, pass-by tests—but not significantly so. The variation between manufacturers was greater than the differences between bus types, as can be seen in Figure 1. The Gillig buses are significantly quieter (at 95% probability level) than the other manufacturers for acceleration from constant-speed—although narrowly *not* significant for acceleration from standstill. Thus, manufacturer design choices may be more significant than diesel bus powertrain in noise emissions.

Table 2. Conventional v. Hybrid Bus—Pass-By Sound Levels
(averages are rounded to nearest whole decibel, full-throttle acceleration, excluding AVS bus)

		EXT. PASS-BY SL (dBA)	
PARAMETER	POWERTRAIN	Const Spd	Standstill
Average	ALL	76	76
	conven.	76	77
	Hybrid	76	75
	CON – HYB	**0**	**2**
Standard Deviation	ALL	2.4	2.7
	conven.	2.6	3.1
	Hybrid	2.4	1.9
Count	ALL	11	11
	conven.	6	6
	Hybrid	5	5

These data suggest that hybrid buses provide no significant benefits under acceleration operations *per industry-standard tests.* While hybrids appear to be somewhat quieter in stationary operations and *may* produce lower noise emissions under acceleration, there is no justification for assuming sound level reductions for hybrid buses under acceleration. On the other hand, since manufacturer design philosophies appears to be a significant factor, aggressive specification of vehicle emissions (for either conventional or hybrid buses) may yield useful benefits.

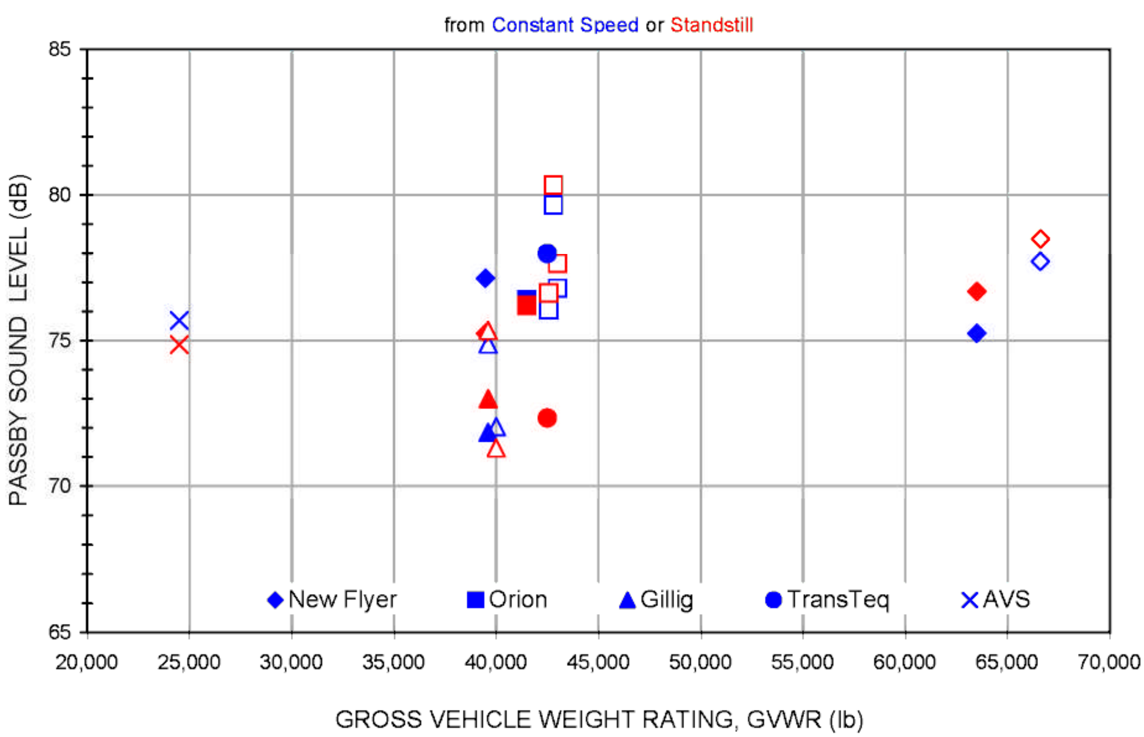

Figure 1. Conventional v. Hybrid Bus—Accelerating Pass-By Sound Levels
HYBRID powertrains = filled symbols, CONVENTIONAL powertrains = open symbols

Accelerating bus noise tests were conducted on a Neoplan 60-foot CNG bus at the Paul Revere Transportation Center in Chelsea, MA. Noise measurements of the bus accelerating from low idle were made at a distance of 50 feet from, and perpendicular to, both sides of the bus. Each test began with the front bumper even with the microphone, and three test runs were conducted for each side. The results of these tests at 50 feet from the bus centerline indicated an average maximum noise level of 80 dBA on the left (street) side of the bus and an average maximum noise level of 78 dBA on the right (curb) side of the bus—with a streetside-curbside average of 79 dBA. These noise levels are approximately 1 to 3 dBA higher than conventional diesel buses.

C. Constant-Speed Pass-By Noise Levels

Maximum noise levels of diesel, hybrid and electric trolleybus pass bys at constant speed are shown in Figure 2. Diesel bus data were measured as part of a study to assess Houston Metro bus fleet baseline noise levels. These data include constant-speed pass bys between 20 and 60 mph and a mixture of transit and suburban buses. These measurements include controlled pass bys from two buses (one MCI and one Neoplan 4700 series) on Beltway 8. Constant-speed pass bys of the Irisbus Civis diesel-electric hybrid were measured between 28 and 42 mph. Electric trolleybus noise levels from constant-speed pass bys were collected between 25 and 35 mph.

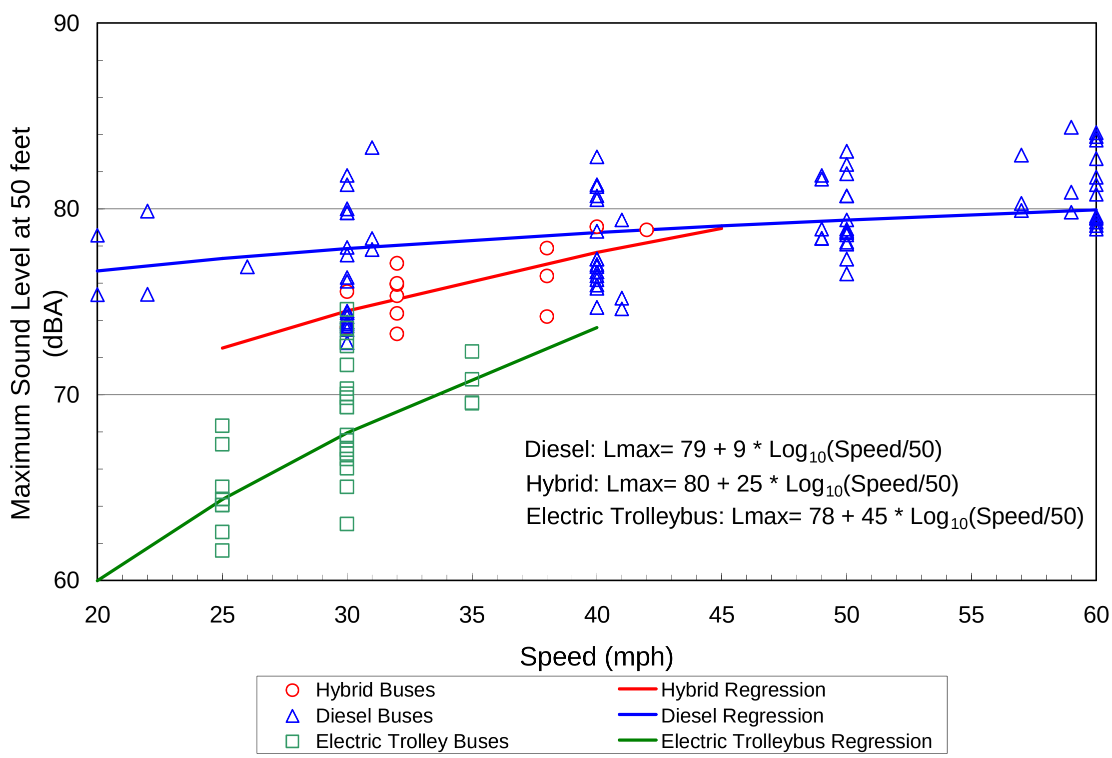

Figure 2. Constant-speed pass-by sound levels for diesel (blue), hybrid (red) and electric trolleybus (green)

This figure shows that at 30 mph hour hybrid buses are approximately 3 dBA lower than conventional diesel buses. At speeds approaching 40 mph, hybrid bus noise levels are within 1 dBA of diesel buses. Electric trolleybuses, in comparison to hybrid buses and conventional buses, are 10 dBA and 7dBA quieter at 30 mph, respectively. At 40 mph, electric trolleybuses are found to be 4 to 5 dBA quieter than hybrid and conventional diesel buses. Although data are not available, as speeds above 40 mph, noise levels of all technology buses are expected to be relatively similar as noise from the tire/pavement-interaction begins to dominate emissions.

3. COMPARATIVE PERFORMANCE OVERVIEW

The bus noise data presented here demonstrate that at under low-idle and high-idle operations there are relatively small differences (0 to 2 dBA) between conventional diesel, CNG and diesel-electric hybrid bus noise emissions. With air-conditioning on, the electric trolleybus was found to have low-idle noise levels of 60 dBA – approximately 5 dBA quieter than other technologies without air-conditioning on. Although measurements of electric trolleybus idle noise levels without air-conditioning were not available, the difference in idling noise levels may be greater than demonstrated here. Under wide-open-throttle operations, stationary noise levels of hybrid buses were shown to be 7 dBA quieter than conventional buses.

Measurements conducted according to SAE J366 show that there is little difference (0 to 2 dBA) between conventional diesel and hybrid buses. CNG buses have not been shown to be quieter than diesel and hybrid buses –in fact, measurements of the 60-foot articulated Neoplan CNG buses are shown to be 2 to 4 dBA louder than conventional and hybrid buses, respectively.

Under low-speed (below 40 mph) constant-speed pass bys, the differences in maximum noise levels among the different bus technologies are greatest. At 30 mph, hybrid buses are 3 dBA quieter than conventional diesel buses and electric trolleybuses are 10 dBA quieter than diesel buses. At speeds 40 mph and above, maximum noise levels for all bus technologies begin to converge as noise from the tire/pavement-interaction begins to dominate.

These data show that the electric trolleybuses have significantly lower noise levels than other technologies. While battery-electric buses are not very common, the same benefits of noise as well as the elimination of catenary/pantograph noise should be expected. While diesel-electric hybrid buses have been found to produce slightly lower noise emissions than conventional diesel buses, particularly under low-speed pass bys, the potential noise benefits of this technology do not seem to have been realized, yet. Differences in noise levels among bus manufacturers seem to be a significant factor—indicating that improvements to hybrid bus designs could prove to be effective in lowering noise levels from hybrid buses. Such design concepts may include better sound isolation of the diesel engine (since it does not require connection to the drive shaft with a series drive train design) or control systems to regulate the operation of the diesel engine in respect of noise.

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[ii] 2006 GM Corp. advertisement appearing in Washington Post announcing the delivery of 50 GM-powered hybrid buses to the Washington Metropolitan Area Transit Authority.

[iii] Source: American Public Transportation Association Survey, New Bus and Trolleybus Market by Power Source, 2005-2010.

[iv] Source: American Public Transportation Association Survey, Bus and Trolleybus Power Sources, 2006.

[v] Barrett, D.E., et al, "Metropolitan Transit Authority of Harris County Bus Noise Baseline Study", prepared for Metropolitan Authority of Harris County, August, 2004.

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Figure 3. Civis diesel-electric hybrid bus

Figure 4. MBTA electric trolley bus (Arnold Reinhold)