Preliminary Estimates of Emissions and Fuel Economy for MUNI's Advanced Technology Buses

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Objective

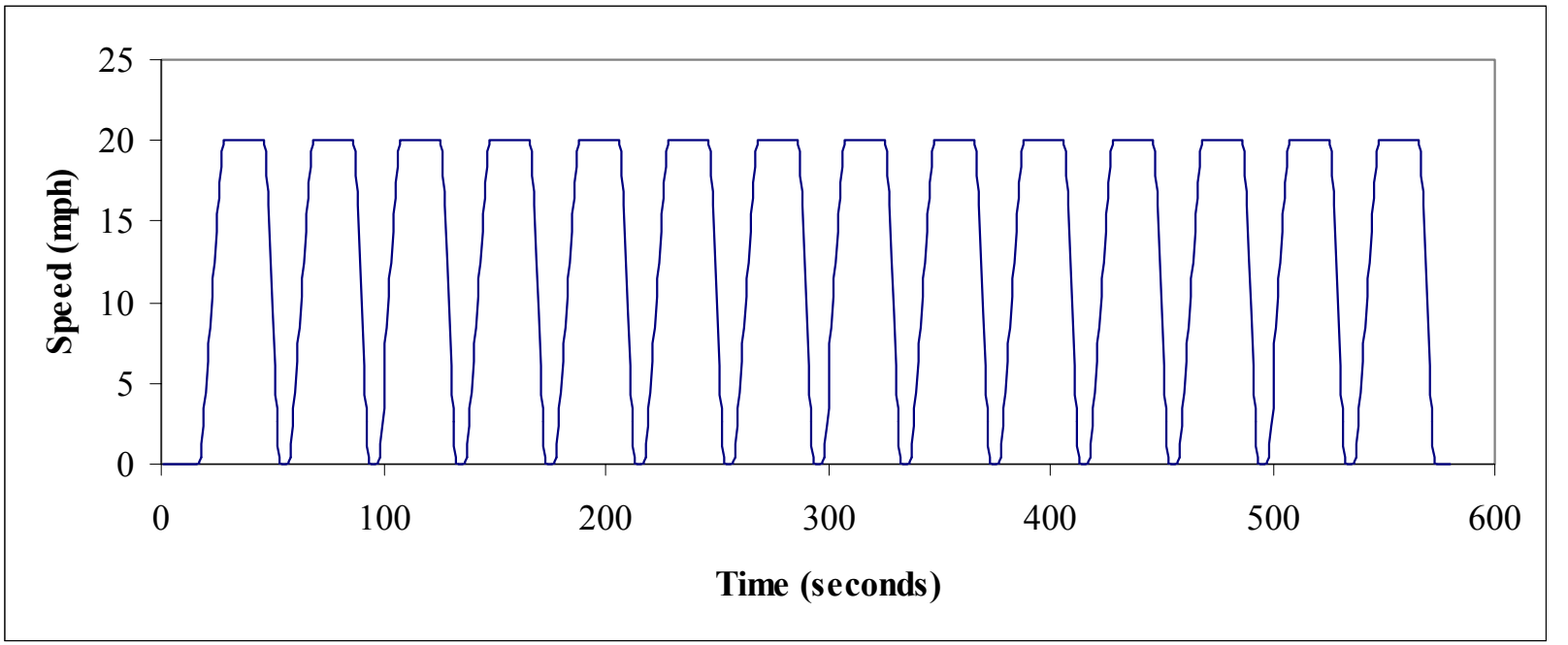
Measure and compare the mass emissions (carbon monoxide, oxides of nitrogen, hydrocarbons, and particulate matter) and energy efficiency of four types of buses: conventional diesel, conventional diesel with particulate trap, compressed natural gas, and hybrid-electric transit buses

Methodology

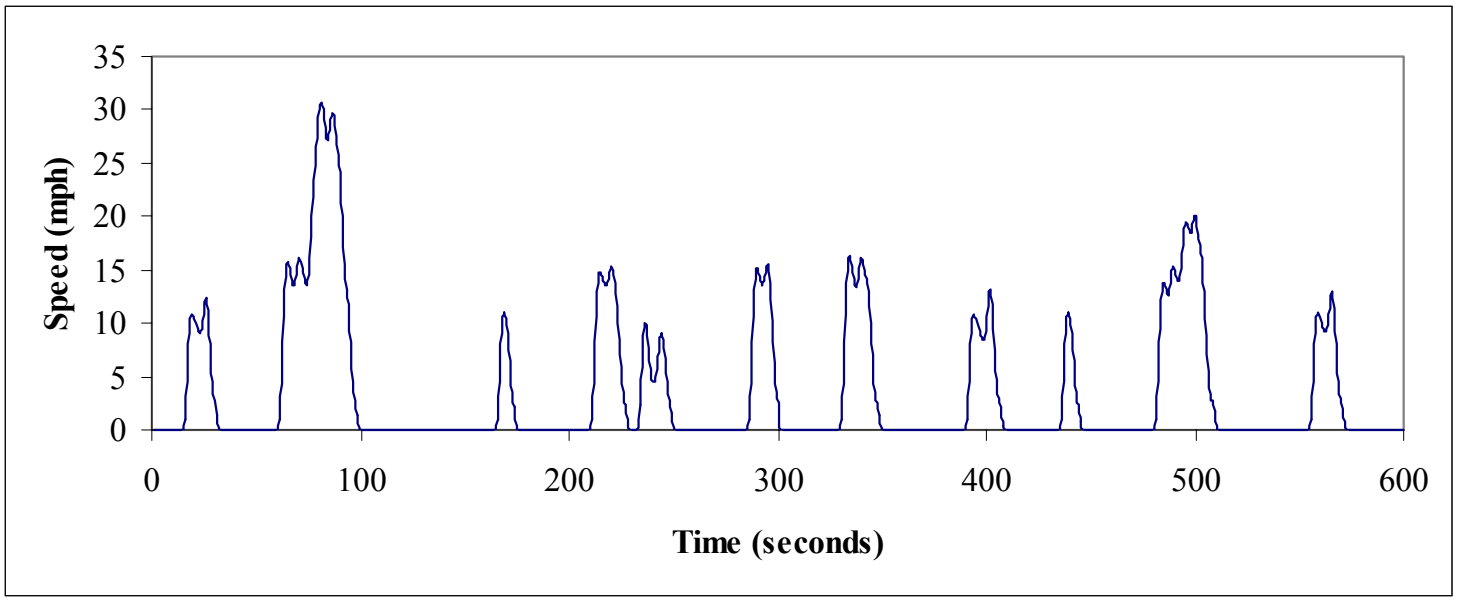
- Manage chassis dynamometer-based testing at the California Truck Testing Service
- Oversee testing using conventional driving cycle test protocols: the Central Business District (CBD) and New York Bus (NY Bus) Cycles, which have been used extensively in previous research
- Compare the results to those from other large advanced technology bus testing projects
- Design a SF specific test, conduct preliminary testing on this cycle, and compare to the results from other cycles

Dynamometer Testing

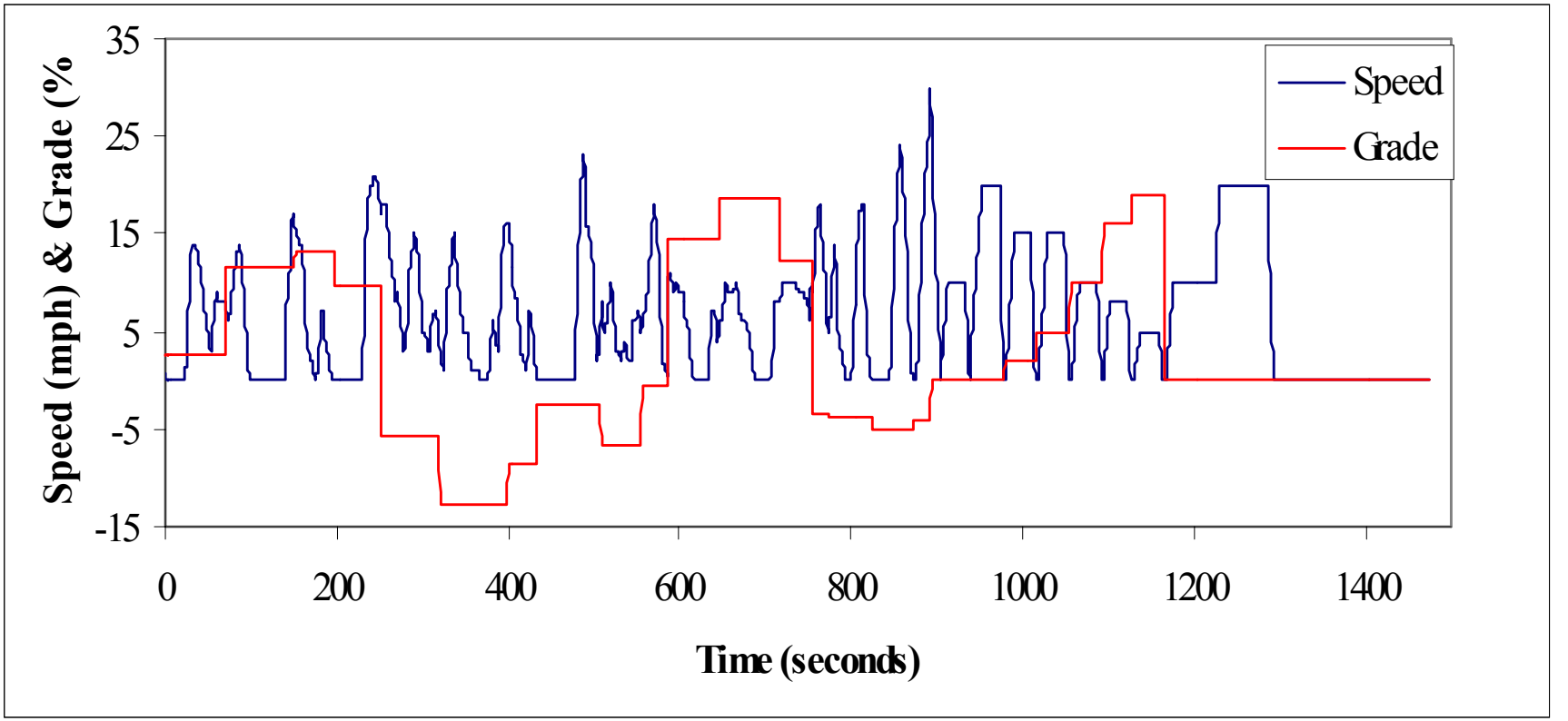
CBD Cycle



NY Bus Cycle


35
30
25
20
15
10
5
0
Speed (mph)
0
100
200
300
400
500
600
Time (seconds)

Preliminary SF Three Route Cycle



SF Three Route Cycle

	Characteristic	Value
Frequent stops/starts	time (s)	586
	distance (mi)	0.99
	avg V (mph)	6.08
	avg V w/o idle (mph)	8.20
	number of stops	4
	vehicles per hour	55
Long upgrade (17%)	time (s)	167
	distance (mi)	0.27
	avg V (mph)	5.84
	avg V w/o idle (mph)	7.43
	number of stops	2
	vehicles per hour	74
Low downgrade (3-5%)	time (s)	138
	distance (mi)	0.33
	avg V (mph)	8.76
	avg V w/o idle (mph)	11.07
	number of stops	2
	vehicles per hour	41

Comparison of Cycles

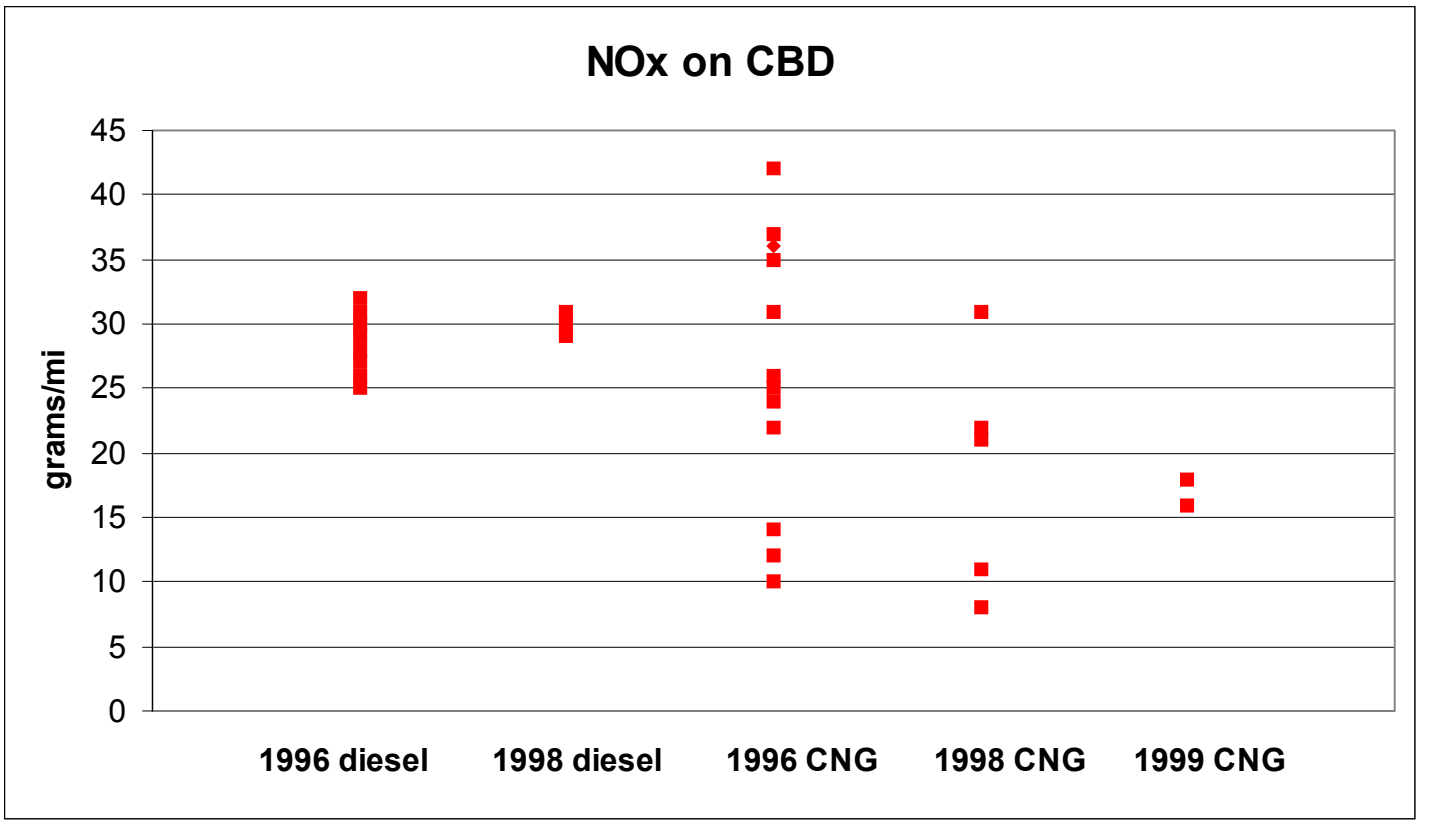
Parameter	CBD	NY Bus	SF 3-Route
time (sec)	574	600	1473
idle (%)	18	58	21
max speed (mph)	20	31	27
average speed (mph)	12.6	3.69	6.79
max accel (mph/s)	1.93	4.43	3.6
max decel (mph/s)	-3.73	-3.35	-1.75
total distance (mi)	2	0.61	2.78

Phase 1 Uncertainties

- Typical variation between tests
- Representativeness of test procedure
- Passenger load
- Correction for SOC
- SF driving cycle inconsistency
- Sulfur interference with trap
- Testing complexity

Variation

“There are no absolutes when referring to bus emissions”



MUNI Preliminary Results v. Other Studies

1) Hybrid and CNG buses offered substantially reduced emissions compared to conventional diesel buses

2) CNG buses demonstrated the lowest NOx emissions followed by the hybrid buses, and then the diesel buses with traps

3) PM emission of CNG, hybrid, and diesel buses with traps were comparable and often below the detectable limits

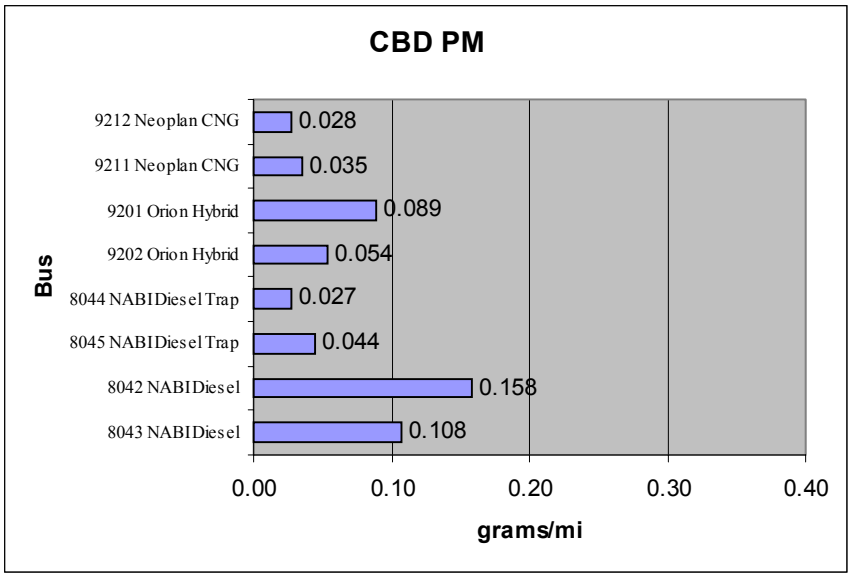
4) Diesel buses exhibited the best fuel economy of any bus; hybrid buses had superior fuel economy during demanding cycles

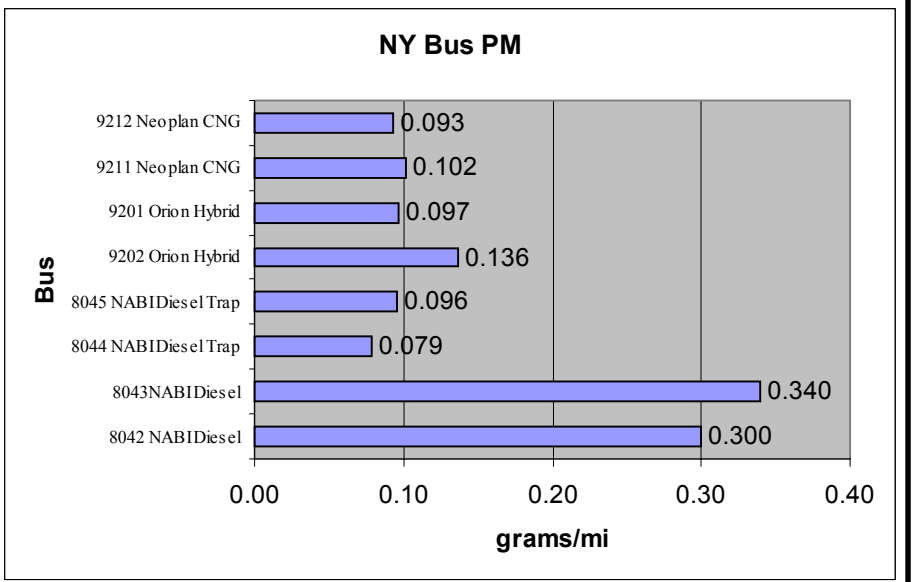
5) CNG buses had the highest CO emissions of any bus

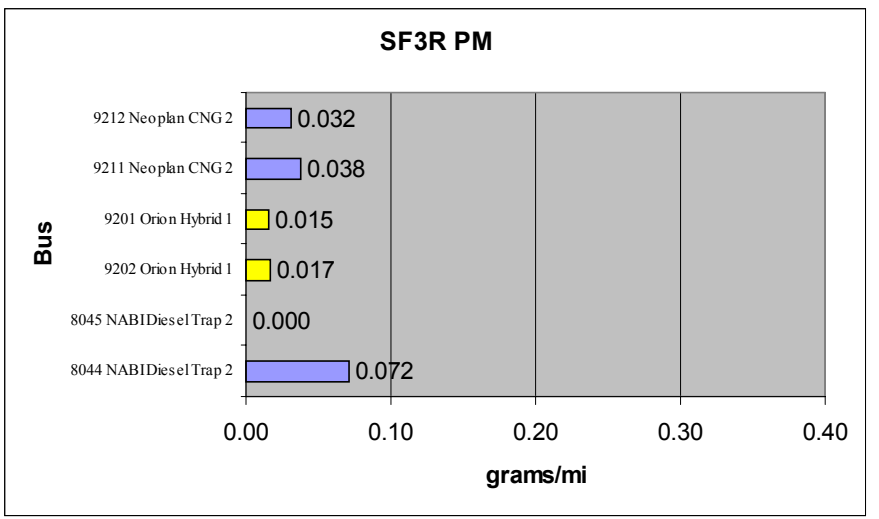
PM

- The detectable limit for PM is approximately 0.05 grams per mile
- On the CBD Cycle, the CNG, hybrid, and diesel bus with trap each had very low PM emissions in the 0.05 range
- PM levels were similarly low for the SF Cycle
- On the NY Bus Cycle, PM emissions of the three buses were again very similar
- As expected PM for all buses was higher on the NY Bus Cycle than on the CBD Cycle

PM





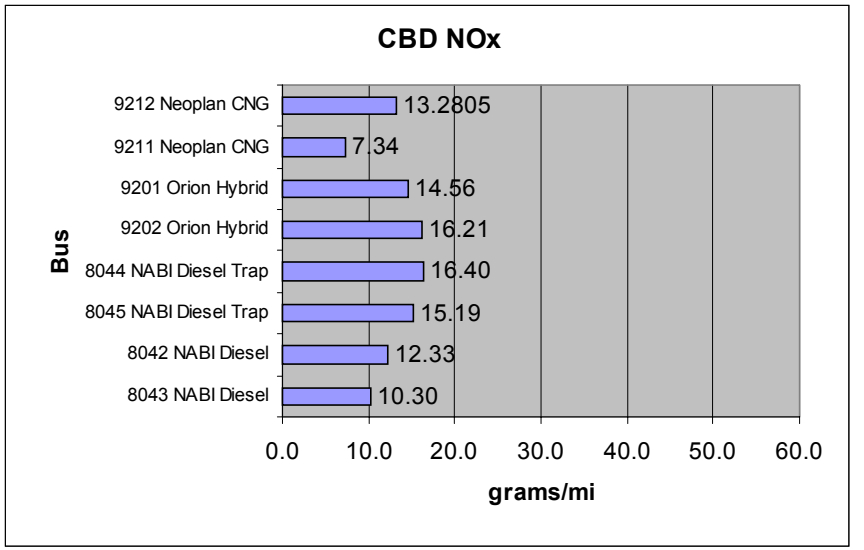


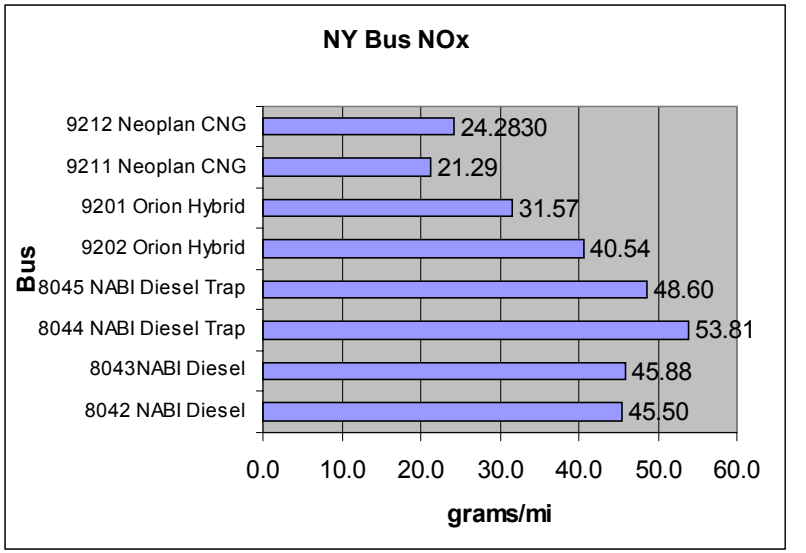
Note: possible effects of sulfur in fuel

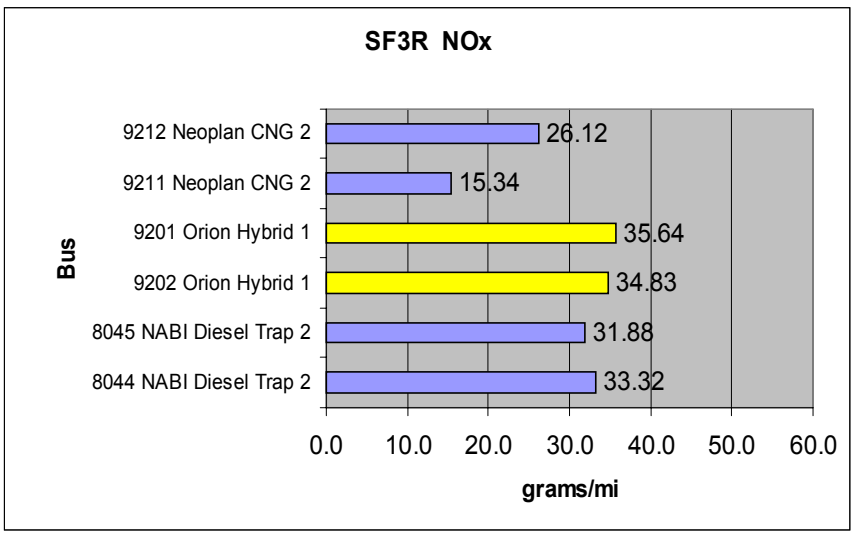
NOx

- The CNG buses demonstrated the lowest NOx emissions followed by the hybrid buses
- On the CBD and NY Bus Cycles, the NOx emissions from the diesel buses and the diesel buses with trap are expected to be similar because the trap does not remove a significant amount of NOx
- We observed that the conventional diesel buses had lower NOx emissions than the hybrid buses; however, this is likely a testing anomaly

NOx


CBD NOx
9212 Neoplan CNG
9211 Neoplan CNG
9201 Orion Hybrid
9202 Orion Hybrid
8044 NABI Diesel Trap
8045 NABI Diesel Trap
8042 NABI Diesel
8043 NABI Diesel
13.2805
7.34
14.56
16.21
16.40
15.19
12.33
10.30
Bus
0.0
10.0
20.0
30.0
40.0
50.0
60.0
grams/mi


NY Bus NOx
9212 Neoplan CNG
9211 Neoplan CNG
9201 Orion Hybrid
9202 Orion Hybrid
8045 NABI Diesel Trap
8044 NABI Diesel Trap
8043NABI Diesel
8042 NABI Diesel
24.2830
21.29
31.57
40.54
48.60
53.81
45.88
45.50
Bus
0.0
10.0
20.0
30.0
40.0
50.0
60.0
grams/mi


SF3R NOx
9212 Neoplan CNG 2
9211 Neoplan CNG 2
9201 Orion Hybrid 1
9202 Orion Hybrid 1
8045 NABI Diesel Trap 2
8044 NABI Diesel Trap 2
26.12
15.34
35.64
34.83
31.88
33.32
Bus
0.0
10.0
20.0
30.0
40.0
50.0
60.0
grams/mi

HC and CO

- CNG buses had by far the highest CO emissions of any bus. Other buses, including the diesel, produced very low CO emissions
- In many areas, CO emissions are not a large concern any longer and the emissions contribution of diesel vehicles in general is small
- Emissions of methane and non-methane are being analyzed
- Many of the HC emissions were within the detection limits of the instruments

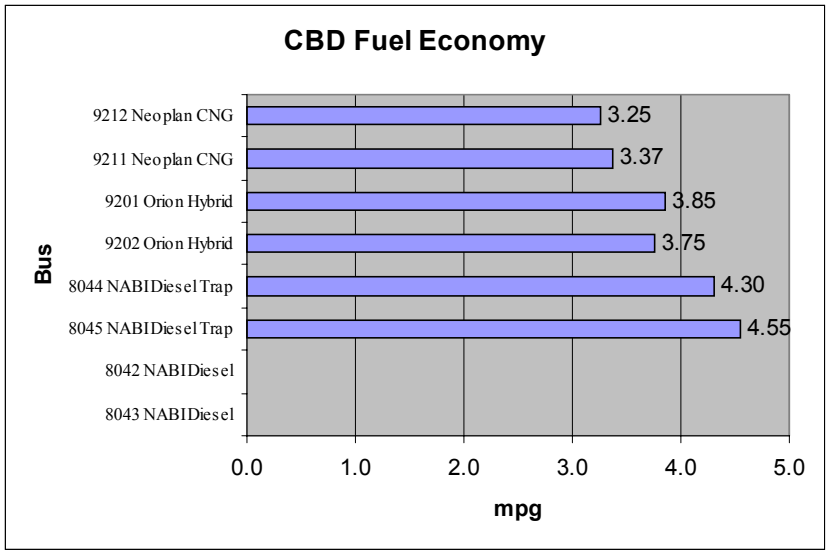
Fuel Economy

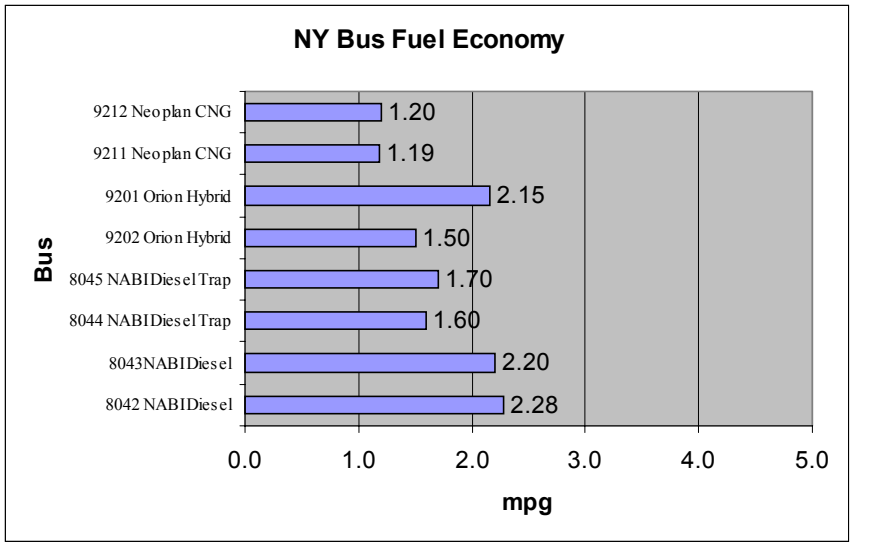
- As expected, fuel economy was poorest for the CNG bus and best for the conventional diesel vehicle
- Fuel economy was much better on the CBD Cycle than on the more demanding NY Bus and SF Cycle
- Although the diesel bus with trap had superior fuel economy, the CNG, hybrid, and diesel trap buses exhibited much less difference in fuel economy on the SF Cycle than on the other test cycles

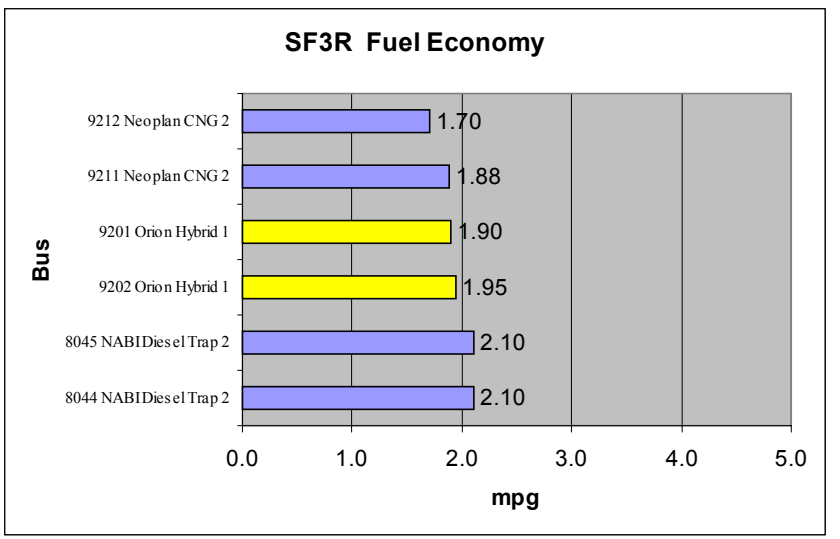
Fuel Economy

- Fuel economy from the diesel bus and the diesel bus with trap were expected to be similar since properly operating traps do not affect fuel economy
- The results of the SF Cycle are consistent with this expectation. However, the buses with traps were more than 20% less efficient than the conventional buses on the NY Bus Cycle

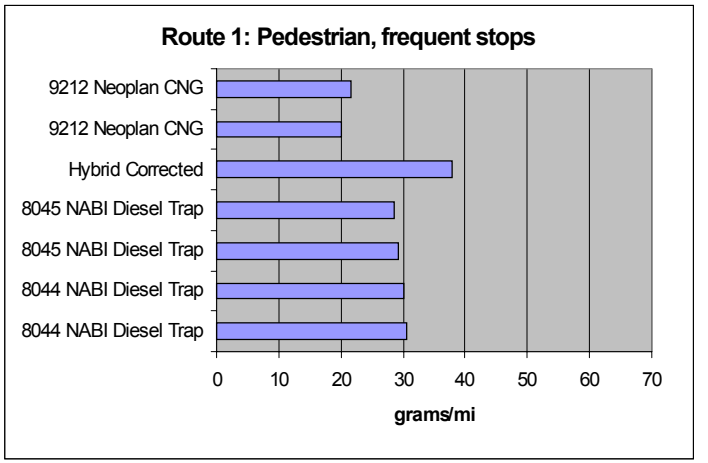
Fuel Economy

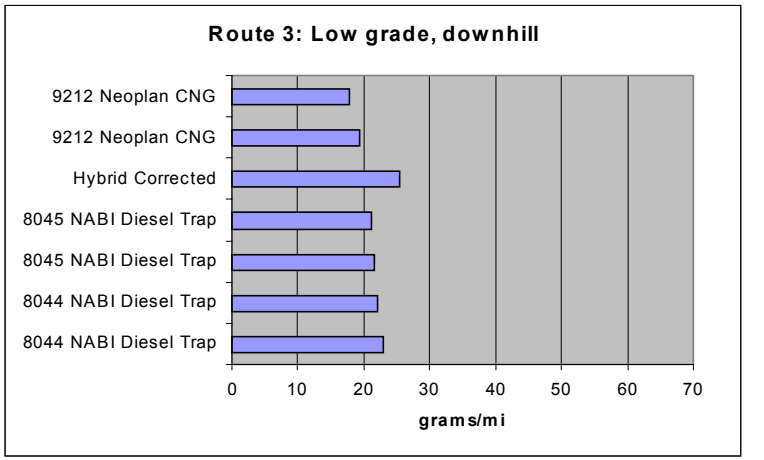


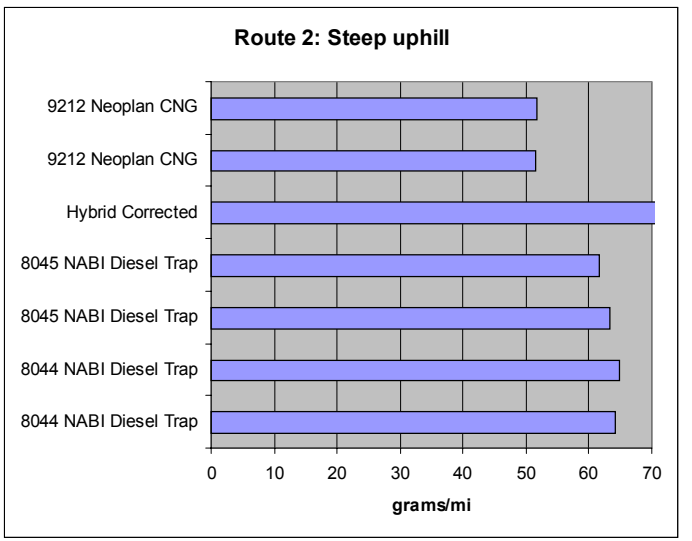


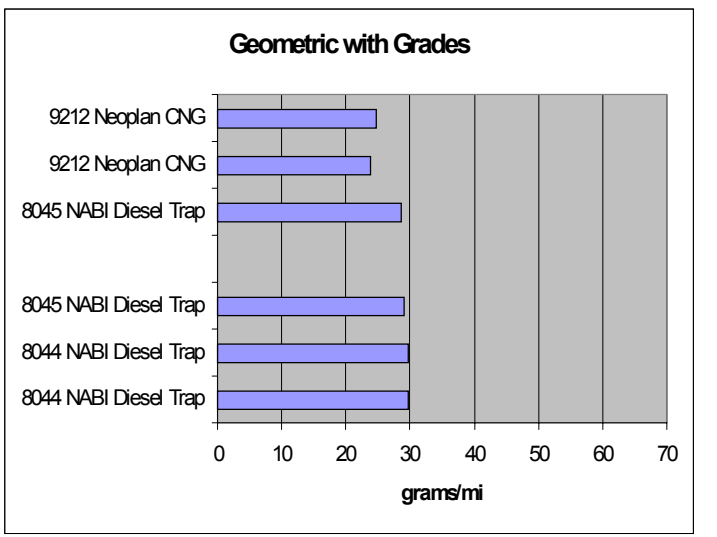


NOx on San Francisco Routes

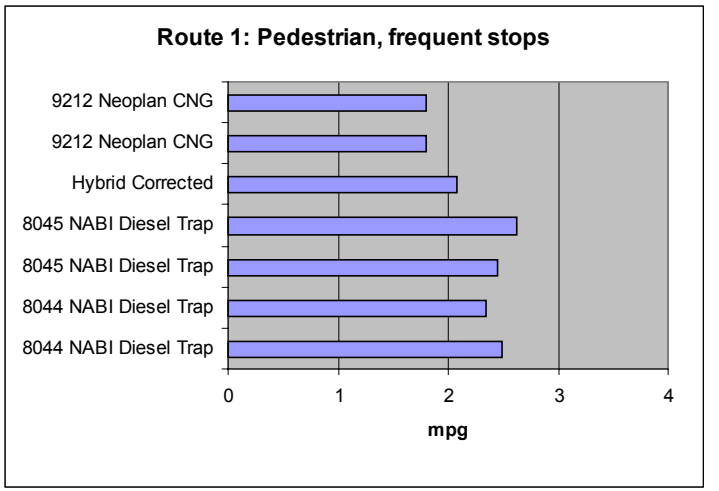


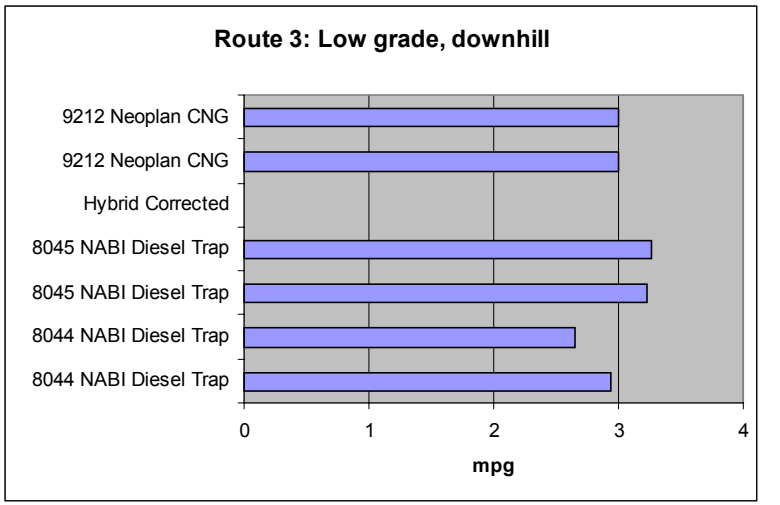


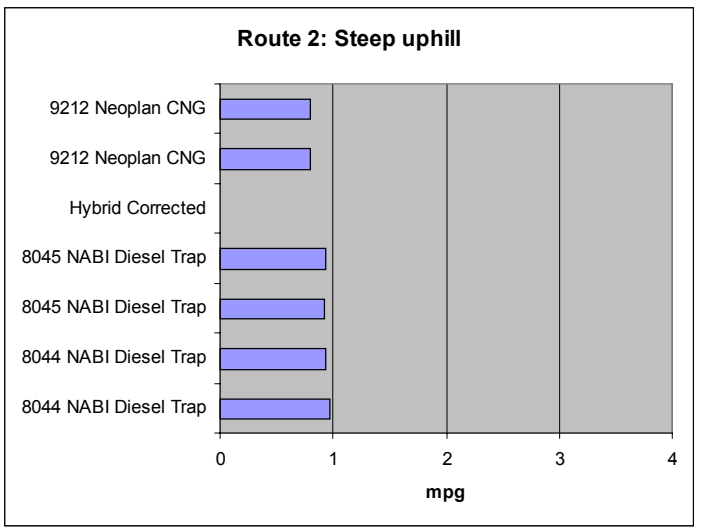


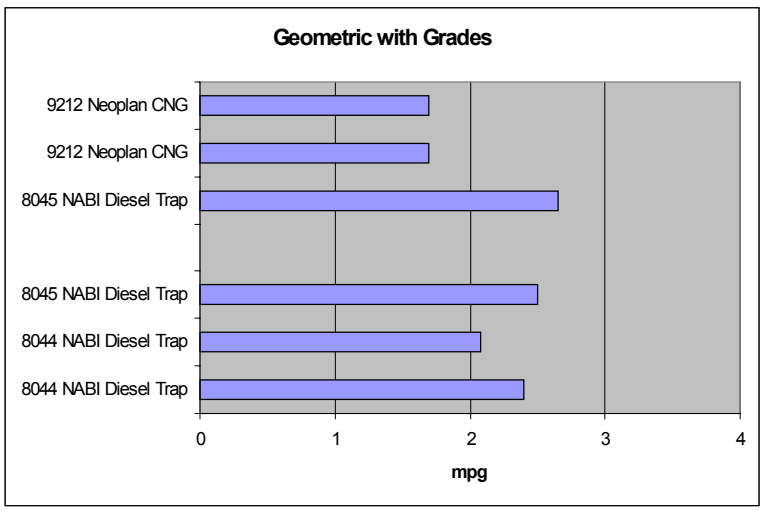


Fuel Economy on San Francisco Routes









Conclusions

Preliminary testing on conventional driving cycles indicated that.....

- The hybrid, CNG, and diesel buses with traps offered greatly reduced emissions compared to conventional diesel buses
- The CNG buses demonstrated the lowest NOx emissions followed by the hybrid buses, and the diesel buses with traps
- PM emission of CNG, hybrid, and diesel buses were similar and often at the detectable limits

Conclusions

- Diesel buses had the best fuel economy
- Hybrid buses had better fuel economy than CNG buses during demanding cycles
- CNG buses had by the highest CO emissions of any bus and inferior fuel economy
- These results were consistent with previous research

Conclusions

- Many of these results will likely hold true for San Francisco as a whole, however, preliminary evidence suggests that differences in emissions and fuel economy between bus types may be less for San Francisco than on the established cycles
- For localized operations, especially those on grade, we anticipate greatly increased emissions and different relationships between the buses
- A San Francisco-specific driving cycle is being developed to determine emissions for buses in San Francisco

Conclusions

- There is a significant level of uncertainty in this these preliminary results
- Testing issues that need to be addressed in the next round include consistent use of low sulfur fuel, final design of the hybrid bus, controlled and representative passenger load, and development of a representative driving cycle