

**Comparison of Clean Diesel Buses to CNG Buses**

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## Outline

- Background
- Regulated Emissions
- Unregulated Emissions
  - Toxicity
  - Particle Size
- Economic Analysis
  - Cost Factors
  - Capital Costs
  - Operating Cost
  - NPV of Life Cycle Costs
- Issues For Future

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## Technologies Compared

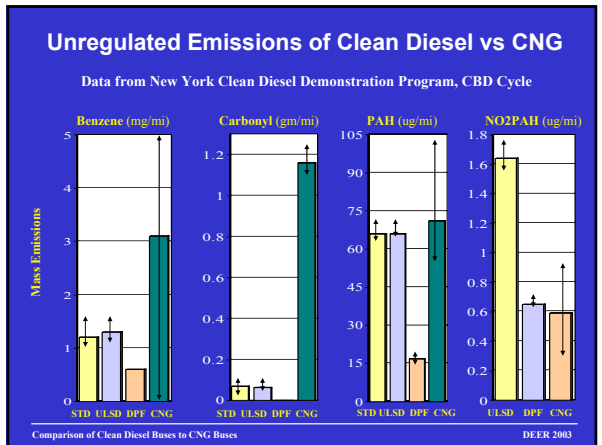
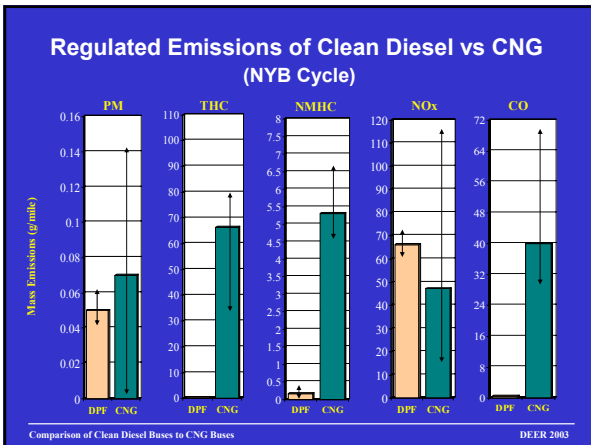
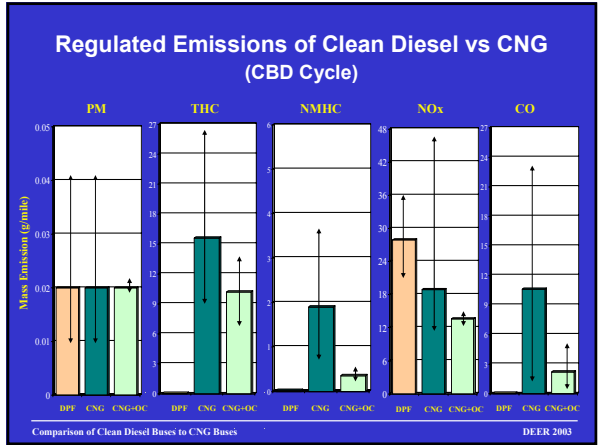
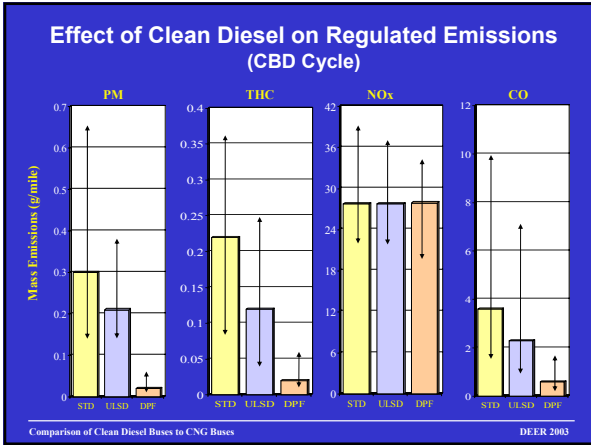
- “Baseline Diesel”
  - Model years 1998 – 2001
  - Diesel Oxidation catalyst (DOC) installed
  - “Standard” on-road diesel fuel (typical 350 PPM sulfur)
  - NOT including EGR or other post 10-02 technologies
- Natural Gas Buses
  - Model years 1998 – 2001
  - Mostly CNG; a few LNG
  - No oxidation catalyst installed
- “Clean Diesel”
  - Model years 1998 – 2001
  - Ultra low sulfur Diesel fuel (<30 PPM sulfur)
  - Diesel Particulate Filter (DPF) installed
  - NOT including EGR or other post 10-02 technologies

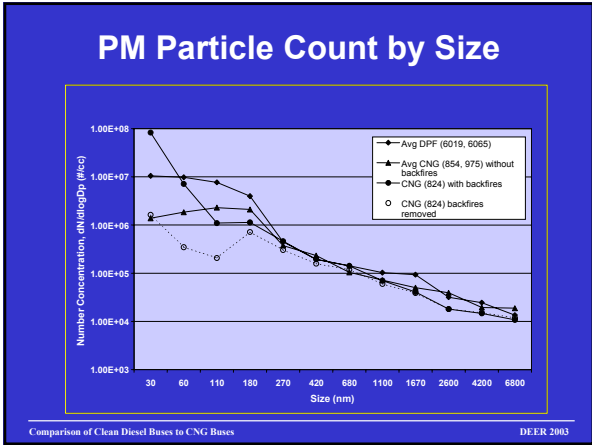
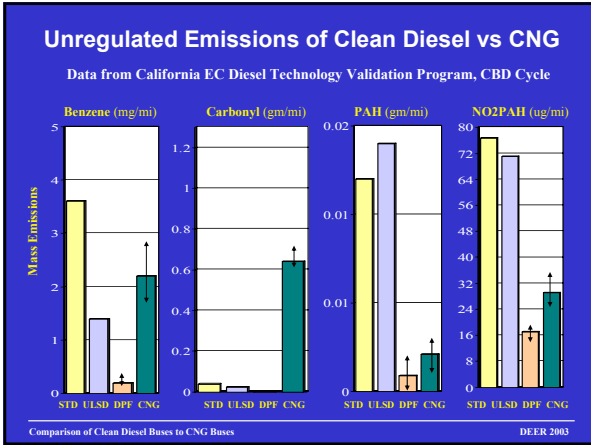
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## Data Sources

- Emissions
  - NY Clean Diesel Demonstration Program
  - California EC-Diesel Technology Validation Program
  - Miscellaneous published sources (WVU, CARB)
- Economic Analysis
  - NYCT data from operating CNG buses since 1995 and Clean Diesel Buses since 2001
  - Published information on CNG costs from LACMTA, GCRTA, and Coast Mountain Bus

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### Emissions Summary

CNG "Better" than Clean Diesel	Clean Diesel "Better" than CNG	CNG & Clean Diesel Equal
NOx	THC NMHC CO Benzene Carbonyl PAH	PM mass PM particle number and size NO2PAH

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### CNG Cost Factors

Compared to STANDARD diesel buses, CNG buses cost more for:

Capital	Operating
<b>Bus purchase</b> - Engines, CNG tanks & piping  <b>Fuel station installation</b> - High pressure compressors  <b>Depot safety modifications</b> - Increased ventilation - Methane detection - remove/mitigate emission sources	<b>NG fuel (+ \$0.11/mile)</b> - Cost of compression - Lower fuel economy  <b>Bus maintenance (+ \$0.20/mile)</b> - Engine, fuel system - Lower reliability  <b>Fuel station maintenance</b> - Heavy duty engines & compressors

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## Clean Diesel Cost Factors

Compared to STD diesel buses, Clean Diesel buses cost more for:

Capital	Operating
DPF purchase & installation - Including spares for cleaning  Diesel fuel station installation - Included only for “apples to apples” comparison – no actual investment required to switch from standard diesel to ULSD	ULSD fuel (+ \$0.04/mile) - Mostly based on increased logistics cost for non-commercial fuel  Annual Cleaning  Cleaning/replacement of “plugged” units - Result of engine upset conditions (5-7.5%/year)

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## Capital Cost Comparison

✓ Incremental costs compared to “standard” diesel for purchasing 200 buses and outfitting one depot

Cost Element	CNG		Clean Diesel	
	Per Bus	Total	Per Bus	Total
Incremental Bus Cost	\$30,000	\$6 million		
CNG Fuel Station	NA	\$5 million		
Depot Modification	NA	\$20 million		
DPF (incl spares)			\$5,900	\$1.2 million
Diesel Fuel Station			NA	\$0.5 million
<b>TOTAL</b>		<b>\$31 million</b>		<b>\$1.7 million</b>

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## Operating Cost Comparison

✓ Incremental annual costs compared to “standard” diesel for operating 200 buses at one depot

Cost Element	CNG		Clean Diesel	
	Per Bus	Total	Per Bus	Total
Incremental CNG Fuel	\$2,860	\$0.6 million		
CNG Fuel Station Maintenance	NA	\$0.9 million		
Incr Bus Maintenance	\$5,200	\$1.0 million		
Incremental ULSD			\$1,040	\$208,000
Diesel Fuel Station Maintenance			NA	\$92,000
DPF replacements			\$137	\$27,400
Annual DPF Cleaning			\$670	\$134,000
<b>TOTAL</b>		<b>\$2.5 million</b>		<b>\$461,400</b>

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## NPV Life-Cycle Analysis

- Discount rate 6%
- Period of analysis – 30 years
- Based on operating 200 buses at one depot location
- Investments based on life cycle of equipment:



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## Life Cycle Cost Comparison

- ✓ Incremental costs compared to “standard” diesel for operating 200 buses at one depot location
- ✓ Does not include overhaul of CNG and diesel engines at mid-life (assumed equivalent)

	CNG	Clean Diesel
NPV of Capital Costs	\$33,653,806	\$3,448,862
NPV of Operating Costs	\$36,651,891	\$6,732,158
NPV of TOTAL COSTS	\$70,305,697	\$10,181,020
Annualized NPV of Total Costs	\$2,343,523	\$339,367

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## Summary

- In comparison to CNG, diesel is inherently more fuel efficient
- While CNG has historically had an inherent emissions advantage, new technologies applied to diesel have dramatically closed the gap
- Even with the new technologies (which have added cost), diesel retains a significant cost advantage over CNG

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## Issues

- Chassis testing shows CNG NOx is much more variable than diesel NOx – implications for “real world” emissions?
- Effect of catalyst on CNG emissions – more data needed
- EGR and other technologies certified to reduce diesel NOx post Oct 2002 – chassis test data required to judge “real world” effects
- Effect of 2007 EPA NOx regulations
  - will NG retain any inherent NOx advantage?
  - Will diesel retain current cost advantage?
- Measurement of unregulated “toxic” emissions – standards required for collection and analysis

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