Incidence of Malfunctions and Tampering and In-Use Emissions for Heavy-Duty Diesel Vehicles

California Air Resources Board

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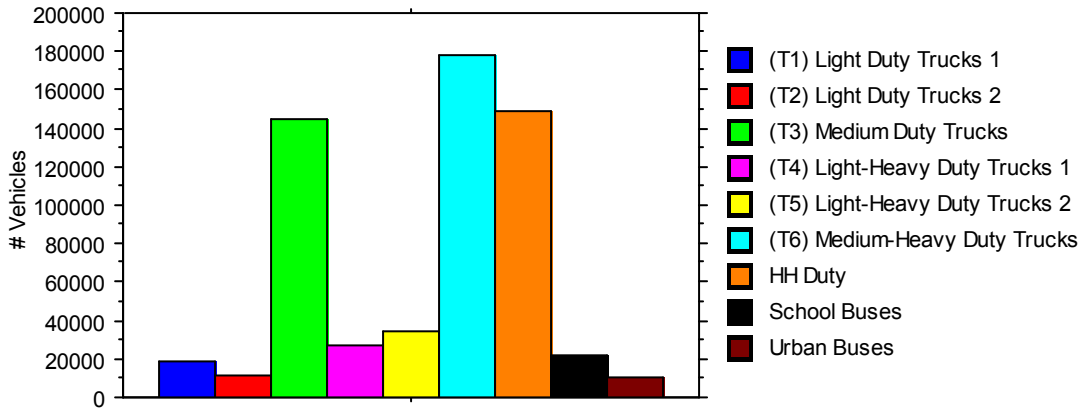
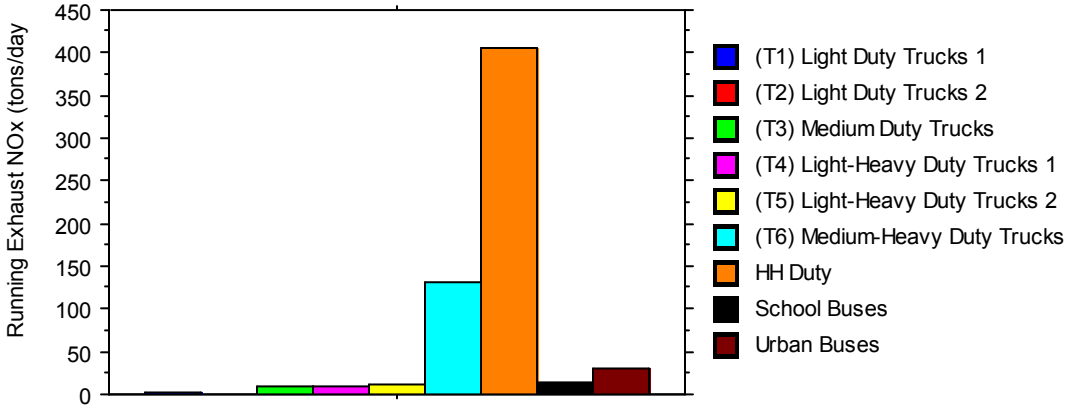
Project Motivation

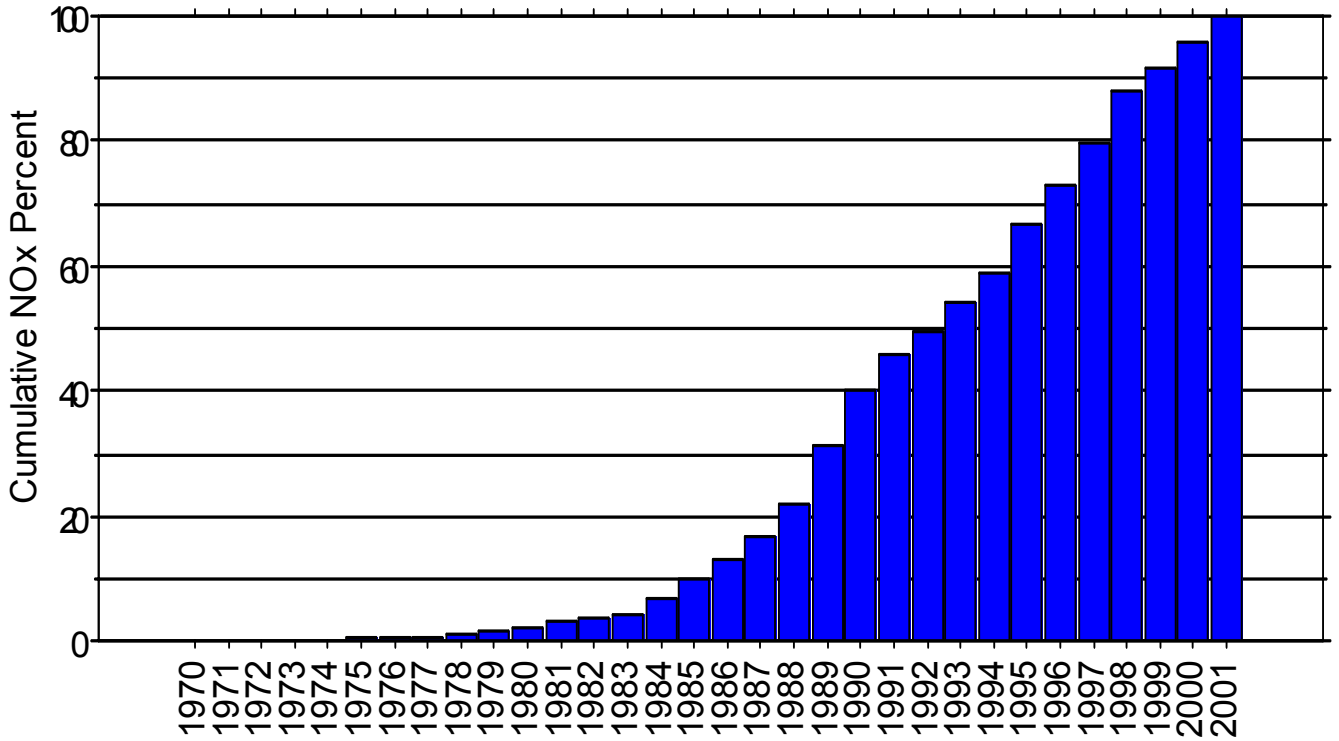
- On-going regulations expected to significantly reduce NOx and PM from new heavy-duty diesel vehicles (HDDVs) /on-road trucks
- For existing trucks California has an existing program but it monitors only smoke opacity
  - Heavy Duty Vehicle Inspection and Periodic Smoke Inspection Program
- CARB needs
  - understand the incidence of malmaintenance and tampering in HDDVs)
  - develop a program to control emissions from in-use HDDVs.
- CARB has conducted several pilot studies in this area.
  - In an earlier Measure 17 or M-17 program, 109 vehicles

Emissions Breakdown by Class of Truck





Emissions Breakdown by Model Year (Class 8)



Current Project

- Included several elements designed to better understand in-use emissions, malmaintenance, and tampering
- Review records of malmaintenance/tampering
  - Warrenty records, inspections, other surveys
- Testing of in-use HDDVs under on-road conditions in Stockton
  - 5 HDDVs tested with the CE-CERT Mobile Emissions Laboratory (MEL)

Tampering and Malmaintenance Records

- Literature Review
- Visual Inspections
- Warranty Records
- Independent repair shop records
- Roadside survey
- Electronic monitoring/downloads

Malfunction and Tampering Rates – 1994-1997

Defect	Radian	EFEE
Injection Timing Advanced	5%	3%
Injection Timing Retarded	3%	3%
Minor Injector Problem	15%	20%
Moderate Injector Problem	10%	10%
Severe Injector Problem	4%	3%
Puff Limiter Mis-Set	0%	4%
Puff Limiter Disabled	0%	4%
Max Fuel High	3%	3%
Clogged Air Filter	8%	16%
Wrong/Worn Turbo	5%	8%
Intercooler Clogged	5%	5%
Other Air Problems	8%	8%
Mech. Failure	2%	2%
Excess Oil Consumption	5%	2%
Electronics Failed	5%	5%
Electronics Tampered	15%	10%
Catalytic Converter Removed	0%	0%
EGR Stuck Open	40%	0%
EGR Disabled	0%	0%

Malfunction and Tampering Rates – EMFAC2007

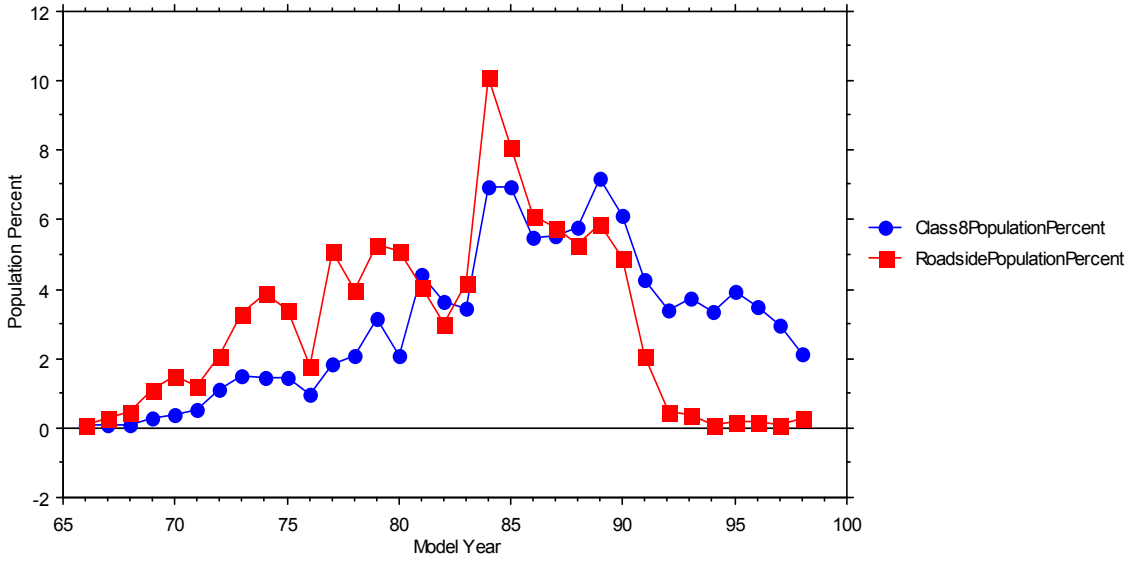
Table 4. Frequency of Occurrence of T&M Acts for HHDDTs[a,b]

T&M Act	EMFAC2002			Revised		
	1994-97	1998-02	2003-06	1994-97	1998-02	2003-06
Timing Advanced	5%	2%	2%	5%	2%	2%
Timing Retarded	3%	2%	2%	3%	2%	2%
Minor Injector Problem	15%	15%	8%	15%	15%	8%
Moderate Injector Problem	10%	10%	5%	10%	10%	5%
Severe Injector Problem	3%	3%	0%	3%	3%	0%
Puff Limiter Misset	4%	0%	0%	4%	0%	0%
Puff Limiter Disabled	4%	0%	0%	4%	0%	0%
Max Fuel High	3%	0%	0%	3%	0%	0%
Clogged Air Filter	15%	15%	15%	15%	15%	15%
Wrong/Worn Turbo	5%	5%	5%	5%	5%	5%
Intercooler Clogged	5%	5%	5%	5%	5%	5%
Other Air Problem	8%	8%	8%	8%	8%	8%
Engine Mechanical Failure	2%	2%	2%	2%	2%	2%
Excessive Oil Consumption	5%	3%	3%	5%	3%	3%
Electronics Failed	3%	3%	3%	3%	3%	3%
Electronics Tampered	5%	5%	5%	**10%**	**15%**	5%
Catalyst Removed	0%	0%	0%	0%	0%	0%
EGR Stuck Open	0%	0%	0%	0%	0%	0%
EGR Disabled	0%	0%	10%	0%	0%	10%

Heavy-Duty Vehicle Inspection Program

- 5,210 records from 1998 to 2002
- Inspectors pull over trucks expected to have problems

Database Year	1998	1999	2000	2001	2002
Number of Vehicles	890	1346	1361	1042	775



Roadside Inspection Results – 1998-2002

Roadside Inspection	EMFAC Group	Observation	Percent
EGR	19	Pass	5.3%
	EGR	Not Applicable	91.5%
		Modified	0.4%
		Disconnected	1.4%
		Missing	1.3%
ACI	12	Pass	45.1%
Air Control Indicator	Other Air	Not Applicable	54.4%
		Modified	0.2%
		Disconnected	0.0%
		Missing	0.3%
CMPTR	15 or 16	Pass	5.4%
Computer	Electronics Failed	Not Applicable	93.9%
	Electronics Tampered	Modified	0.1%
		Disconnected	0.1%
		Missing	0.5%
PCV	12	Pass	97.0%
	Other Air	Not Applicable	0.0%
		Modified	0.7%
		Disconnected	1.1%
		Missing	1.1%
TAC	12	Pass	93.4%
Thermostatic Air Cleaner	Other Air	Not Applicable	0.6%
		Modified	0.3%
		Disconnected	0.9%
		Missing	4.8%
AAIR	12	Pass	93.9%
Auxilary Air	Other Air	Not Applicable	1.0%
		Modified	0.5%
		Disconnected	2.0%
		Missing	2.6%
FUELINJ	3,4,5	Pass	93.1%
	Fuel Injection	Not Applicable	6.4%
		Modified	0.4%
		Disconnected	0.0%
		Missing	0.1%

Warranty Repair Data – 1993-1999

- Warrenty claims must be reported when > 1% or 25 engines/vehicles in an engine family

Defect	This study	EFFE
1. Injection Timing Advanced	<1%	3%
2. Injection Timing Retarded	<1%	3%
3. Minor Injector Problem	**1.7%**	**20%**
4. Moderate Injector Problem	**22.95%**	**10%**
5. Severe Injector Problem	<1%	3%
6. Puff Limiter Mis-Set	NA	2%
7. Puff Limiter Disabled	NA	4%
8. Max Fuel High	<1%	3%
9. Clogged Air Filter	<1%	16%
10 Wrong/Worn Turbo*	**59.0%**	**8%**
11 Intercooler Clogged	<1%	5%
12 Other Air Problems	<1%	8%
13 Mech. Failure	1.6%	2%
14 Excess Oil Consumption	<1%	2%
15 Electronics Failed	**64.5%**	**5%**
16 Electronics Tampered	<1%	10%
17 Catalytic Converter Removed	NA	0%
18 EGR Stuck Open	<1%	0%
19 EGR Disabled	<1%	0%
* 8% without 1997		

Non-fleet Repair Facility Records

- Results based on survey from a single repair facility

Defect	Number	This study	EFEE
1. Injection Timing Advanced	30	6%	3%
2. Injection Timing Retarded	20	4%	3%
3. Minor Injector Problem	80	16%	20%
4. Moderate Injector Problem	40	8%	10%
5. Severe Injector Problem	20	4%	3%
6. Puff Limiter Mis-Set		0%	4%
7. Puff limiter disabled		0%	
8. Max Fuel High	10	2%	3%
9. Clogged Air Filter	**20**	**4%**	**16%**
10. Wrong/Worn Turbo	10	2%	8%
11. Intercooler Clogged	15	3%	5%
12. Other Air/fuel Problems	10	2%	8%
13. Mech. Failure/	**60**	**12%**	**2%**
14. Excess oil consumption	**70**	**14%**	
15. Electronics Failed	**55**	**11%**	**5%**
16. Electronics Tampered	10	2%	10%
17.Catalytic Converter Removed	5	1%	0%
18. EGR Stuck Open		0%	0%
19. EGR Disabled		0%	0%

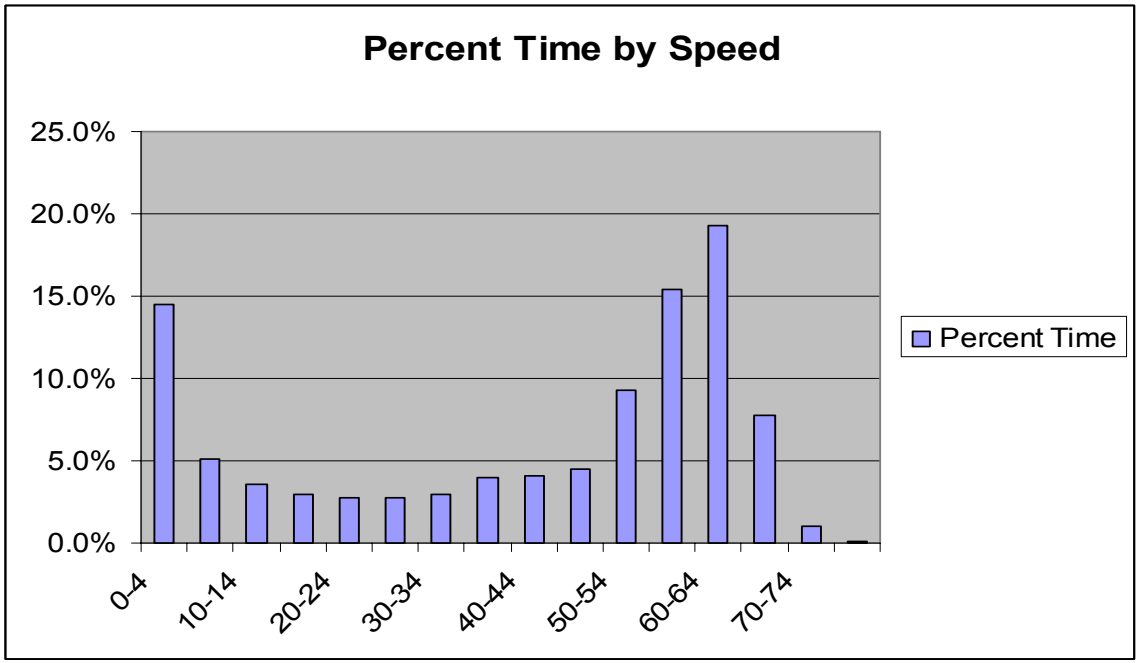
Roadside Driver Survey

- 58 HHDV drivers in 2002
- Drivers asked if they had experienced any problems in past 12 months

Defect	This study	EFEE
1. Injection Timing Advanced		3%
2. Injection Timing Retarded		3%
3. Minor Injector Problem	7.8%	20%
4. Moderate Injector Problem	3.9%	10%
5. Severe Injector Problem	3.9%	3%
6. Puff Limiter Mis-Set	0%	4%
7. Induction problems	2.0%	
8. Max Fuel High		3%
9. Clogged Air Filter	7.8%	16%
10. Wrong/Worn Turbo	3.9%	8%
11. Intercooler Clogged	3.9%	5%
12. Other Air/fuel Problems	7.8%	8%
13. Mech. Failure/	2.0%	2%
14. Valve lash	3.9%	
15. Electronics Failed	0%	5%
16. Electronics Tampered		10%
17.Catalytic Converter Removed		0%
18. EGR Stuck Open		0%
19. EGR Disabled		0%
Throttle delay	2.0%	
Other	9.8%	

Electronic Scan Tool Survey

- Downloads of Engine ECM data
- Can determine if engine reflashed to “non-standard” personality
- 7 vehicles – 6 no changes – 1 reflashed to factory setting
- Speed and RPM distributions



Summary/Conclusions – Malmaintenance & Tampering

- Reviewed about 7,000 records
- Warranty Repair (998) incident levels comparable to EMFAC (except higher for fuel injectors, turbos, & electronics)
- Visual inspections (5,210) indicated visible tampering (<1%)
- Roadside survey (78) malfunctions comparable to EMFAC
- Repair facility (500) records – comparable to EMFAC

- Overall, decided that current EMFAC tampering/malmaintenance factors were adequate

In-use Emissions Testing

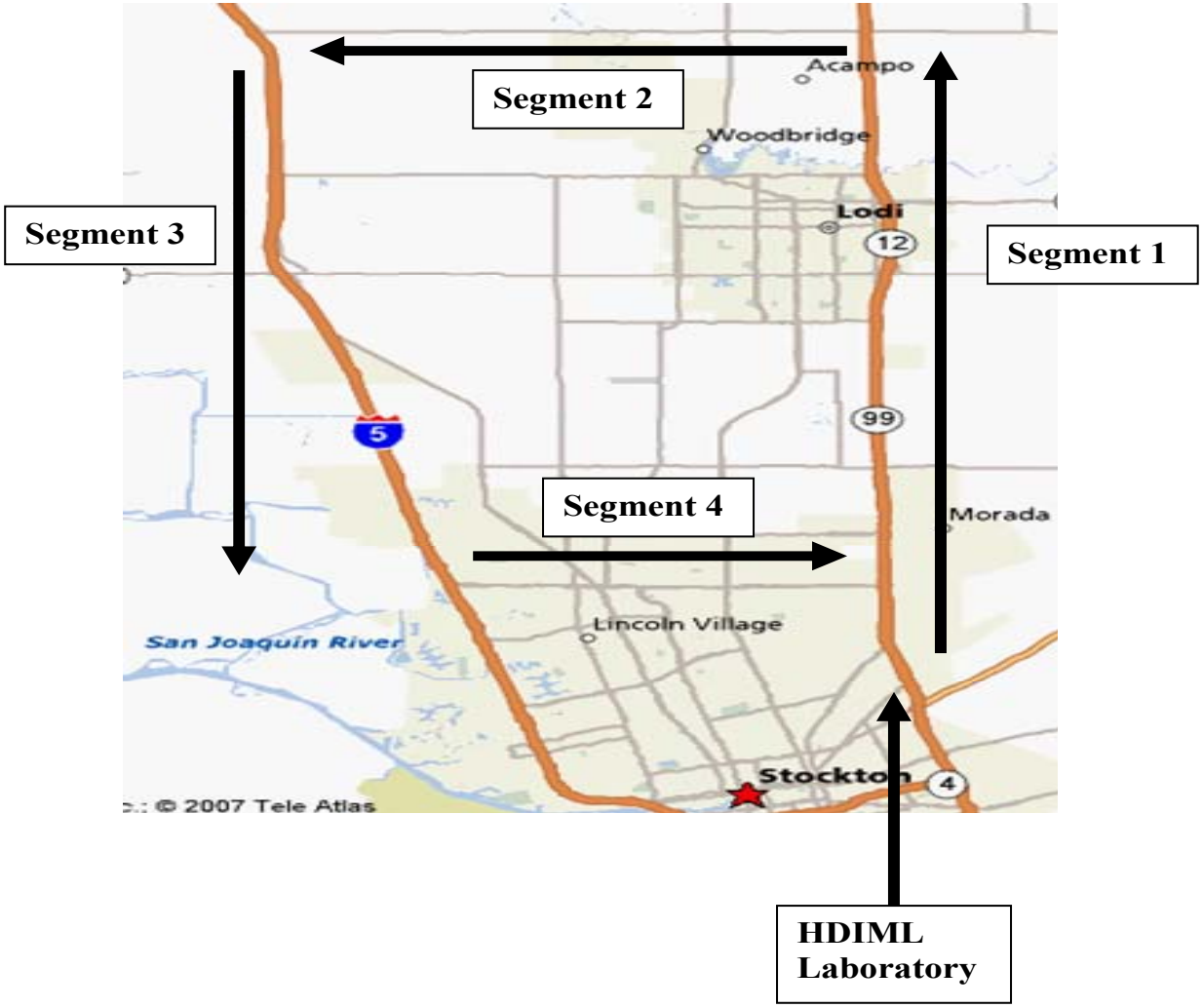
- Testing of 5 HDDVs near Stockton, CA
  - 1996-2004, various manufacturers
- Testing conducted using CE-CERT's MEL
- Varying operating conditions
  - Highway cruise, lower speed cruise, surface streets, power lugs

Test Fleet

Year	Engine	Chassis	Odometer (miles)
1996	Cummins M-11	Freightliner	337,024
2000	Caterpillar C-15	Freightliner	17,826
2002	Detroit Diesel Series 60	Freightliner	181,328
2003	Mack AC427	Mack	107,567
2004	Cummins ISM	International	7,664

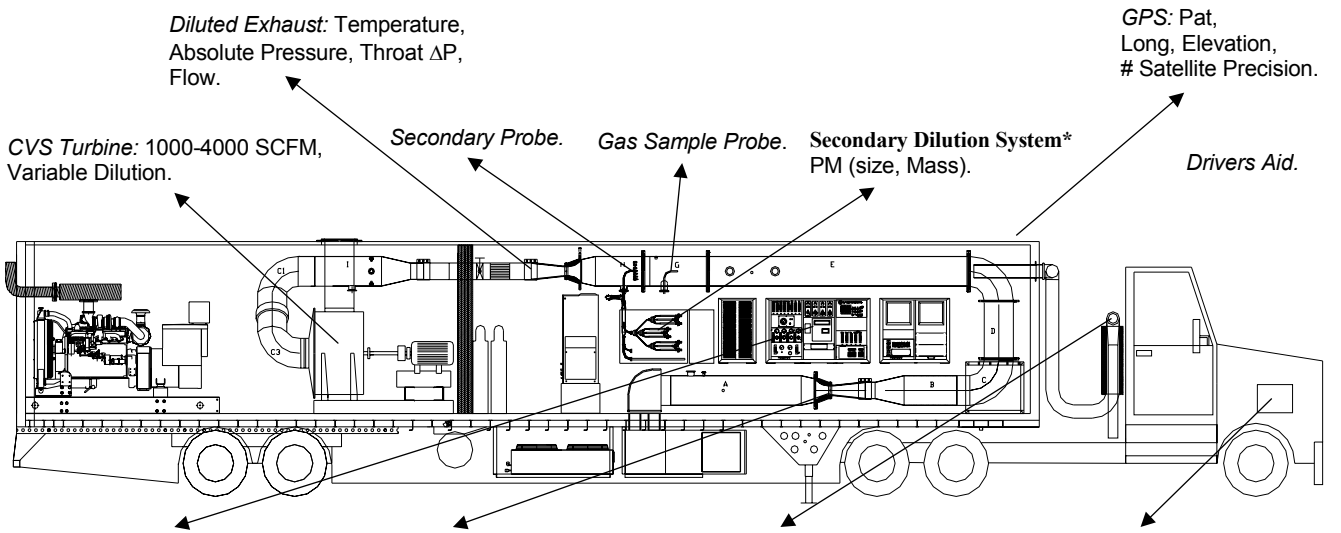
Test Route

Figure 1. Map of In-use Test Route

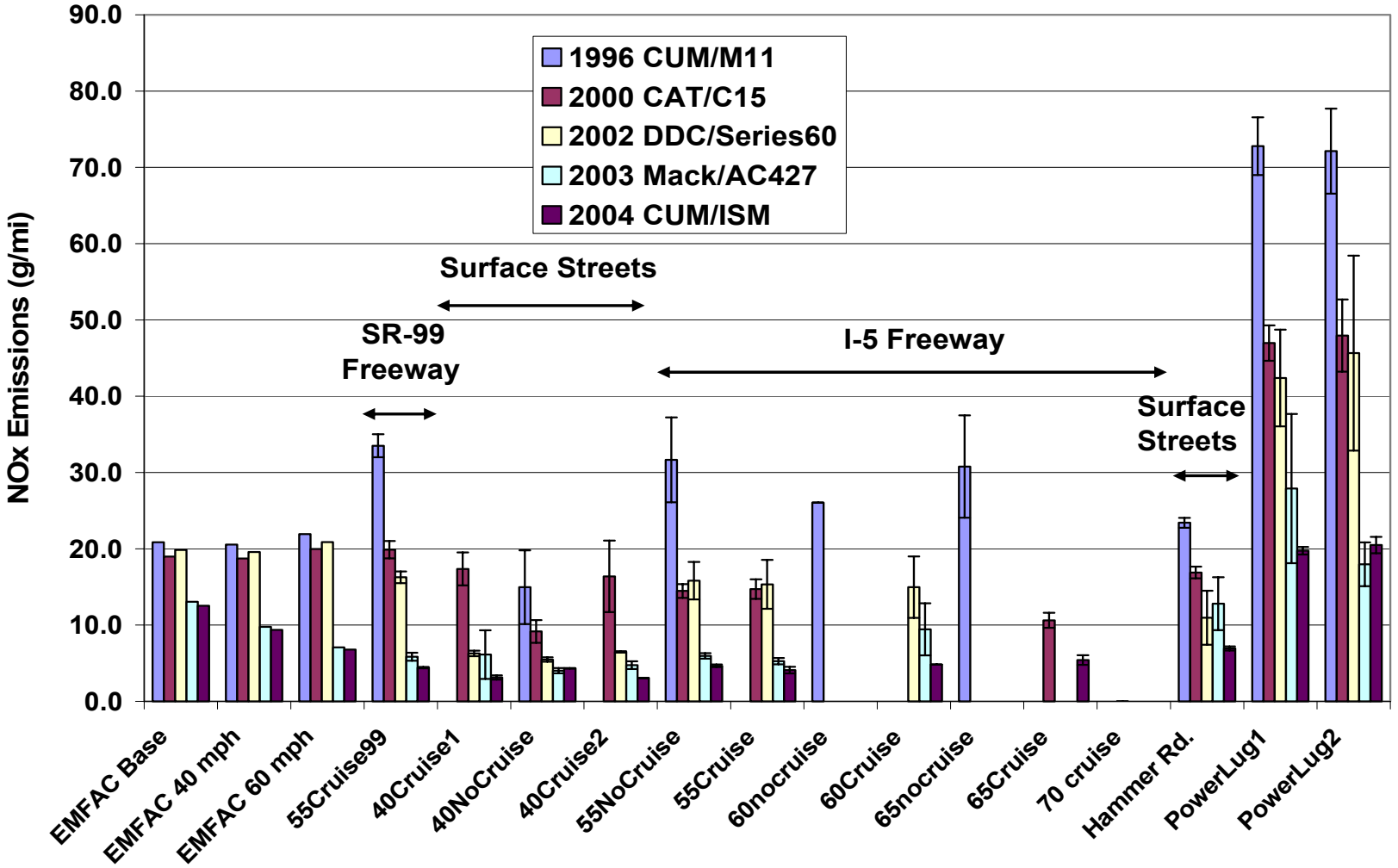


Mobile Emissions Laboratory (MEL)

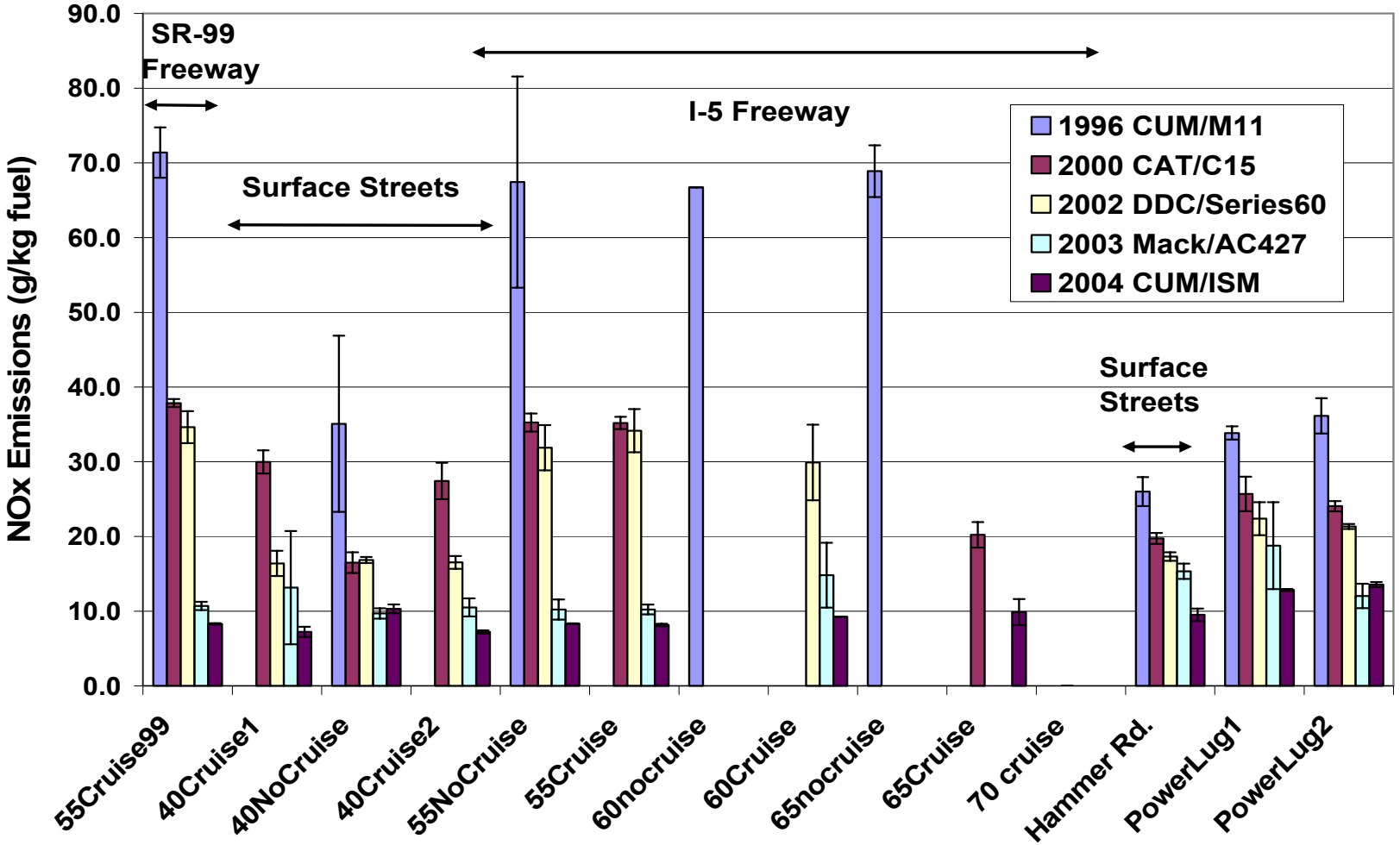
Mobile Emissions Laboratory (MEL) Schematic



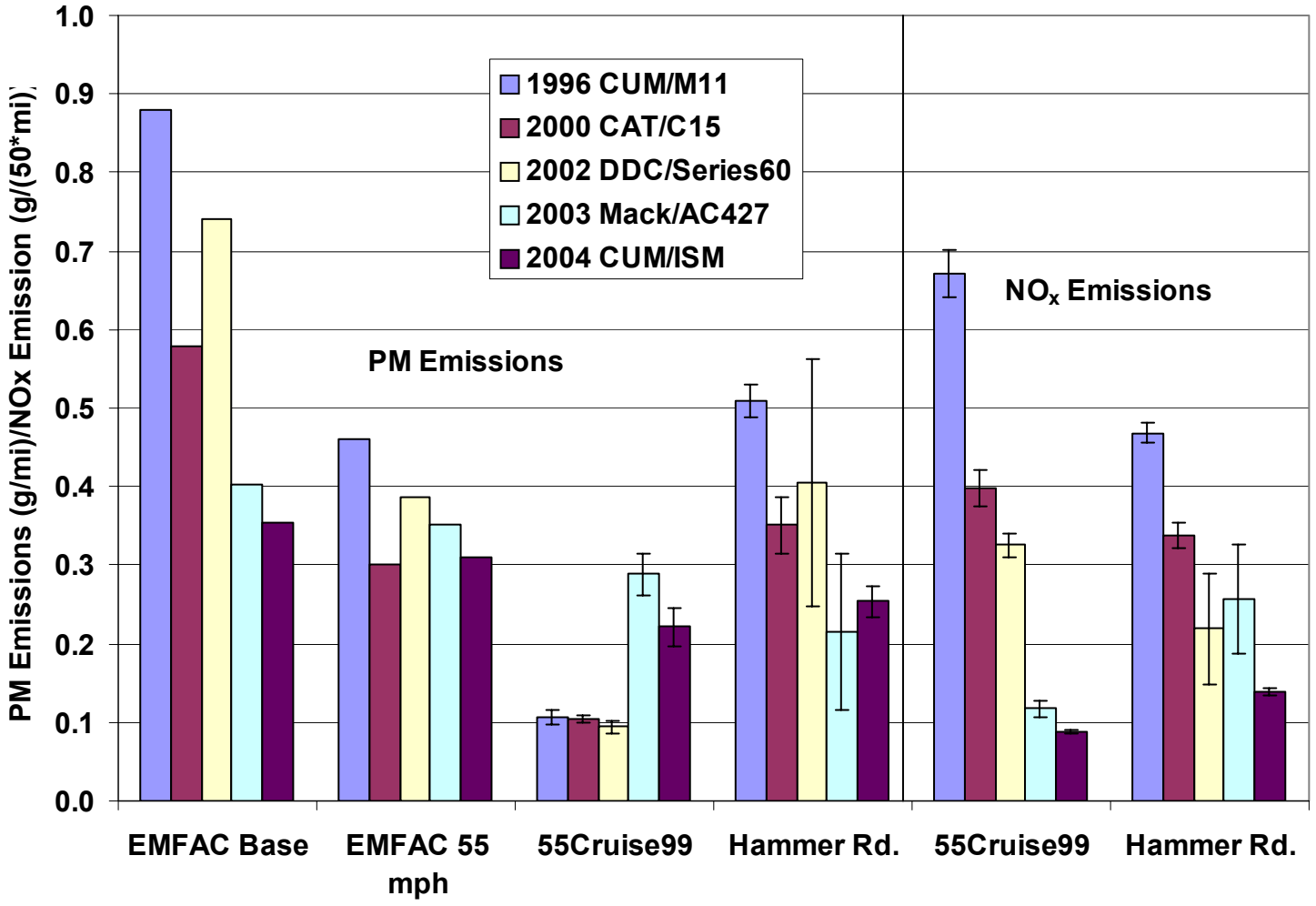
NO_x Emissions



NO_x Emissions – Fuel Specific



PM Emissions



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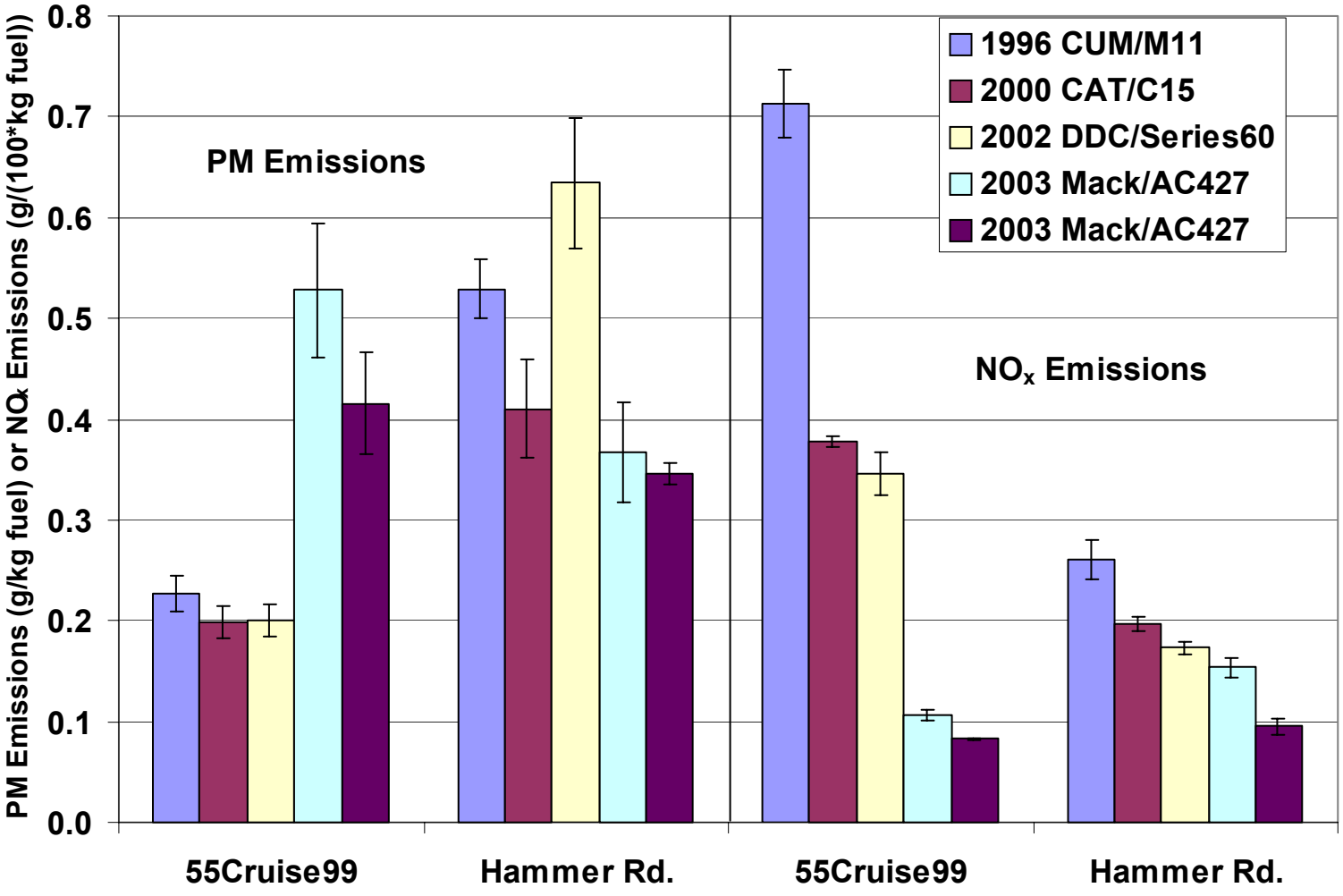
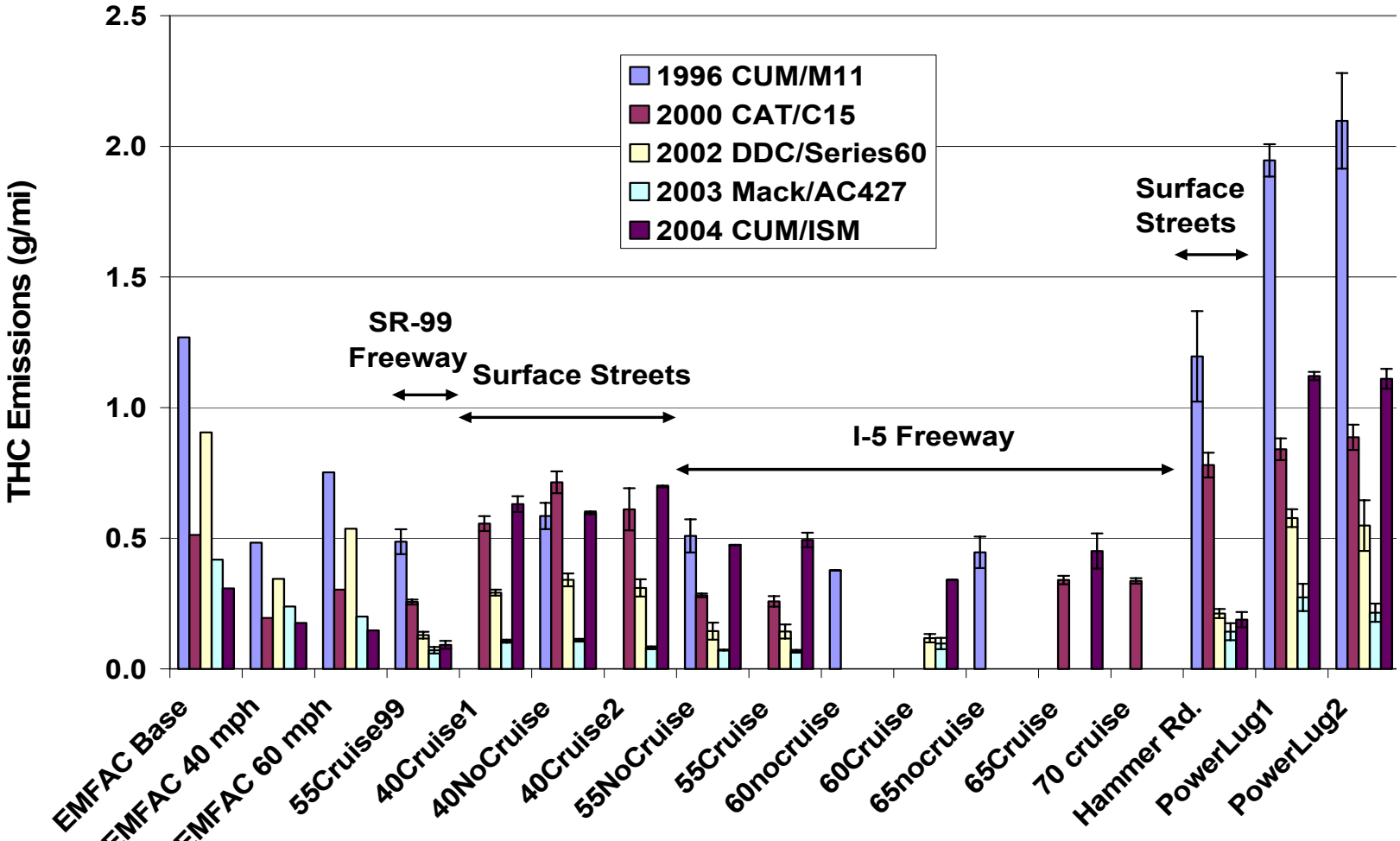
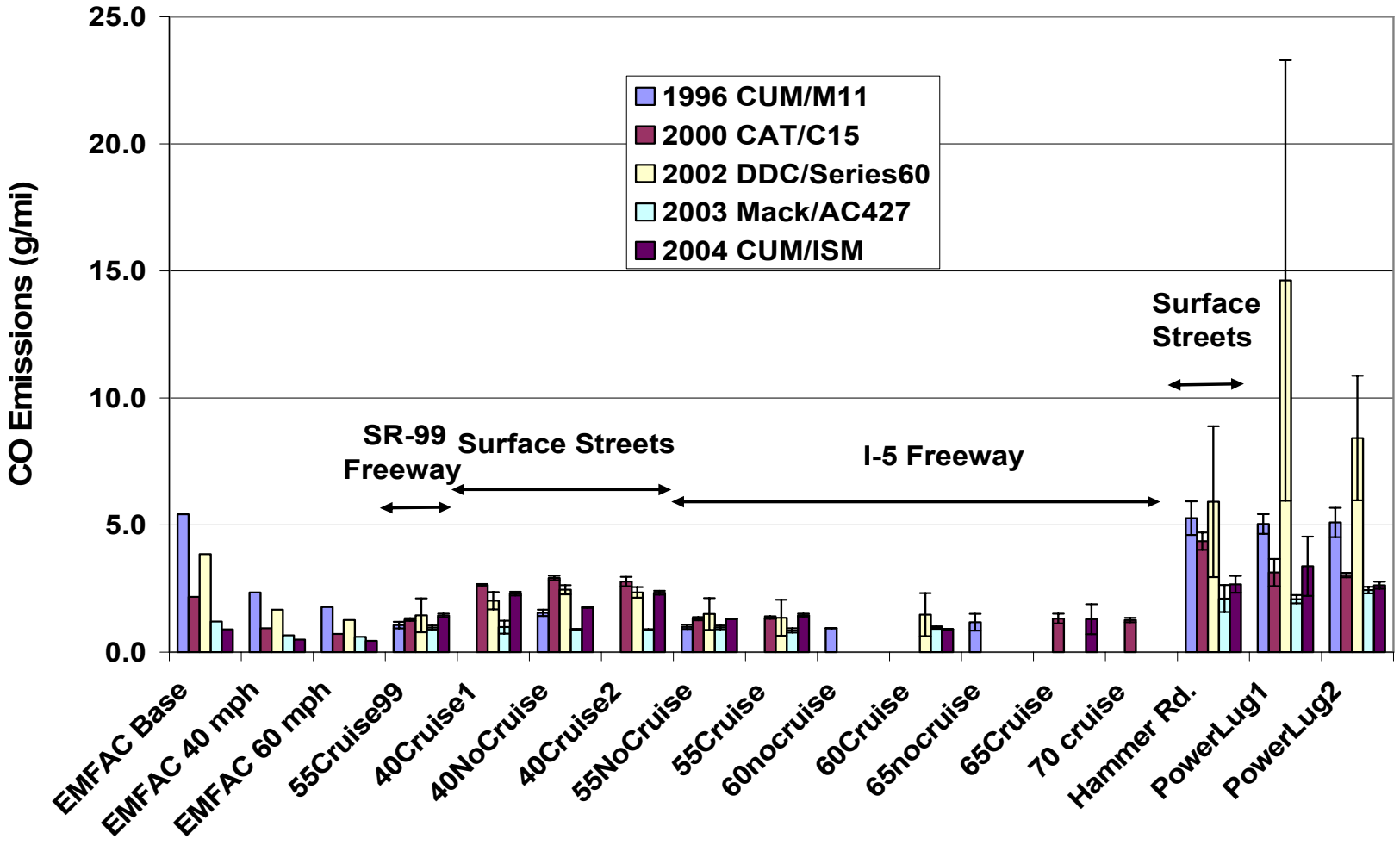


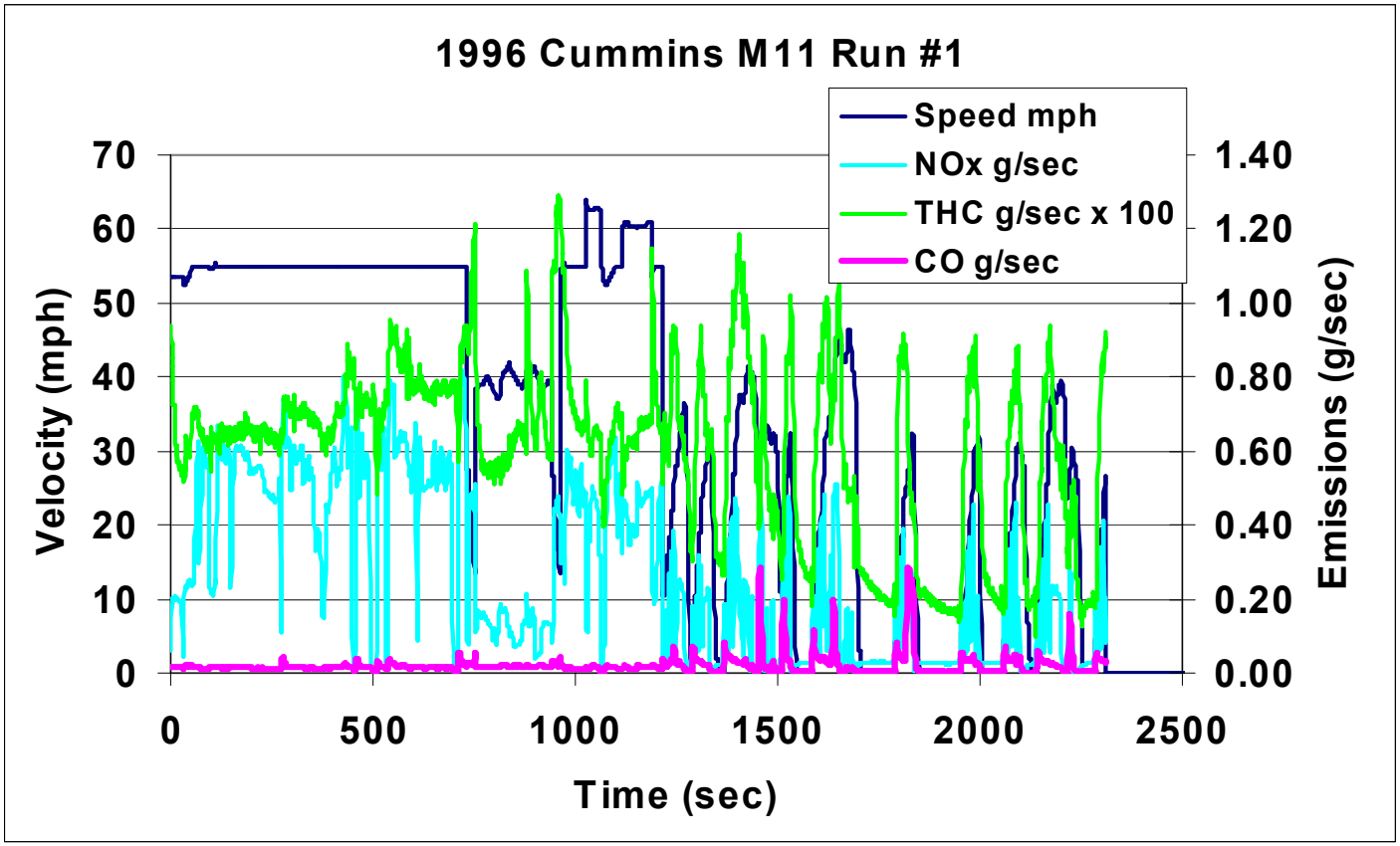
THC Emissions



CO Emissions



Real-Time Emissions from MEL



Summary/Conclusions from Emissions Testing

- Overall
  - Depend on pollutant, vehicle, and driving condition
  - Real-time emissions: transient /depend on engine operation
- NO_x
  - Some vehicles higher NO_x for higher speeds (≥55 mph vs. 40 mph/surface street) while others did not
  - The oldest vehicle, 1996 truck, had the highest emissions for nearly all types of driving
- PM
  - Surface street driving: oldest vehicle had highest PM emissions
  - Highway driving: 2 newest vehicles had the highest PM emissions
  - Some vehicles had higher PM emissions on the surface streets vs. highway
  - For newer vehicles on highway there appeared to be a NO_x/PM tradeoff
- THC
  - THC emissions generally higher for surface streets and 40 mph cruise compared to highway driving
- CO
  - CO generally higher on surface streets vs. highway
  - CO emissions under steady state generally low (1 -3 g/mi)