Effect of Natural Gas Fuel Composition on Vehicle Emissions and Performance

Program to Evaluate the Implications of Gas Variability in California

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Presented By:

Tom Durbin, George Karavalakis, Kent Johnson, Maryam Hajbabaei, and Wayne Miller

University of California, Riverside
Bourns College of Engineering
Center for Environmental Research and Technology

Project Motivation

- LNG and NG demand likely to increase over next few decades.
- Sources for California's natural gas needs
  - Current needs largely met by domestic and Canadian imports
  - Potential LNG imports via Costa Azul facility in Baja, Mexico
  - "grand fathered" local sources of NG (Los Angeles basin)
- NG from a wider range of sources is expected to have more variation in composition and properties.
- Broader ranges of NG composition and properties could impact performance and/or emissions of vehicles.

Program Plan

- A 2-phase program was developed in conjunction with Project Advisory Committee.
- Phase 1: Light-Duty Vehicle Testing
  - 2 vehicles on 4 blends.
- Phase 2: Chassis dynamometer testing of heavy-duty vehicles.
  - 4 vehicles on 5-7 blends.
- Project funding from California Energy Commission (CEC), California Air Resources Board (CARB), and South Coast Air Quality Management District (SCAQMD)

NG Light-Duty Vehicle Testing

- 2 Vehicles
  - 2006 Honda Civic GX, SULEV certified, OEM
  - 2002 Ford Crown Victoria, ULEV certified, OEM, older technology
  - 4 fuel blends

Gas #	Description	methane	ethane	propane	I-butane	N_2	MN	Wobbe #	HHV	H/C
1	Baseline, Pipeline gas	96.05	1.79	0.37	0.17	1.62	97	1345	1021	3.94
2	CARB certification gas	90.20	4.04	2.03		3.73	86	1329	1038	3.84
3	Hi Wobbe	83.92	9.43	3.79	1.86	1.00	68	1438	1177	3.63
4	Modified gas 3	84.03	6.86	3.76	1.85	3.50	68	1385	1131	3.66

- FTP and Unified Cycle with 3 replicates on each fuel + Power Curves
- Testing in CE-CERT's Vehicle Emissions Research Laboratory

Light-Duty Testing Summary Results

- Clear trends for fuel economy, CO_2 and NMHC
  - gases with the higher energy contents provided better fuel economy on a volumetric basis and some higher power levels
  - blends with heavier hydrocarbons and lower H/C ratios, generally had higher CO_2 emissions
  - NMHC emissions were very low, but did increase for the two fuels with the highest levels of heavier hydrocarbons for both vehicles
- No clear trends for THC, NO_x, and CO.
  - THC emissions showed higher emissions for fuels with higher levels of methane for the Crown Victoria, but no trends for the Honda.
  - CO emissions were higher for two fuels with highest Wobbe numbers for Honda under some test conditions, including the cold-start phases, but did not show significant fuel differences for Crown Victoria.
  - Changing fuel composition showed only limited fuel effects for NO_x emissions for the two vehicles.

Heavy-Duty Chassis Dynamometer Testing

- Testing at CE-CERT's Heavy-Duty Chassis Dynamometer Test Facility
- Test Vehicles
  - Transit Bus with a 2009 Cummins ISL-G 8.9L – new engine to be representative of the future fleet
  - Refuse Hauler with a Cummins 8.3L C-Gas Plus – comprises a large fraction of waste hauler populations
  - Transit Bus with a 2003-2004 John Deere 8.1L 6081H engine – Older vehicle – substantial fraction of school bus population
  - New vehicle - TBD
- 5-7 fuel blends
- Test cycles
  - Buses – Central Business District
  - William H. Martin – refuse truck cycle
- Measurements
  - Power map – 4-5 speeds
  - NH_3 with TDL, Carbonyls on subset
  - PM #/size – 3022 CPC, UCR's f-SMPS
  - Nano-SMPS

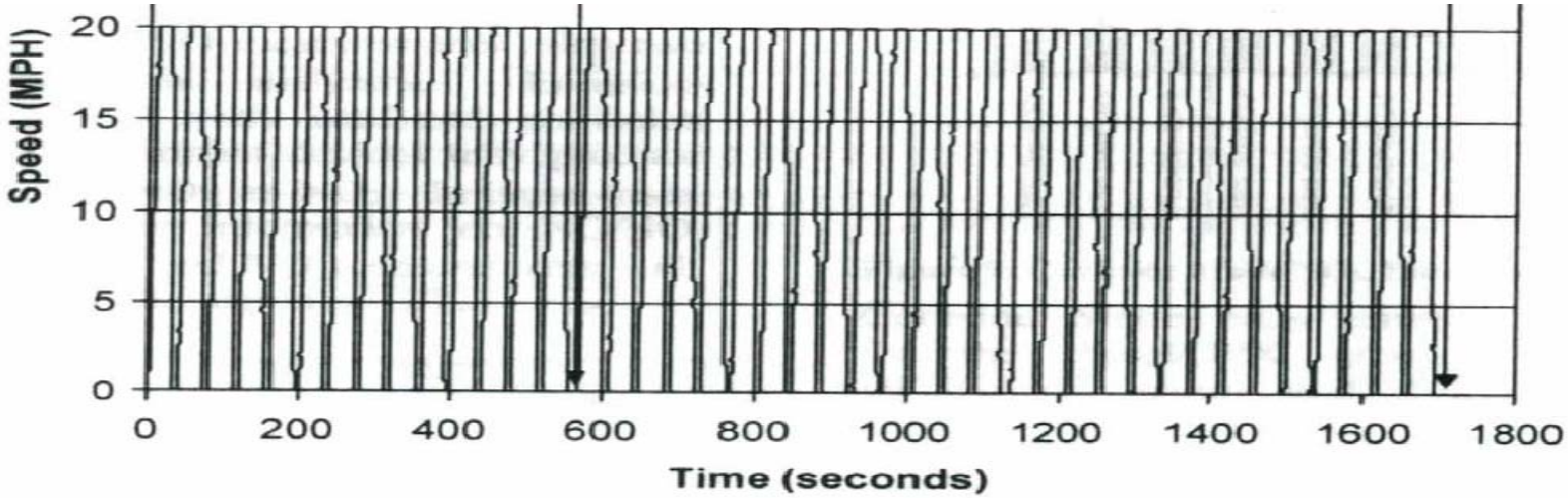
Gas blends for HD Chassis Dyno Testing

Gas #	Description	methane	ethane	propane	I-butane	N_2	CO_2	MN	Wobbe #	HHV	H/C ratio
1	Baseline, Texas Pipeline	96	1.8	0.4	0.15	0.7	0.95	99	1339	1021	3.94
2	Baseline, Rocky Mountain Pipeline	94.5	3.5	0.6	0.3	0.35	0.75	95	1361	1046	3.89
3	Peruvian LNG	88.3	10.5	0	0	1.2	0	84	1385	1083	3.81
4	Middle East LNG-Untreated	89.3	6.8	2.6	1.3	0	0	80	1428	1136	3.73
5	Associated High Ethane	83.65	10.75	2.7	0.2	2.7	0	75.3	1385	1115	3.71
6	Associated High Propane	87.2	4.5	4.4	1.2	2.7	0	75.1	1385	1116	3.70
7	L-CNG fuel	98.4	1.2	0.3	0	0	0	103.1	1370	1029	3.96

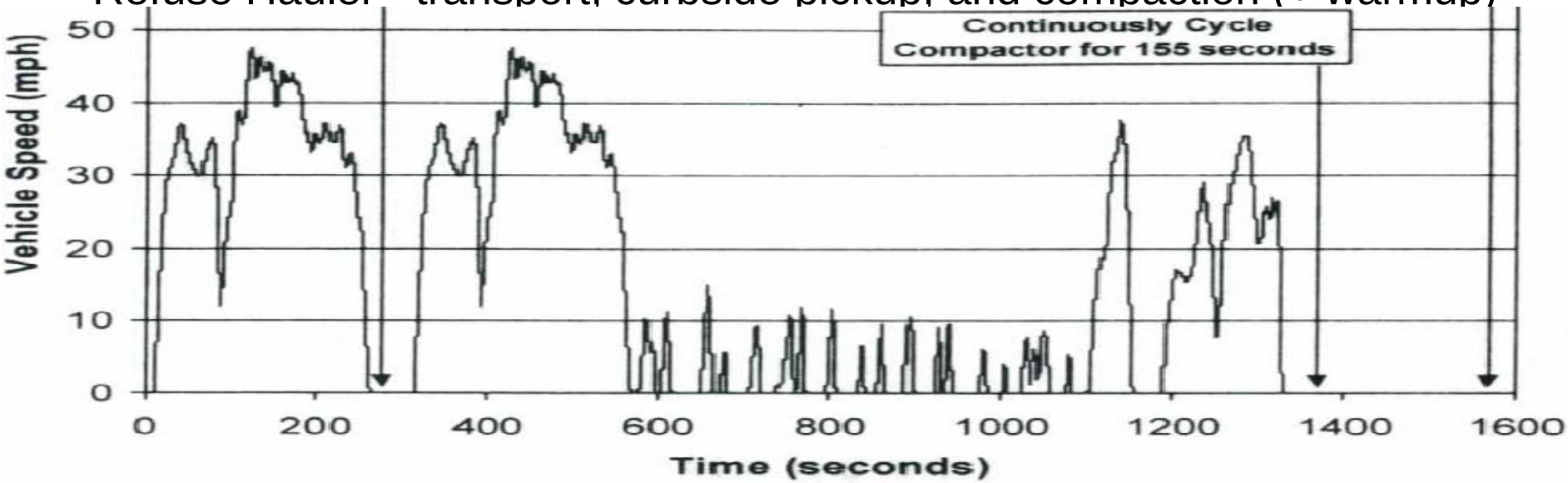
- 7th gas was an in-use L-CNG fuel for the waste hauler

Heavy-Duty Test Cycles

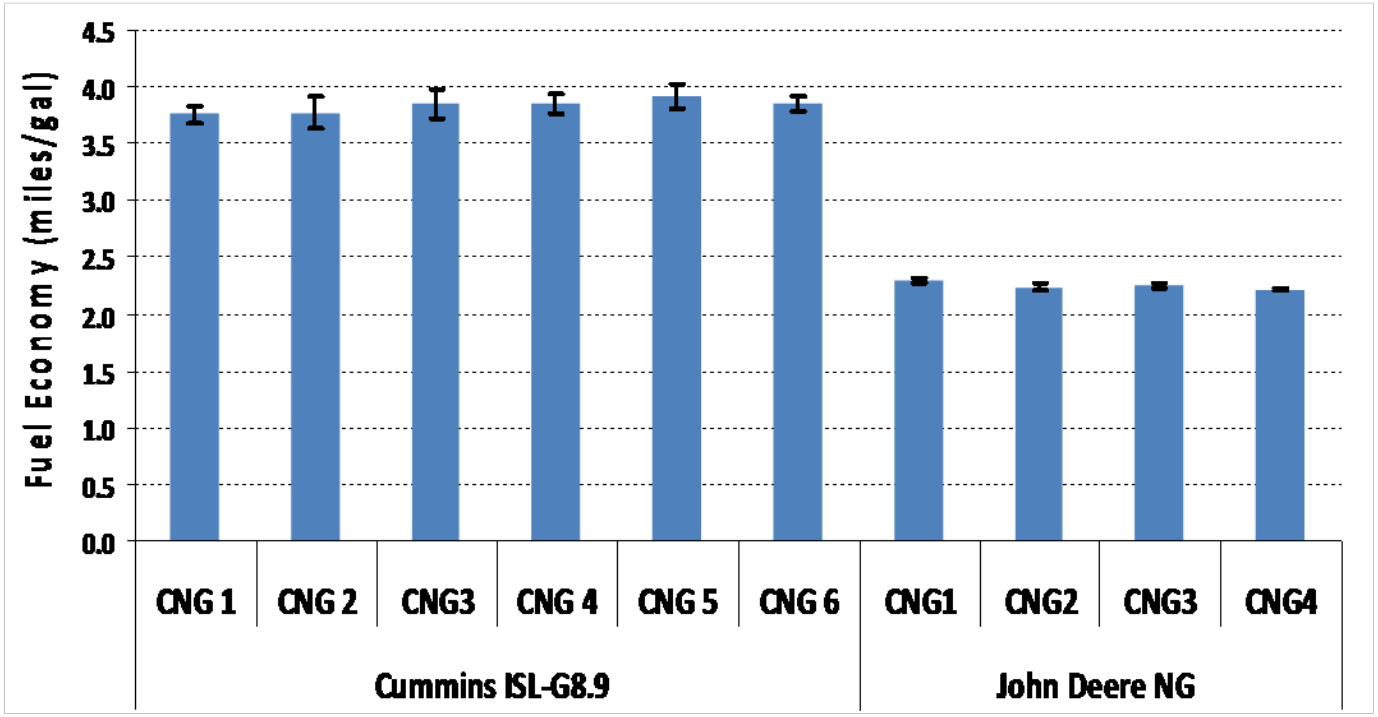
- Central Business District



- Refuse Hauler - transport, curbside pickup, and compaction (+ warmup)

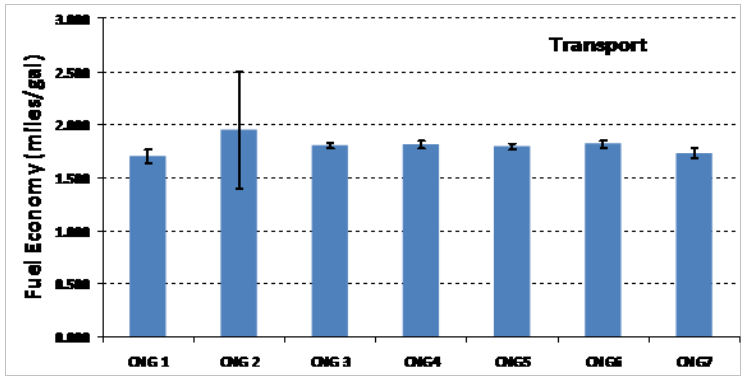


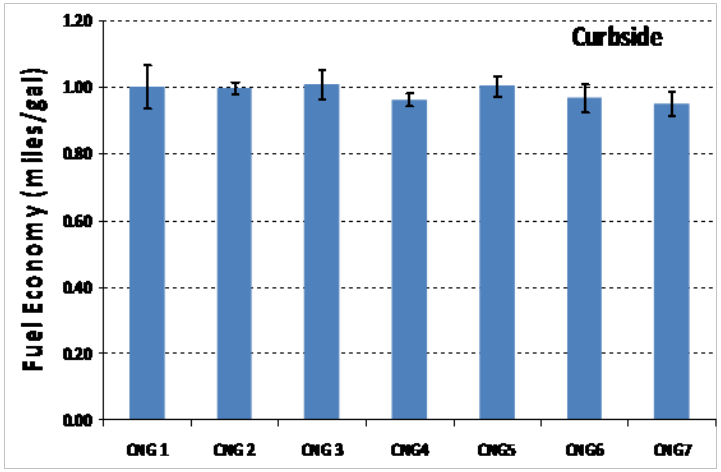
Heavy-Duty Tests – Fuel Economy (Two Buses)

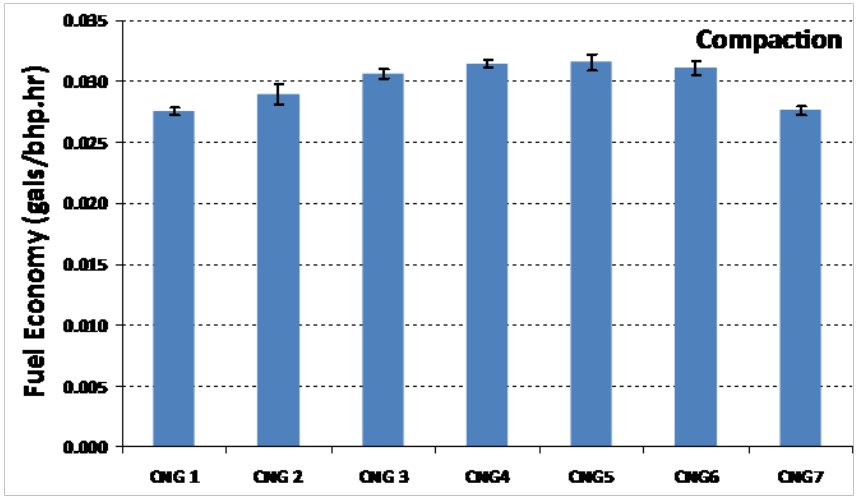


- No consistent/statistically significant trends between the fuels.
- Higher fuel economy for the newer engine technology.
- **Cummins bus** <u>higher</u> fuel economy for the <u>high</u> Wobbe Number & energy content gases.
- **John Deere** <u>lower</u> fuel economy for the <u>high</u> Wobbe Number & energy content gases.

Heavy-Duty Tests – Fuel Economy (Waste Hauler Truck)

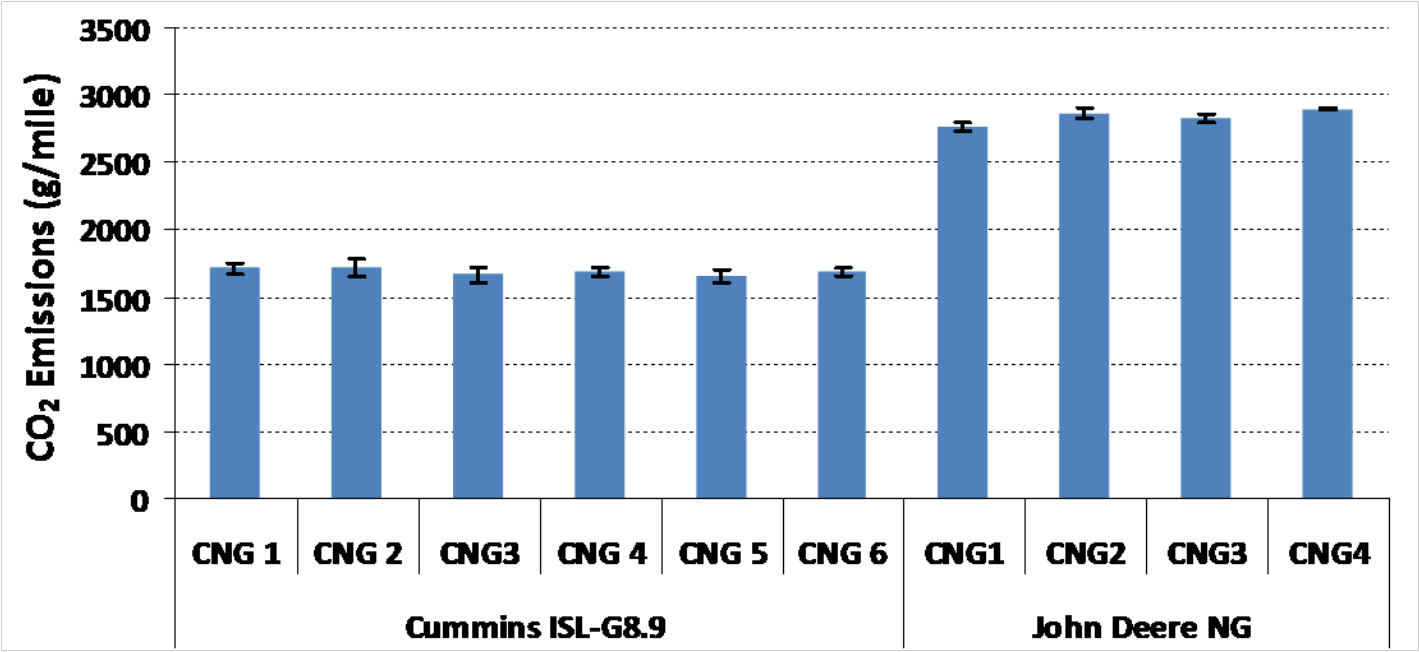






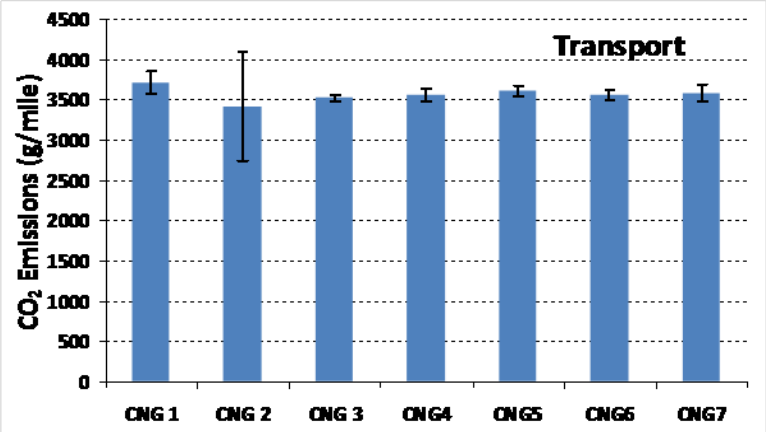
- Waste hauler showed stronger fuel effects for **transport & compaction** with <u>higher</u> fuel economy for the <u>higher</u> energy content gases.
- For the **curbside** phase, fuel economy differences were <u>minimal</u>.

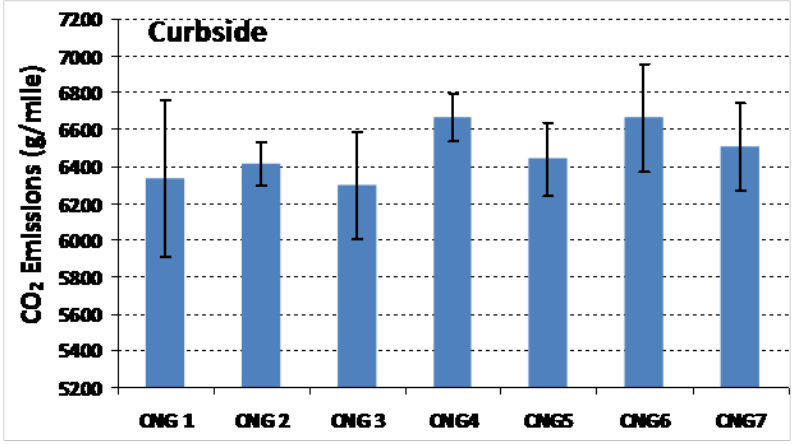
Heavy-Duty Tests – CO_2 (Two Buses)

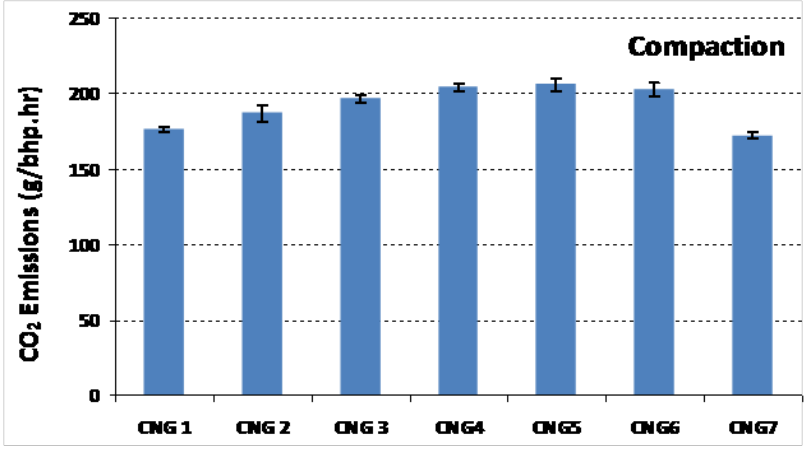


- Lower CO_2 emissions for the newer engine technology, consistent with the fuel economy results
- **Cummins bus** no strong trends between the fuels observed.
- **John Deere bus** limited trends of <u>higher</u> CO_2 emissions for some fuels with <u>lower</u> H/C ratios

Heavy-Duty Tests – CO_2 (Waste Hauler Truck)

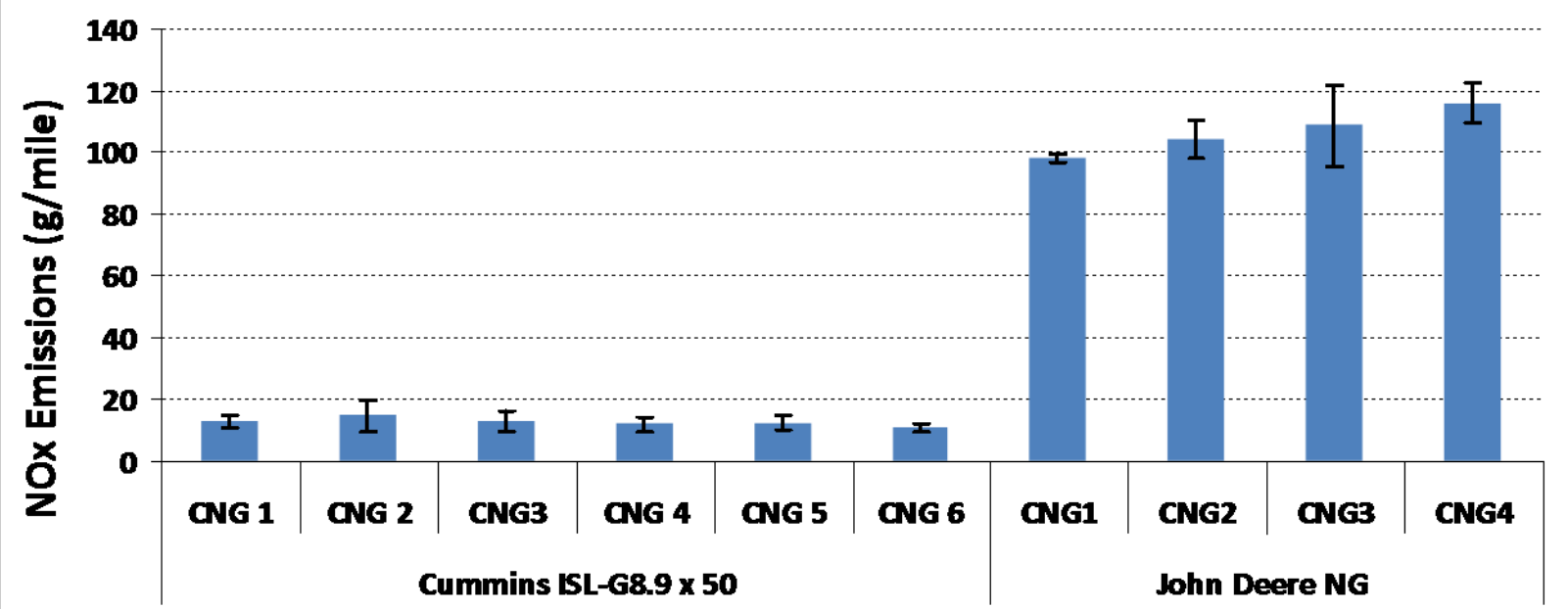






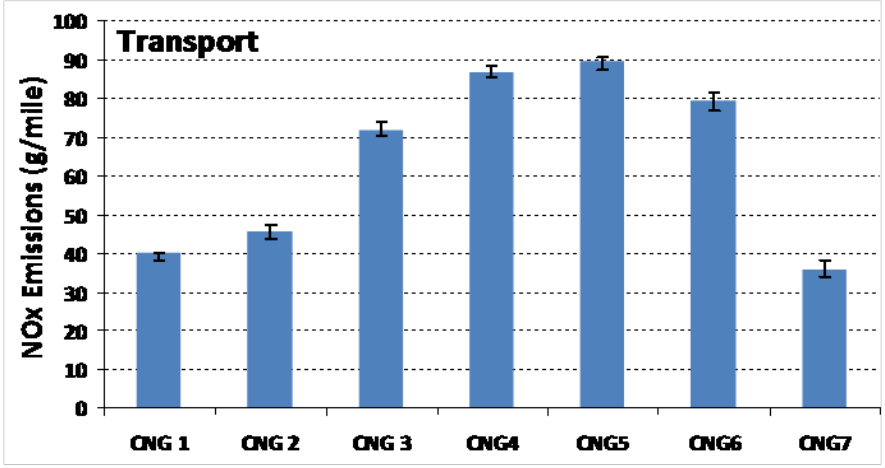
- For **compaction**, <u>higher</u> CO_2 emissions for fuels containing the <u>higher</u> levels of hydrocarbons, and corresponding <u>lower</u> H/C ratios.
- **Transport and curbside** phases showed less consistent effects, with only CNG1 for the transport showing higher CO_2 emissions.

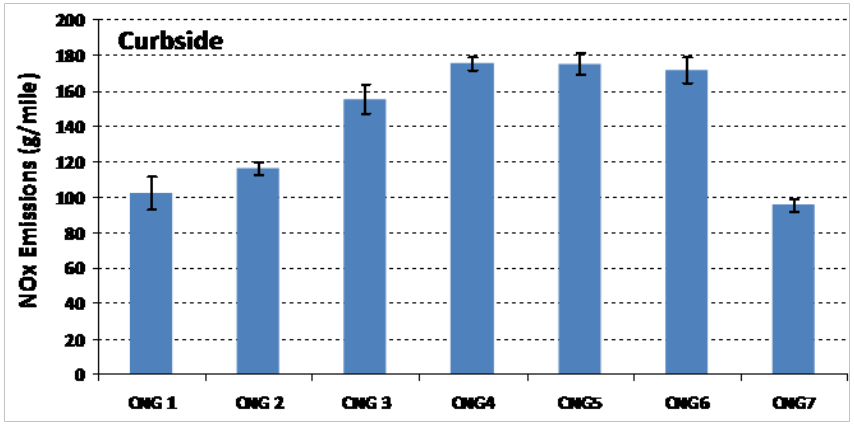
Heavy-Duty Tests – NO_x (Two Buses)

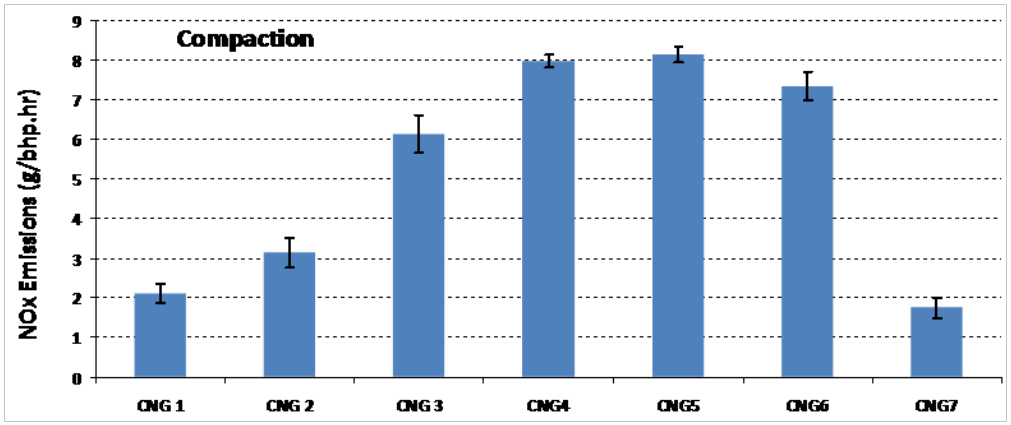


- **Cummins bus** lower NO_x emissions and showed no real fuel trends.
- **John Deer bus** higher NO_x emissions for the gases containing higher hydrocarbons and Wobbe numbers. Only statistically significant for CNG1 and CNG4

Heavy-Duty Tests – NO_x (Waste Hauler Truck)

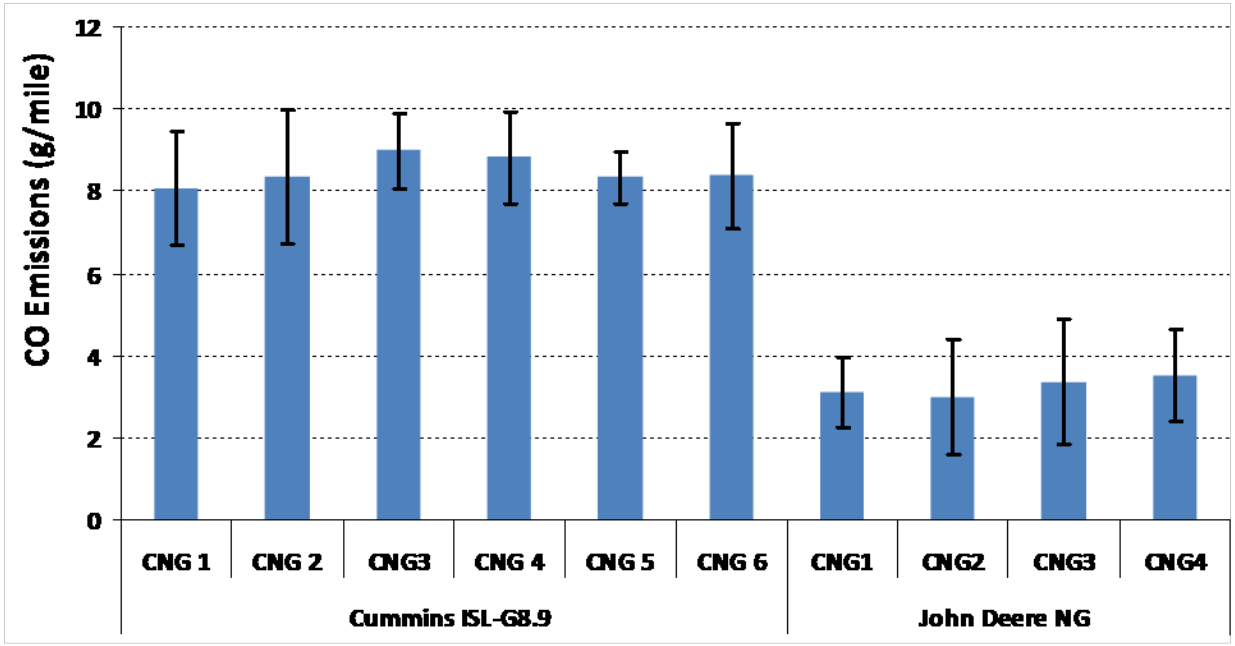






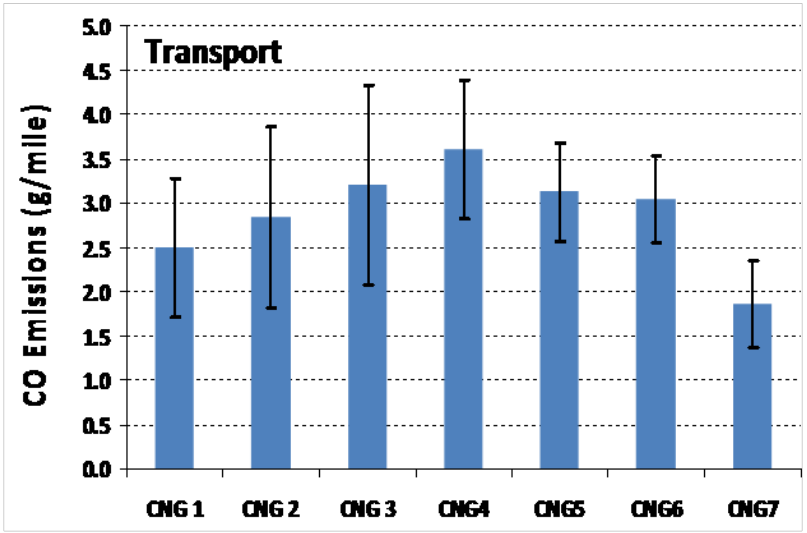
For <u>all three segments</u>, <u>higher</u> NO_x emissions for gases with <u>higher</u> hydrocarbons

Heavy-Duty Tests – CO (Two Buses)

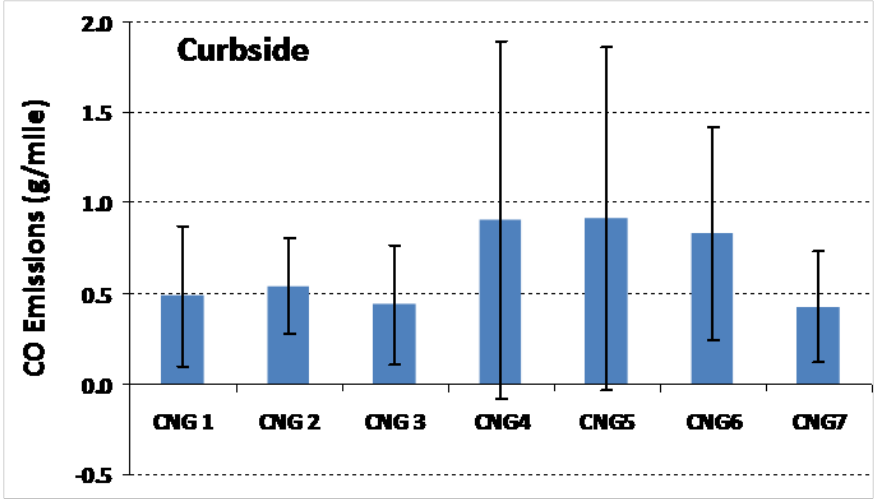


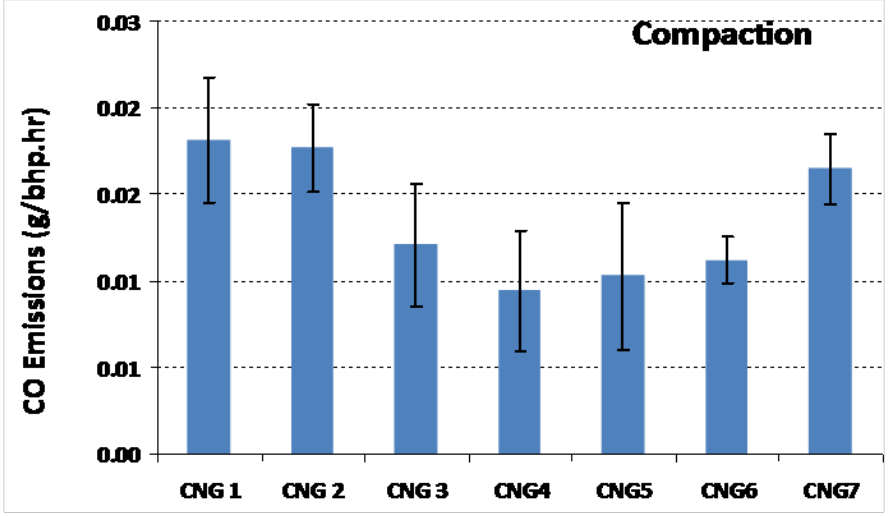
- The differences in CO emissions were not statistically significant.
- The CO emissions were significantly higher for the newer **Cummins**

Heavy-Duty Tests – CO (Waste Hauler Truck)



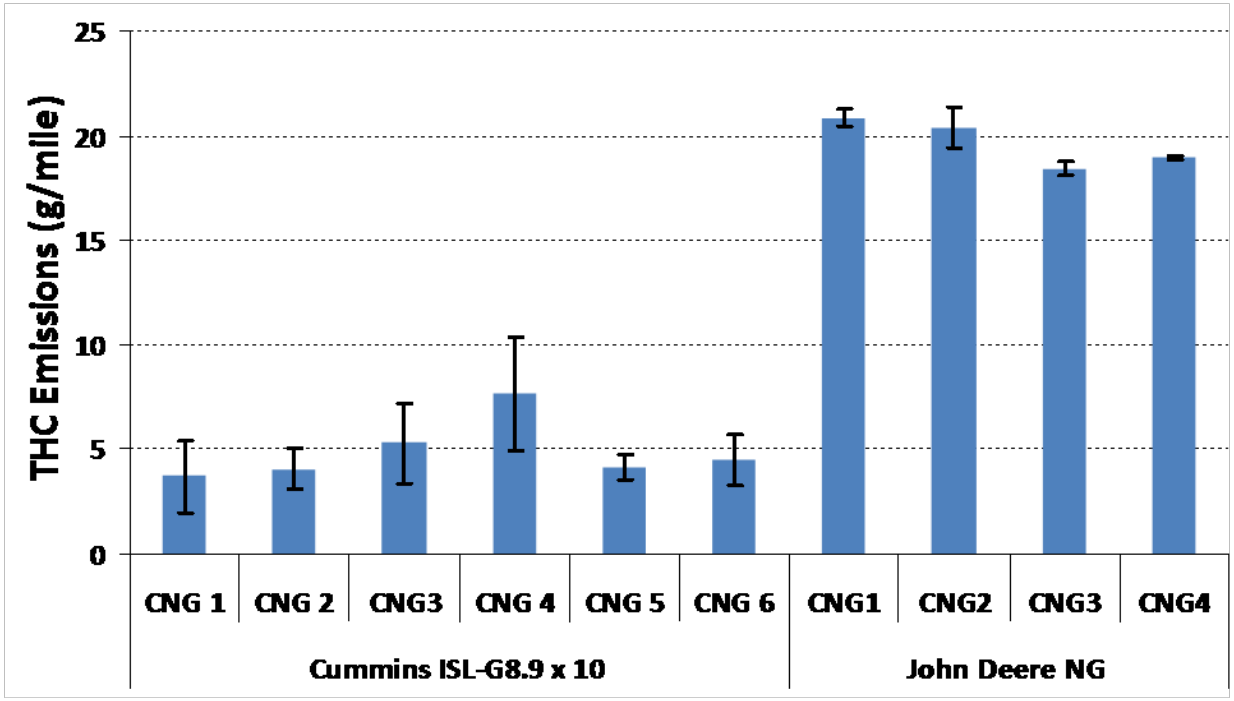
For the **transport and curbside** segments, there were some trends of <u>higher</u> CO emissions for CNG4, CNG5, and/or CNG6, but these were not statistically significant differences.





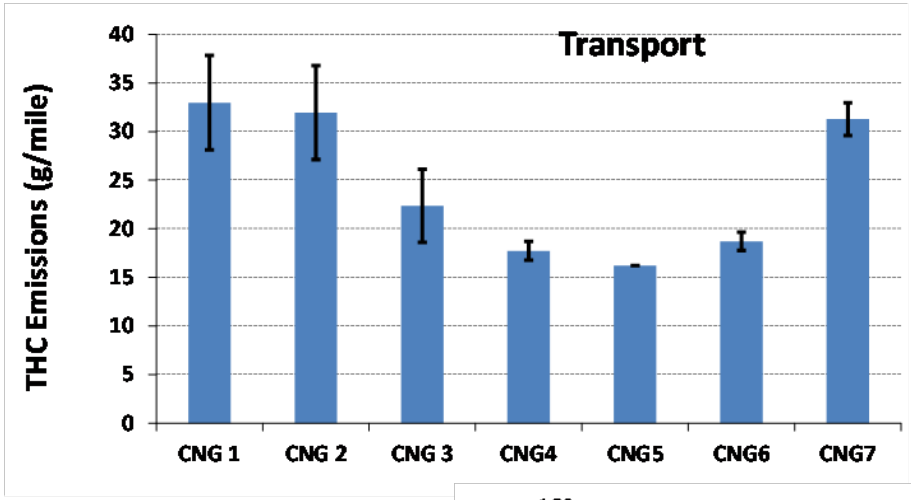
CO emissions for the CNG3, CNG4, CNG5, and CNG6 gases were substantially lower than those of CNG1, CNG2, and CNG7 gases, for the **compaction**, with this reduction being statistically significant.

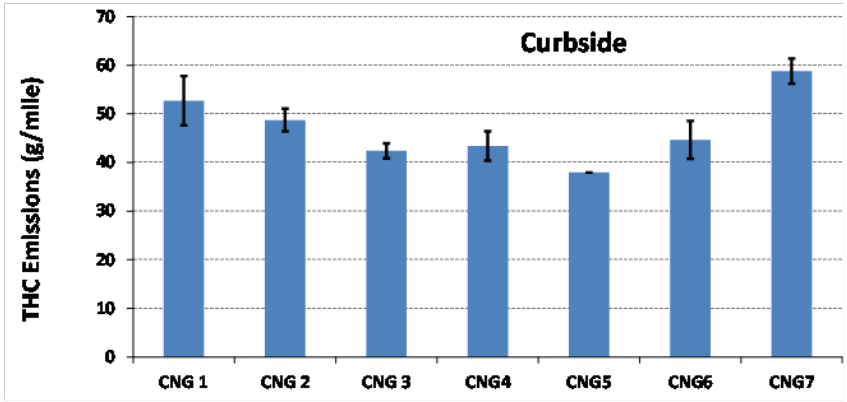
Heavy-Duty Tests – THC (Two Buses)

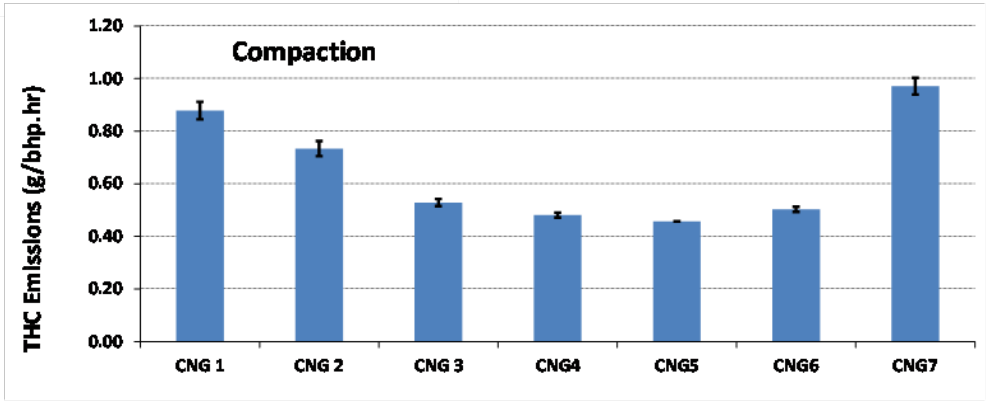


- THC emissions were significantly lower for the **Cummins**, since this bus was fitted with a TWC, while the John Deere bus was not.
- The buses showed opposite trends with respect to fuel methane content.
- **Cummins bus** an increase in THC emissions for CNG4 gas compared to the baseline CNG1
- **John Deere bus** a statistically significant reduction in THC emissions for the CNG3 and CNG4 gases was found compared to CNG1.

Heavy-Duty Tests – THC (Waste Hauler Truck)

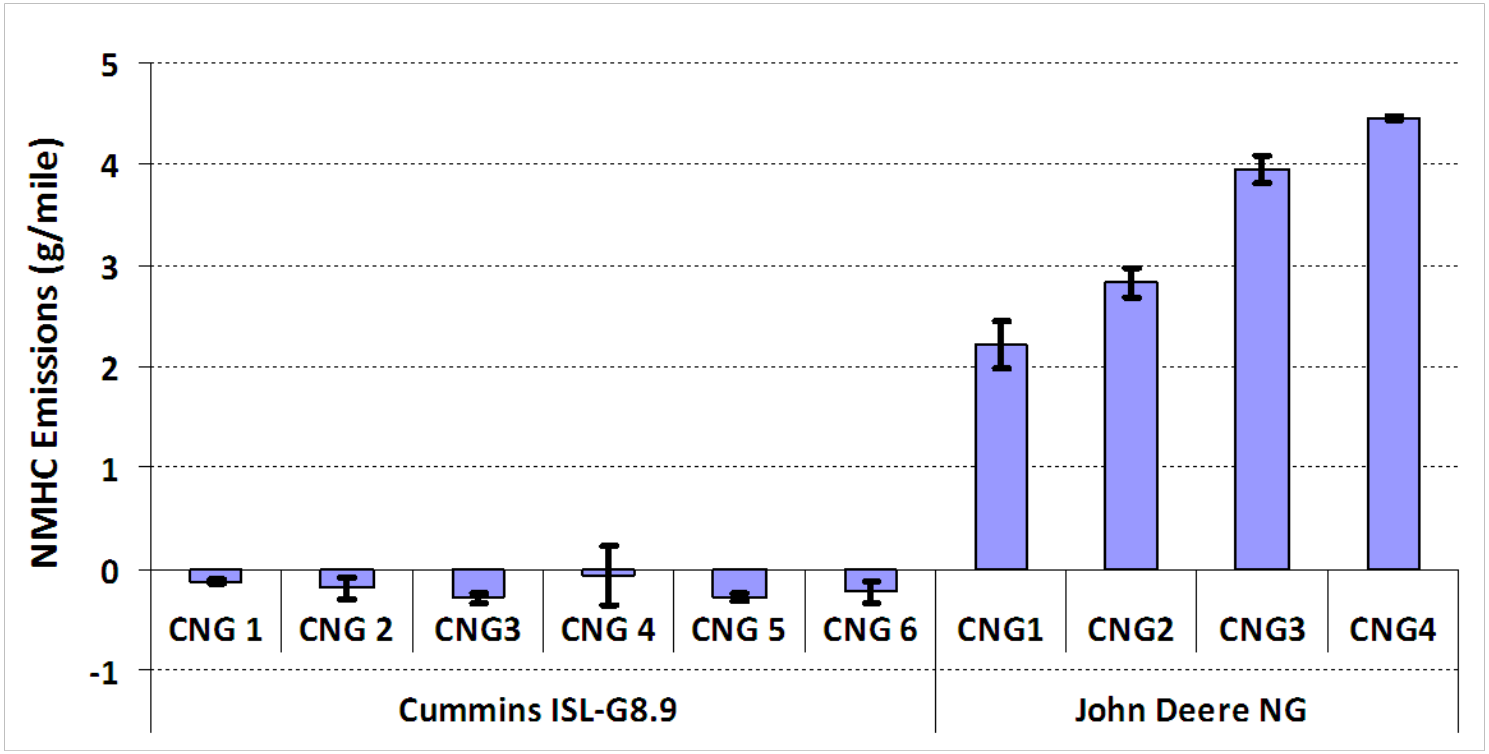






For all the three segments, the gases contained higher hydrocarbons, such as CNG3, CNG4, CNG5, and CNG6, produced lower THC emissions than the baseline CNG1 and CNG2 and CNG7 gases.

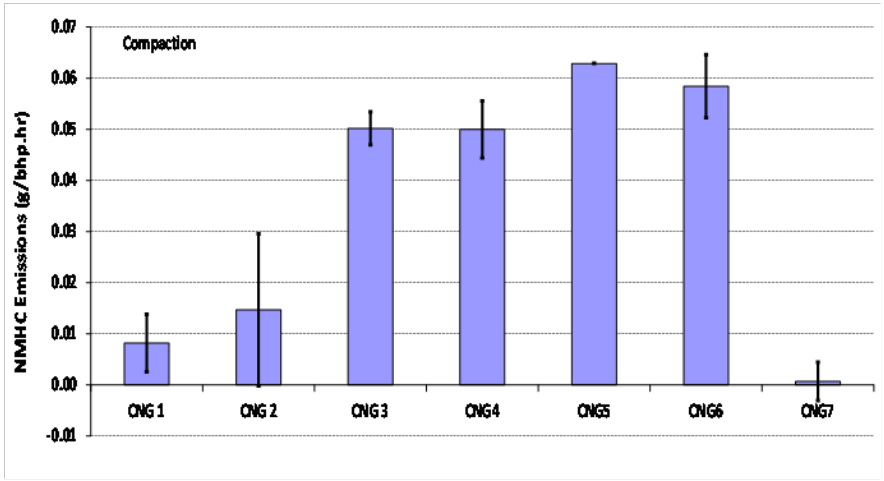
Heavy-Duty Tests – NMHC (Two Buses)



- **Cummins bus** NMHC emissions below the detection limits.
- **John Deere bus** NMHC higher for the CNG3 and CNG4 gases compared to CNG1 and CNG2. This was attributed to the higher levels of NMHC in the compositions of these fuels.

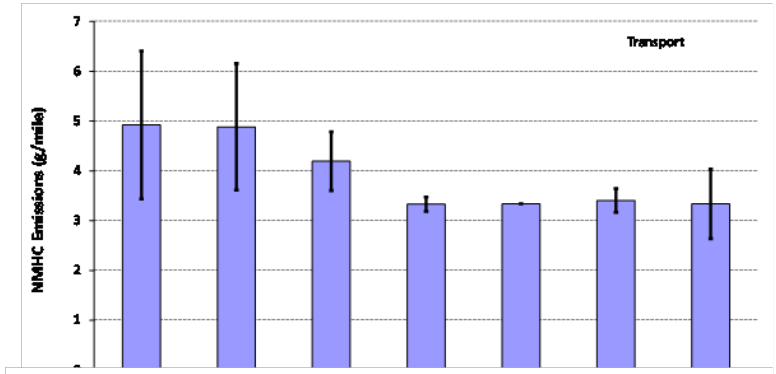
Heavy-Duty Tests – NMHC (Waste Hauler Truck)

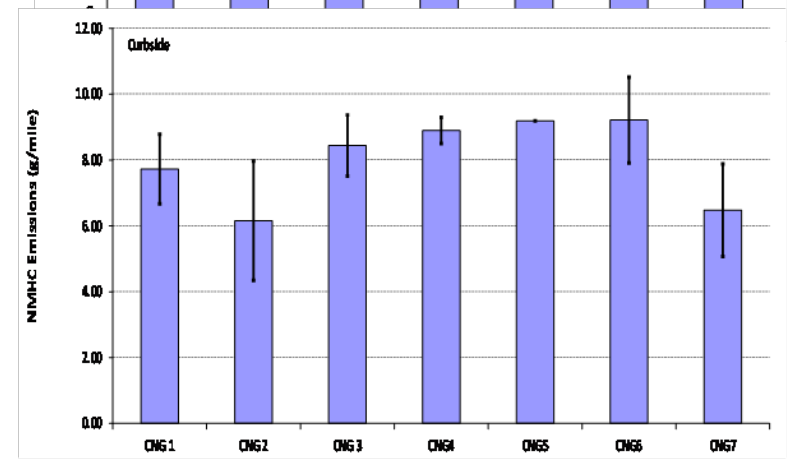
Overall, Very low emissions for all segments.



For the **compaction** phase, CNG3, CNG4, and CNG6, with their higher levels of hydrocarbons, exhibited NMHC increases when compared to CNG1, CNG2, and CNG7 gases.

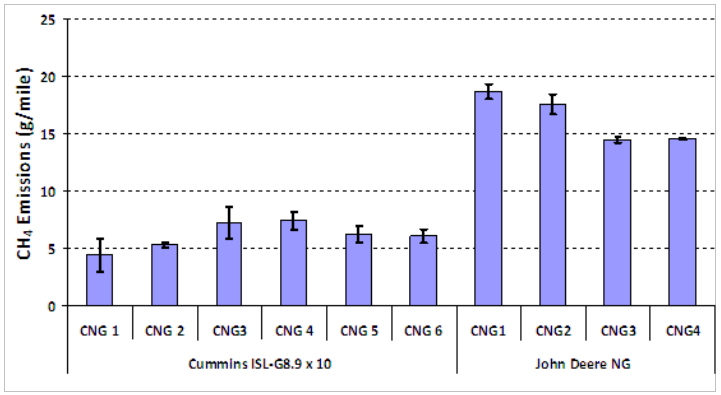
For **transport** phase , gases with higher hydrocarbons produced lower NMHC emissions compared to CNG1 and CNG2 gases.

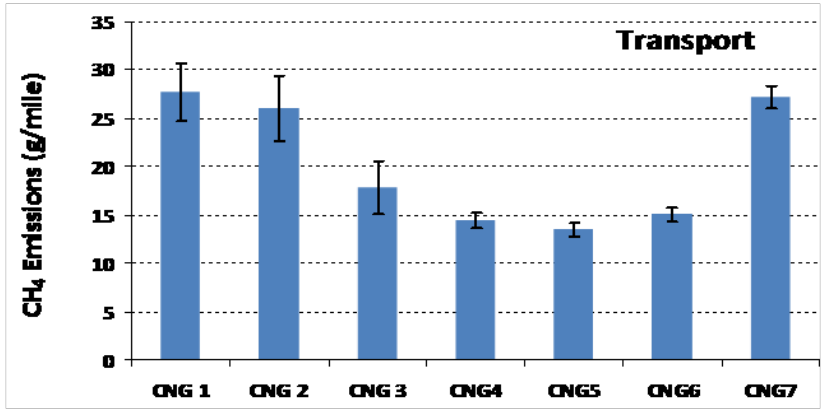


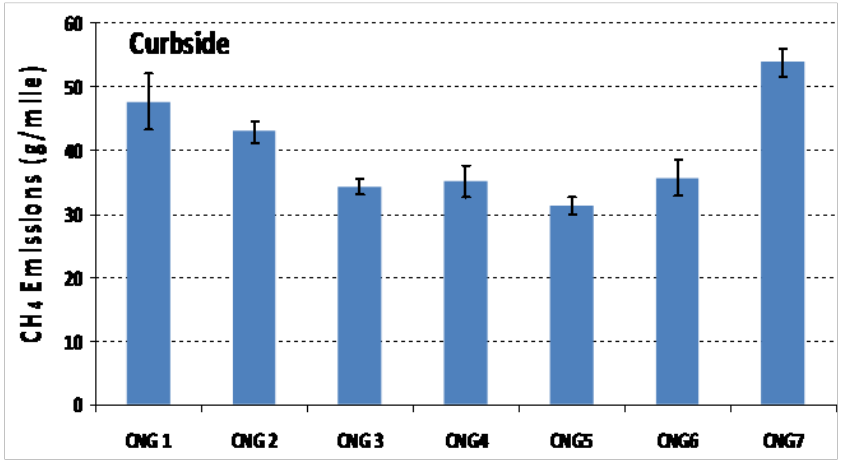


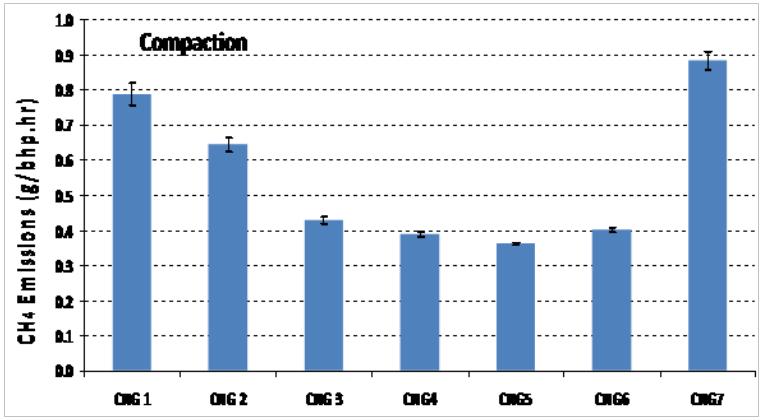
For the **curbside** phase, no statistically significant differences were found between fuels.

Heavy-Duty Tests – CH_4 (Two Buses & Waste Hauler Truck)







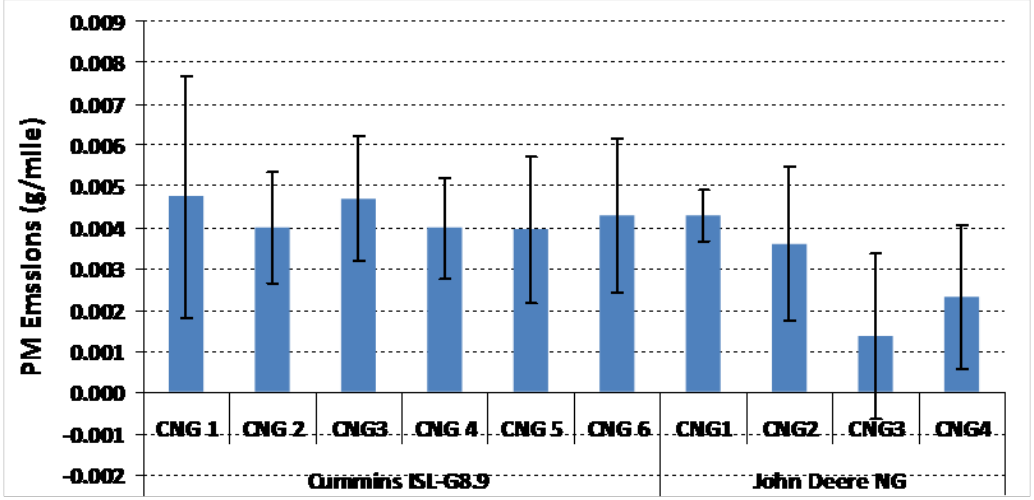


<u>Higher</u> CH_4 emissions for fuels with higher methane content, except for **Cummins bus.**

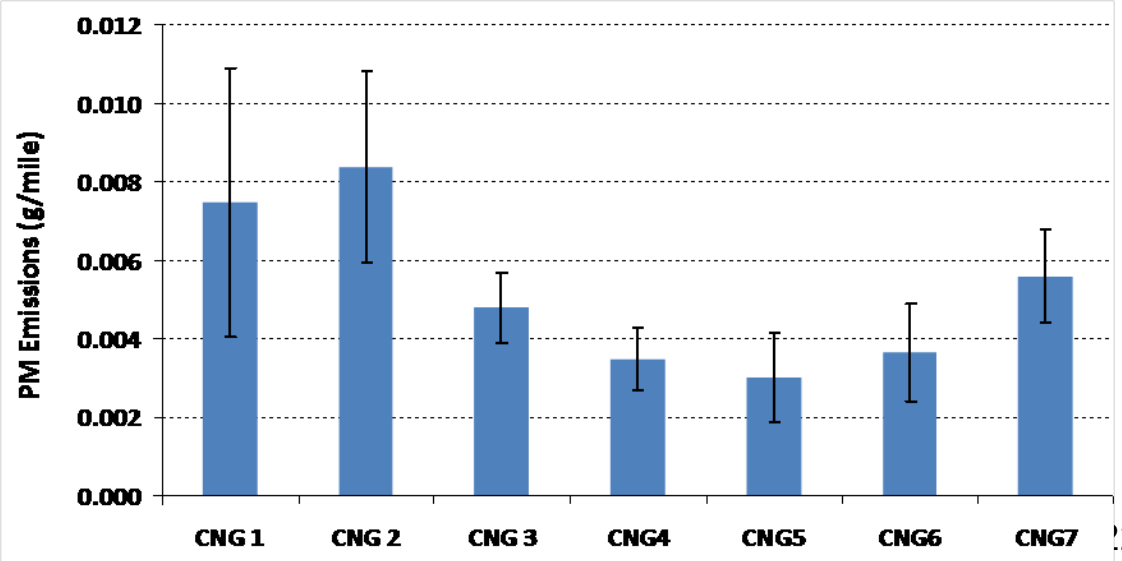
Heavy-Duty Tests – PM Mass

John Deere bus, only CNG1, CNG2, and CNG4 had PM mass above the detection limit, with the emissions of CNG1 being higher than those of CNG4.

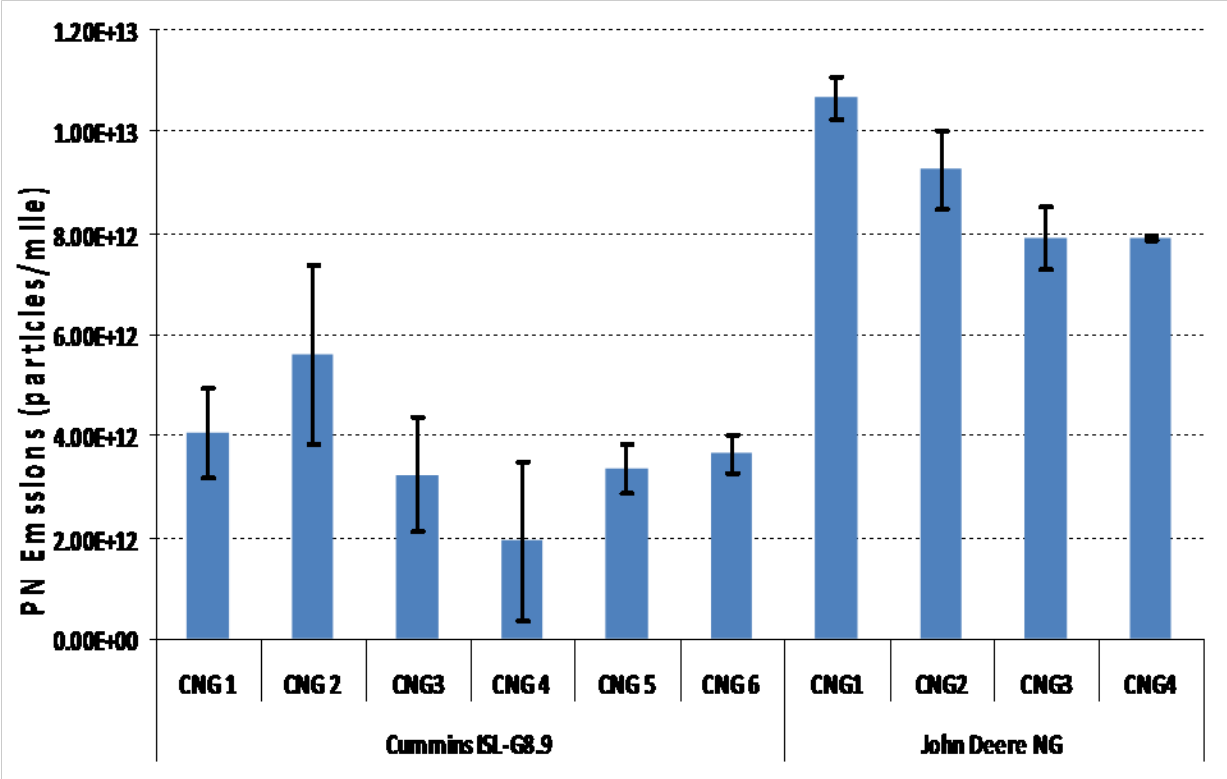
Cummins bus, there were essentially no differences between PM mass for different fuels.



Waste hauler showed lower PM mass for gases with higher hydrocarbons.

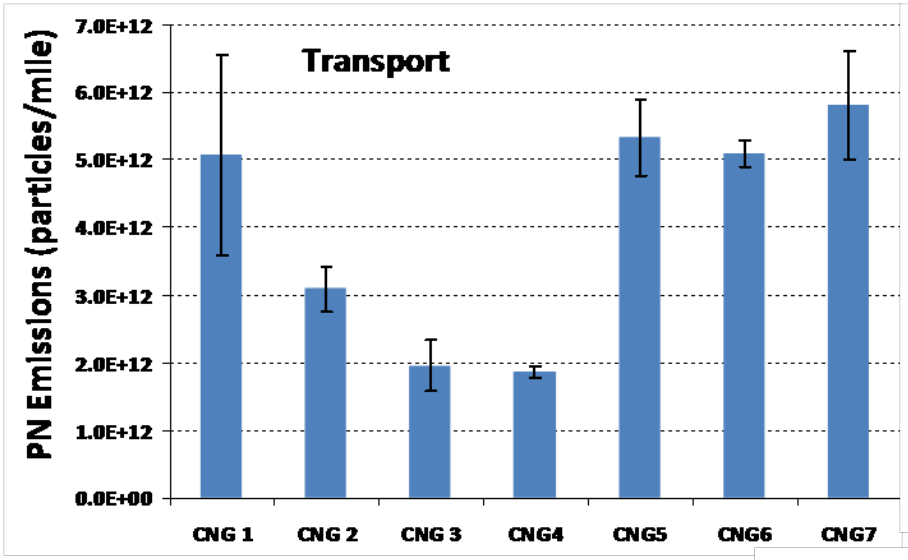


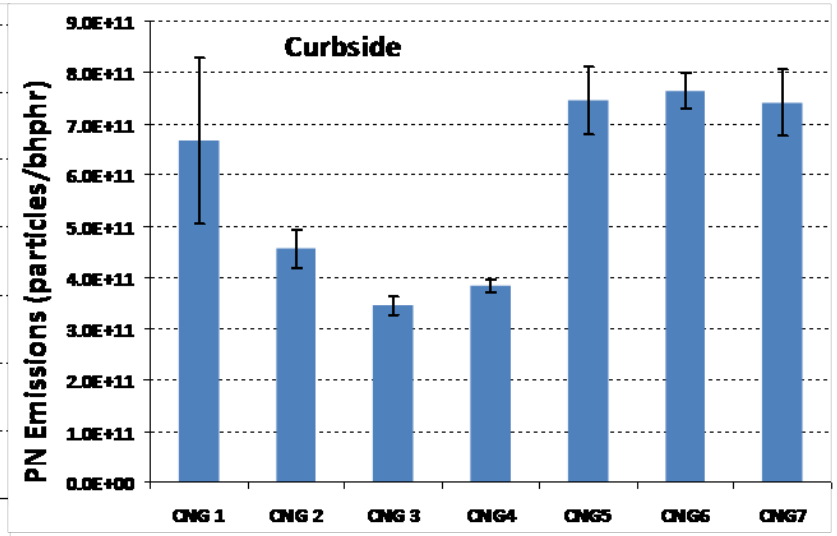
Heavy-Duty Tests – Particle Number (Two Buses)



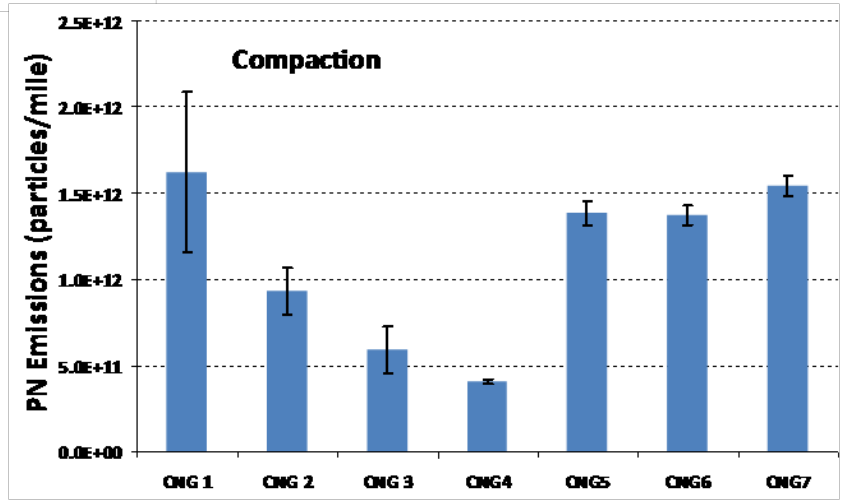
- PN for Cummins bus were found to be an order of magnitude lower than those from the older John Deere bus.
- **Cummins bus** lower PN emissions for fuels with higher hydrocarbons
- **John Deere bus** all test gases compared CNG1 showed a statistically significant reduction in PN emissions

Heavy-Duty Tests – Particle Number (Waste Hauler Truck)





The gases containing <u>higher</u> hydrocarbons produced <u>lower</u> PN emissions than CNG1, CNG2, and CNG7, with the exception of CNG5 and CNG6, which exhibited similar levels of PN emissions with CNG1 and CNG7 gases.



Heavy-Duty Testing Summary Results

- Some emissions trended higher for blends with more hydrocarbons/higher Wobbe Number
- Fuel Economy waste hauler compaction & transport & Cummins bus (not sign.)
  - But not for waste hauler curbside (no effect) or JD bus (opposite effect)
- CO_2 for waste hauler compaction & JD bus (some trends)
  - No strong trends for Cummins bus or waste hauler transport/curbside
- NO_x waste hauler (all segments) and JD bus
  - No strong trends for Cummins bus
- NMHC for waste hauler compaction & JD bus
  - But not for waste hauler transport (opposite effect) curbside (no effect) or Cummins bus (No emissions)

Heavy-Duty Testing Summary Results

- Some emissions trended lower for blends with more hydrocarbons/higher Wobbe Number
- THC waste hauler (all segments) and JD bus
  - But not for Cummins bus (opposite effect)
- CH_4 waste hauler (all segments) and JD bus
  - But not for Cummins bus (opposite effect)
- PM mass and PN waste hauler (all segments, except PN gas #5/#6) and JD bus (some PM trends)
  - No trends for Cummins bus for PM mass & limited trends for PN

- General
  - Cummins bus had lowest emissions, except for CO
    - Did not show strong fuel effects
  - Fuel effects stronger for compaction vs. curbside
  - CO did not show strong trends (except compaction)

Program Schedule

- Light-duty Testing
  - Memorandum completed and journal article published
- Heavy-Duty Chassis Testing
  - Testing on first three vehicles done in Spring /early summer 2011
    - Draft memorandum circulated to PAC
  - Retesting of one NG bus in March 2012
  - Additional testing on a fourth vehicle in spring 2012

Acknowledgements

- Funding Provided by
  - California Energy Commission under Contract Agreement No. 500-07-012
  - California Air Resources Board under Interagency Agreement No. 09-416
  - South Coast Air Quality Management District Contract No. 09290