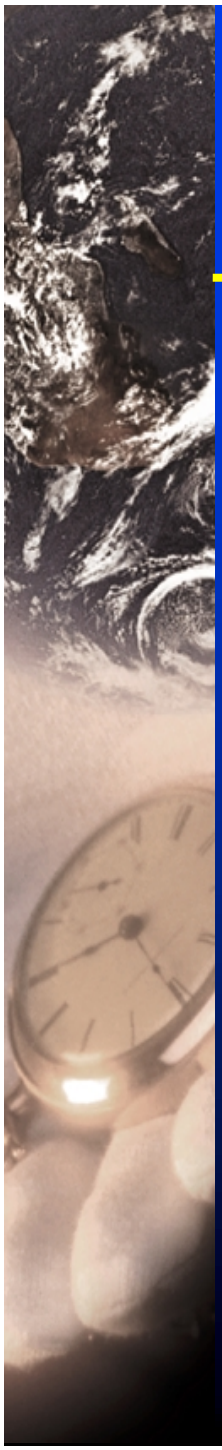


Natural Gas Buses: Separating Myth from Fact

Paul Norton

National Renewable Energy Laboratory

Center for Transportation Technologies and Systems

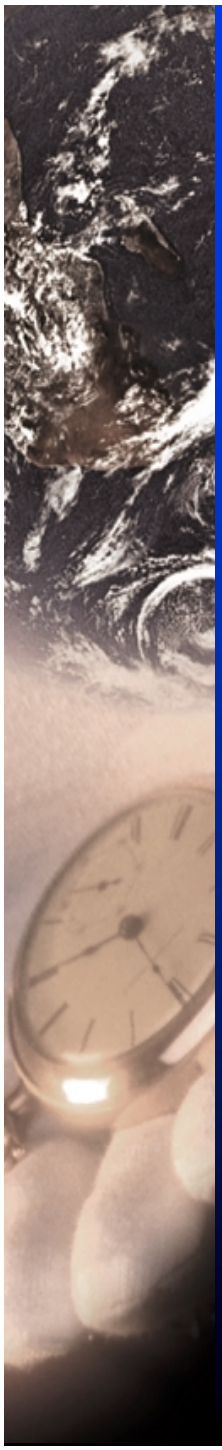
David Rodgers and Dennis Smith

U.S. Department of Energy

Office of Technology Utilization

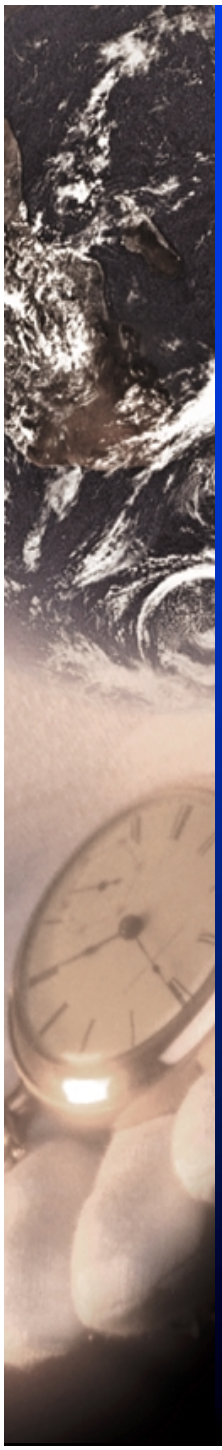
"Get on Board"

A South Coast Air Basin Alternative Fuel & Electric Transit Bus Workshop



Myth

CNG buses emit as much particulate matter (PM) as diesel buses



Fact

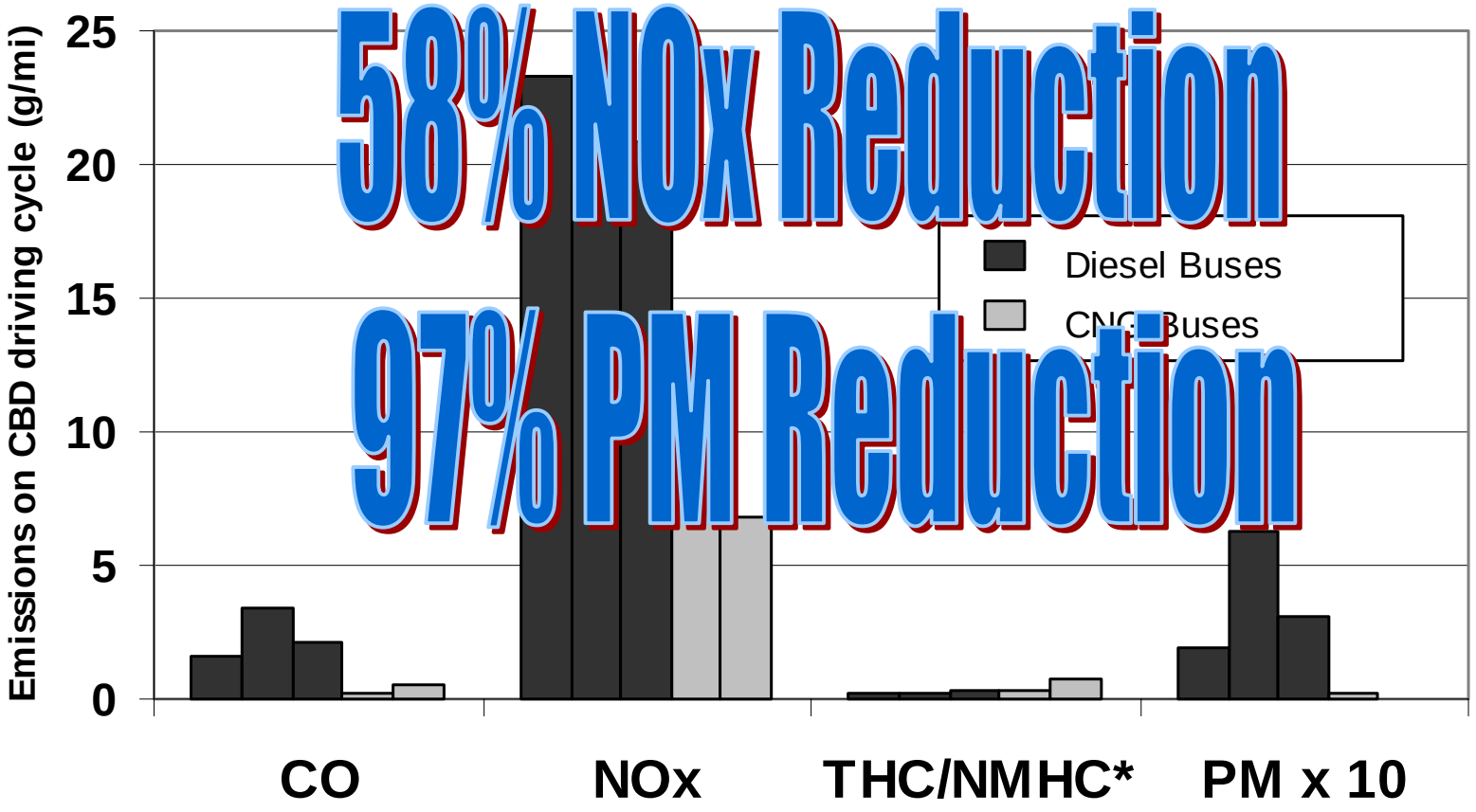
In chassis dynamometer testing by the West Virginia University, CNG buses consistently emit dramatically less particulate matter (PM) than diesel buses.

WVU Transportable Chassis Dynamometer

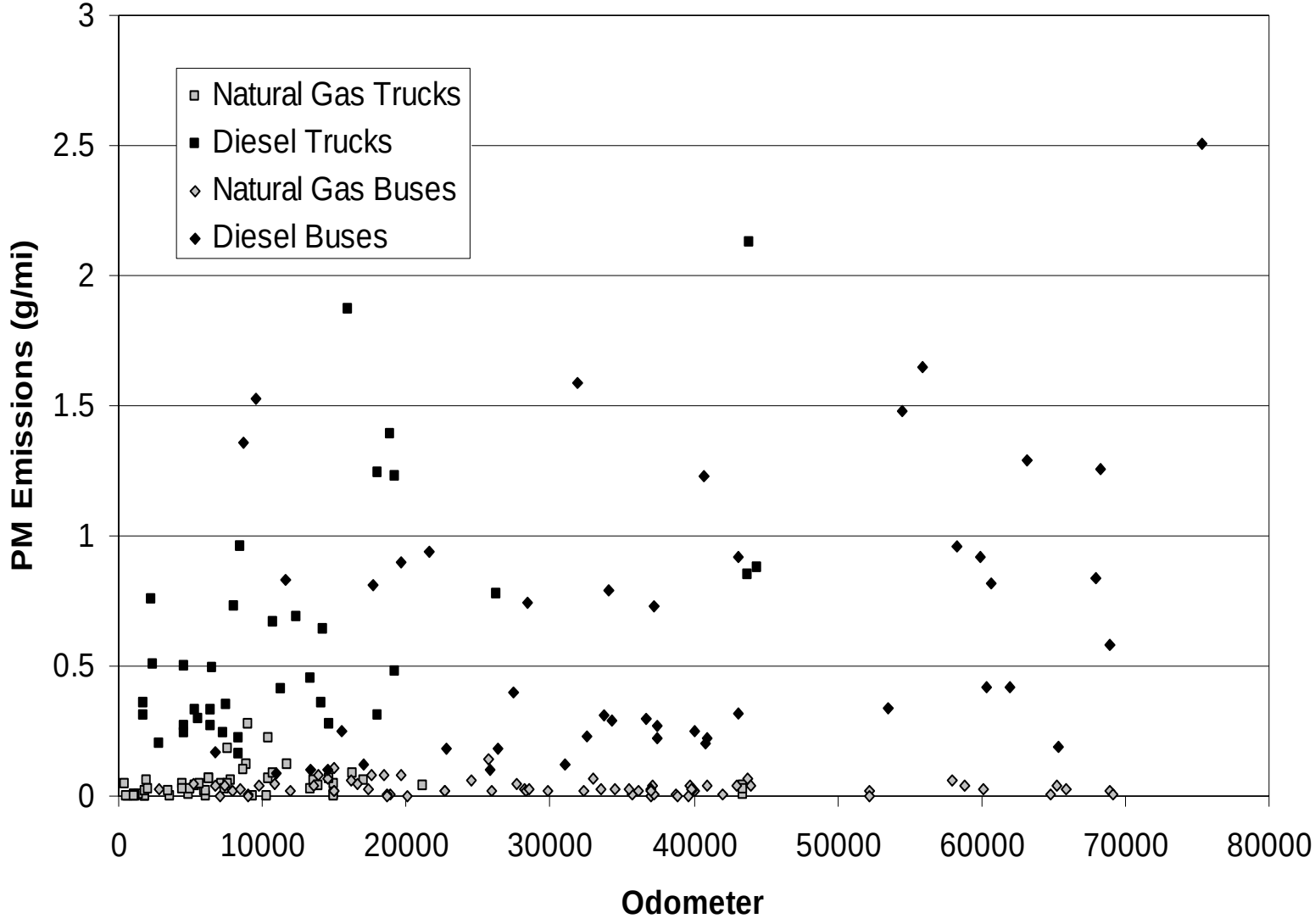
WVU Transportable Chassis Dynamometer

Boulder SKIP Buses

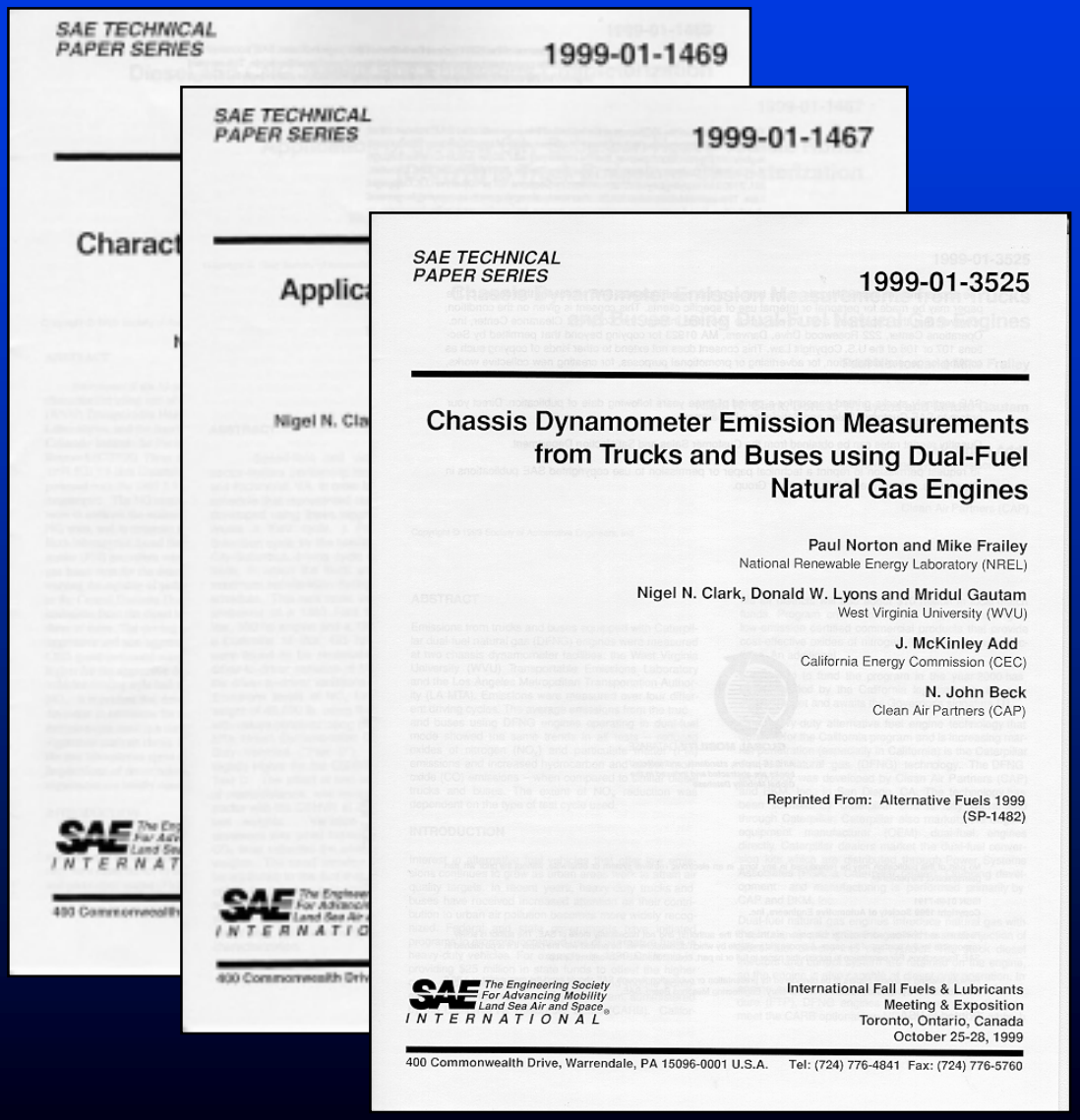
Emissions from Boulder, Colorado CNG and Diesel Buses
(Cummins B5.9G and ISB engines)

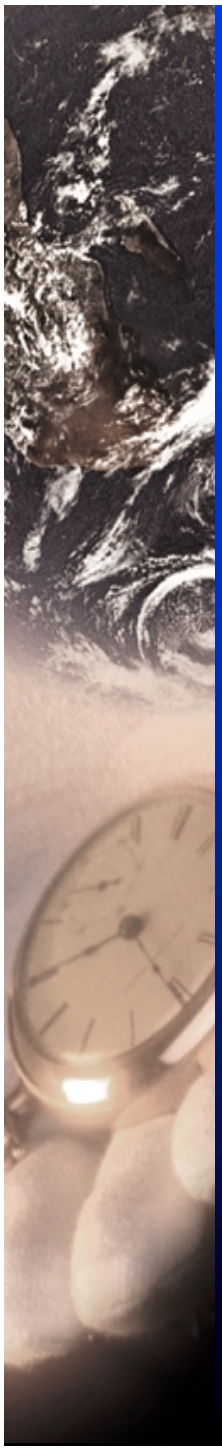


PM Emissions 1994 - present



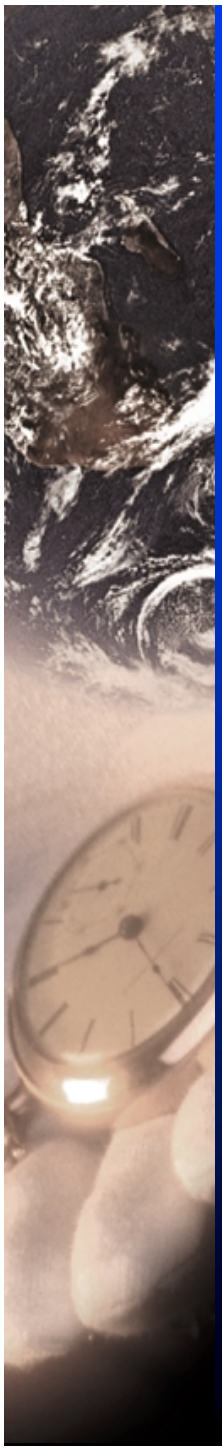
Publications of Emissions Results





Myth

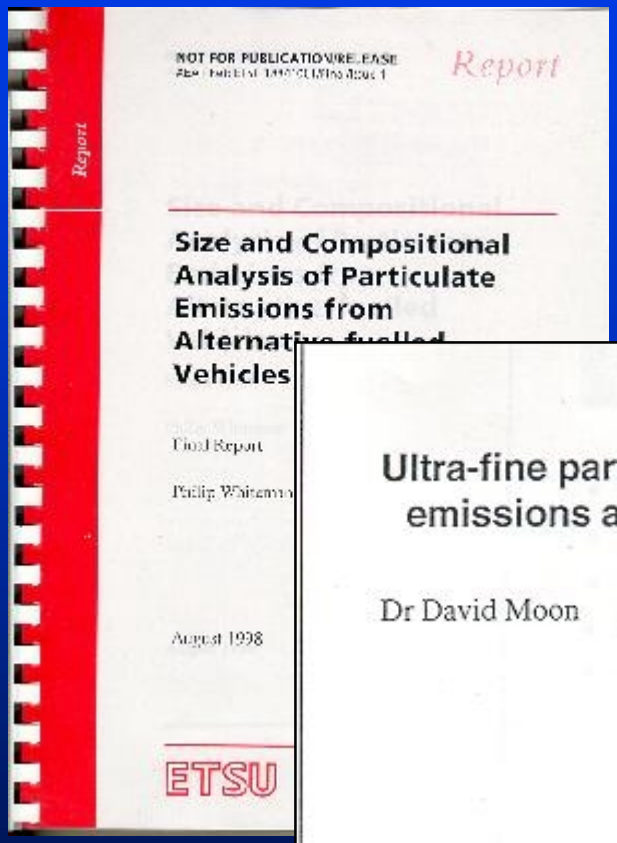
There is conclusive data showing that CNG buses emit more ultrafine particles than diesel buses

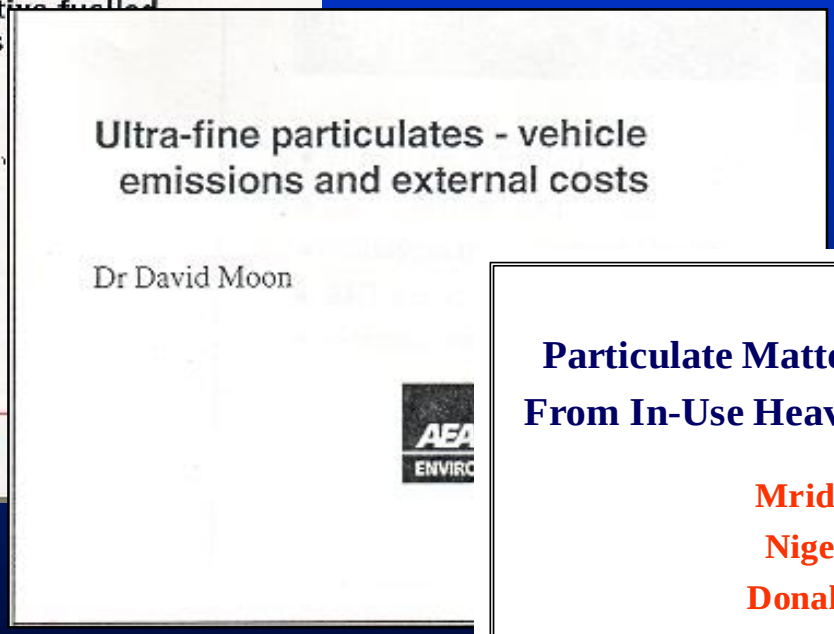


Fact

Particle size distribution measurement ultra fine particle counting are developing technologies and initial data is mixed.

PM Sizing Studies





Windsor Worksh

Particulate Matter and NO_X Emissions From In-Use Heavy-Duty Diesel Vehicles

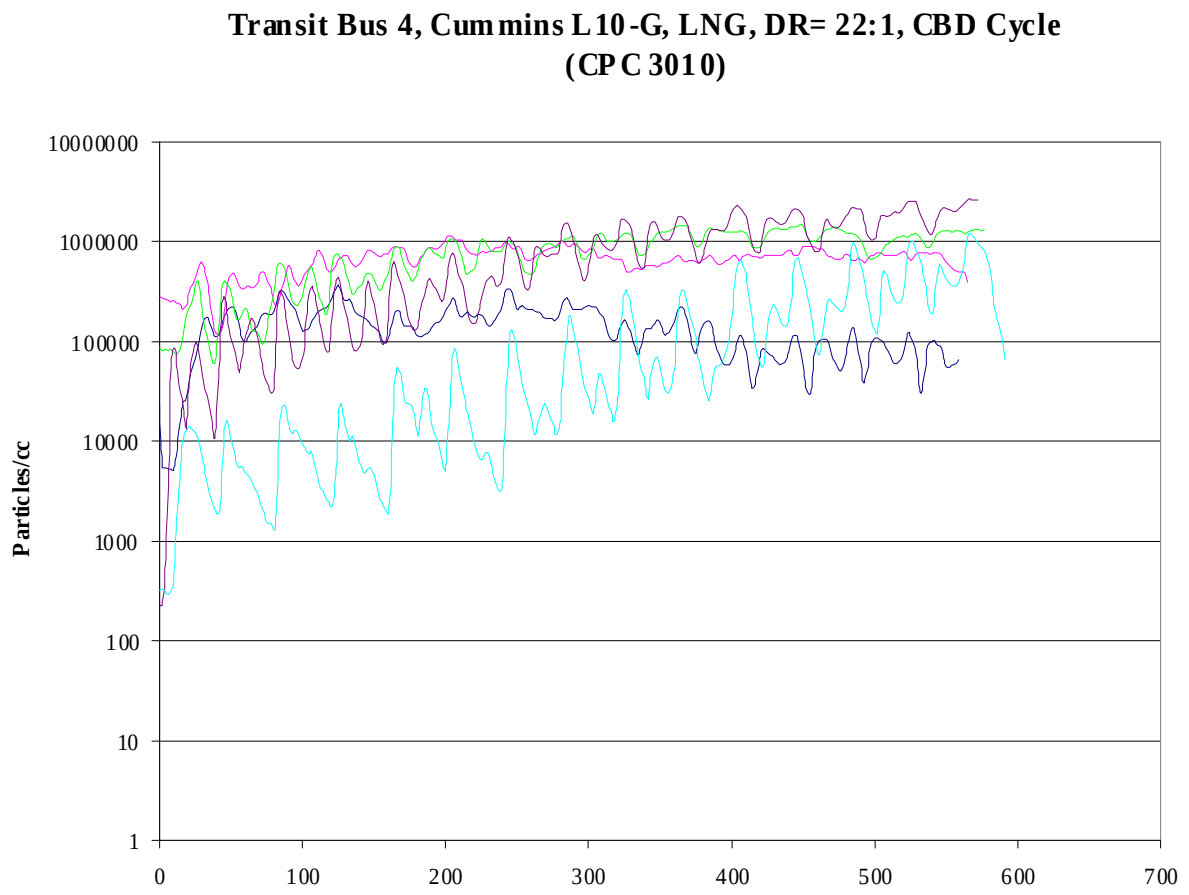
Mridul Gautam
Nigel N. Clark
Donald W. Lyons

National Research Center for Alternative Transportation Fuels, Engines and Emissions

West Virginia University, Morgantown, WV 26506 | Department of Mechanical and Aerospace Engineering | College of Engineering and Mineral Resources

World Truck Conference 1999

WVU Presentation

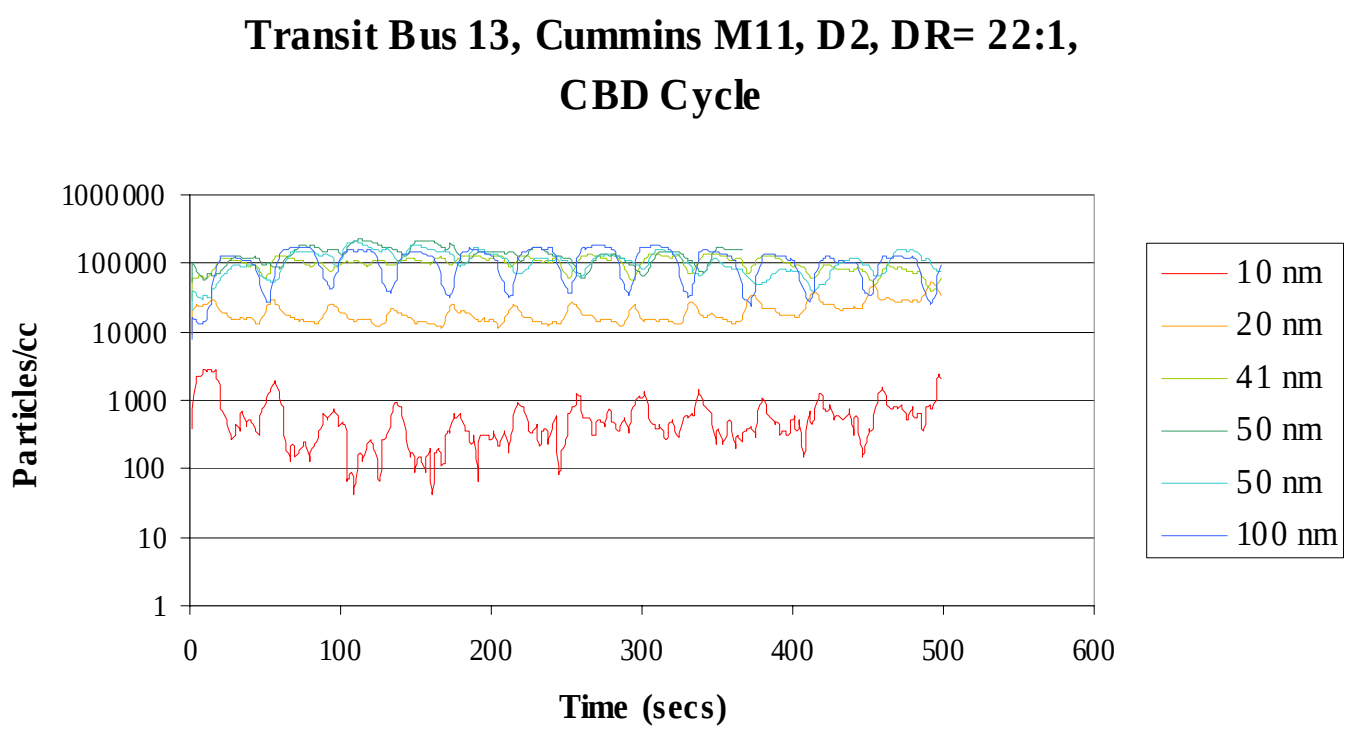


West Virginia University

College of Engineering and Mineral Resources

CEMR

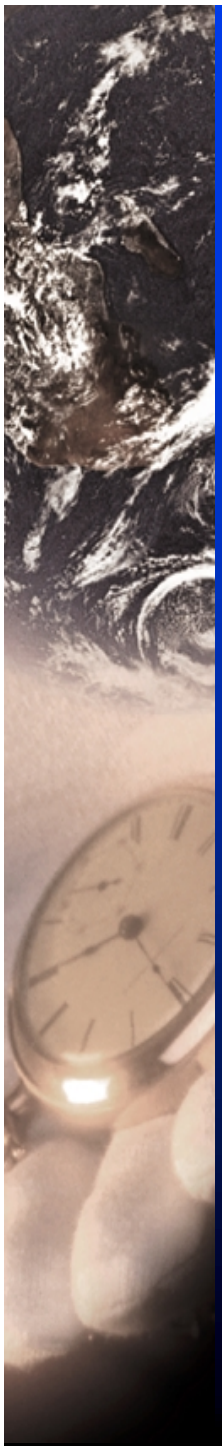
WVU Presentation



West Virginia University

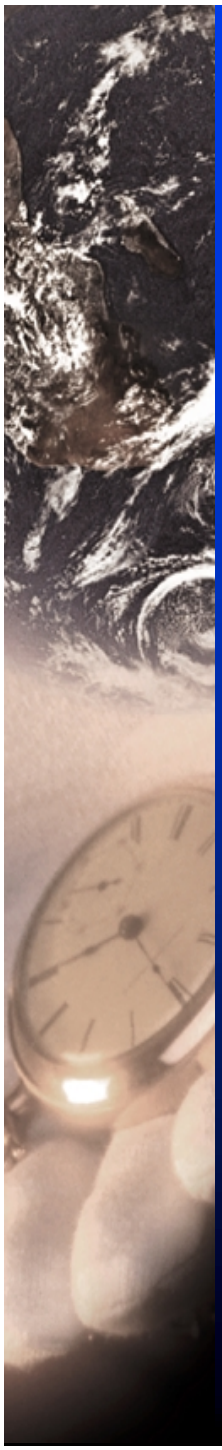
College of Engineering and Mineral Resources

CEMA



WVU Presentation

- “CNG vehicles exhibit very low PM mass emission rates. But, number count of nanoparticles may be very high.”

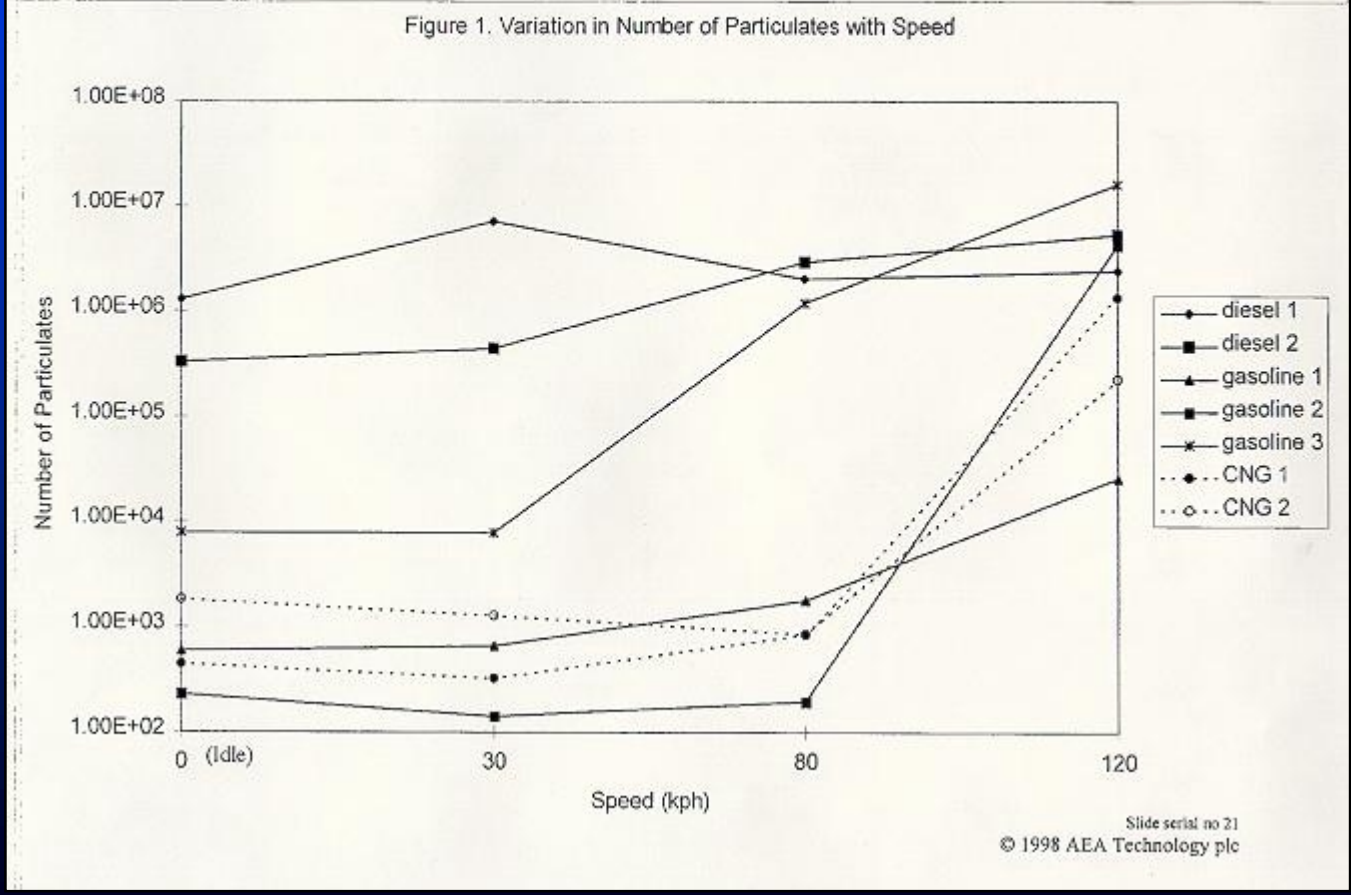


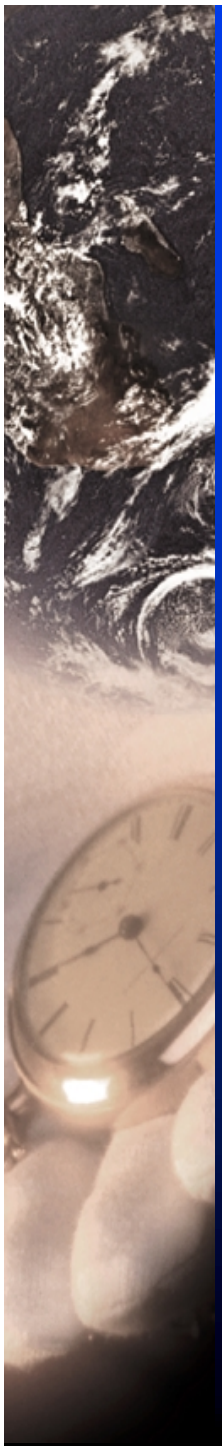
ETSU Study Findings

- Studied a dedicated CNG Chrysler Caravan and a
- The CNG van "…produced remarkably low particle emissions, in terms of overall mass."
- "For the greater part, the mean size of the particles emitted was found to be similar to those from gasoline vehicles"
- However, CNG "..produced large numbers of small particles at a high, steady road speed"
- "It must be said that the original set of LPG data…look very odd…." "… they suggest a peak particle size of 10 nm or less." "the repeat LPG runs…peak size … is similar to that found in the past for gasoline engines.."

AEA Presentation

Particulate sizing for CNG (Greenwood et al 1996)





AEA Presentation

- Diesel vehicles emitted at least 10-times as many particles at idle than spark ignited engines
- CNG vehicles emitted fewer particles than diesel up to about 120 kph (75 mph) at which point “For the CNG vehicles, the number of particles emitted is of the same order as for the diesel vehicles.”
- “Lubricating oil combustion may account for a significant proportion of the total amount of particulate produced when operating on gaseous fuels.”

EPA PM Sampling Methods Report

REVIEW OF DIESEL PARTICULATE MATTER SAMPLING METHODS

FINAL REPORT

Prepared by

[redacted]

[redacted]

January 31, 2003

"Recent laboratory tests… showed that a prototype, low-emission [diesel] engine produced increased numbers of nanoparticles when tested under laboratory conditions, however it is unclear whether this increase was due to the engine or to the laboratory test conditions."

http://www.me.umn.edu/centers/cdr/Proj_EPA.html

EPA PM Sampling Methods Report

Size distribution depends on….

- Engine type
- Instrumentation used
- Method of dilution
- Dilution ratio
- Temperature of dilution air
- Composition of dilution air
- Particle residence time in system
- Chemical composition of exhaust
- etc.

http://www.me.umn.edu/centers/cdr/Proj_EPA.html

EPA PM Sampling Methods Report

REVIEW OF DIESEL PARTICULATE MATTER SAMPLING METHODS

FINAL REPORT

Prepared by

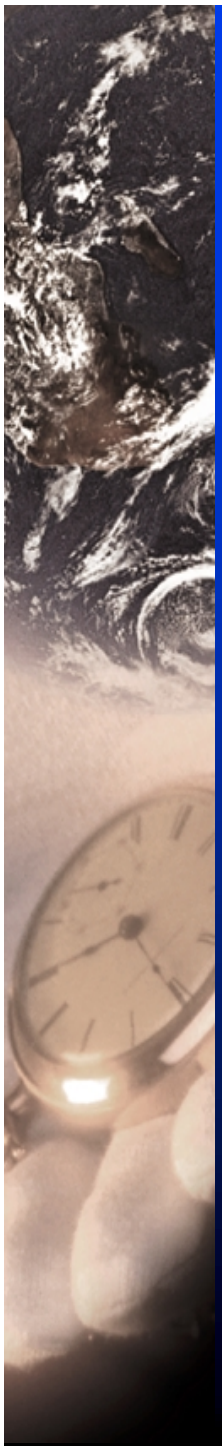
[redacted]

[redacted]

January 31, 2005

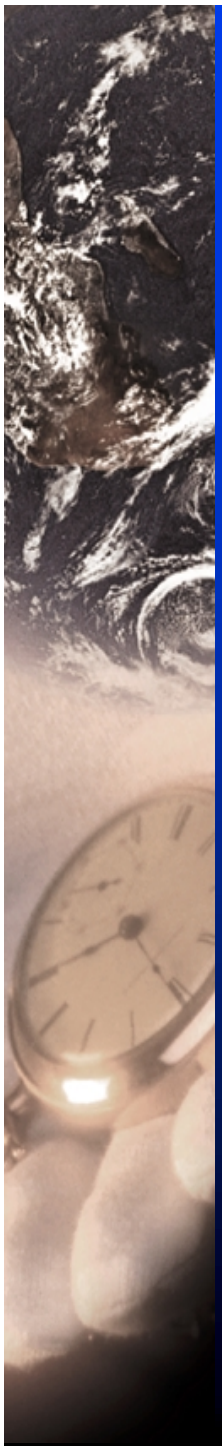
"The strongest driving force for gas to particle conversion occurs in the critical dilution ratio range (5-50:1), roughly the same range produced by the typical laboratory dilution tunnel system 3-20:1. These conditions are not representative of real-world conditions."

http://www.me.umn.edu/centers/cdr/Proj_EPA.html



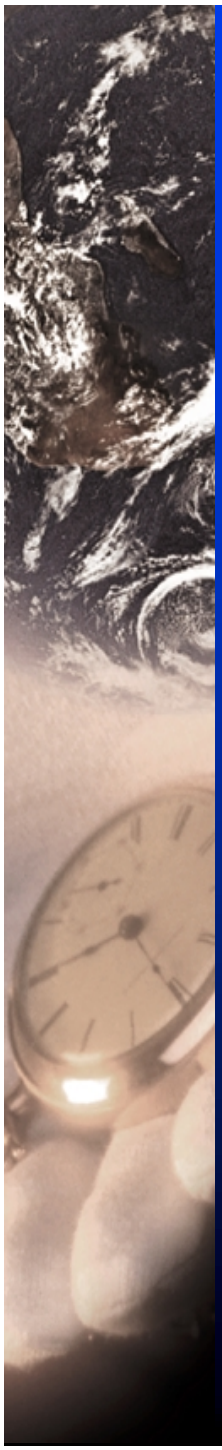
Myth

Buses with modern diesel technology can now match the emissions of a natural gas bus.



Fact

Some diesel technology under development can match the particulate matter emissions of current commercial natural gas buses



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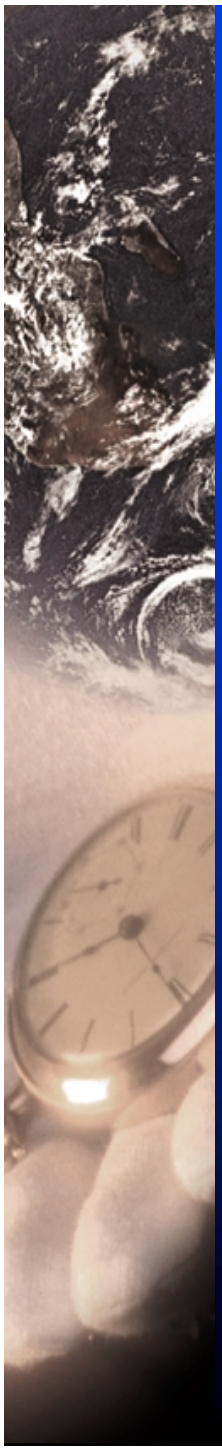

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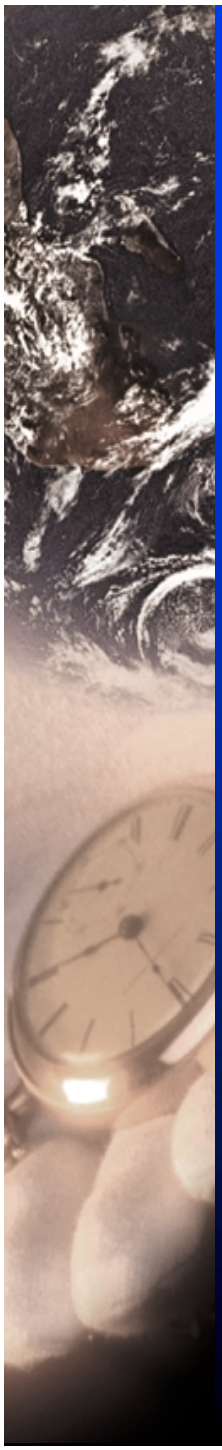
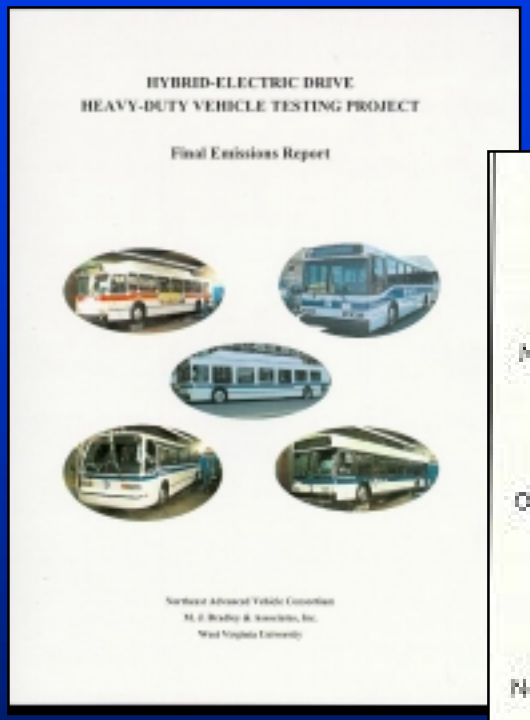
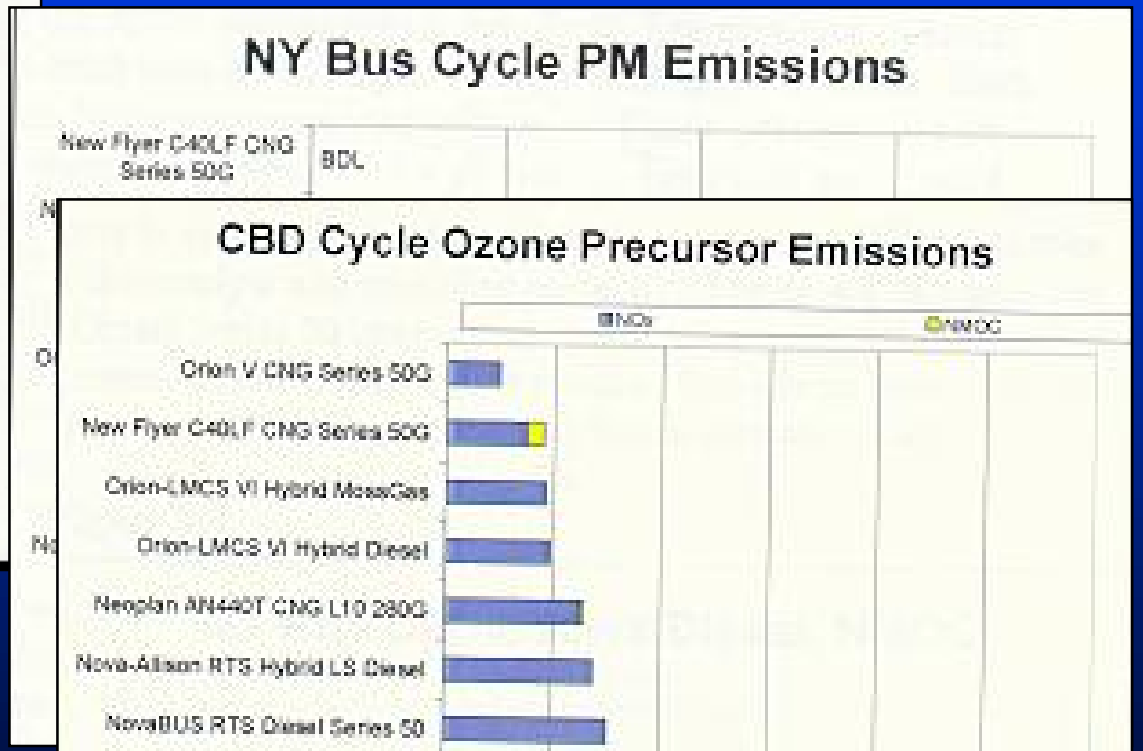


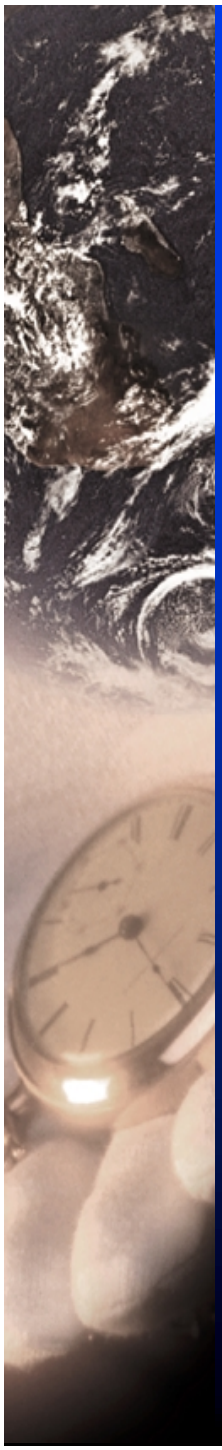
Fact

Some diesel technology under development can match the particulate matter emissions of current commercial natural gas buses

NAVC Hybrid Bus Report



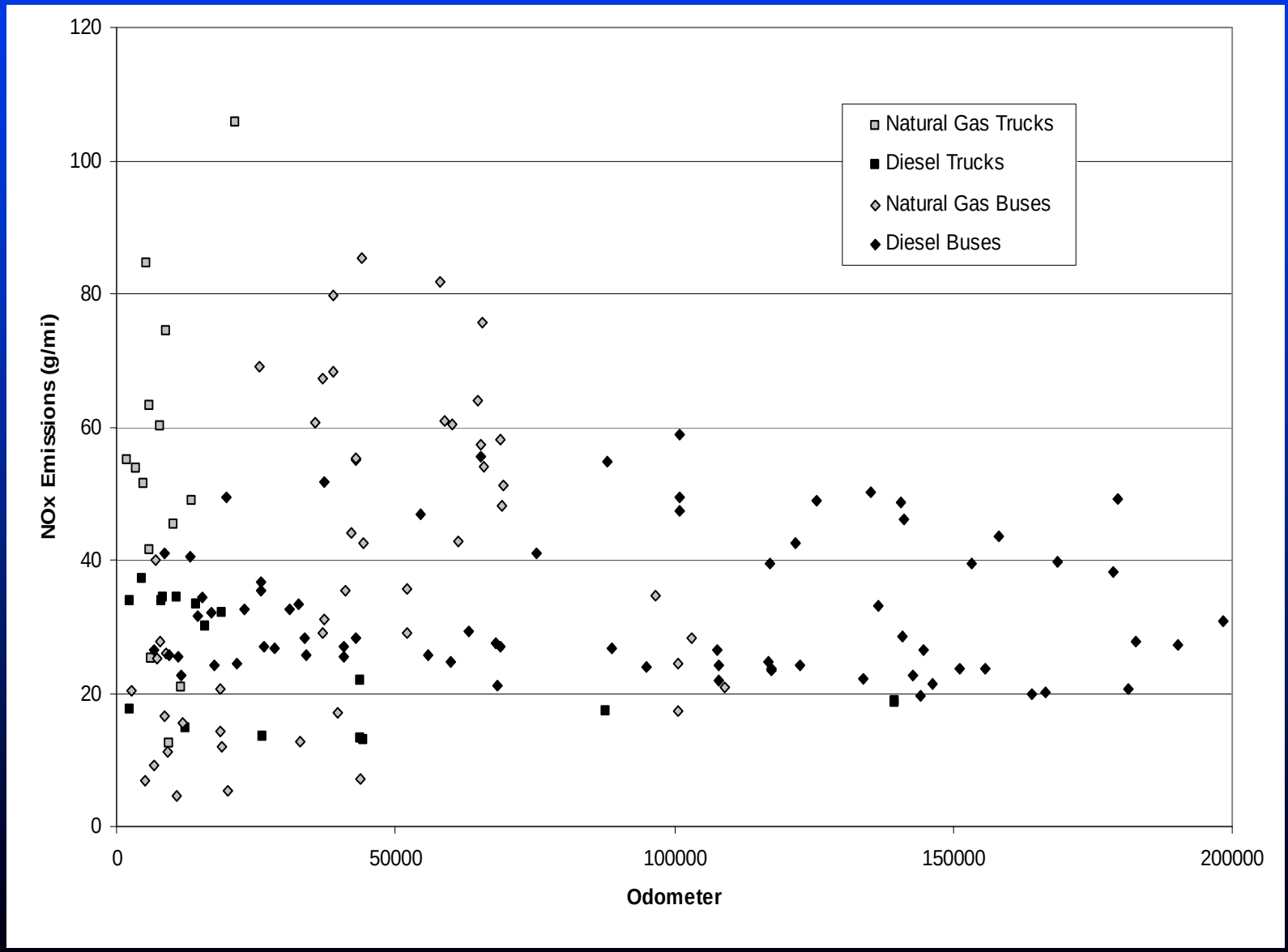




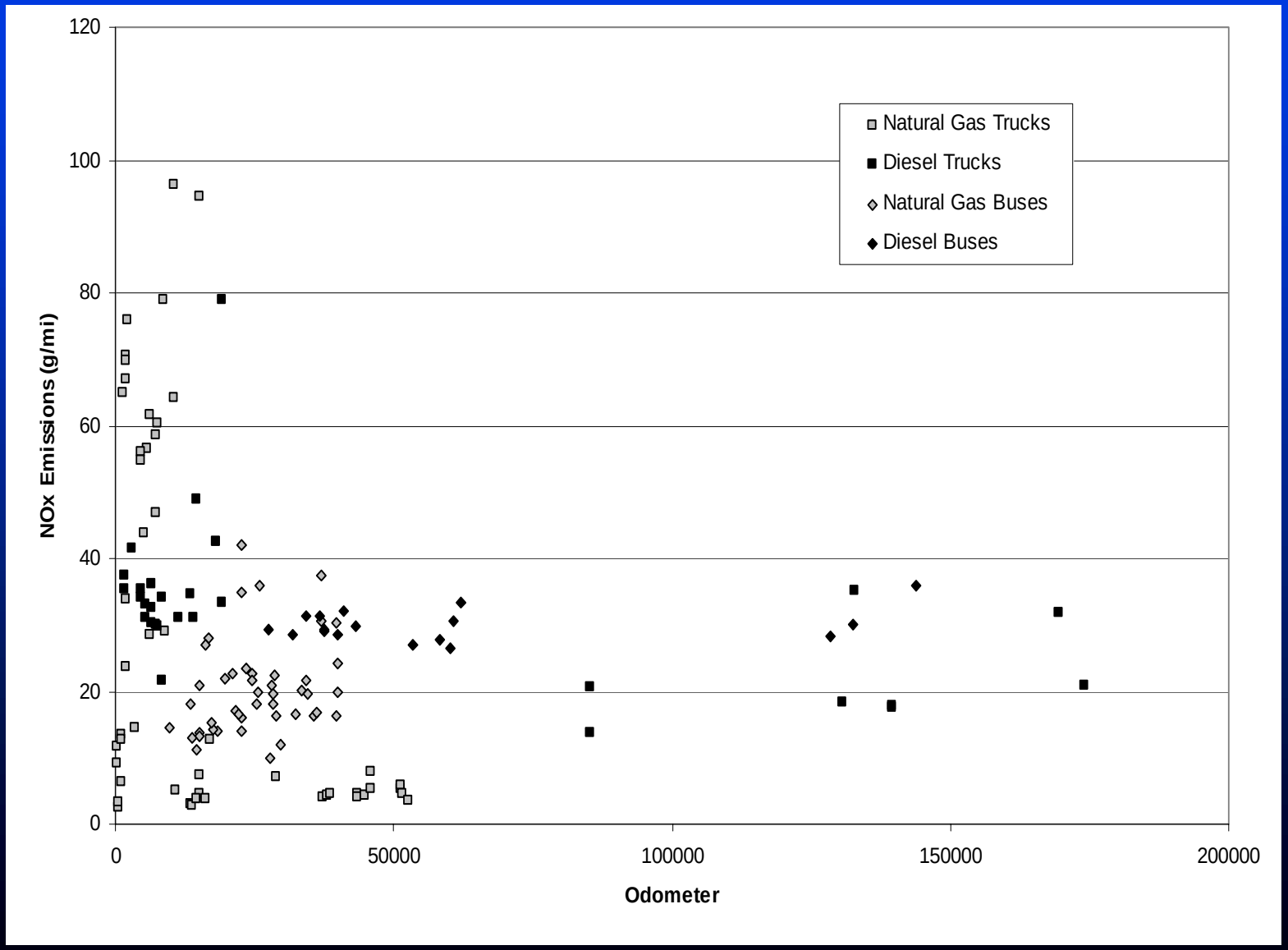
NAVC Hybrid Bus Report

- "The CNG-like particulate emissions of these diesel hybrid-electric buses were facilitated by the use of low sulfur diesel fuel and catalyzed particulate filters."
- "NO_x emissions from the DDC Series 50G engine CNG buses were consistently 50 to 60 percent lower than a conventional diesel bus."
- "CNG buses set the ozone precursor benchmark with hybrid-electric buses a close second."
- Lowest NO_x emissions for CNG = 9.7 g/mile
  Lowest NO_x emissions for diesel hybrid = 18.5 g/mi (CBD test cycle)

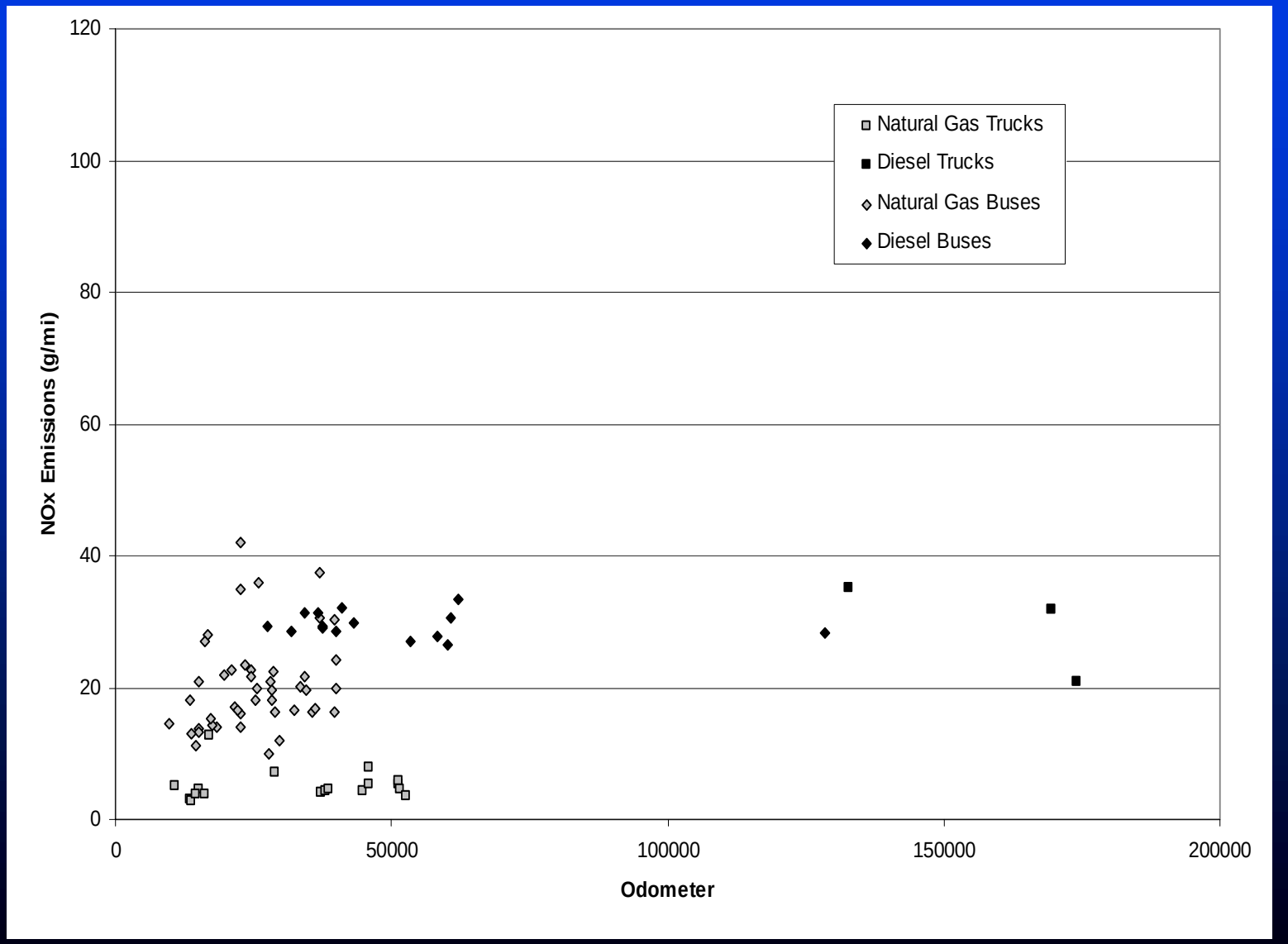
NOx Emissions Pre-1994

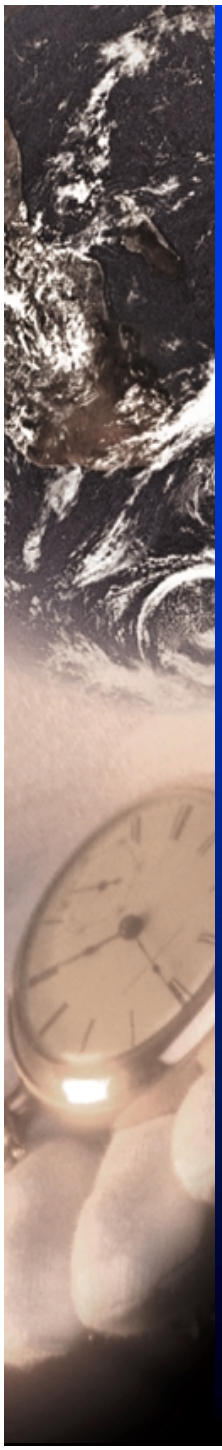


NOx Emissions 1994 - 1997



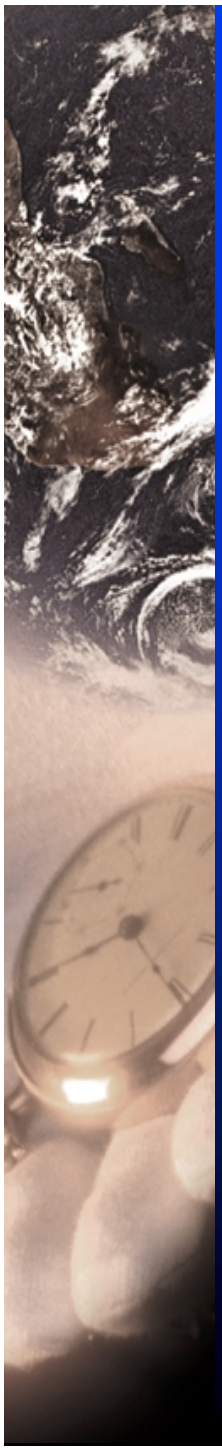
NOx Emissions 1996 - 1997





Myth

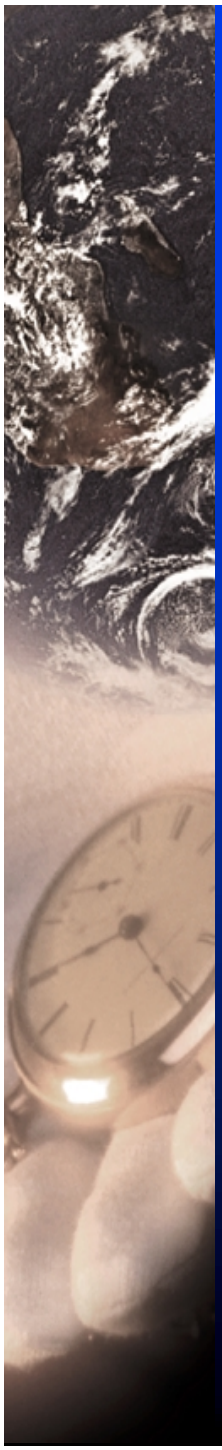
Natural gas vapors
are toxic to breathe.



Fact

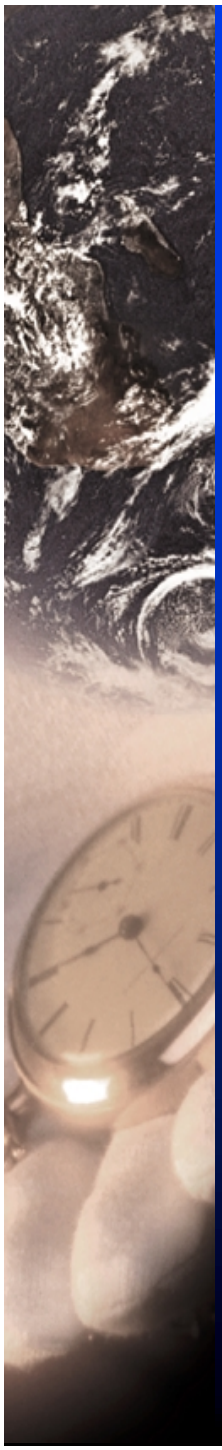
Natural gas vapors are odorless and non-toxic to breathe.

Gasoline and diesel vapors, however, do contain toxics that are dangerous to ingest or breathe.



Myth

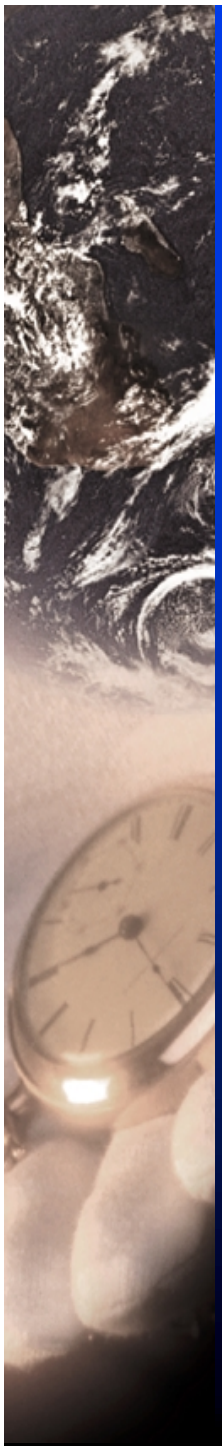
CNG bus maintenance garages and refueling facilities are more dangerous than diesel facilities.



Fact

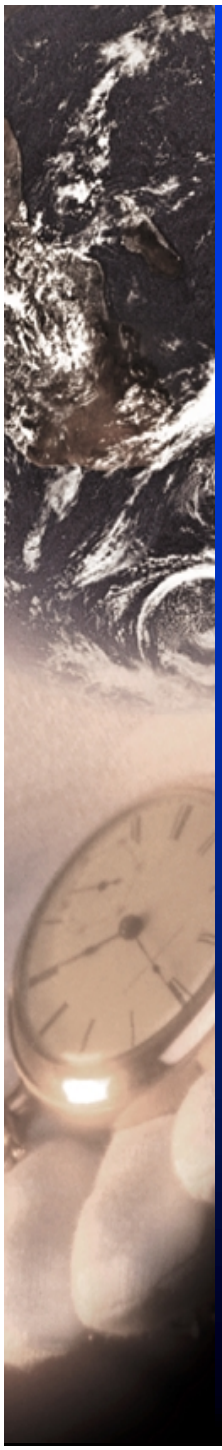
Each fuel requires facility design and use of safety and fire protection equipment designed specifically for the fuel used.

Diesel bus facilities typically store more fuel (~100,000 gal) than CNG facilities (~500 gal).



Myth

CNG buses cost more than diesel buses.

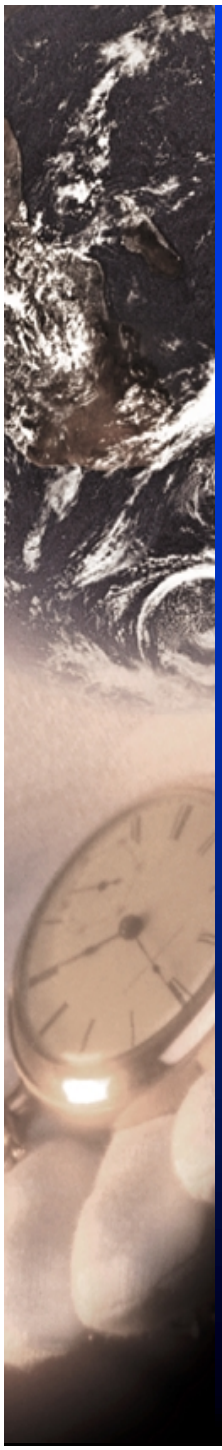


Not a Myth!

A full-size CNG transit bus costs about $40,000 to $50,000 more than a comparable diesel bus.

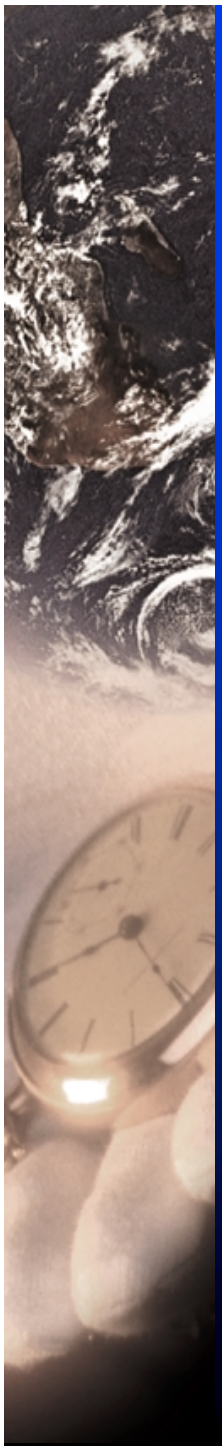
A full- size diesel bus costs around $250,000 to $300,000.

A full-size diesel hybrid bus currently costs about $385,000.



Myth

CNG buses are always more expensive to operate than diesel buses.

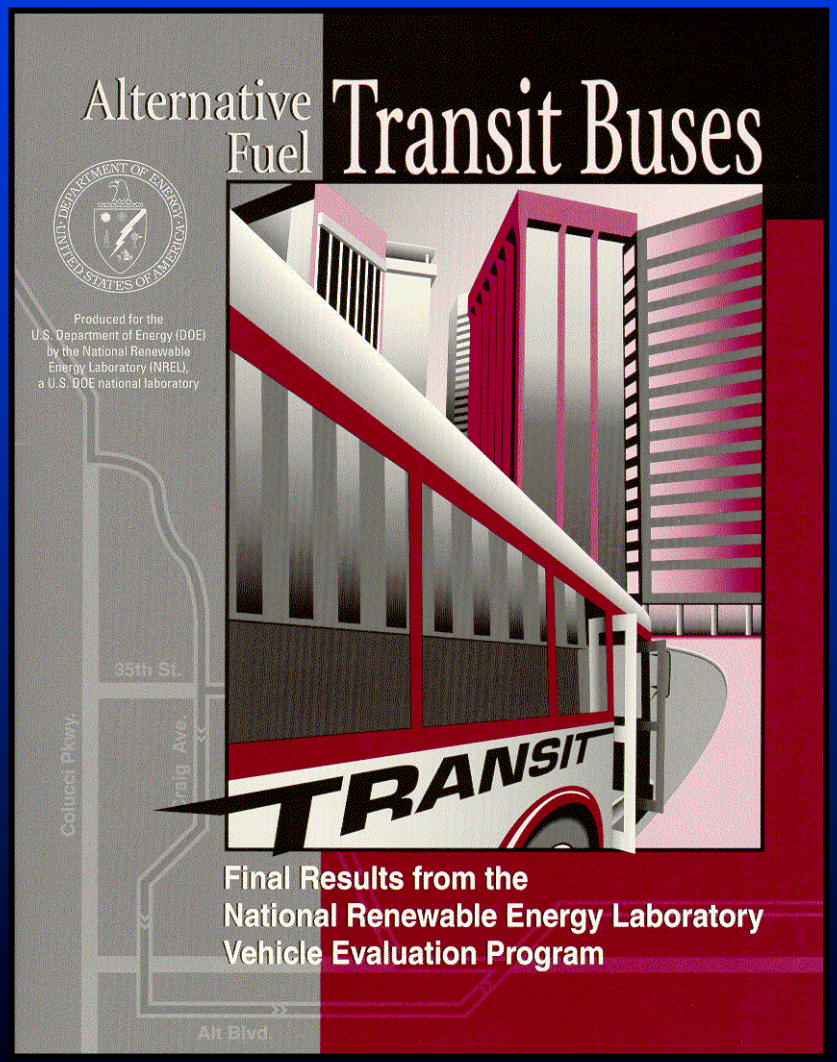


Fact

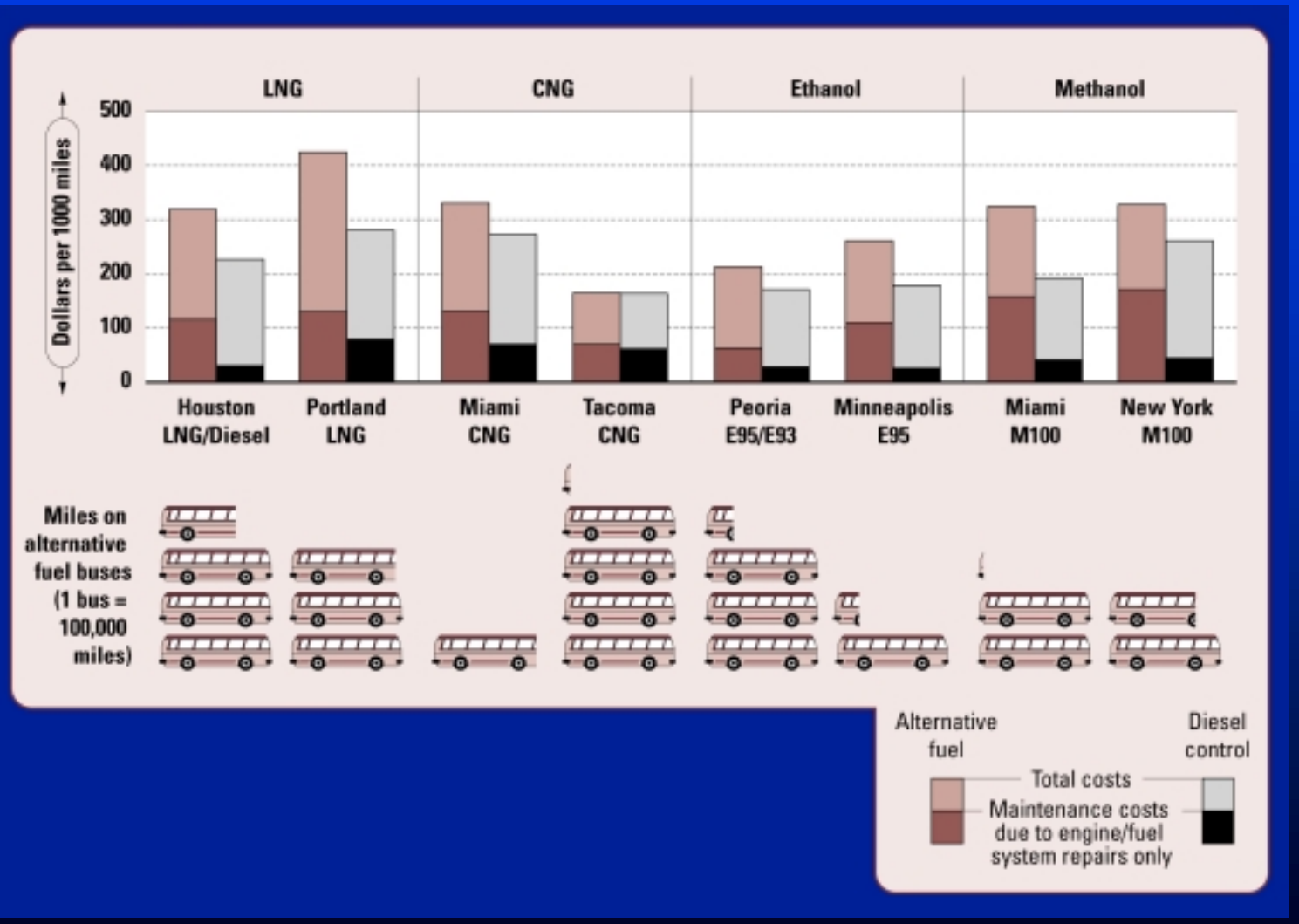
Natural gas buses can have equal or less operating cost than diesel buses.

The cost comparison is strongly affected by natural gas and diesel fuel prices.

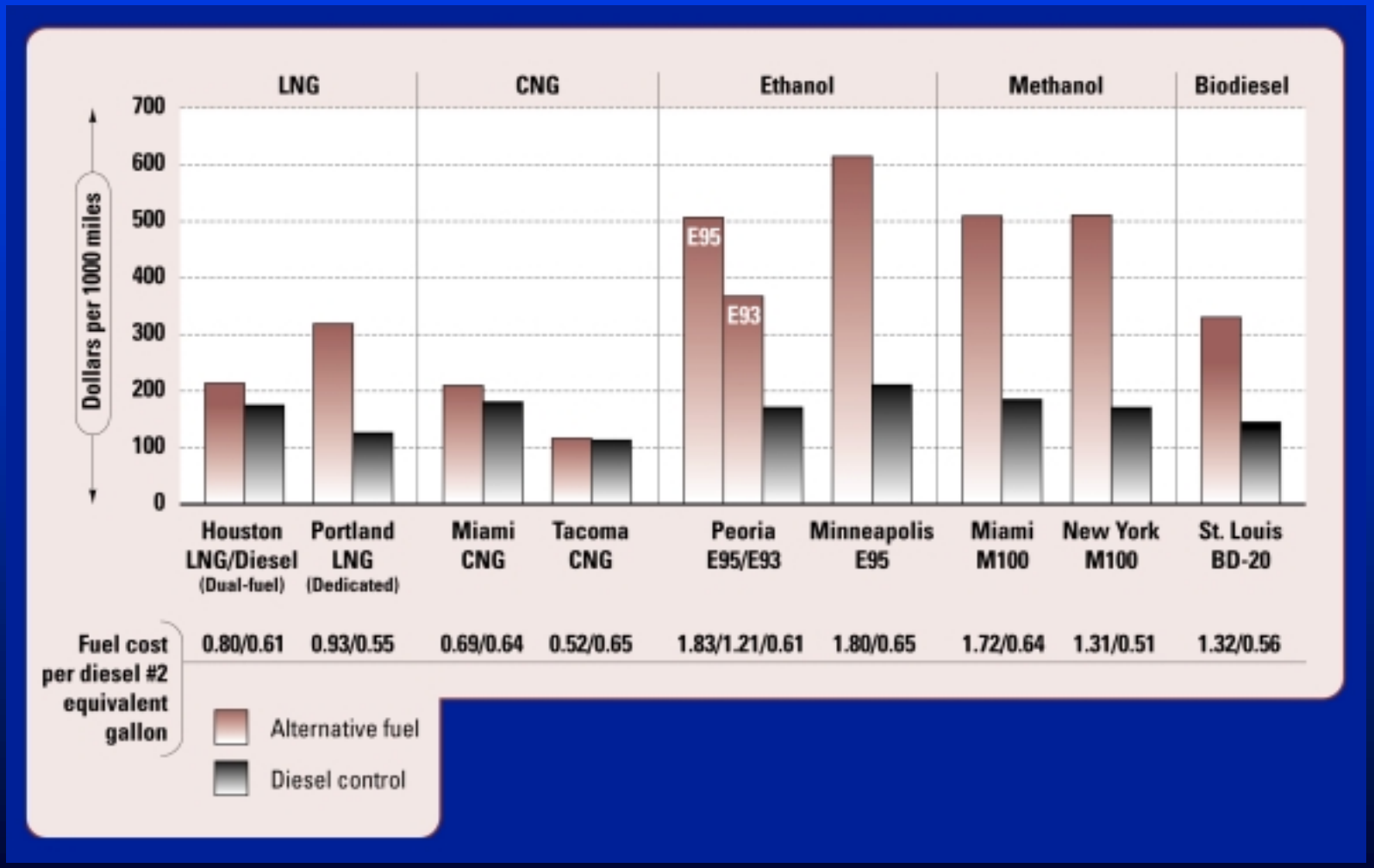
Alternative Fuel Transit Bus Program



Maintenance Costs



Fuel Cost


LNG
CNG
Ethanol
Methanol
Biodiesel
Dollars per 1000 miles
700
600
500
400
300
200
100
0
E95
E93
Houston LNG/Diesel (Dual-fuel)
Portland LNG (Dedicated)
Miami CNG
Tacoma CNG
Peoria E95/E93
Minneapolis E95
Miami M100
New York M100
St. Louis BD-20
Fuel cost per diesel #2 equivalent gallon
0.80/0.61
0.93/0.55
0.69/0.64
0.52/0.65
1.83/1.21/0.61
1.80/0.65
1.72/0.64
1.31/0.51
1.32/0.56
Alternative fuel
Diesel control

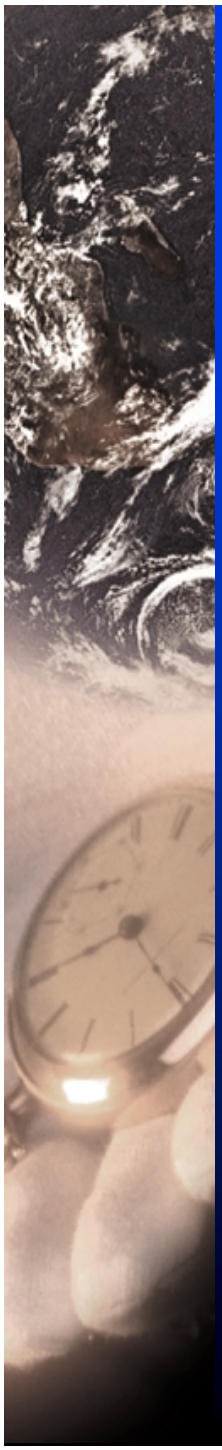
Pierce Transit Buses

Tacoma, Washington

40-ft BIA Orion Buses

1991/92 Cummins L10-240G and 1994 L10-260G engines

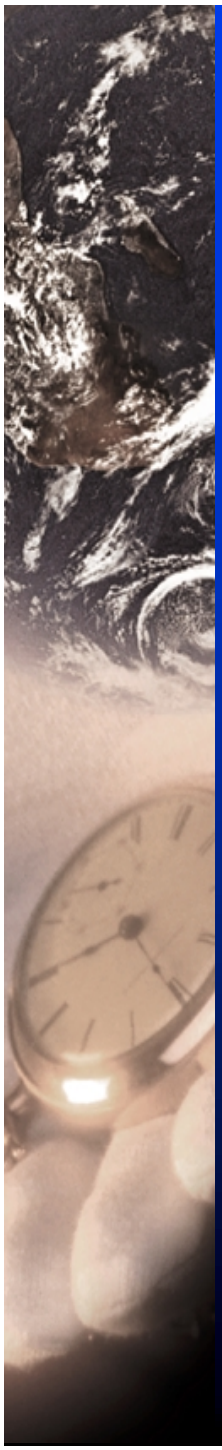
Roof mounted cylinders



Pierce Transit's Fuel Cost

- Now buying CNG as a commodity
- Cost $0.30 per diesel equivalent gallon (129,000 Btu)

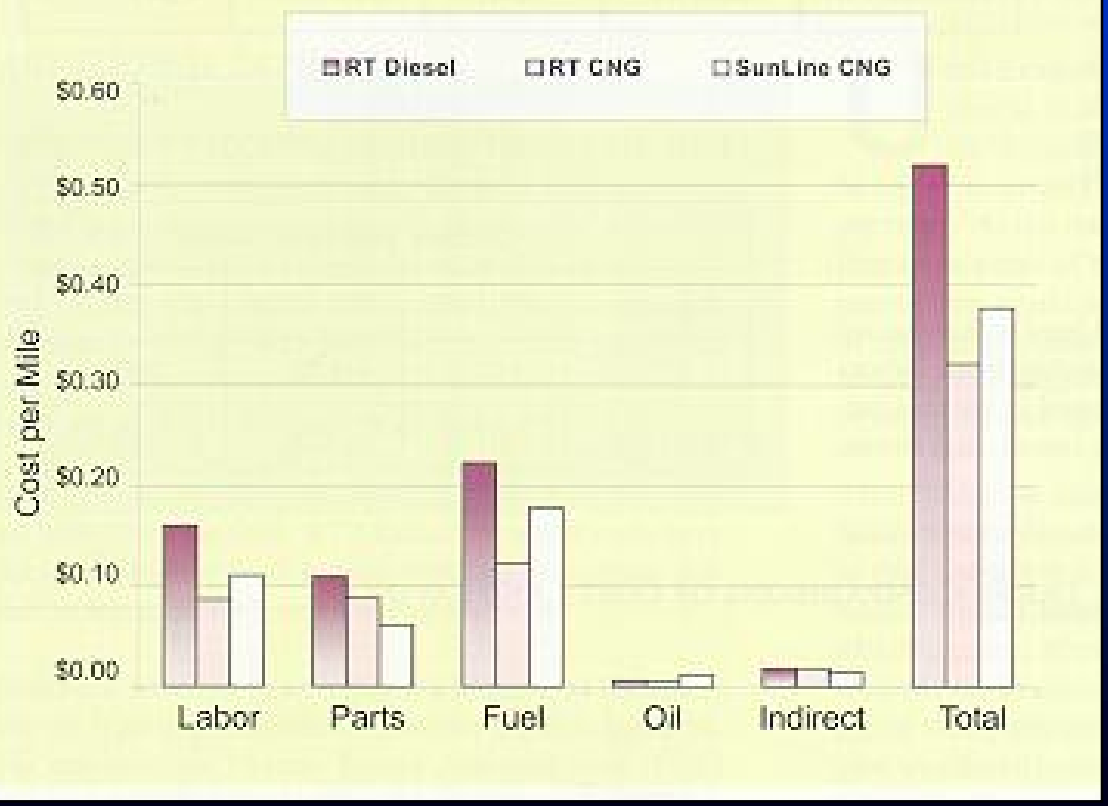
	Diesel Bus	CNG Bus
Fuel Cost (D2gal)	$0.65	$0.30
MPEG (D2gal)	5.8 mpg	4.5 mpeg
Fuel Cost per Mile	$0.11 / mile	$0.07 / mile

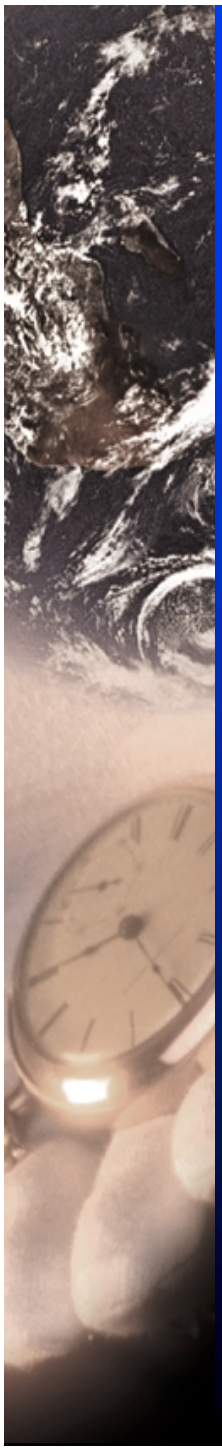


Three Year Comparison of Natural Gas and Diesel Transit Buses

Revised August 1999

FIGURE 1. FY 1997 CNG VS. DIESEL COST PER MILE





Summary

- Sound bites on natural gas buses are often oversimplified and may be misleading - dig in and study the details!
- Current natural gas buses offer emission benefits in comparison to diesel buses and diesel hybrid buses.
- Natural gas buses cost more to buy than diesel buses
- Natural gas buses can have equal or less operating cost as diesel buses …. Fuel cost can make a big difference.


5902X
590X