Advanced Fuels in HDV Applications

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Fuel Sources

- Diesel-like Fuels
  - Traditional Petroleum Sources
  - Biodiesel (Soy)
  - Synthetic Fischer-Tropsch Fuels (Coal & Gas)
  - Other Bio-derived Products
- Fuels for Alternate Engines (including SI)

Fischer-Tropsch Fuel

- Displaces petroleum demand using coal or natural gas as energy source
- Offers ultra low sulfur specification
- Usually has high cetane rating (paraffinic)
- Enables use of particulate matter aftertreatment
- Used in diesel blends
- Widely demonstrated in pure form

California F-T Study

(Yosemite Waters Trucks)

- Funding from DOE & SCAQMD
- Study by NREL & WVU
- Three rounds of testing
- Previous SAE papers http://www.nrel.gov/vehiclesandfuels/npbf/pubs_liquid.html

Vehicles in the Study

Vehicle	
Manufacturer	International
Model Number	4300-DT466
Model Year	2001
GVWR/Curb Weight	26,000 lbs / 13,200 lbs
Test Weight	20,500 lbs
Transmission Type	5-Speed Automatic
Transmission Manufacturer	Allison
Transmission Model	2000
Engine	
Manufacturer	International
Model	DT466
Configuration	Inline 6 Cylinder
Model Year	2001
Peak Power	195 hp @ 2300 rpm
Peak Torque	500 ft-lb

Fuels in the Study

Property	**Test Method**	**Shell GTL**	**CARB**
Density (g/ml)	ASTM D4052	0.7838	0.8299
API Gravity	ADTM D287	49	38.9
Pour Point (C)	ASTM D97	-6	-26
Cloud Point (C)	ASTM D2500	1	-9
Sulfur (ppm)	ASTM D5453	0.5	153
Total Aromatics (%mass)	ASTM D5186	1.4	21.8
Polynuclear Aromatics	ASTM D5186	<0.1	3.4
Cetane Number	ASTM D613	79.5	55.4
IBP (C)	ASTM D86	208.9	176.4
T50 (C)	ASTM D86	299.0	261.4
T90 (C)	ASTM D86	331.1	323.6

Transportable Laboratory

Laboratory consists of two trailers which are transported using heavy-duty tractors

Chassis Dynamometer Trailer

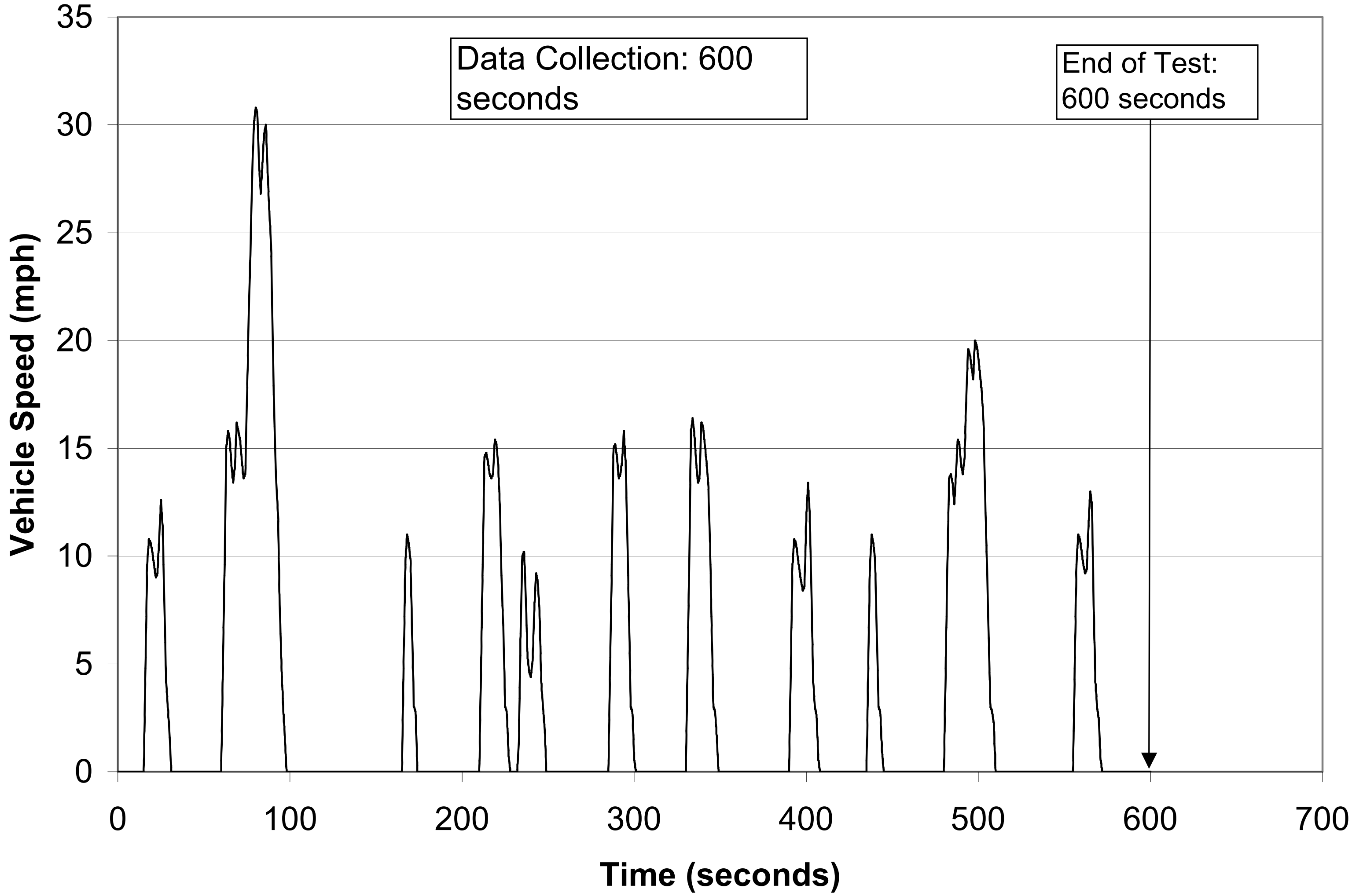
- **Incorporates flywheels and power absorbers**
- **Drive is through hub adapters**
- **Inertia is mimicked by flywheels**
- **Road-load is provided by eddy-current absorbers**
- **Vehicle is operated by a driver following a speed-time trace on a computer monitor.**
- **Exhaust is routed to a full-scale dilution tunnel mounted on the emissions trailer**

Transportable Laboratory

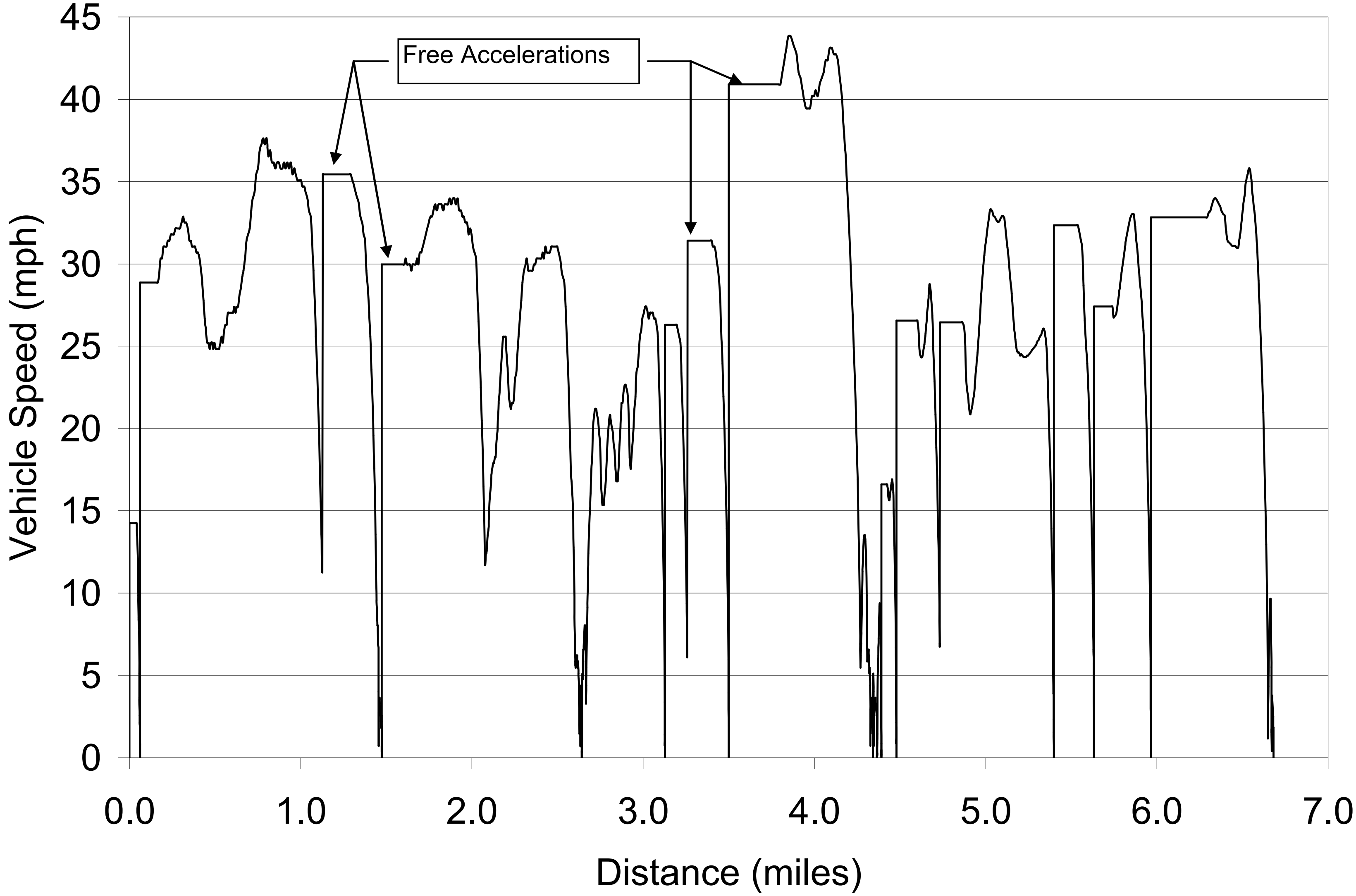
Emissions Measurement and Data Acquisition Trailer

- **Trailer houses the emissions measurement equipment, data acquisition and dynamometer controls.**
- **Full-scale dilution tunnel mounted on emissions trailer.**
- **Dilute exhaust flow control using a critical flow venturi.**
- **Dilute exhaust concentrations of HC, CO, NOx and CO2 are continuously monitored and recorded.**
- **Particulate matter measured using filter media with secondary dilution capabilities.**
- **Additional equipment to measure non-regulated species.**

Driving Schedules – NY Bus

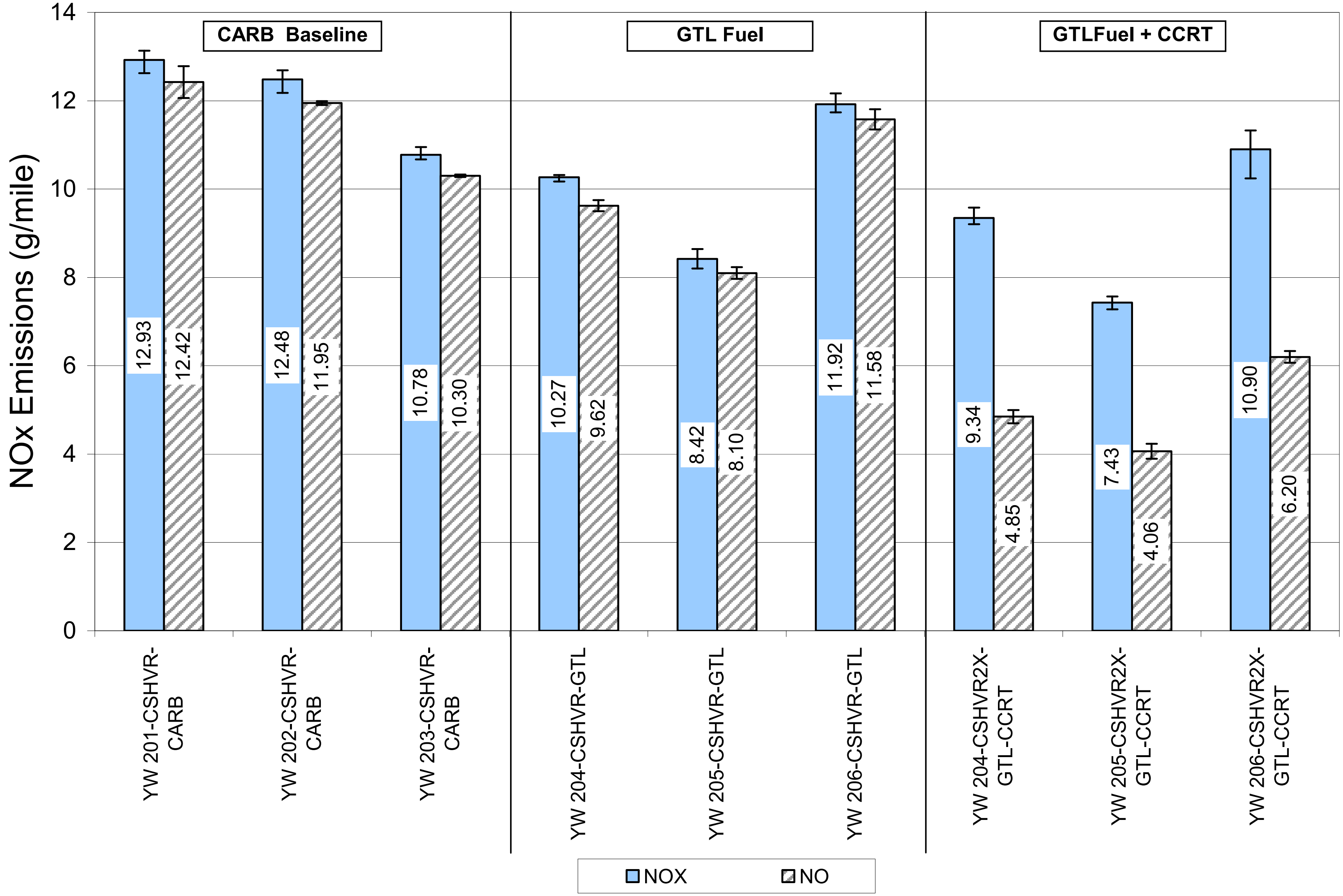


Driving Schedules - CSHVR



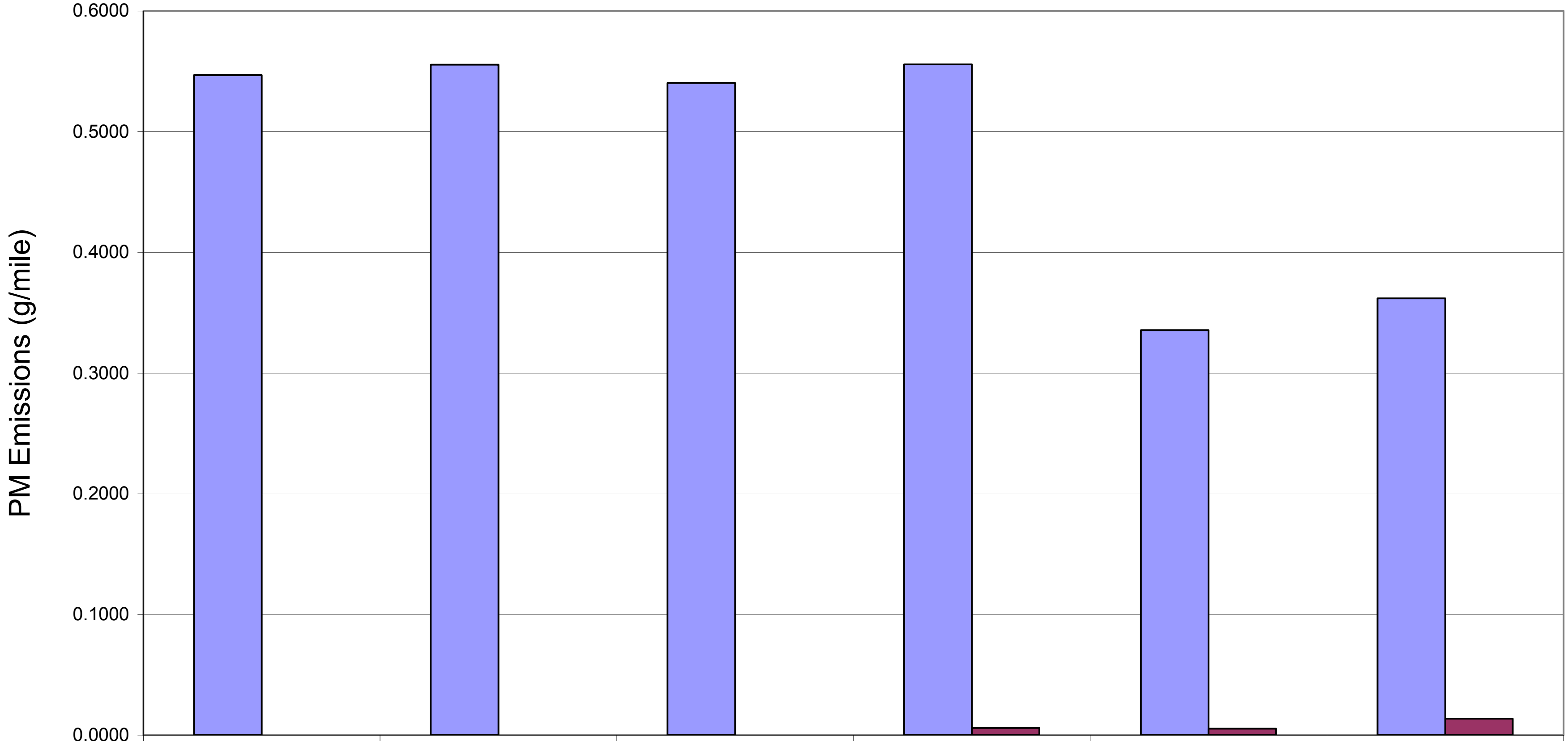
Emissions Data: Round 3 CSHVR

Reduced NOx on FT Fuel



Yosemite Waters Study: Effect of Aftertreatment on PM Emissions

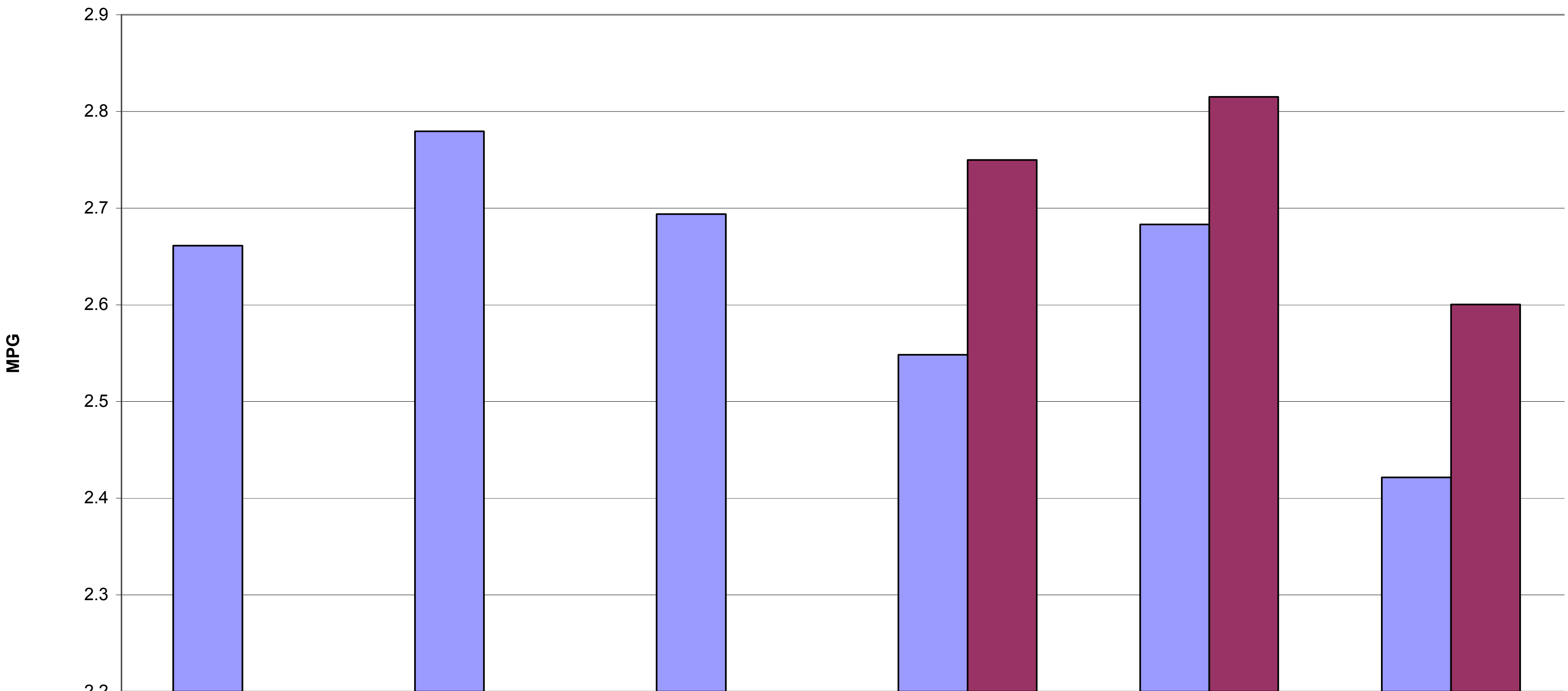
Trucks 201, 202, 203 – CARB diesel / Trucks 204, 205 206 - FT



	YW 201	YW 202	YW 203	YW 204	YW 205	YW 206
None	0.5469	0.5556	0.5404	0.5558	0.3356	0.3620
JM-CRT				0.0059	0.0055	0.0137

Yosemite Waters Study: Effect of Fuel/Aftertreatment on Fuel Economy

Note expanded scale: no substantial effect of fuel or aftertreatment



	YW 201	YW 202	YW 203	YW 204	YW 205	YW 206
None	2.7	2.8	2.7	2.5	2.7	2.4
JM-CRT				2.7	2.8	2.6

Syntroleum Study

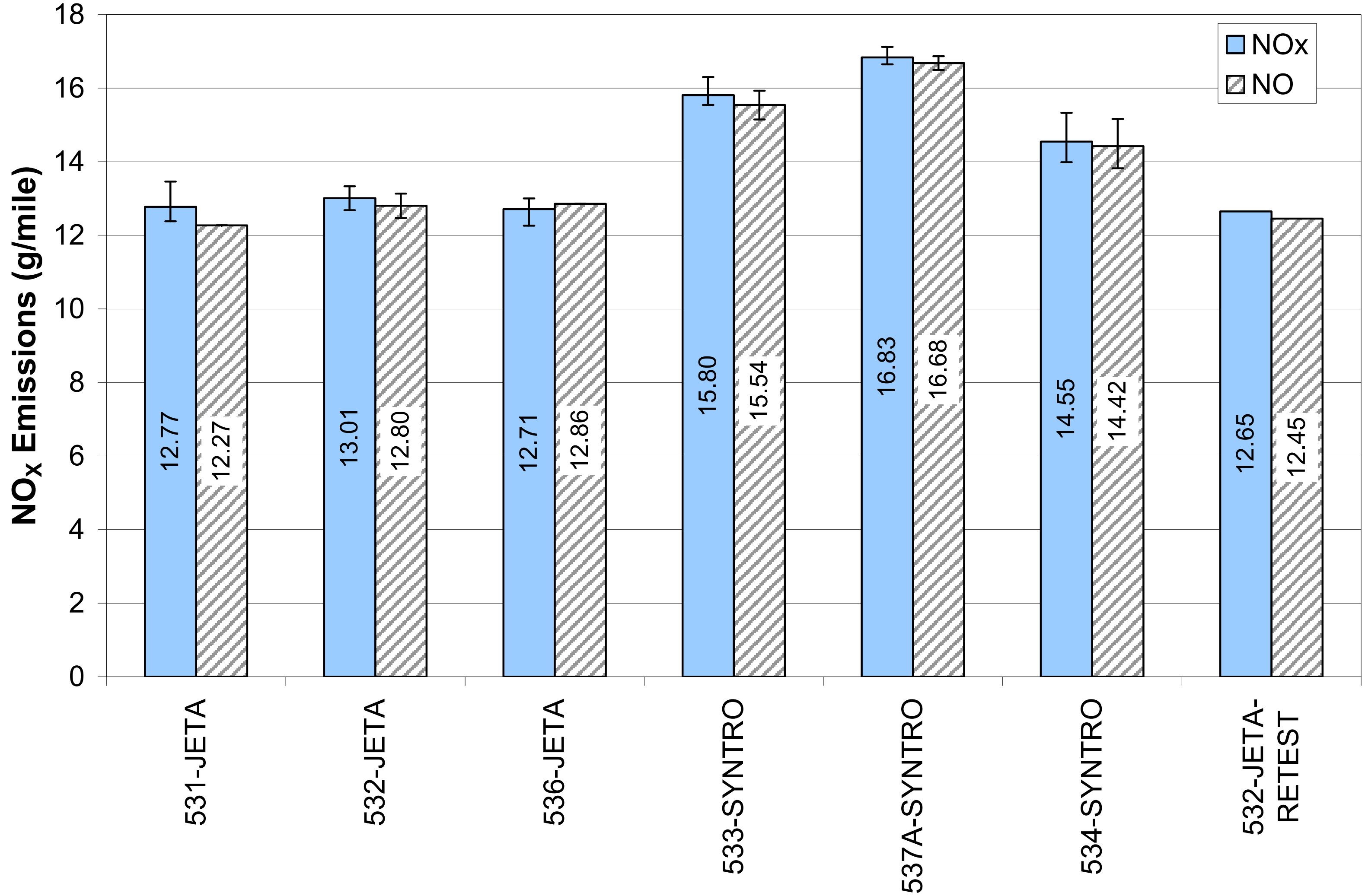
- DOE funding, through ICRC
- Transit buses in Washington DC
- Tour buses in Denali National Park

Denali Vehicles

Aramark Transit Bus Specifications				
Chassis	MY 2004 Thomas			
Engine Manufacturer/Model	MY 2004 Cat C7 ACERT			
Engine Ratings	230hp @ 2400rpm			
After-treatment System	Diesel Oxidation Catalyst			
Transmission Type	5-speed Automatic			
GVWR/Curb Weight	36200 / 21830 lb			
Bus Number	**VIN**	**Engine Serial Number**	**Odometer Reading**	**Fuel Type**
531	1T88U2C2751149858	KAL23694	8602	JETA
532	1T88U2C2951149859	KAL23696	7645	JETA
536	1T88U2C2X51149970	KAL24268	8144	JETA
533	1T88U2C2351149860	KAL24396	8086	SYNTRO
534	1T88U2C2551149861	KAL24760	6068	SYNTRO
537A	1T88U2C2151149971	KAL24425	6507	SYNTRO

Denali Emissions Data

Synthetic fuel increased NO_X emissions



Denali Results Summary

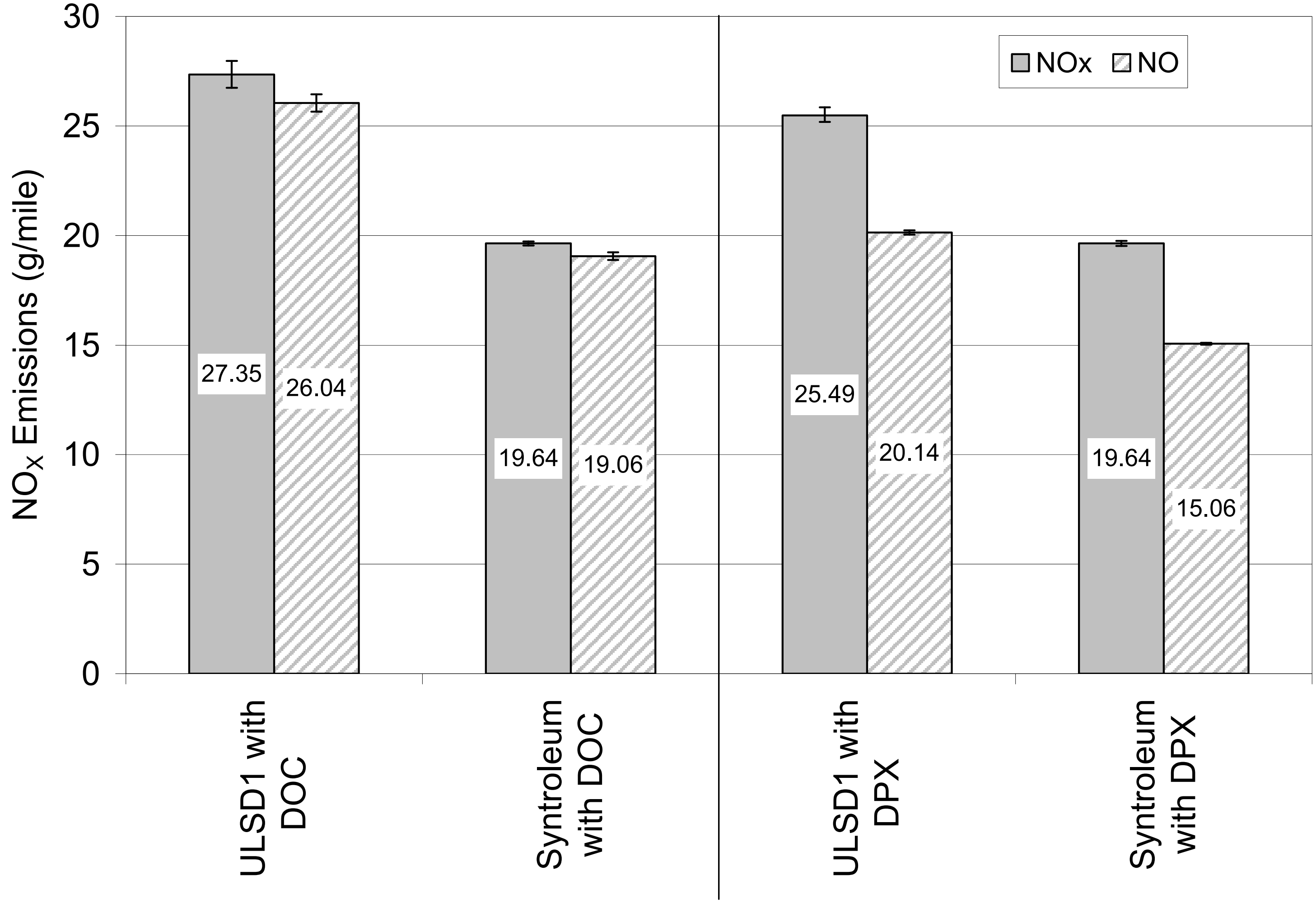
- Use of Syntroleum S-2 reduced particulate emissions by approximately 25% compared to the low sulfur Jet A fuel.
- CO emissions reduced by approximately 68% compared to the Jet A fuel.
- Syntroleum S-2 fuel resulted in a reduction in HC emissions of 81% relative to Jet A.
- Unexpected NO_X increase cause is not fully investigated. New engine technology combined with high cetane. Long term operation.
- No significant difference in fuel economy observed between Syntroleum S-2 and Jet A.

WMATA Vehicle Details – Phase 1

All data from one bus

WMATA Transit Bus Number 2027 Specifications		
Chassis	MY 2000 Orion	
Engine Manufacturer/Model	MY 1999 Detroit Diesel Corporation Series 50	
Engine Ratings	275hp @ 2100rpm	
After-treatment System	Diesel Oxidation Catalyst	
Transmission Type	4-speed Automatic	
GVWR/Curb Weight	42,540 / 28,800 lb	
VIN	1VH6H2A23Y6600264	
Engine Serial Number	04R0031355	
Odometer Reading	218466	
WVU Test Sequence Number	**Fuel Type**	**Exhaust Aftertreatment**
4178	ULSD1	Engelhard DPX
4181	ULSD1	OEM DOC
4184	Syntroleum S-2	OEM DOC
4187	Syntroleum S-2	Engelhard DPX

WMATA Phase 1 NO_X



28% NOX reduction

23% NOX reduction

WMATA Vehicle Details – Phase 3

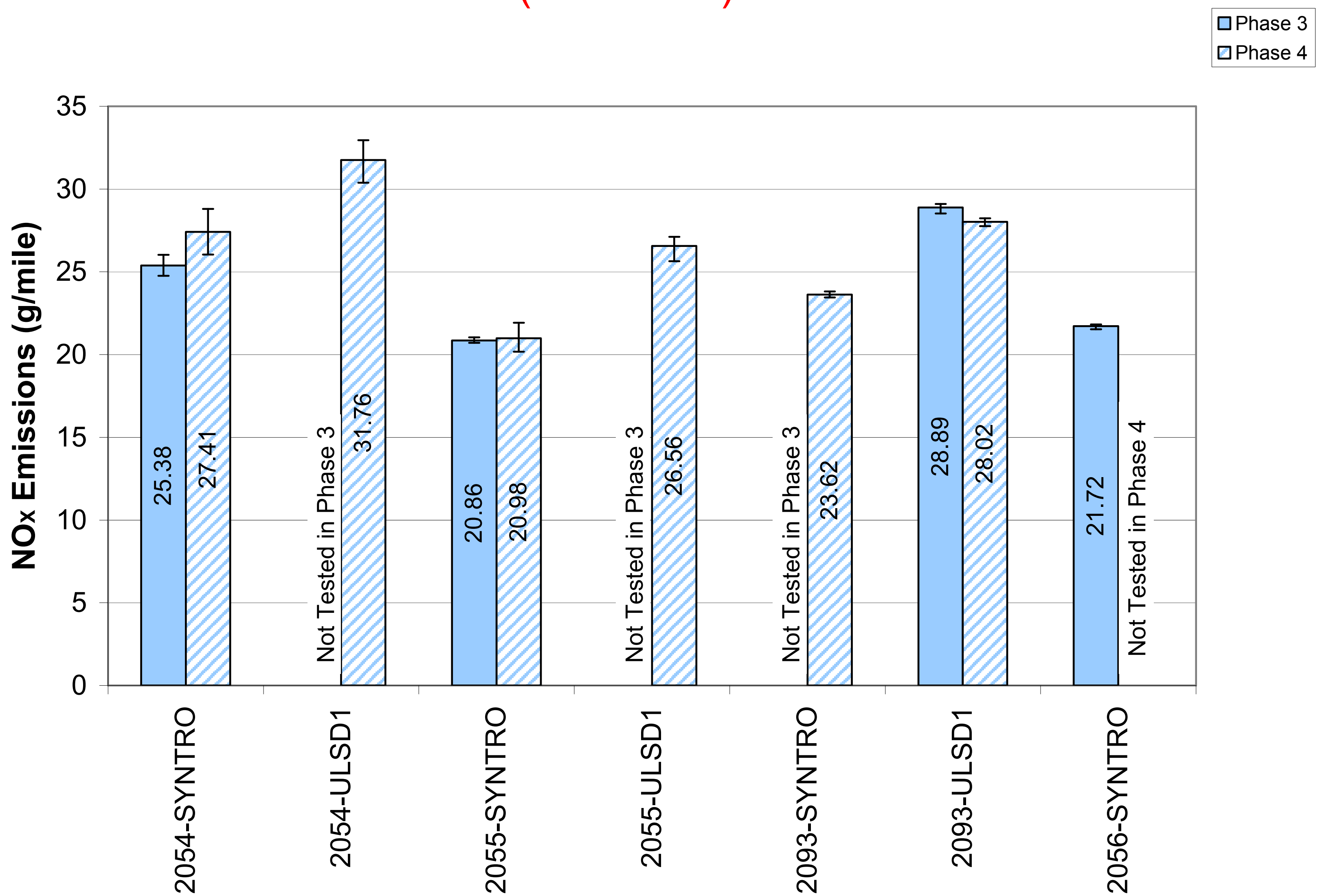
WMATA Transit Bus Specifications				
Chassis	MY 2000 Orion			
Engine Manufacturer/Model	MY 20009 Detroit Diesel Corporation Series 50			
Engine Ratings	275hp @ 2100rpm			
After-treatment System	Diesel Oxidation Catalyst			
Transmission Type	4-speed Automatic			
GVWR/Curb Weight	42,540 / 28,800 lb			
Bus Number	**VIN**	**Engine Serial Number**	**Odometer Reading**	**Fuel Type**
2093	1VH6H2A25Y6600332	04R0032003	181,688	ULSD1
2092	1VH6H2A23Y6600331	04R0032000	207,038	ULSD1
2094	1VH6H2A27Y6600333	04R0032183	194,125	ULSD1
2054	1VH6H2A28Y6600292	04R0031458	216,793	SYNTRO
2056	1VH6H2A21Y6600294	04R0031395	197,420	SYNTRO
2055	1VH6H2A2XY6600293	04R0031626	202,369	SYNTRO

WMATA Vehicles – Phase 4

WMATA Transit Bus Specifications			
Chassis	MY 2000 Orion		
Engine Manufacturer/Model	MY 20009 Detroit Diesel Corporation Series 50		
Engine Ratings	275hp @ 2100rpm		
After-treatment System	Diesel Oxidation Catalyst		
Transmission Type	4-speed Automatic		
GVWR/Curb Weight	42,540 / 28,800 lb		
Bus Number	**VIN**	**Engine Serial Number**	**Odometer Reading**
2054	1VH6H2A28Y6600292	04R0031458	252,652
2055	1VH6H2A2XY6600293	04R0031626	236,676
2093	1VH6H2A25Y6600332	04R0032003	216,937

WMATA Phase 3/4 NO_X Emissions

(Six buses)



WMATA Phase 3/4 Summary

- NO_X emissions produced by the Syntroleum S-2 fuel were reduced by 16 percent compared to ULSD1 fuel due to the low aromatic content and high cetane number.

- On average PM emissions when the buses were fueled with Syntroleum S-2 fuel were reduced by 35 percent compared to ULSD1 fuel.

- HC and CO emissions were similarly reduced when the buses were fueled with Syntroleum S-2 fuel. HC emissions were reduced by 30 percent and CO emissions were reduced by 24 percent compared to ULSD1 fuel.

- Carbon dioxide and fuel economy results were very similar for both types of fuels.

Biodiesel

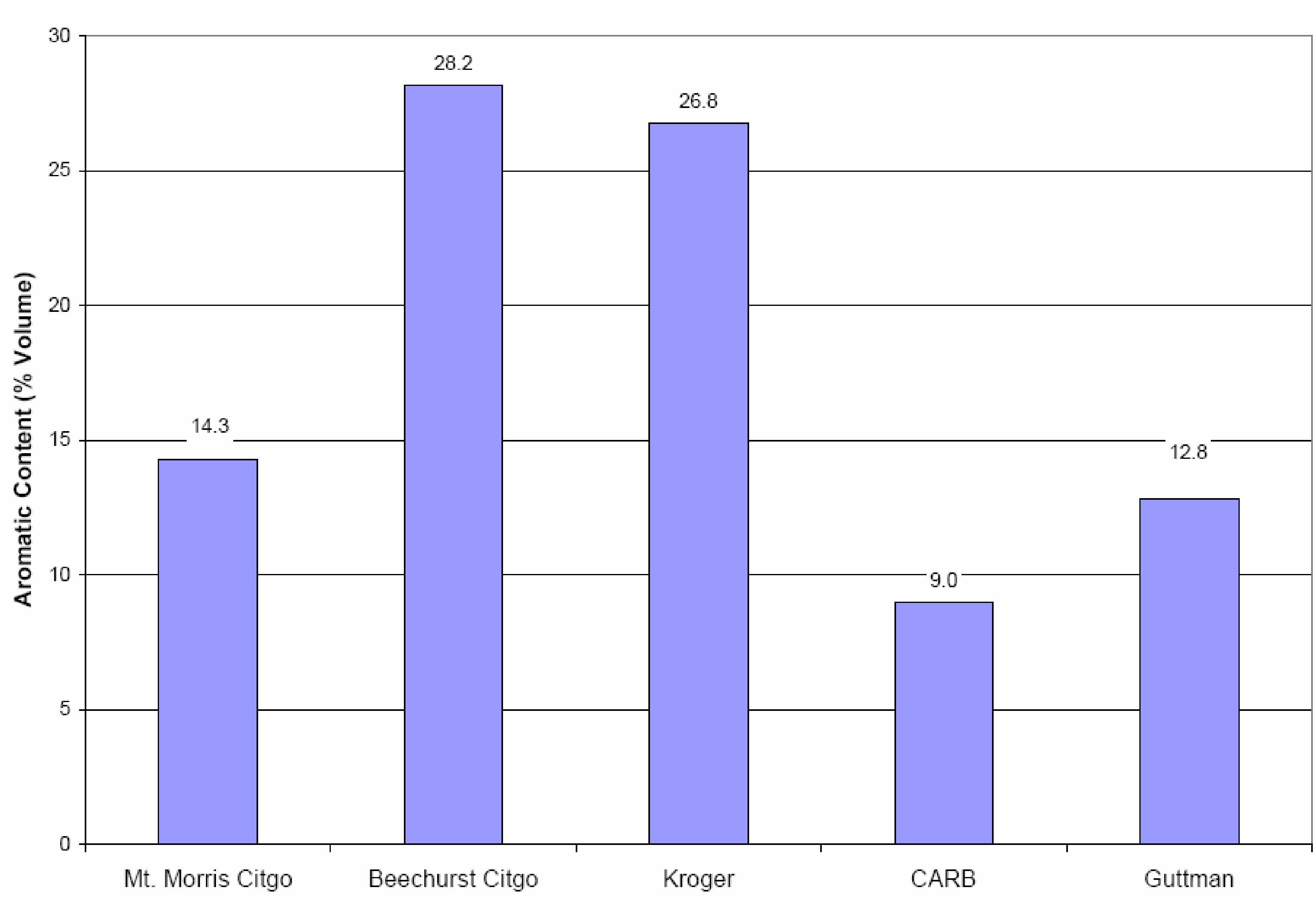
- Displaces petroleum demand using agricultural and waste products
- Offers reduced particulate emissions (advantage eroded in 2007)
- Little or no modification required for use in compression-ignition engines
- Essentially no sulfur and aromatics, biodegradable, reduced toxicity
- Varying effect on NO_X emissions

Biodiesel NO_X Effects are Variable

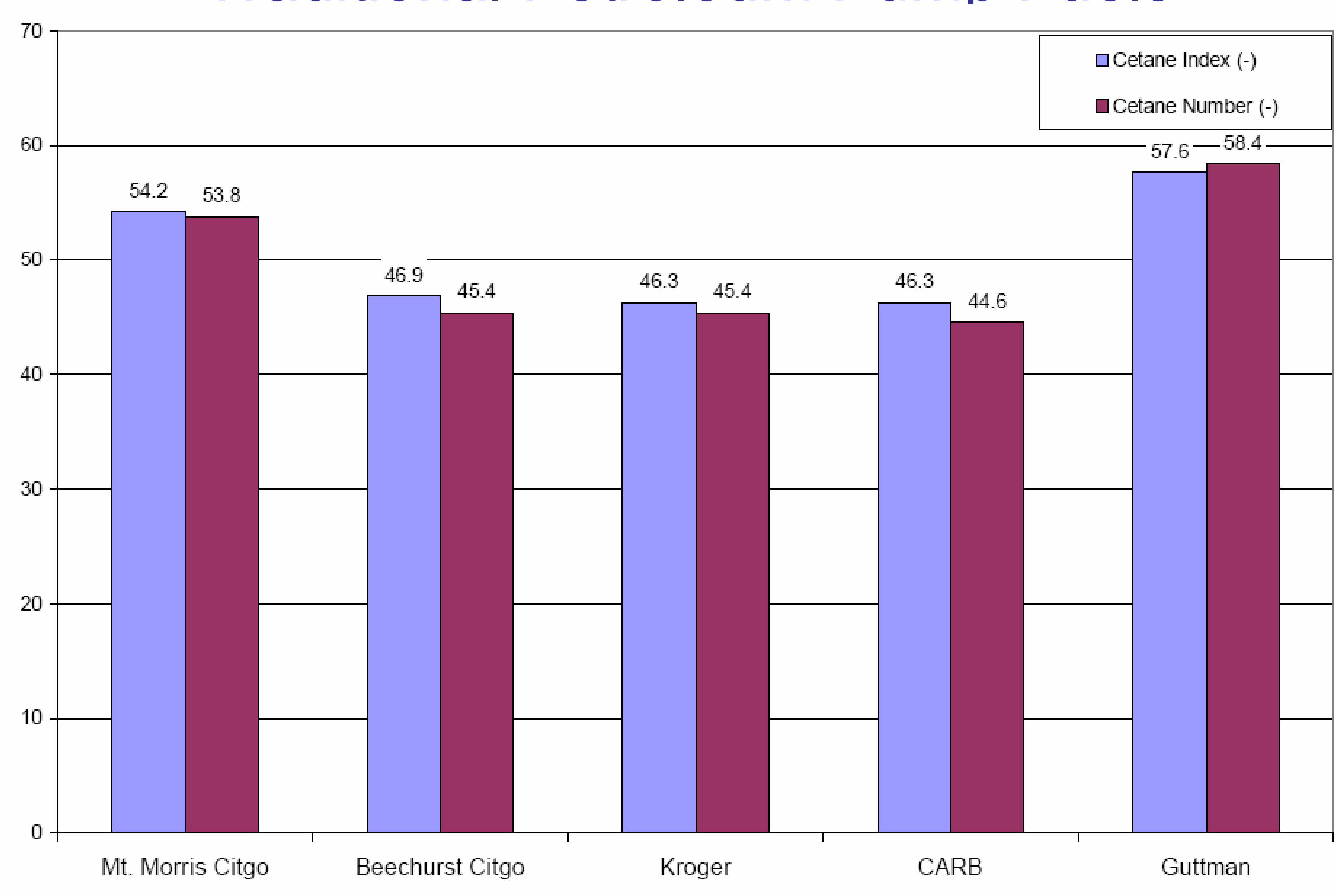
- Chassis vs. Engine?
  - Full power operation or prescribed load
  - Test schedule, average load factor
- Biodiesel Quality Variation?
- Baseline Diesel Composition?

Fuel Property Variation: Petroleum Diesel Fuel

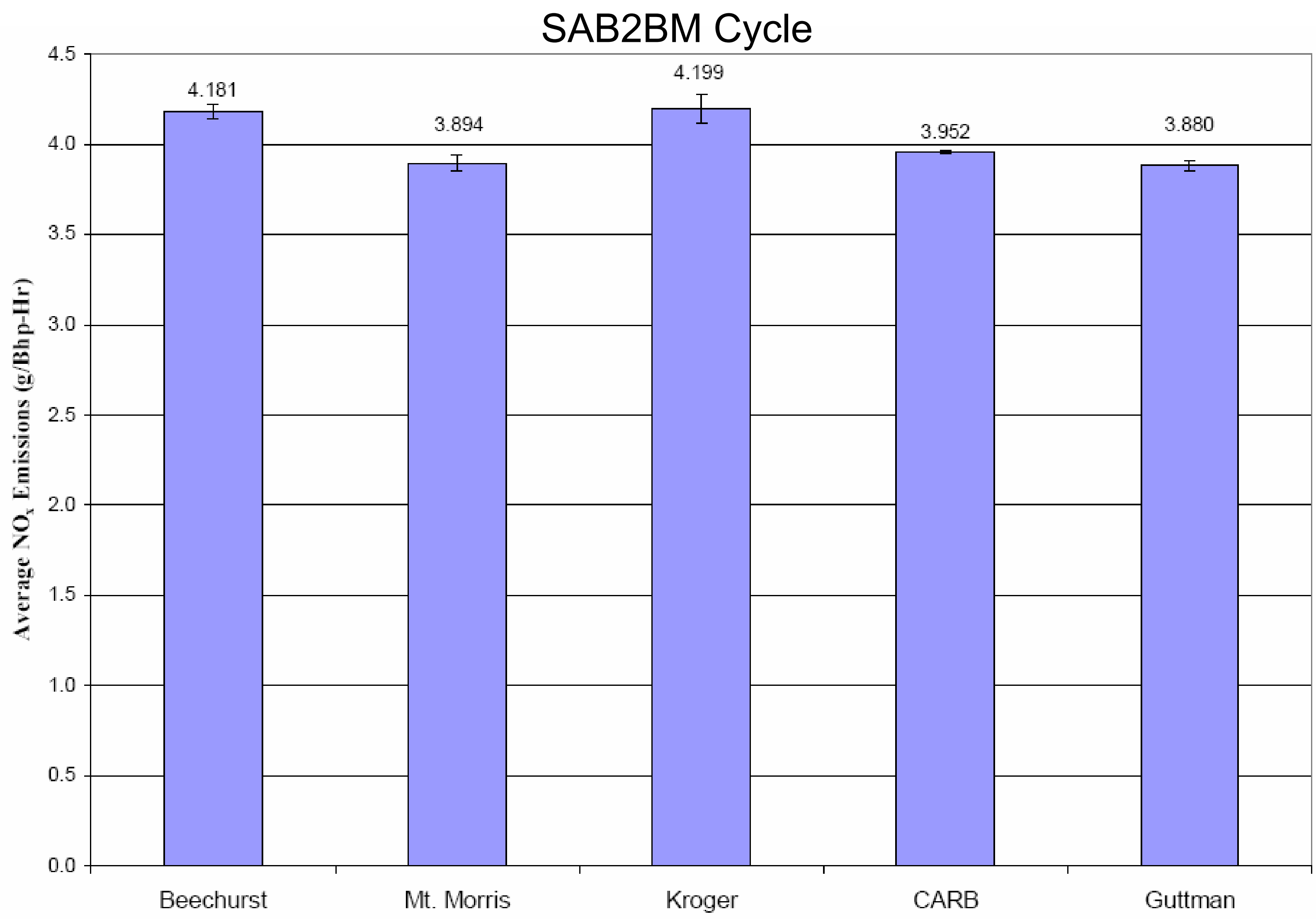
(Thesis of John Gibble, WVU – Thompson/Gibble Research)



Fuel Property Variation: Traditional Petroleum Pump Fuels



Emissions Variation: Traditional Diesel Fuels



Conclusions

- Fischer-Tropsch Fuels enable PM aftertreatment
- Fischer-Tropsch fuels reduce NOx in traditional diesel engines, but effects may not translate proportionally to other engine technologies
- Biodiesel NOx effects may be attributed to both biodiesel blend-stock and diesel composition
- Benefits with HCCI/LTC are not yet quantified (fuel weight may be selected)

(Thanks to NREL / Teresa Alleman, WMATA, ICRC / Steve Bergin)