



## The Transit Bus Niche Market For Alternative Fuels:

### ***Module 10: Emissions Benefits of Alternative Fuel and Advanced Technology Transit Buses***

## **Clean Cities Coordinator Toolkit**

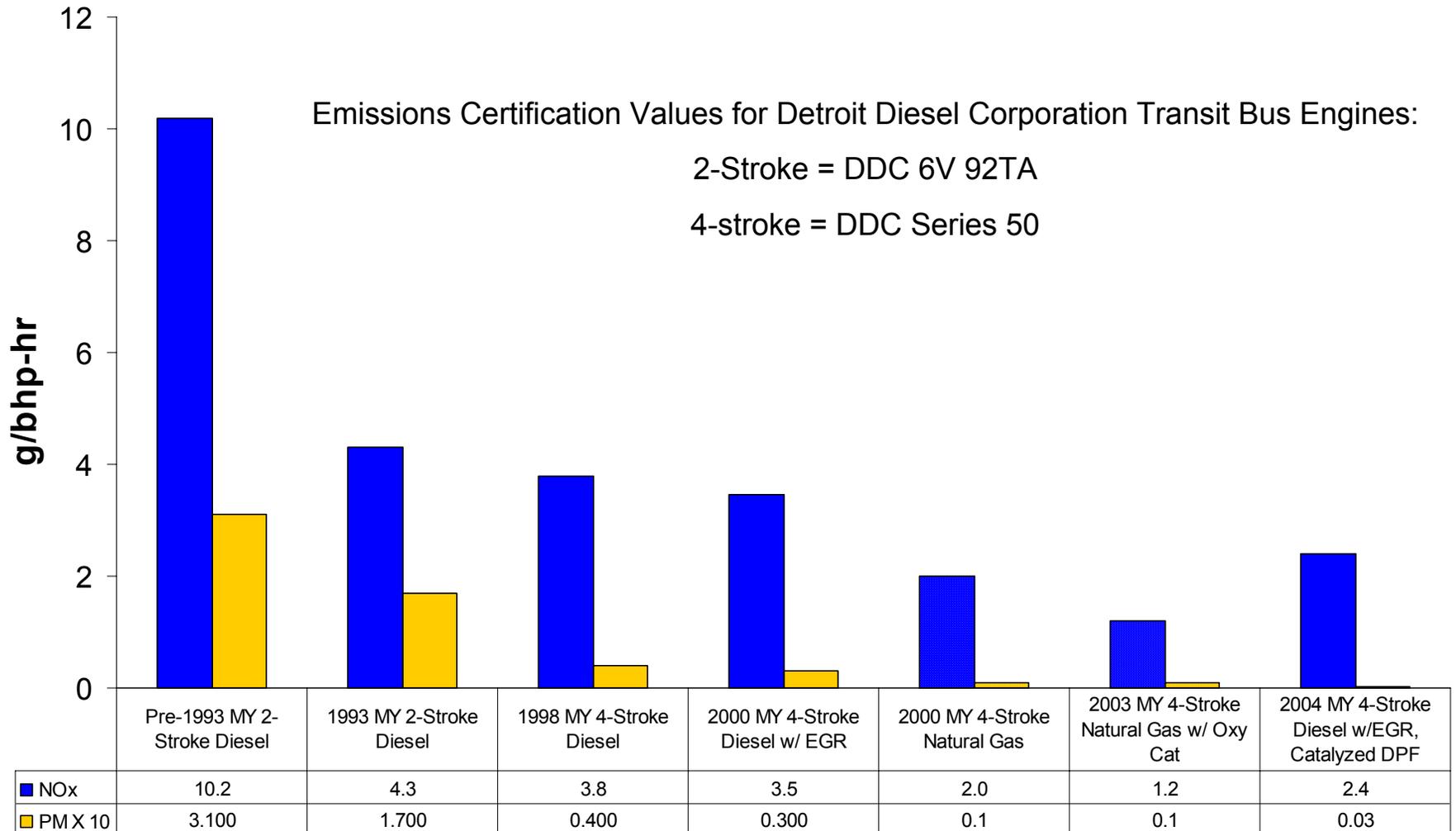
**Prepared by  
TIAX LLC, Irvine Office**

**December 2003**

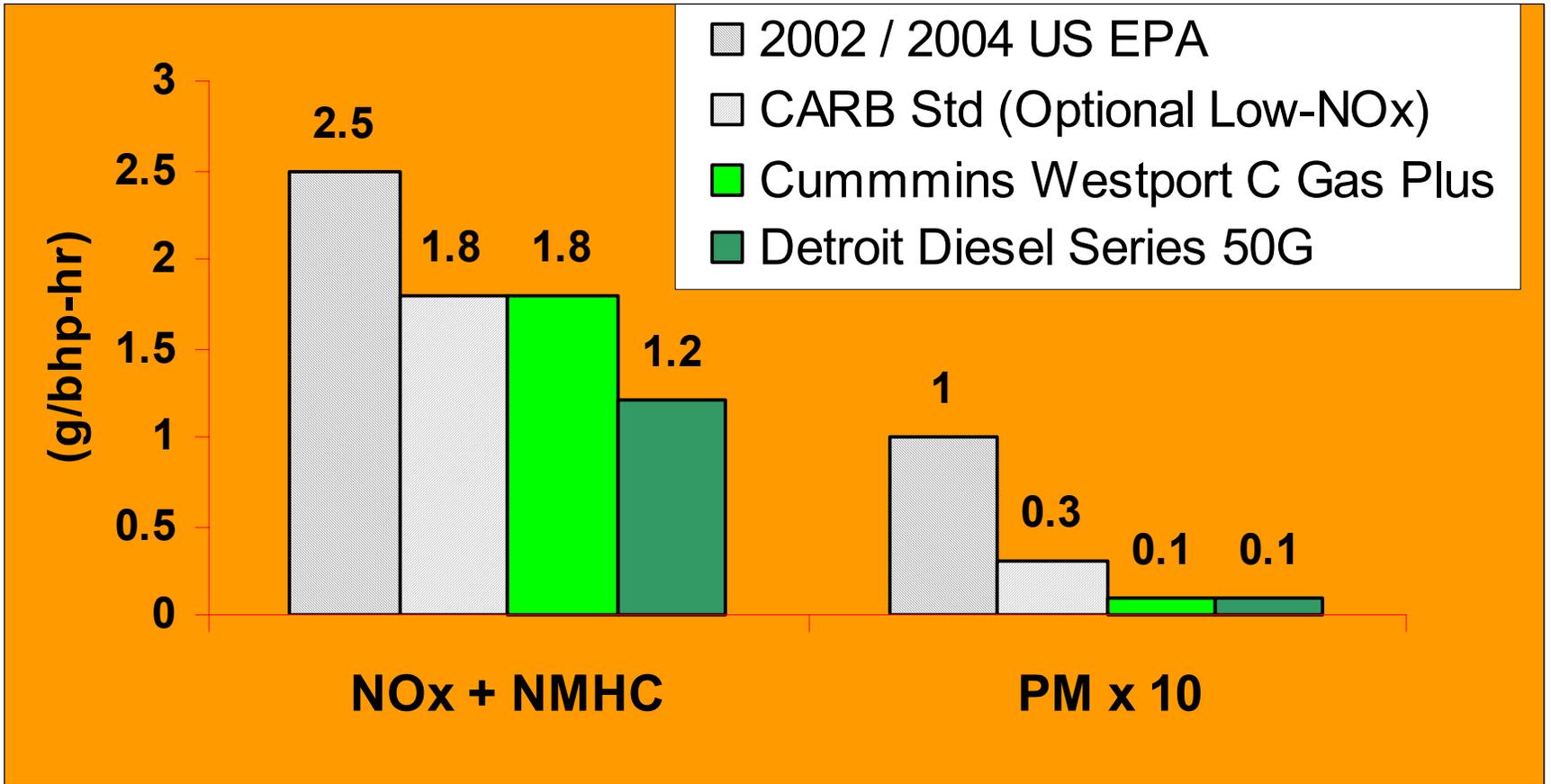


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# Transit Engines: a Decade of Progress with Cleaner Technologies & Fuels



# Today's Two Major Natural Gas Transit Engines Are Very Low Emitting



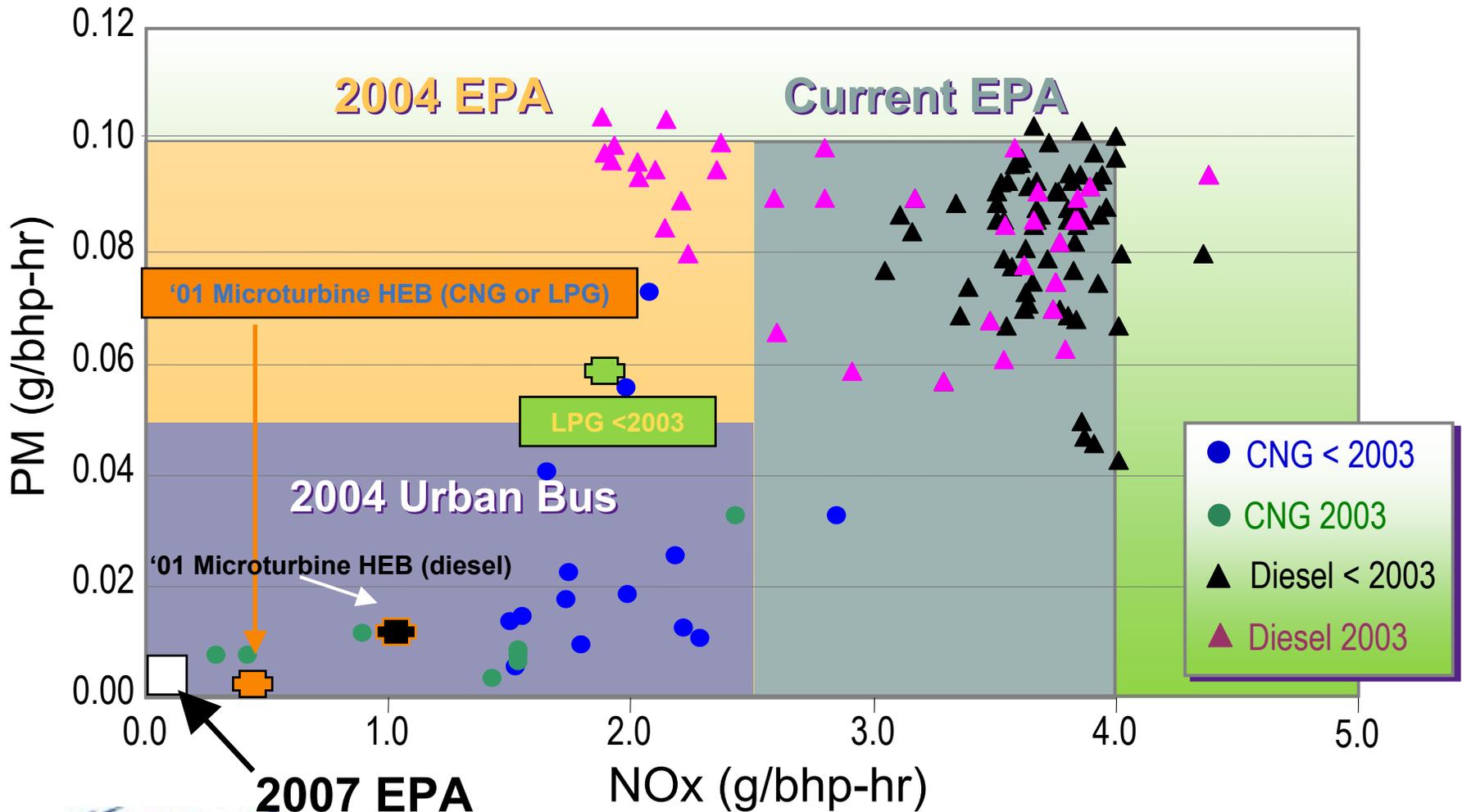
Sources: certification data from Cummins-Westport and Detroit Diesel Corporation

The majority of new alternative fuel transit buses purchased over the next few years will be powered by these two engines. **John Deere also offers very low-emission NG engines for transit (e.g., WMATA's recent purchase).**



# Alternative fuel engines are the “gold standard” for low emissions in HDVs

This slide is from a presentation by Kevin Walkowicz of NREL, entitled “Engine and Vehicle Integration Activity Session,” U.S. DOE NGV Technology Forum Technical Committee Meeting, January 28, 2003. TIAX added data points for LPG and microturbine engines.



# EPA's 2007 / 2010 Emission Standards Allow Averaging, Banking, & Trading

Pollutant	Emission Standard (g/bhp-hr)	Percent of Engine Sales, MY 2007-2009	Percent of Engine Sales, MY 2010
PM	0.01	100%	100%
NO <sub>x</sub>	0.20	50%	100%
NMHC	0.14	50%	100%

PM = Particulate Matter; NO<sub>x</sub> = Oxides of Nitrogen; NMHC = Non-Methane Hydrocarbons  
 g/bhp-hr = grams per brake-horsepower hour

- **Flexibility Provided:**

- Phase in of NO<sub>x</sub> standard through MY 2009
- Averaging across engine families
- Credits for early intro of low-emission engines
- Banking for later use, or trading among OEMs

- **Implications to How OEMs Will Comply:**

- **MY '07 to '09:** averaging, advanced EGR, *possible* SCR or lean-NO<sub>x</sub> catalyst
- **MY 2010:** requires still-unproven engine and emissions control technologies



## California's Standards for Heavy-Duty Engines are Similar, but Complex . . .

Model Year	NO <sub>x</sub> and PM Emission Standards (g/bhp-hr) <sup>a</sup>			
	Heavy-Duty Vehicles		Urban Buses	
	NO <sub>x</sub>	PM	NO <sub>x</sub>	PM
1996 – 2003	--	--	4.0	0.05 <sup>b</sup>
1998 – 2003	4.0	0.10	--	--
October 1, 2002 <sup>c</sup>	2.4 <sup>d</sup> or 2.5 <sup>e</sup>	0.10	2.4 <sup>d</sup> or 2.5 <sup>e</sup>	0.05 <sup>b</sup>
2004 – 2006	2.4 <sup>d</sup> or 2.5 <sup>e</sup>	0.10	2.4 <sup>d,f</sup> or 2.5 <sup>e,f</sup> 0.5 <sup>g</sup>	0.03 <sup>f</sup> 0.01 <sup>g</sup>
2007 +	0.2	0.01	0.2	0.01

<sup>a</sup> g/bhp-hr = grams per brake-horsepower-hour

<sup>b</sup> in-use standard of 0.07 g/bhp-hr

<sup>c</sup> These standards are applicable to Settlement Agreements (Consent Decree) engines

<sup>d</sup> NO<sub>x</sub> plus Non-Methane Hydrocarbons (NMHC)

<sup>e</sup> NO<sub>x</sub> plus NMHC with 0.5 g/bhp-hr NMHC cap

<sup>f</sup> For Transit Agencies on the California Air Resources Board (CARB) Alternative Fuel Path, these standards are applicable to alternative fuel engines

<sup>g</sup> For Transit Agencies on the CARB Diesel Path, these standards are applicable to both alternative fuel and diesel engines; for Transit Agencies on the Alternative Fuel Path, these standards are applicable to diesel engines

# **How do Transit Buses Compare for Emissions in “Real-World” Testing?**

**(Chassis Dynamometer Testing  
of Diesel, Alternative Fuel, and  
Hybrid-Electric Transit Buses)**

## What “Apples to Apples” **In-Use** Emissions Testing Has Been Done?

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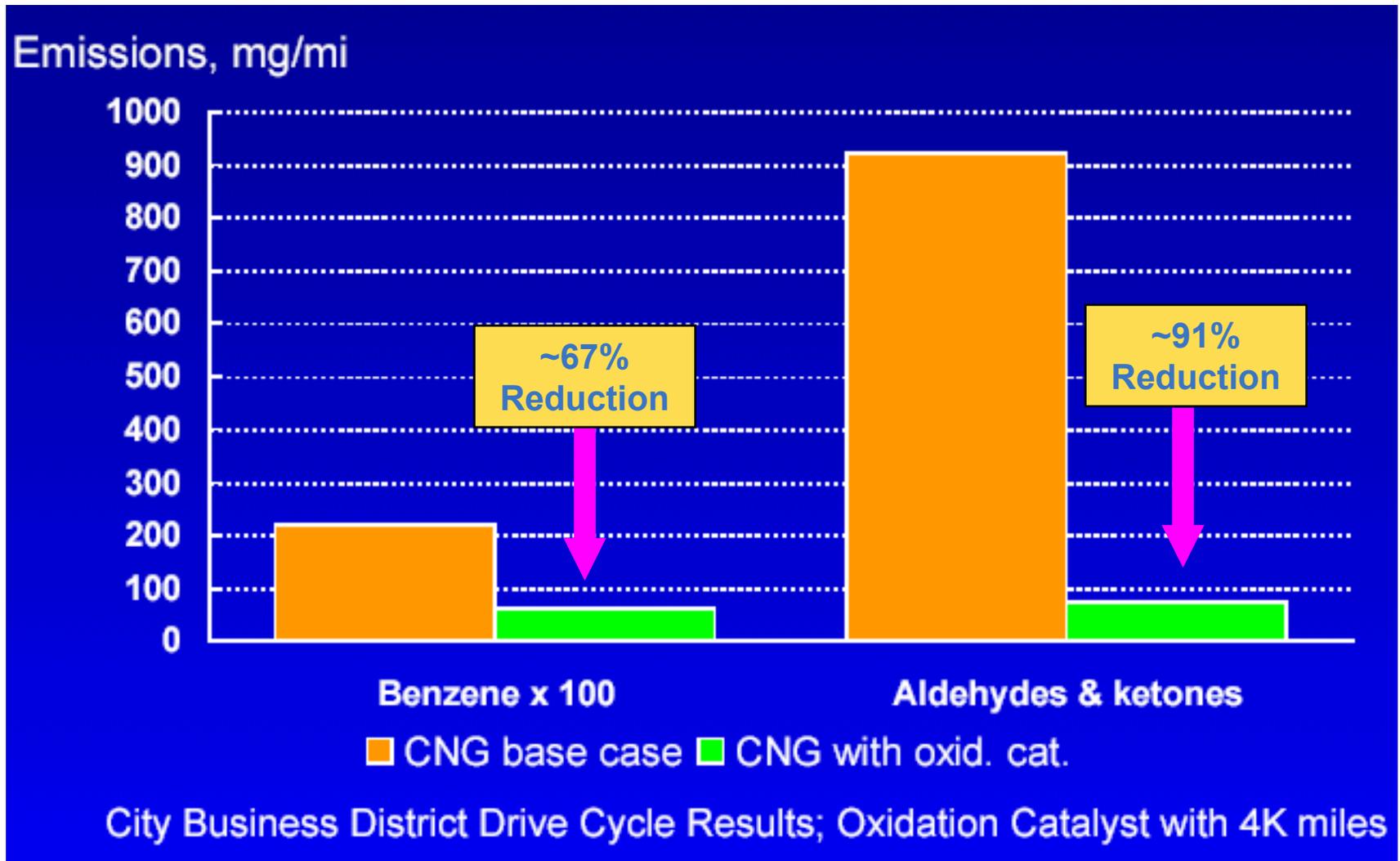
- So far, **not much**
- While various sources have cited emissions data of alternative fuels vs. diesel . . . .
- . . . . past comparisons have usually involved too many variables:
  - bus age, manufacturer, model, etc.
  - iterations of engine technology (e.g., various phases of Cummins L10 G technology)
  - use of after-treatment on buses
- The issues are complex -- objective parties should be leary when assessing data cited by special interests *on either side of the debate*
- Some good comparative data are beginning to emerge
- More chassis dynamometer emissions tests of emerging transit bus technologies are needed . . . . . and planned

## Early Studies Indicated Both CNG and Clean Diesel Needed Improvement

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- In 2001, California Air Resources Board tested two transit bus technologies:
  - 2000 MY CNG bus with a DDC Series 50G engine (no catalyst)
  - 1998 MY diesel bus with a DDC Series 50 engine using ULSD and a Johnson-Matthey Continuously Regenerating Technology (CRT) PM trap
- Results indicated that
  - the CNG bus had high emission levels for aldehydes and air toxics (e.g., 1,3 butadiene), suggesting that further control (aftertreatment) was needed
  - the CRT-equipped LSD bus had encouraging overall emissions, but exhibited a substantial increase in the amount of NO<sub>x</sub> emitted as NO<sub>2</sub> (which has negative air quality implications)
- In 2002, CARB installed an oxidation catalyst and re-tested the CNG bus
- Conclusion: “oxidation catalysts for CNG applications offer significant benefits” and are “significantly superior” to CRT-equipped ULSD buses in terms of controlling total PM **mass**
- More work needs to be done on both technologies to target “ultra-fine” PM
- More work needs to be done on diesel traps to keep NO<sub>2</sub> levels low
- Full study at: <http://www.arb.ca.gov/research/cng-diesel/cng-diesel.htm>

# Oxidation Catalysts Have Greatly Reduced Air Toxics from CNG Buses



Source: graph from Manufacturers of Emissions Controls (MECA), citing California Air Resources Board data



## Emissions Testing at Washington Metro Area Transit Authority (July '02)

- Five CNG and 4 “green” diesel transit buses were emissions tested on the WVU portable chassis dynamometer
- CNG Buses:
  - 2001 MY New Flyer with 280 HP Cummins C-Gas Plus (8.3 L) engines
  - each equipped with an oxidation catalyst
  - All buses were low mileage
- Diesel Buses
  - 2000 MY Orion with 320 HP DDC Series 50 diesel (8.5 L) engines
  - Operated on ULSD (19 ppm)
  - Each equipped with an oxidation catalyst
  - Two of 4 buses were low mileage

### On Average:

- NO<sub>x</sub> reduced 53% for CNG
- TPM reduced 85%for CNG
- CO reduced 89%for CNG

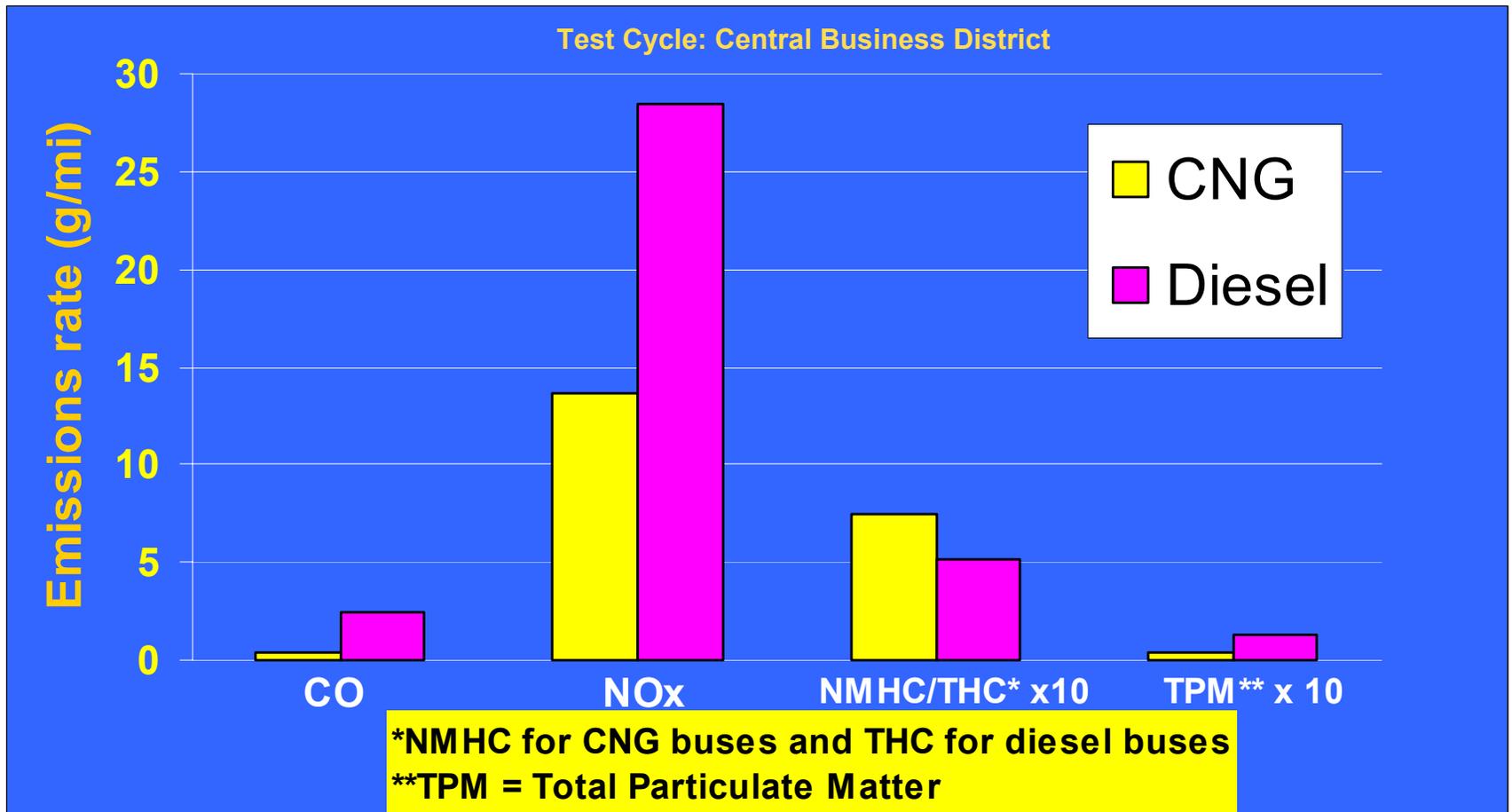
**Next:** more advanced buses of both kinds will be tested in mid 2004



WMATA's CNG bus fleet (photo by Leslie Eudy of NREL)

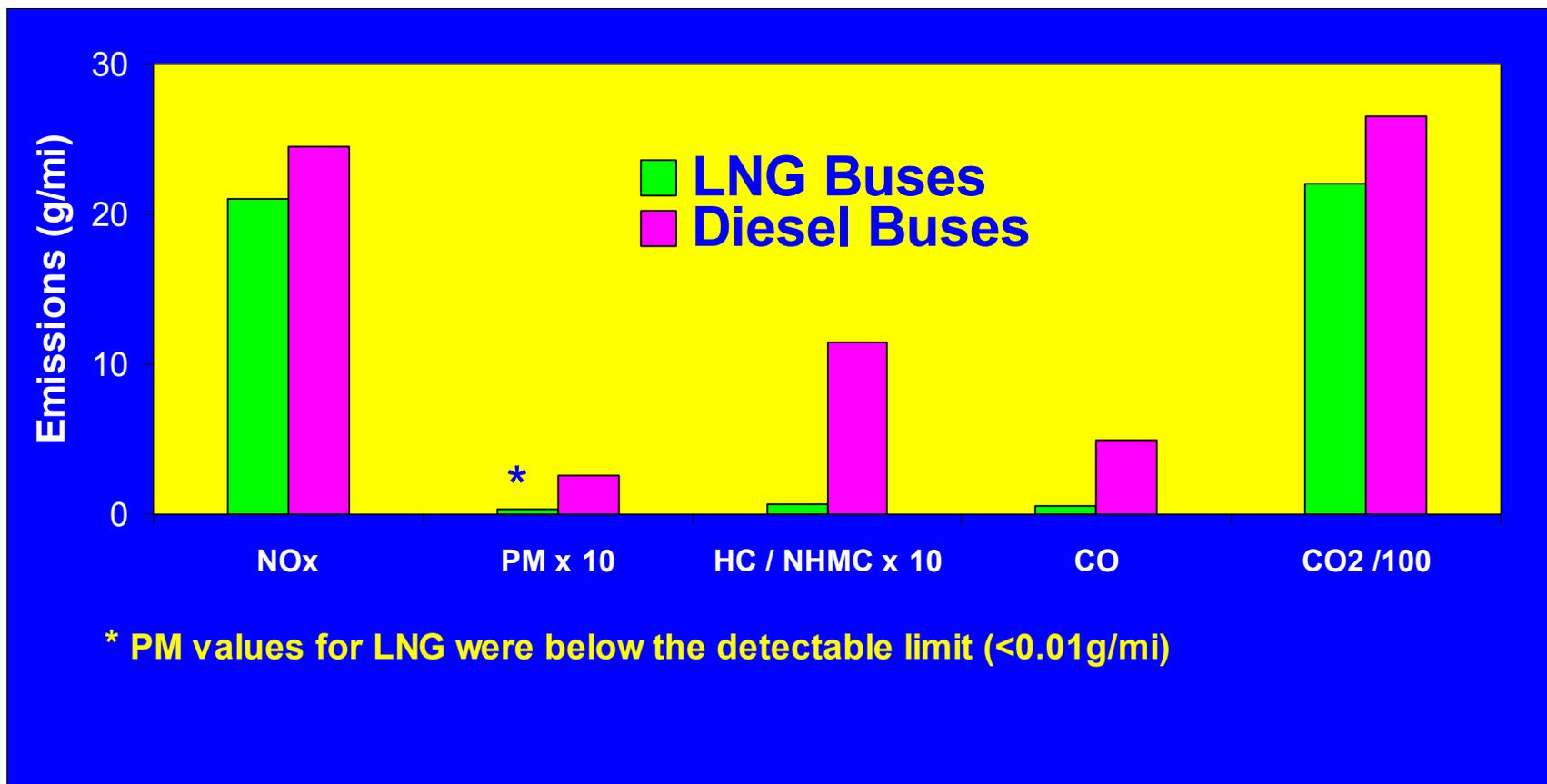
## Chassis Dyno Test Results of CNG and “Clean” Diesel at WMATA

- Average emissions from 5 CNG and 4 diesel buses are depicted below
- Diesel buses using ULSD and oxidation catalyst; CNG using oxidation catalyst



See DOE / NREL summary report: <http://www.nrel.gov/docs/fy03osti/33280.pdf>

## Testing at DART Also Showed Significant NOx and PM Reductions (LNG Buses)



**Notes: Averages for tests conducted by WVU, CBD cycle. 10 LNG and 5 diesel buses - all 1998 NovaBUS RTS-style with oxidation catalysts. LNG engine: Cummins L10-280G. Diesel engine: Cummins M11-280.**

## Emissions Performance of *Dedicated* AF Engines Continues to Improve

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- Current technology for heavy-duty AF engines, such as lean-burn, closed-loop, and electronic fuel management system, has enabled them to ***approach*** diesel-like fuel economy and performance, **while emitting only one-half of the NOx and PM emissions compared to certified diesel engines**
- The application of oxidation catalysts to the Cummins-Westport C Gas Plus and the Detroit Diesel Series 50G engine reduced emissions of formaldehyde (95%), 1,3 butadiene (below detection), NMHC (>88%) carbonyls, and other non-criteria pollutants that were of concern
- Potential post 2007 engine and after-treatment technologies for diesel are generally applicable to lean-burn natural gas engines as well
- Higher after-treatment efficiencies may be achievable, because dedicated (spark-ignited) alternative fuel engines operate at higher temperatures
- Future mid-size NG engines (e.g., C Gas Plus) will likely be closed-loop stoichiometric with 3 way catalyst technology
- **In other words, alternative fuel engines for transit applications can continue to offer progressively lower emission levels . . . but all technologies must meet the same standards by 2010**

# Development of New Heavy-Duty Engines Under DOE's NGNGV Program

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## Technologies

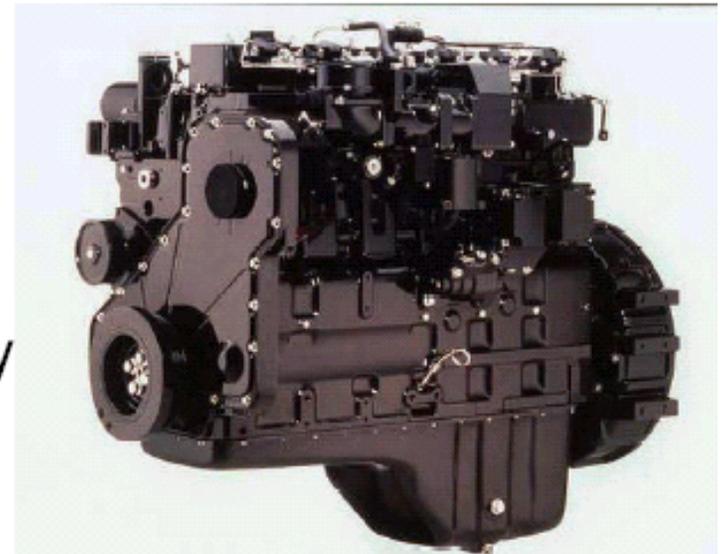
- Cummins C (8.3L) engine and EGR
- Stoichiometric air/fuel ratio
- 3-way oxidation catalyst

## Significance

Potential for lower cost exhaust AT equipment, very low exhaust emissions, and med- to (light) heavy duty application capability

## Ratings & Emission Targets

- 280 hp, 950 ft-lb
- 0.2 NO<sub>x</sub>, 0.01 PM



Source: National Renewable Energy Laboratory, "Next Generation Natural Gas Vehicle Activity," presentation by Mike Frailey, Margo Melendez and Richard Parish, Sept. 9-10, Albany New York.

## How “Clean” Are Hybrid-Electric Buses? NAVC Conducted Testing:

**Test matrix: HEBs with advanced aftertreatment vs. pre-2000 NG buses w/ oxy cats:**

Bus OEM	Bus Chassis	Drive	Engine / Model Year	Fuel	Aftertreatment
NovaBUS	RTS	3 speed	DDC Series 50 / 1998	Diesel <sup>A</sup>	Oxidation Catalyst
Neoplan	AN440T	5 speed	Cummins L10 280G / 1998	CNG	Oxidation Catalyst
New Flyer	C40LF	5 speed	DDC Series 50G / 1999	CNG	Oxidation Catalyst
Orion	V	5 speed	DDC Series 50G / 1999	CNG	Oxidation Catalyst
Orion	VI Hybrid	LMCS Hybrid	DDC Series 30 / 1997 & 1998	Diesel-Electric <sup>B</sup>	NETT Particulate Filter Trap
NovaBUS	RTS Hybrid	Allison Hybrid	DDCVMM 642 DI / 1991 (1998 engine)	Diesel-Electric <sup>C</sup>	Johnson Matthey Regenerative Particulate Trap

A – The NovaBUS was tested on D1, and MossGas® diesel fuels.

B – The Orion-LMCS bus was tested on D1, low sulfur D1, and MossGas diesel fuels.

C – The Nova-Allison bus was tested on low sulfur D1 diesel fuel.

### Findings:

- Diesel hybrids with advanced after-treatment (catalyzed PM filters and LSD) were significantly lower-emitting than conventional diesel buses
- Comparisons to pre-2000 CNG buses w/ oxy cats were also favorable

**Northeast Advanced Vehicle Consortium** study on emissions from hybrid buses (February 2000) can be found at: <http://www.navc.org/Navc9837.pdf>

**NOTE: New rounds of testing on latest models and technologies are needed**



## Emissions Module: Summary and Conclusions

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- The NG versions of the two major bus engines (C Gas Plus and DDC S50G) are still the lowest-emitting, mainstream transit bus engines available
- These engines nearly achieve 2007 NOx levels today (given NOx averaging to 1.2 g/bhp-hr)
- Oxidation catalysts have greatly enhanced their overall emissions benefits
- More “apples-to-apples” tests of in-use transit buses are needed and planned
- Diesel engines will meet 2007 using EGR, after-treatment and fleet averaging, but larger-sized engines (e.g., in 40 ft. transit buses) will face tough challenges
- Diesel buses will become more expensive, less fuel efficient and possibly less durable as they move ahead to meet 2007 and 2010 standards
  - Capital and maintenance costs: use of advanced (“hard”) EGR, SCR, lean-NOx adsorbers, particulate filters, oxidation catalysts, hybrid drivetrains
  - Fuel costs: ultra-low sulfur diesel (**note: hybrid efficiency may offset this**)
- Alternative fuel (AF) engines also need to incorporate advanced technologies, but **they don’t have “as far to go”** to meet 2007 and 2010 standards
- AF engines will further benefit from transfer of advanced diesel technologies
- Hybridization (diesel/electric, NG/electric, LPG/electric) holds strong promise