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**TRANSIT BUS TECHNOLOGY  
DEVELOPMENTS IN US/EUROPE:  
A LOOK AT THREE CITIES  
(LA, NY, Paris)**

**Lew Fulton  
International Energy Agency, Paris  
Fuel Quality and Alternative Fuels Workshop  
Delhi, May 3, 2001**



# IEA SUSTAINABLE BUS PROJECT

## Our Project in a Nutshell

- IEA has launched a one year project to investigate technology and system needs of bus systems around the world, and explore the feasibility of specific improvement projects in selected cities.
- Three main parts to the study:
  - **TECHNOLOGY REVIEW:** conduct review of conventional and advanced propulsion systems for buses, emissions impacts, etc. Also look at other bus-related technologies, and review recent activities around the world that are serving to improve and implement these technologies.
  - **CITY BUS SYSTEM REVIEW:** Review current bus and transit systems in large cities around the world, technology and system-related needs and goals, and the fit between identified needs and available technologies and other potential solutions.
  - **SELECT AND WORK WITH CITIES:** Determine cities that are a “good fit” for our project, and select a number to work with to scope out potential projects for a subsequent implementation phase.



# THE IEA BUS PROJECT

- **Work with Authorities in Selected Cities**
  - Sao Paulo, Mexico, Dhaka, **Bangalore**, Indonesian Cities
  - Probably Shanghai or other City in China, San Salvador?
- **Evaluate Bus System and Technology Options**
- **Help Develop Plans for Bus and System Improvements**
- **Help Design Technology and System Evaluations (ASIF)**
- **Understand and Overcome Local Barriers**
- **Bring in IEA Experience (LA, New York, Paris)**
- **Work with Bus and Fuel Companies**
  - Volvo, Scania, Daimler, GM, Shell, BP
- **Assist with Implementation Efforts where Possible**



## **Recent Advanced-technology Bus Experience in Three Cities: Los Angeles, New York, and Paris**

- **LA: Analysis of new CNG and new as well as older diesel buses, including cost and emissions analysis.**
- **NY: Emission tests of ULSD fuel, advanced catalyst/filters, CNG and hybrid (diesel-electric) buses**
- **Paris: Emission tests of ULSD, CNG, LPG, and “Aquazole” solution (for older buses)**



## **LA County Metropolitan Transportation Authority (LACMTA)**

- **Operates largest CNG bus fleet in the world (1355 CNG buses by December 2000)**
- **Plans to replace entire fleet by CNG by 2004 (about 1000 additional buses)**
- **Recently published a planning document containing a review of CNG v. Diesel costs and emissions**



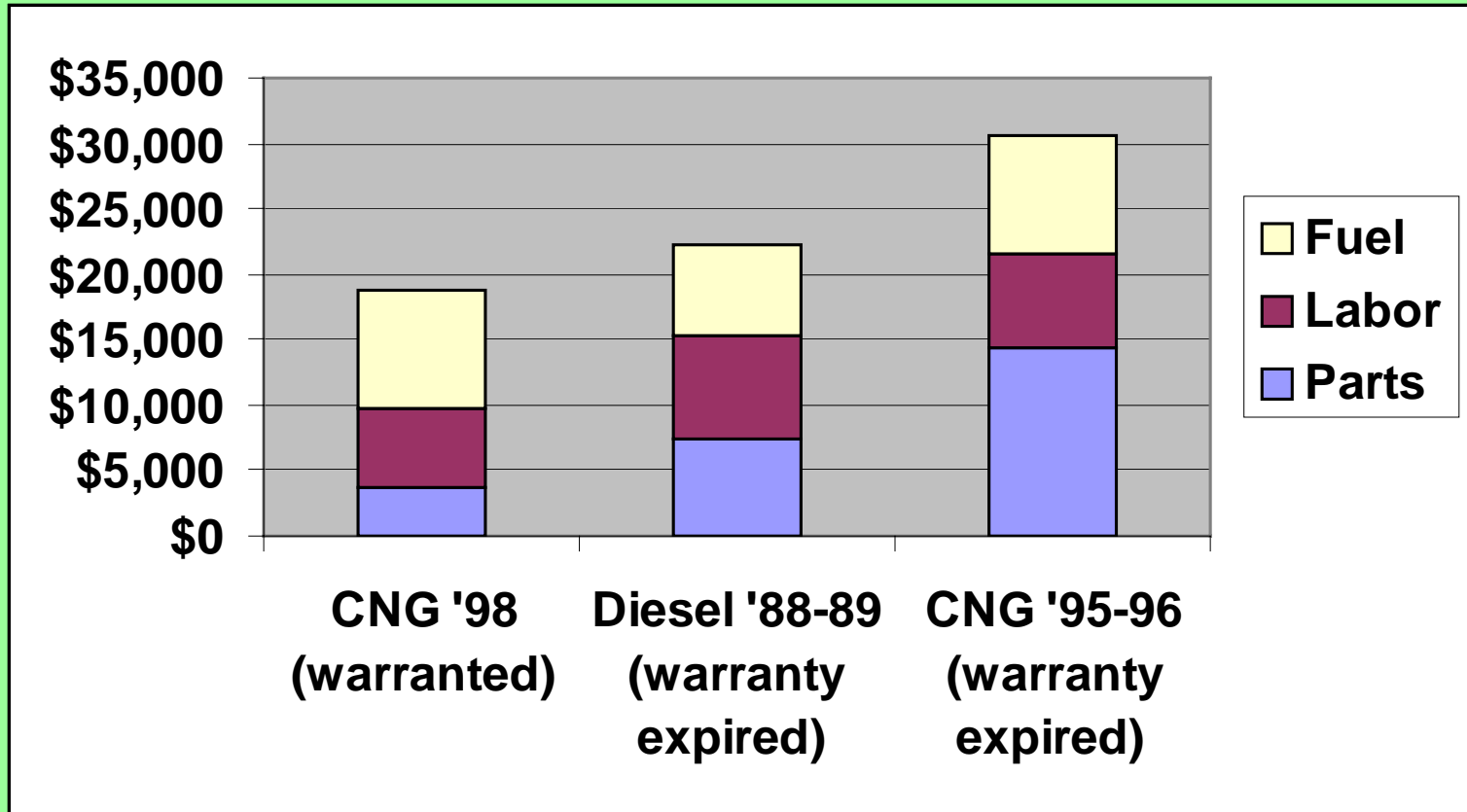
# Los Angeles County MTA Report: Comparison of Diesel and CNG Bus Characteristics

From LACMTA: “Fuel Strategies for Future Bus Procurements”, 1999

- Report reviews several recent comparisons of CNG and diesel buses in terms of costs, and has a hypothetical emissions analysis
- Takes issue with several previous studies that have compared newer CNG buses with older diesel buses
- Concludes that the shift to a fleet of CNG buses will be expensive:
  - While new CNG busses have lower life-cycle costs than the buses they replace, they are estimated to be much higher than new those for *new* diesel buses would be.
  - Higher CNG maintenance costs, especially replacement parts costs, are a key factor



# LA: CNG v. Diesel Bus Estimated Annual Operating Cost (1998)





## LA Report: Emissions Findings

- **Assuming diesels just meet future emissions requirements, CNG buses are expected to outperform diesels for NOx and PM**
- **However, difference is small; a fleet of 100% CNG buses vs. 50% diesel in 2004 amounts to a difference of 0.05% of regional emissions of NOx and 0.1% of regional emissions of PM**
- **NOx reduction cost from going to all CNG buses estimated at \$32k to 46k per tonne.**



## NY City Transit Authority (NYCT)

- Large fleet of diesel and alternative fuel vehicles
- Plans for large-scale expansion of CNG and hybrid diesel buses
- Number of buses in Operation and Projections for 2006:

	2001	2006
Diesel	4257	3311
CNG	221	649
Hybrid	11	390
Total	4489	4350



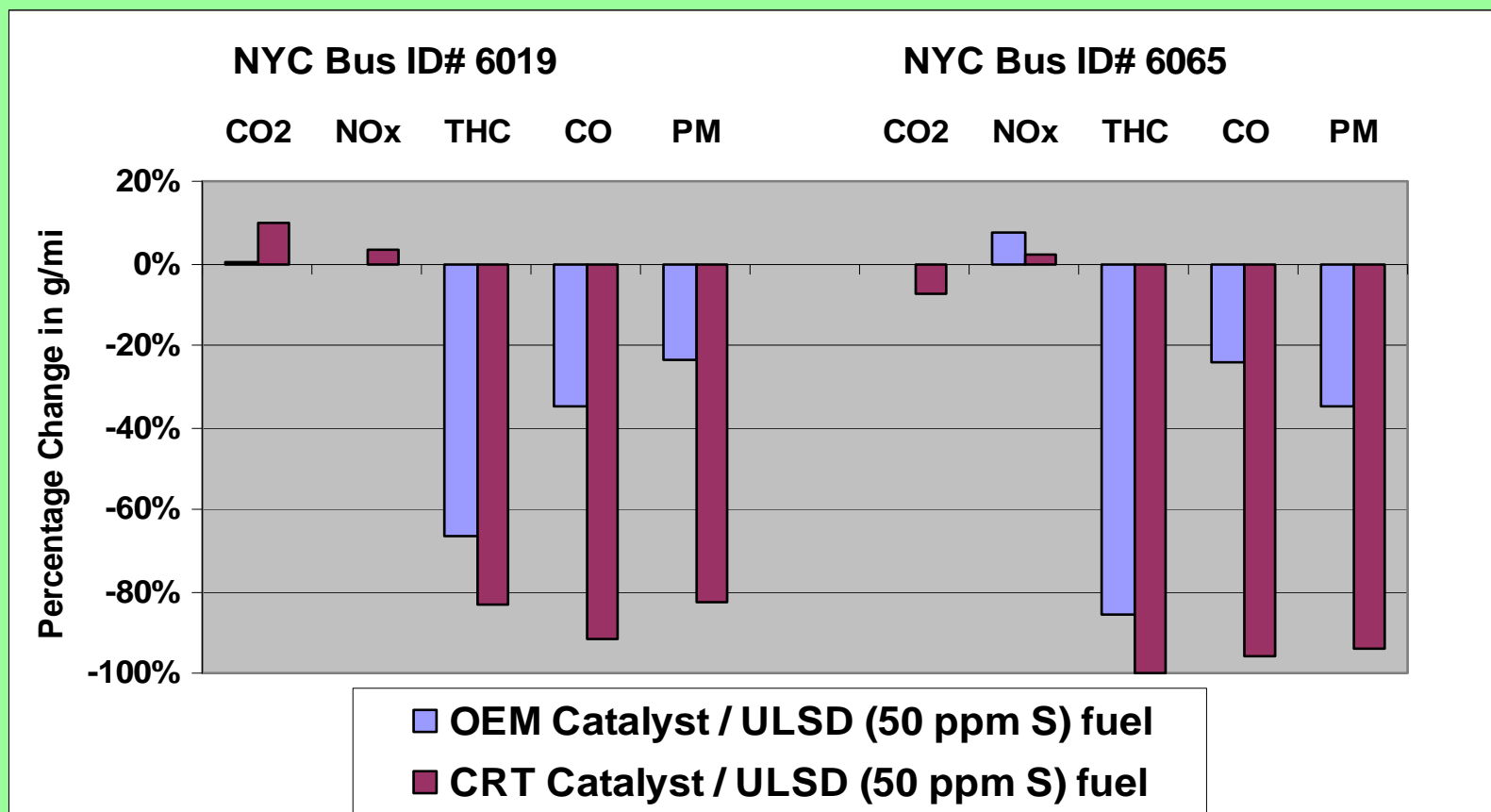
## **NYCT: Clean Diesel / Advanced Emissions Control also a Priority**

- **25 1999 MY buses with advanced continuously regenerating technology (CRT) filter**
- **Johnson Matthey catalyst / filter, designed to trap fine particulates and then burn them off with hot NO<sub>2</sub>**
- **2 CRT-equipped buses have undergone detailed emissions testing with:**
  - **OEM Catalyst on standard (350 PPM S) fuel**
  - **OEM Catalyst/ ultra low sulfur diesel (30 PPM)**
  - **CRT system / ultra low sulfur diesel (30 PPM)**



# Results of NYCT Diesel Bus Emissions Tests (Lanni et al, SAE 2001-01-05110)

Impacts from ULSD and advanced catalyst, compared to base bus (OEM catalyst, 350 PPM S fuel)





## **NYCT: Future Plans for Diesels**

- **NYCT has contracted for ULSD (ultra low sulfur diesel fuel (<50 PPM) for its entire diesel fleet for the next three years starting in September 2000**
- **NYCT has contracted to retrofit 500 buses with CRT filters starting from September 2000**



# Comparison of CNG Bus Emissions in NY and LA on Common Test Cycles

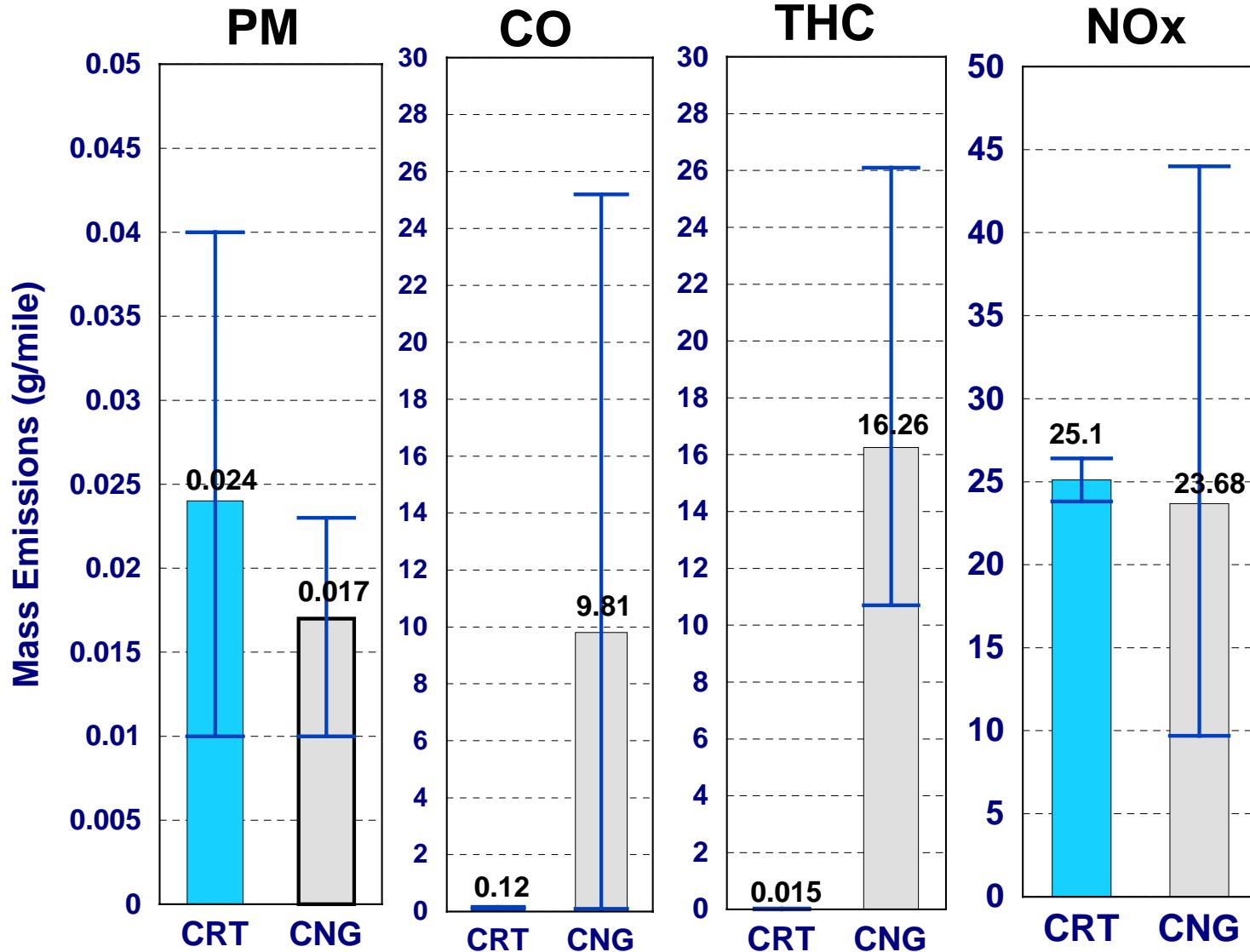
(From: “ Emissions Results from Clean Diesel Demonstration Program with CRT™ Particulate Filter at New York City Transit” Presentation, undated presentation provided by Dana Lowell, NYCT)

Engine Type	Bus No.	Location	Test Cycle	Test Location	F.E. (mpg)	CO2 (g/mile)	NOx (g/mile)	THC (g/mile)	CO (g/mile)	PM (g/mile)
1999 Ser 50G **	824	NYCT	CBD	Env. Canada		2112	44	19	20	0.090
1999 Ser 50G	824	NYCT	CBD	U. West Virginia	3.2	2264	15.9	23.1	12.9	0.020
1999 Ser 50G	854	NYCT	CBD	U. West Virginia	3	2421	13.8	18	12.4	0.010
1998 Ser 50G		NYDOT	CBD	U. West Virginia	2.6	2785	9.7	26.06	10.8	0.020
1998 L10G		Mass PA	CBD	U. West Virginia	3.1	2392	25	15.2	0.6	0.020
1996 L10G	4642	LAMTA	CBD	MTA/CARB	4.39	2239	27.43	10.722	25.16	0.023
1996 L10G	4740	LAMTA	CBD	MTA/CARB	3.74	2688	42.39	11.34	0.08	0.013
<b>Average Emission</b>			<b>CBD</b>		<b>3.37</b>	<b>2505</b>	<b>23.66</b>	<b>16.26</b>	<b>9.81</b>	<b>0.017</b>
1999 Ser 50G	824	NYCT	NY Bus	Env. Canada		5064	60	77	54	0.060
1999 Ser 50G	824	NYCT	NY Bus	U. West Virginia	1.3	5560	29.8	101	42	0.010
1999 Ser 50G	854	NYCT	NY Bus	U. West Virginia	1.3	5660	22.6	57.9	32.3	0.010
1998 Ser 50G		NYDOT	NY Bus	U. West Virginia	1.1	6535	15.3	73.34	31.7	0.110
1998 L10G		Mass PA	NY Bus	U. West Virginia		6090	113	70.24	29	0.140
1996 L10G	4642	LAMTA	NY Bus	MTA/CARB	1.9	4754	22.47	51.26		0.085
1996 L10G	4740	LAMTA	NY Bus	MTA/CARB	1.74	5696	99.89	35.15	8.67	0.105
<b>Average Emission</b>			<b>NY Bus</b>		<b>1.47</b>	<b>5623</b>	<b>51.87</b>	<b>66.56</b>	<b>32.95</b>	<b>0.074</b>

\*\* Emission data appears to be significantly different from the rest; Hence not used for average and in graphs

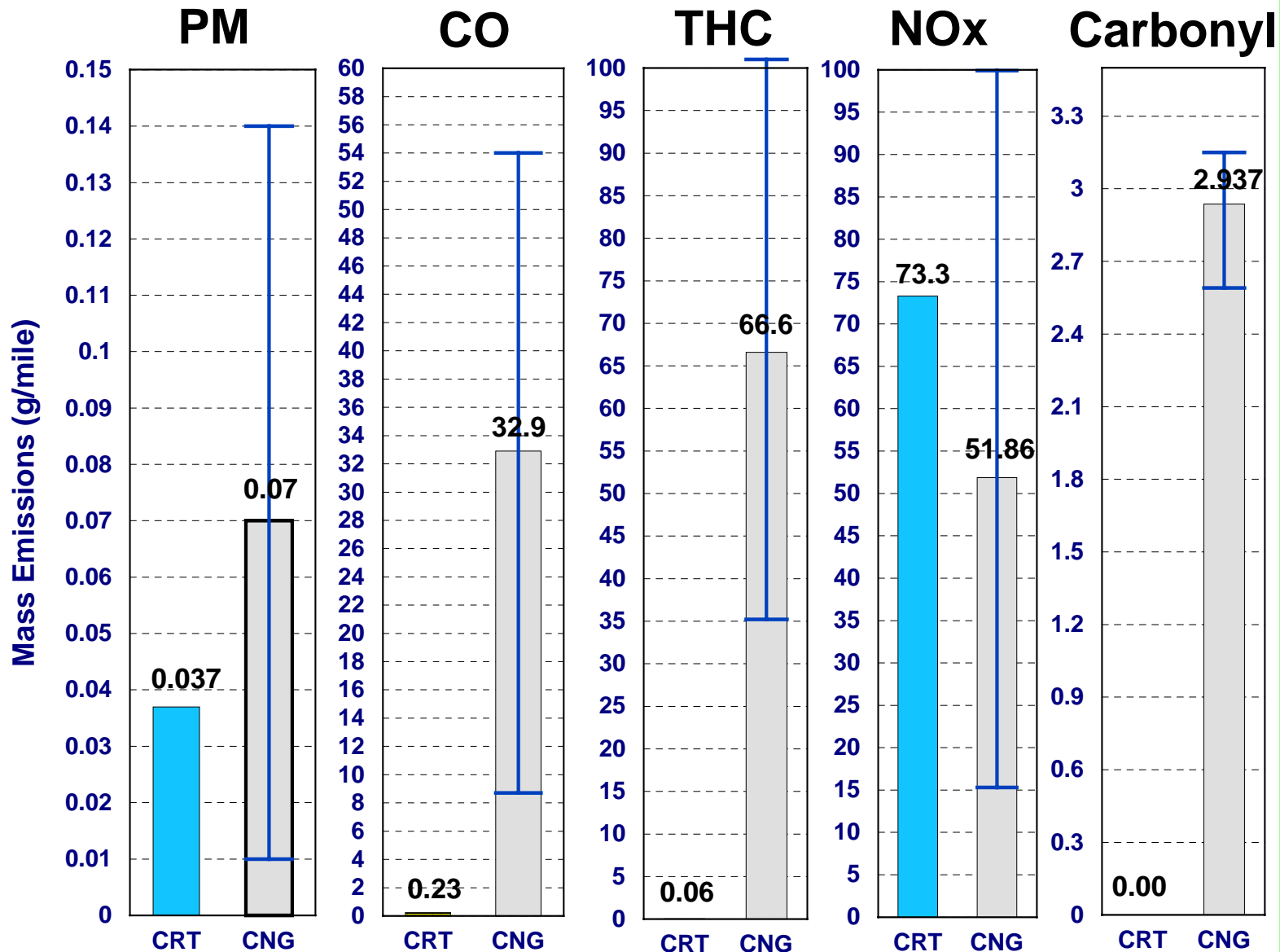


# Emissions Test Results - CRT vs. CNG CBD Cycle



# Emissions Test Results - CRT vs. CNG

## NY Bus Cycle





## **NYC Conclusions Clean Diesel vs. CNG**

- **PM emissions from CRT-equipped buses appear to be about equivalent to those from CNG buses**
  - Average PM emissions with CNG is lower on CBD cycle, but higher on NY Bus cycle
  - Much wider range of values with CNG, especially on NY Bus cycle
- **CO and HC emissions from CRT-equipped buses are much lower than those from CNG buses**
- **NOx emissions are generally lower from CNG buses than from CRT-equipped buses, but show a wider range of variability**
- **Carbonyl emissions from CNG buses are much higher than from CRT-equipped buses.**



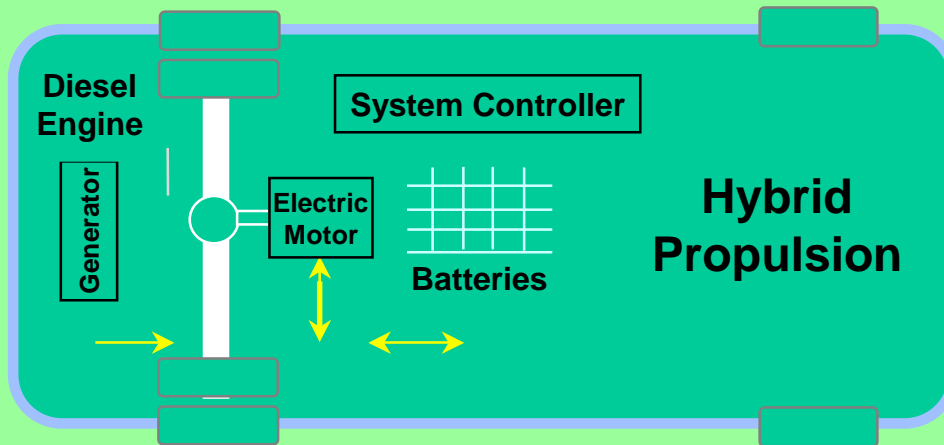
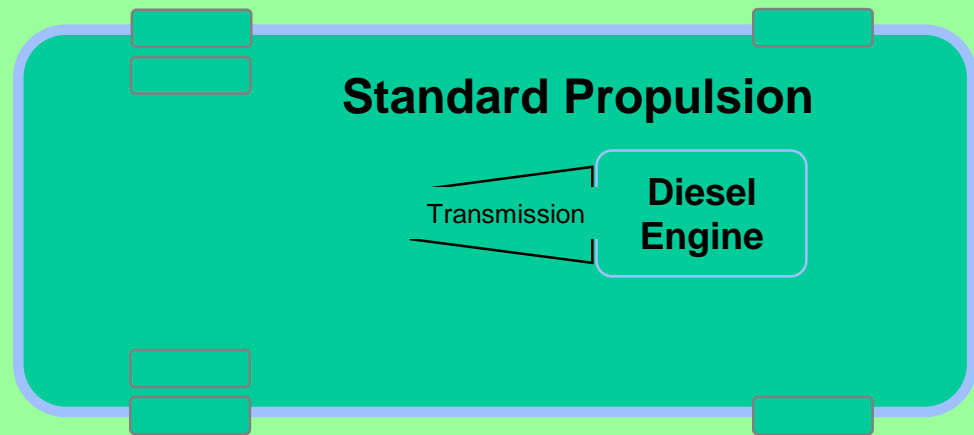
## **NYCT: Hybrid Electric Buses**

- **Hybrid Electric buses combine a diesel engine and electric drive components**
- **Improved performance**
  - **Significant emissions reduction**
  - **Increased fuel economy**
  - **Smooth and quiet operation**
- **Avoids the infrastructure costs of CNG - no special fuel handling is required**



# Hybrid vs. Conventional System

Large IC Engine  
and Mechanical  
Transmission



Small IC Engine  
Generator  
Electric Drive Motor  
Energy Storage  
System Controller



## NYCT Hybrid Bus Programs

- **Successful prototype in 1996 (Orion/GE)**
- **Two pilot fleets of hybrid buses ordered**
  - **10 Orion/BAE buses delivered**
  - **5 Nova/BAE buses due in 2001**
- **125 additional Orion/BAE buses ordered for delivery starting late 2001**
- **Hybrid retrofit for RTS bus - revenue service testing completed March 2000 (Allison/Nova)**
- **175 hybrid buses to be awarded this year**



## Revenue Service Experience

- **Hybrid buses in service since Sept. 1998**
- **230,000 revenue miles accumulated to date**
- **Very positive - for a brand new technology, have exceeded expectations**
- **Experience to date compares favorably to other new technology introductions**
- **NYCT is very encouraged for the future**

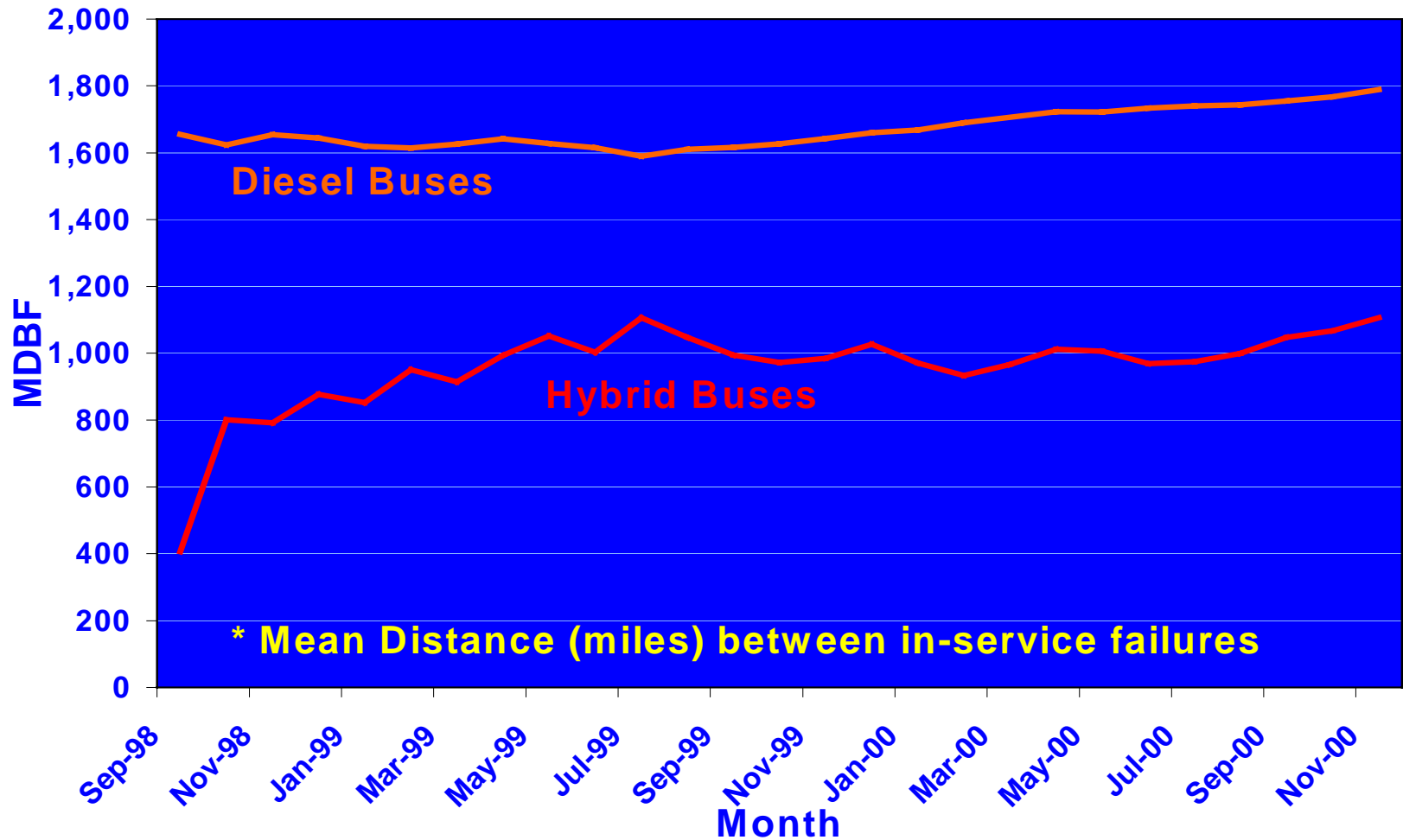


## **NAVC Emissions Testing**

- **Diesel hybrid electric buses offer emissions comparable to CNG buses**
- **50-90% lower PM than standard diesel buses**
- **30-60% lower NOx and HC**
- **20-40% lower greenhouse gases than CNG or standard diesel**
- **Significantly better fuel economy than CNG or standard diesel**
- **Emissions testing data is available online at [www.navc.org/emissionsreport.html](http://www.navc.org/emissionsreport.html)**

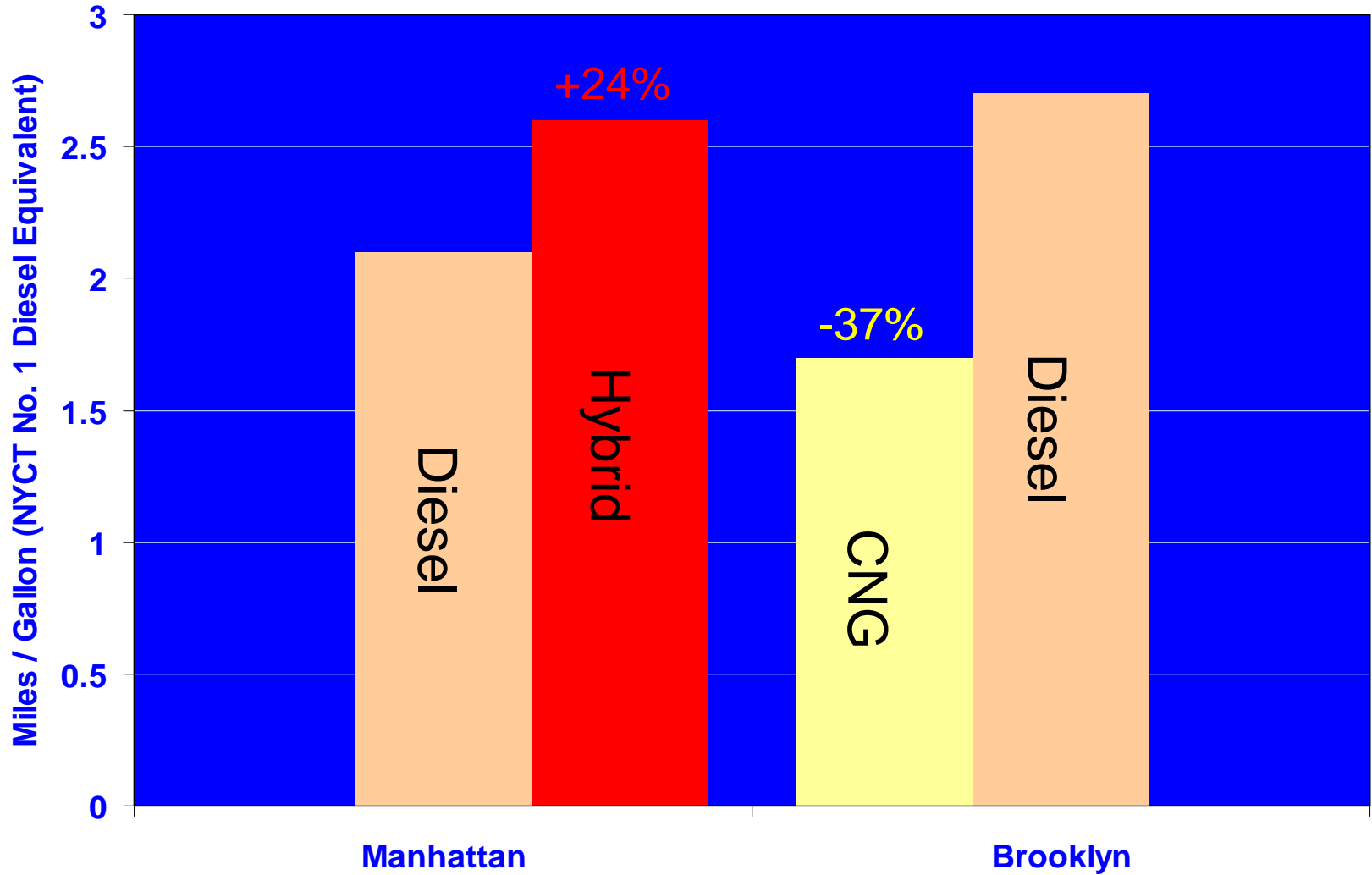


# Hybrid Bus Reliability (MDBF\*)





# Hybrid Bus Fuel Economy (MPG)





## Hybrids: Current Issues

- **Battery reliability and life - Replace Electrosource batteries with Hawker or Optima to improve reliability and life expecting ultracapacitors to be the final solution**
- **Catalytic exhaust filter is being redesigned; exhaust temperature and backpressure are being monitored to optimize emissions and reliability**
- **Wiring and software modifications are being completed to more closely control engine speed**
- **On track for continued ramp-up of hybrids to nearly 400 by 2003.**



## Paris: Recent tests by RATP

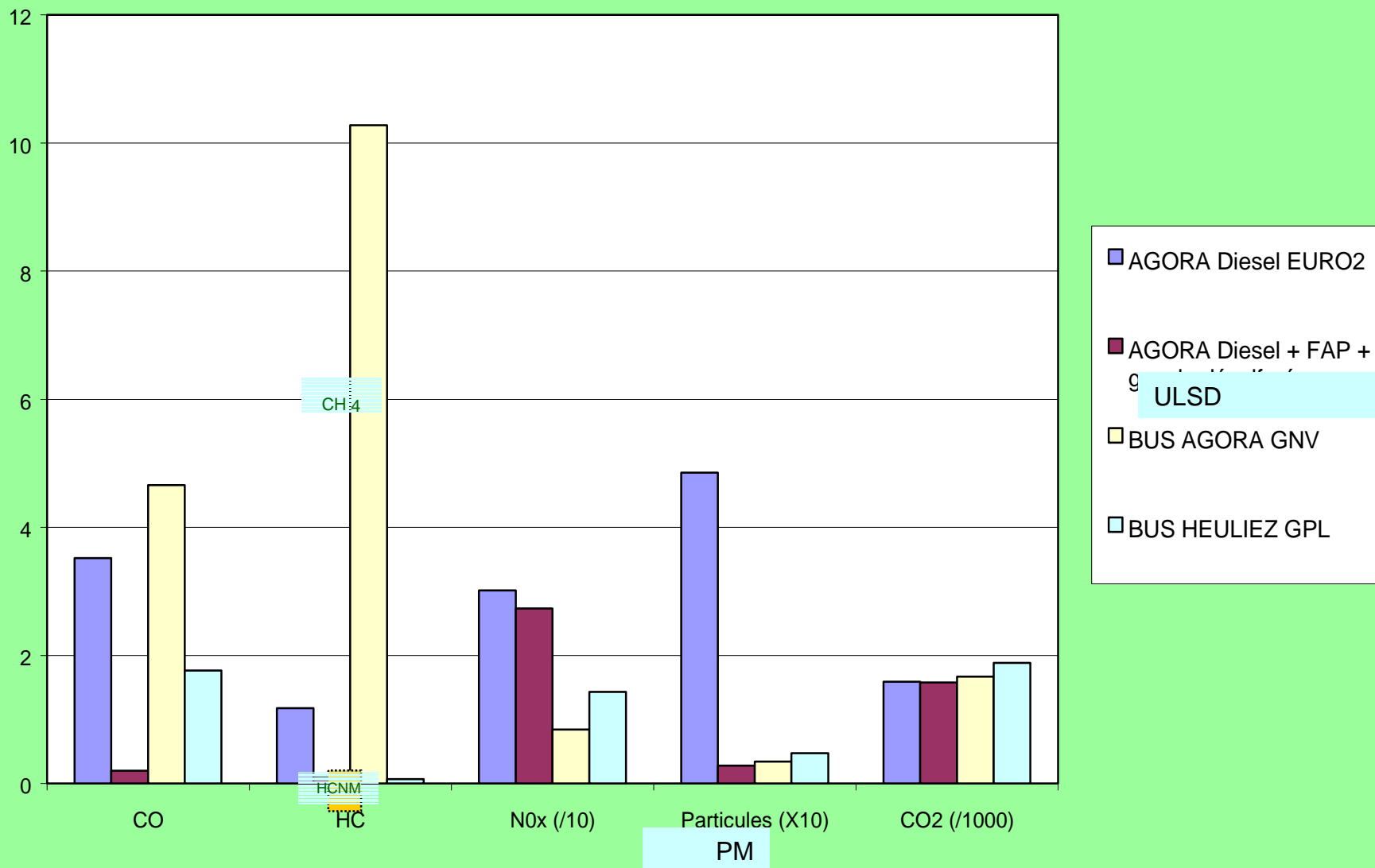
From RATP, “Bilan des Experimentations Bus Ecologiques: Document de Synthèse, Octobre 2000

- **RATP operates about 4000 buses.**
- **By 2002, RATP plans to replace all buses older than 10 years with one of three types.**
- **Status by end of 2000**
  - 53 CNG buses procured
  - 57 LPG buses procured
  - 700 diesel buses were equipped with catalyst/filters, operating on Low-sulfur diesel



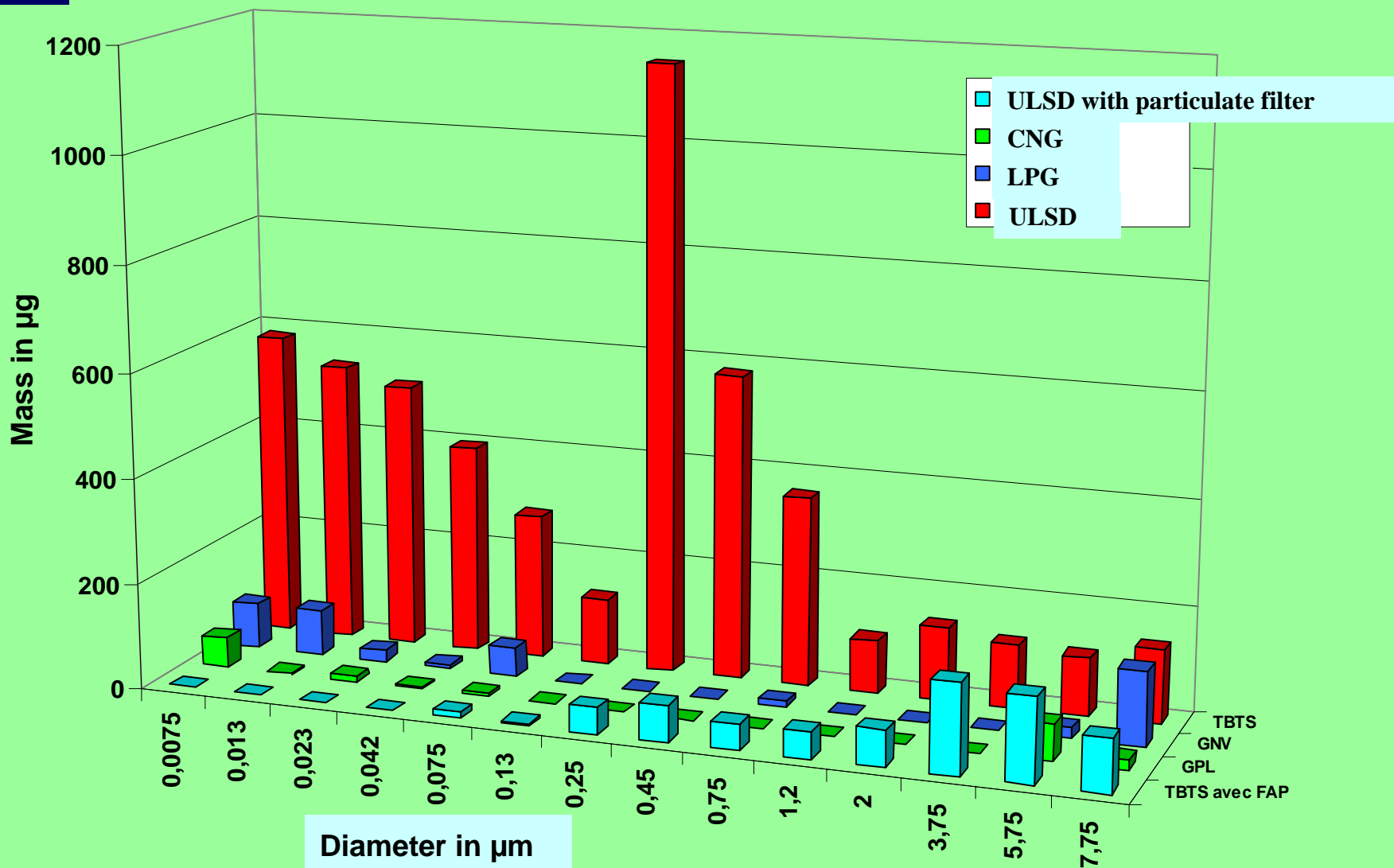
# RATP: Results of Emissions Tests

Test on chassis dynamometer using ADEME-RATP bus cycle (UTAC)





# RATP Emissions Tests: Distribution of Particulate Size





# Recent Experience with Diesel-water Emulsions

- **SAE 2000-01-1915 (Barnes et al) reports on London tests of water-blend diesel with city buses and finds the following:**
  - In buses with new engines but no emissions control equipment, tested on two test cycles (London “inner” and “outer” the water blend fuel (WBF) (10% water) gave very similar emissions as low-sulfur diesel (<50ppm) for HC and CO, and somewhat lower emissions of NOx and PM.
  - In buses equipped with a catalyst, WBF provided significant reductions of HC, NOx and PM compared to same buses running on ULSD (both reduced emissions of HC and CO over 90% v. buses without catalysts)
  - In buses equipped with a particulate filter (but no catalyst) the two fuels were comparable except for PM where WBF significantly outperformed ULSD on one test cycle but the opposite occurred on another (less urban) cycle.
  - The rub: tested buses had around an 8% power loss with the 10% diesel-water blend and a 3-8% fuel consumption increase.



## Conclusions and Implications for Delhi

- Emissions from (New) European and NA Diesel buses have been dropping dramatically in recent years.
- Diesel buses equipped with state-of-art catalyst/filters and using low-sulfur diesel appear to have PM, CO, HC, and toxic emissions comparable or lower than CNG, maybe still higher NOx.
- Hybrid diesels appear to hold promise for the not-too-distant future.
- Key Questions:
  - Costs: how much further cost reduction can be achieved with hybrids
  - DURABILITY: of new technologies, like hybrids and CRT filters?