# Comparison of Real-World Fuel Use and Emissions for Dump Trucks Fueled with B20 Biodiesel Versus Petroleum Diesel (Paper No. 06-1078)

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# Project Objectives

1. Characterize baseline real-world in-use on-road emissions of selected heavy duty diesel vehicles, including those fueled with B20, under normal duty cycles;
2. Characterize the episodic nature of emissions and fuel
3. Identify factors responsible for variability in emissions and fuel use, include operating mode, load, and fuel type

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# Fuel Properties of Petroleum versus Soy-Based Biodiesel

| Property | Diesel | **B20** | B100 |
|---|---|---|---|
| LHV (BTU/lb) | 18,730 | **18,100** | 15,800 |
| Specific Gravity | 0.84 | **0.85** | 0.89 |
| Cetane No. | 44 | **46** | 54 |
| Carbon, wt-% | 86.4 | **84.5** | 76.9 |
| Hydrogen, wt-% | 13.6 | **13.3** | 12.1 |
| Oxygen, wt-% | 0.00 | **2.20** | 11.0 |
| Cloud point (°F) | 18 | **20** | 40 |
| Flash point (°F) | 150 | **180** | 260 |
| Pour point (°F) | -4 | **9** | 34 |
| Initial Boiling Point (°F) | 352 | **373** | 573 |
| Distillation Point (T90, F) | 603 | **640** | 666 |
| Aromatics, vol-% | 30 | **24** | 0 |
| Viscosity@40ºF | 2.6 | **2.9** | 4.1 |

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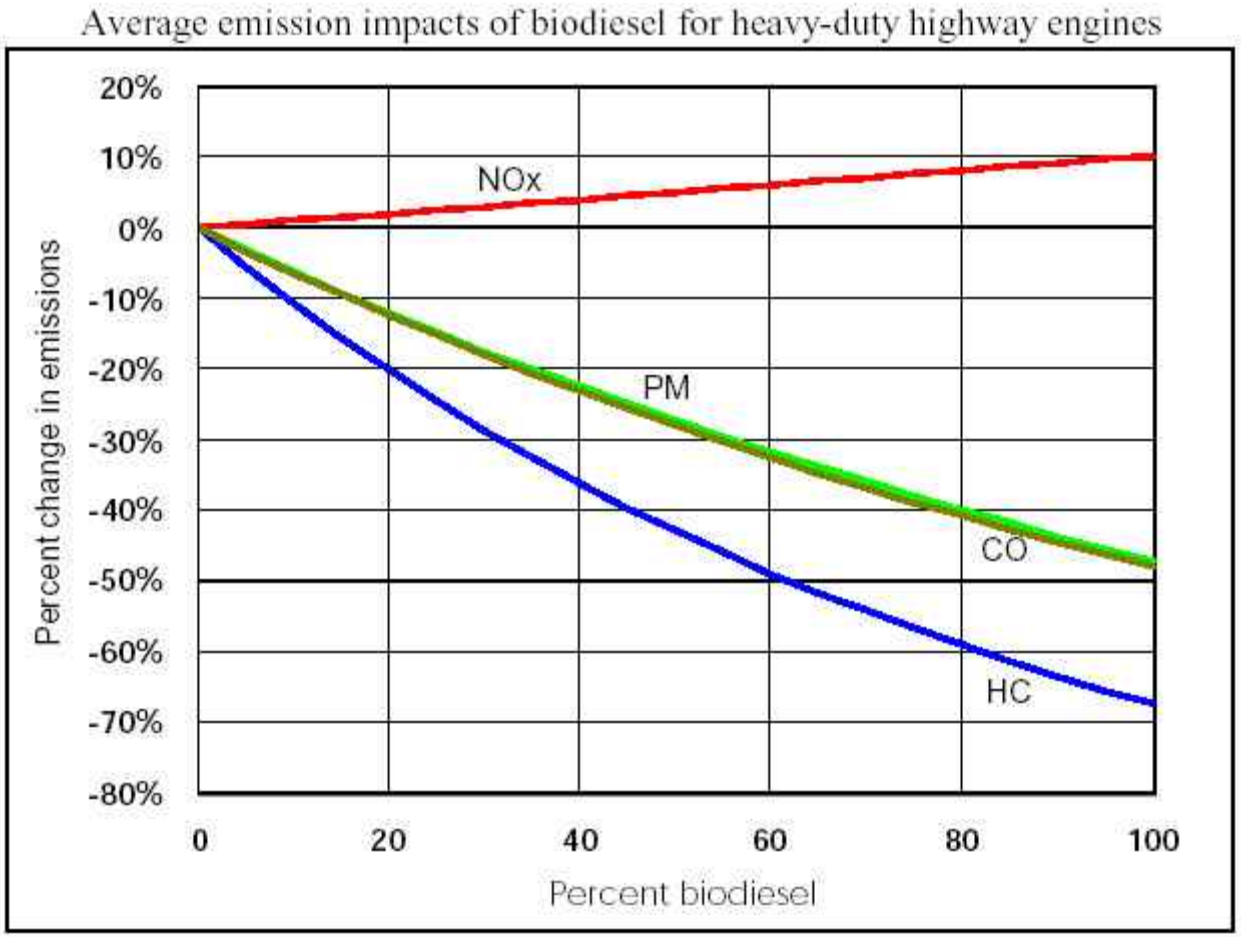
# Emissions Impact of Biodiesel Versus Diesel (EPA, 2002)




Source: EPA (2002) "A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions."

# Fuel Consumption and $CO_2$ Emissions

- B20 biodiesel has less energy density on a mass (-3%) or volume basis (-2%)
- B20 has slightly higher carbon intensity per BTU (1%)
- Therefore, we expect a small increase in fuel consumption and in $CO_2$ emissions
- A portion of the carbon in B20 is from renewable sources; the net carbon emissions are less than that of petroleum diesel

# Potential Concerns with Biodiesel

- Typical concerns regarding B20 biodiesel can include:
  - A small loss of maximum power at full load (e.g., on the order of 2 to 5 percent)
  - B100 blend stock acts as a solvent; can create an initial pluggage problem for the fuel filter
  - Higher cloud point: possible difficulties in fuel handling at cold temperatures
- NCDOT modifications: replace the fuel filter
- Vehicles have highest activity in summer months

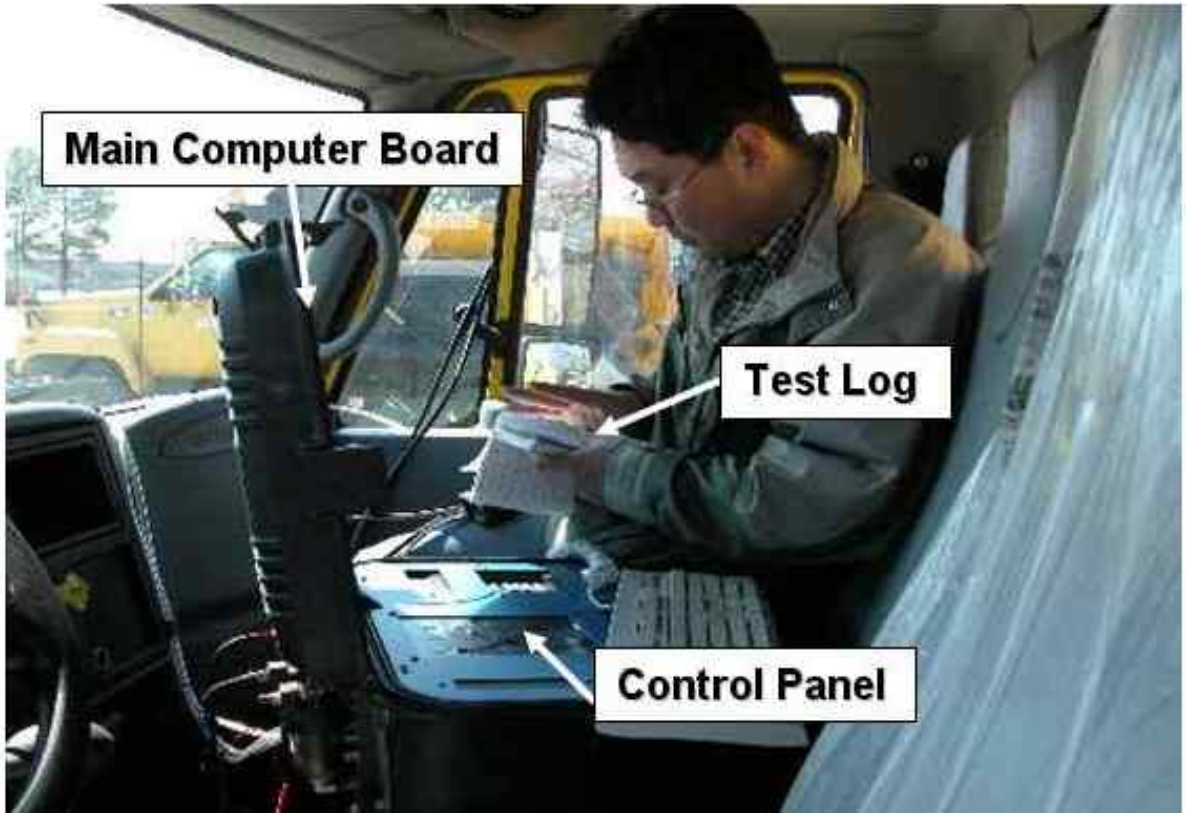
# Measuring Fuel Use and Emissions

- Engine dynamometer
  - Steady state, modal tests
  - Transient tests
- Chassis dynamometer
- Remote Sensing
- Tunnel Studies
- On-Board Instrumentation

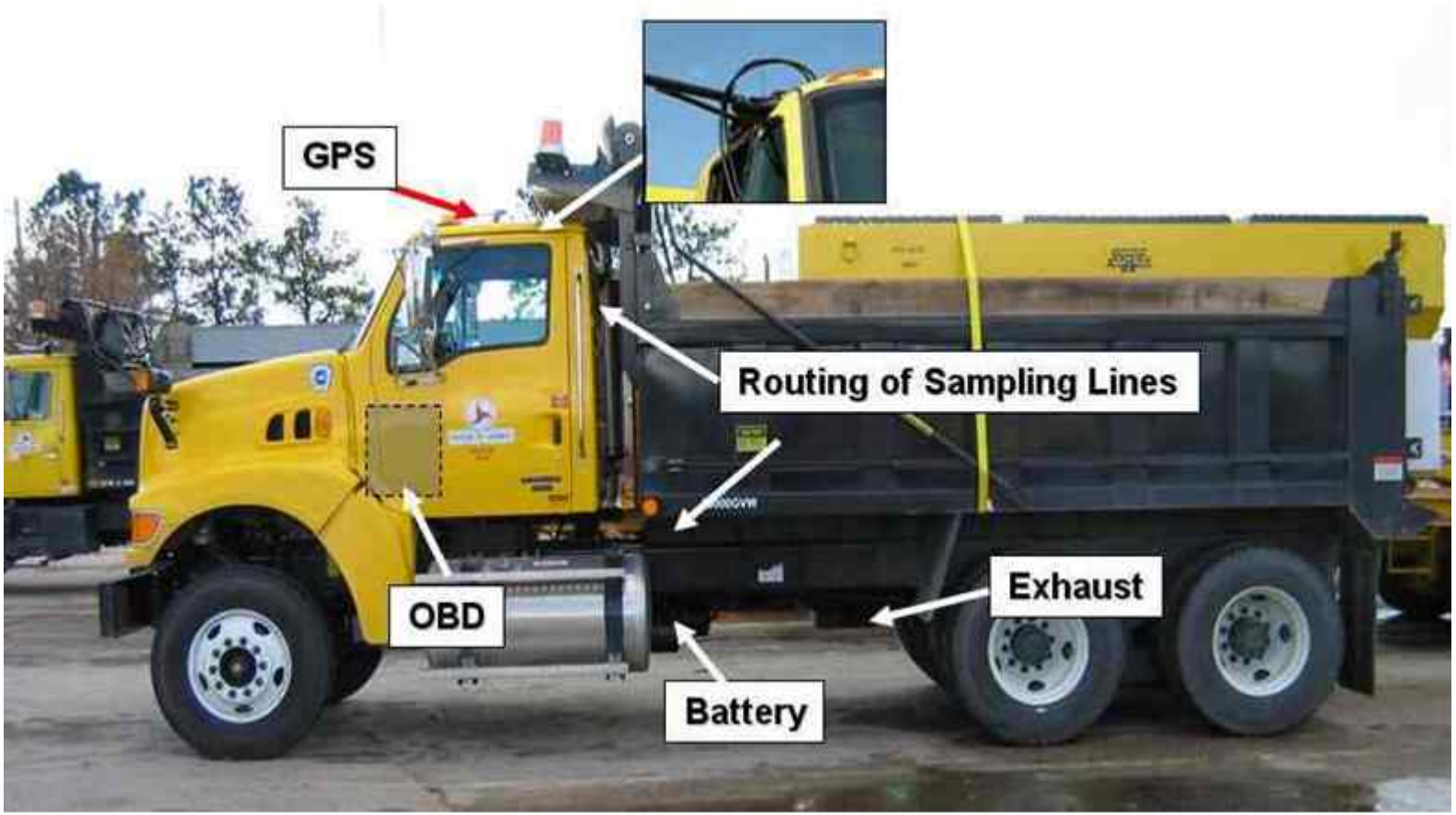
# Portable Emission Measurement System (PEMS)

- Montana System
  - Clean Air Technologies International, Inc.
  - Carry-on Luggage shape
  - Weight: 35 *lbs.*
  - 13.8 *volt* with 5~18 *amps.*
- 2 Gas Analyzers
  - NO and $O_2$ measured with electro-chemical sensors
  - HC, CO, and $CO_2$ measured using non-dispersive infrared (NDIR)
- 1 Particulate Matter Analyzer (based on light scattering)
- Global position system (GPS)
- Engine scanner to obtain engine RPM, manifold air pressure, and intake air temperature from diagnostic link

# Setting Up the Instrument



# Vehicle in Motion with Instrumentation



# Field Study

- Portable Emission Measurement System
- NCDOT in-use dump trucks
  - Single rear axle – “Single”
  - Double rear axle – “Tandem”
  - Tier 1 and Tier 2 engines
- Drivers – NCDOT
- Duty cycles – real world activity

“Single”

“Tandem”

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# Tested Vehicles

| Vehicle Type | Number Tested | |
|---|---|---|
| Single – Tier 1 | 4 | |
| Single – Tier 2 | 2 | |
| Tandem – Tier 1 | 4 | |
| Tandem – Tier 2 | 2 | |

All vehicles are part of NCDOT Division 5

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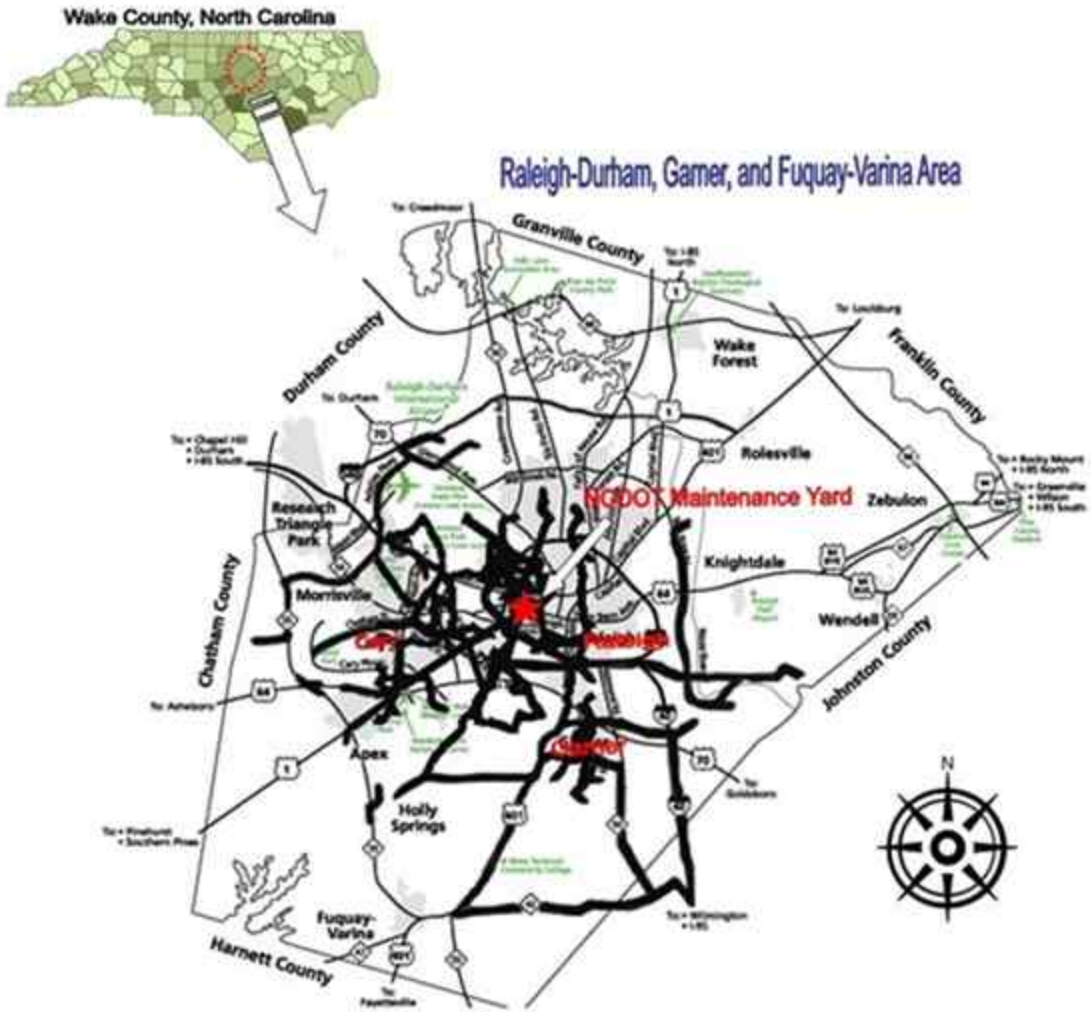
# Study Region:
# Wake County, North Carolina



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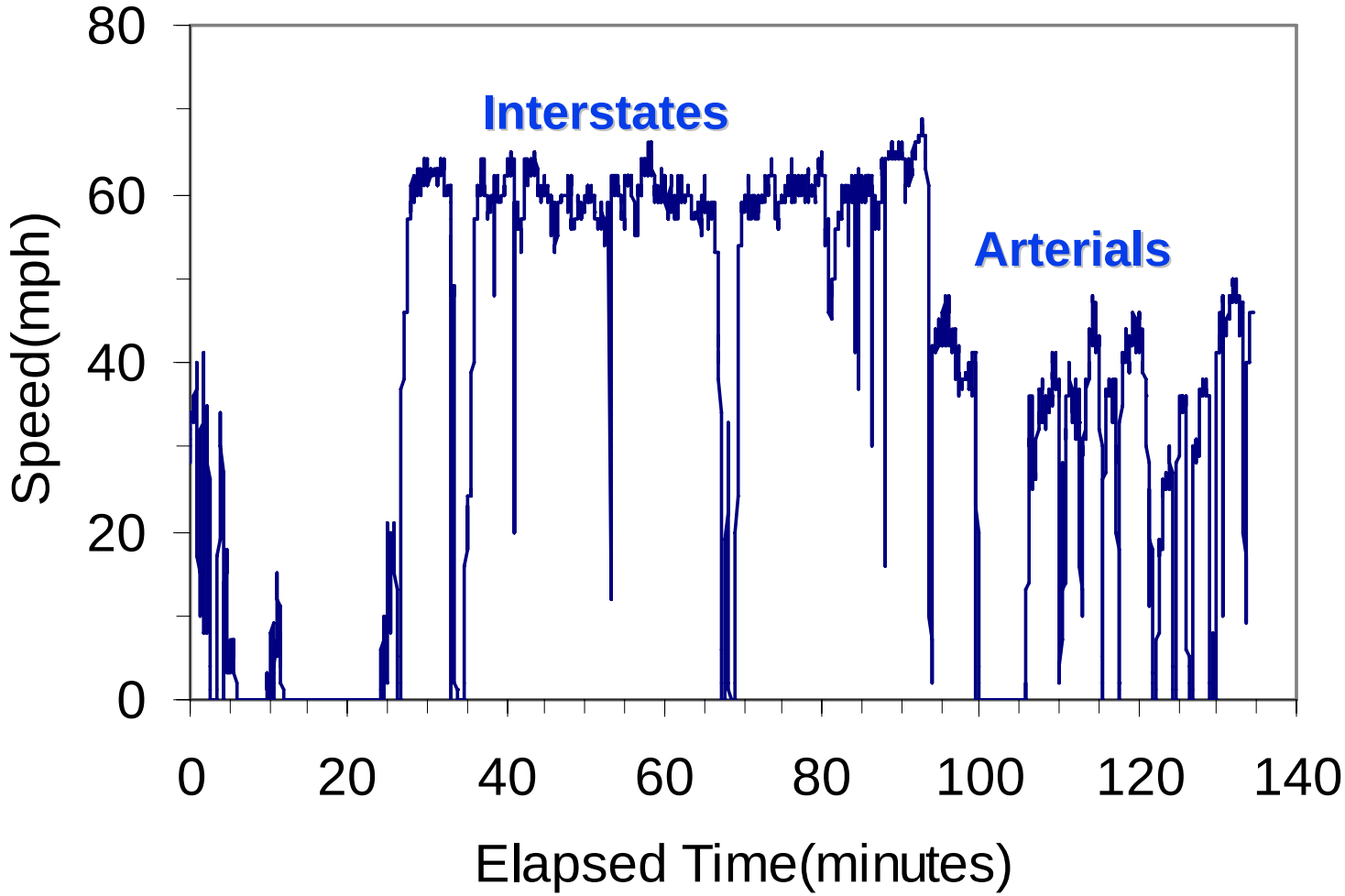
# Summary of Vehicles, Drivers, Duty Cycles, and Loads

| Vehicle Type | Vehicle Weight (tons) | Average Load (tons) | Total Weight (lb) | Rated GVW (lb) | Ratio Loaded to Unloaded Weight |
|---|---|---|---|---|---|
| Single Axle | 7.2 | 7 | 28400 | 33000 | 1.97 |
| Tandem | 10.8 | 14.5 | 50600 | 50000 | 2.34 |

| Vehicle Type | Vehicle Number | B20 | | Pet. Diesel[c] | | Number of Cycle | | Load Type | | Load Weight (tons) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Driver | Date | Driver | Date | B20[a] | PD[b] | B20[a] | PD[b] | B20[a] | PD[b] |
| Tandem | **507** | Kirby | 1-Sep | Kirby | 8-Nov | 4 | 7 | Wood | stone | 13.8 | 14.6 |
| | **578** | Joe | 5-Aug | Charles | 28-Oct | 4 | 4 | Asphalt | Dirt | 15.1 | 14.1 |
| | **579** | Ron | 27-Jul | Ron | 15-Oct | 7 | 2 | Sand | Sand | 14.7 | 14.8 |
| | **580** | Keeven | 25-Aug | Keeven | 5-Oct | 4 | 3 | Asphalt | Asphalt | 15.2 | 16.7 |
| | **125** | Keeven | 7-Dec | Keeven | 30-Nov | 4 | 4 | Stone | Stone | 14.3 | 14.5 |
| | **126** | Charles | 2-Dec | Charles | 1-Dec | 4 | 5 | Stone | Stone | 13.2 | 12.8 |
| Single Axle | **4743** | David | 10-Aug | Keeven | 21-Oct | 4 | 3 | Sand | Stone | 7.12 | 8.06 |
| | **4750** | Mike | 8-Oct | Ricky | 2-Nov | 2 | 5 | Dirt | Wood | 7.1 | 5.98 |
| | **4869** | Howard | 31-Aug | David | 27-Oct | 2 | 2 | Sand | Dirt | 7.74 | 5.94 |
| | **4870** | James | 20-Aug | Scott | 29-Oct | 5 | 6 | Dirt | Stone | 7.1 | 7.86 |
| | **6117** | Todd | 17-Aug | Todd | 20-Oct | 7 | 5 | Dirt | Stone | 7.14 | 6.83 |
| | **6123** | Willard | 6-Oct | Willard | 3-Nov | 4 | 12 | Dirt | Dirt | 7.2 | 5.85 |

# Example of a Real World Speed Profile



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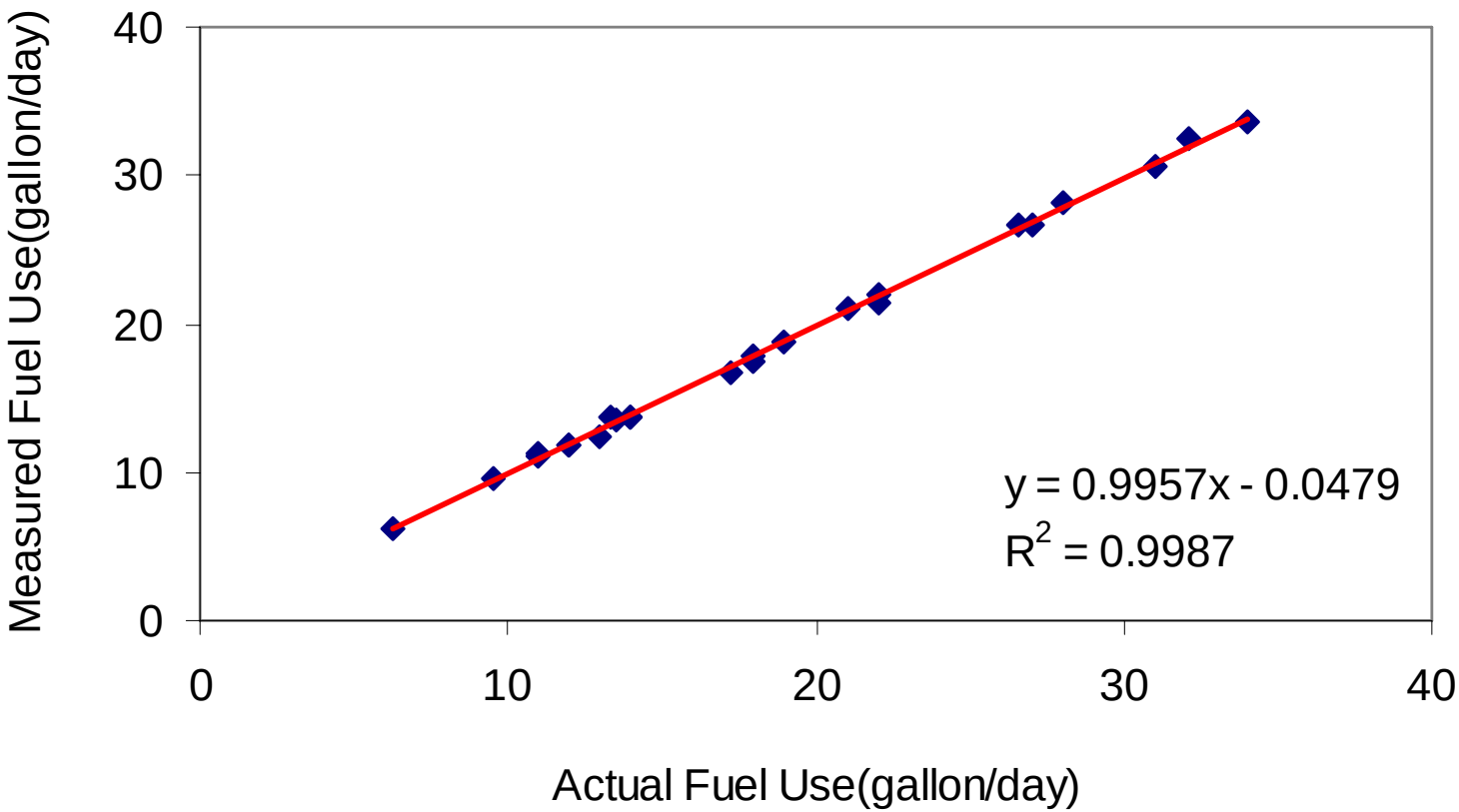
# Validation of Overall Fuel Use



# Definition of Operating Modes

- ***Idle***: S = 0, A = 0
- ***Acceleration*** (positive change in speed)
  - Low, PD ≤ 20
  - Medium, 20 < PD ≤ 50
  - High, PD > 50
- ***Cruise***
  - Low, S < 30 mph
  - Medium, 30 ≤ S < 45 mph
  - High, S ≥ 45 mph
- ***Deceleration*** (negative change in speed)
- ***Dumping*** – operation of the rear bed
- "***Power Demand***" (PD) = Speed (S) x Acceleration (A)

# Measurement Results

- Activity patterns for each vehicle
- Loaded versus unloaded fuel use and emissions
- Modal fuel use and emissions
- Comparison of B20 versus Petroleum Diesel

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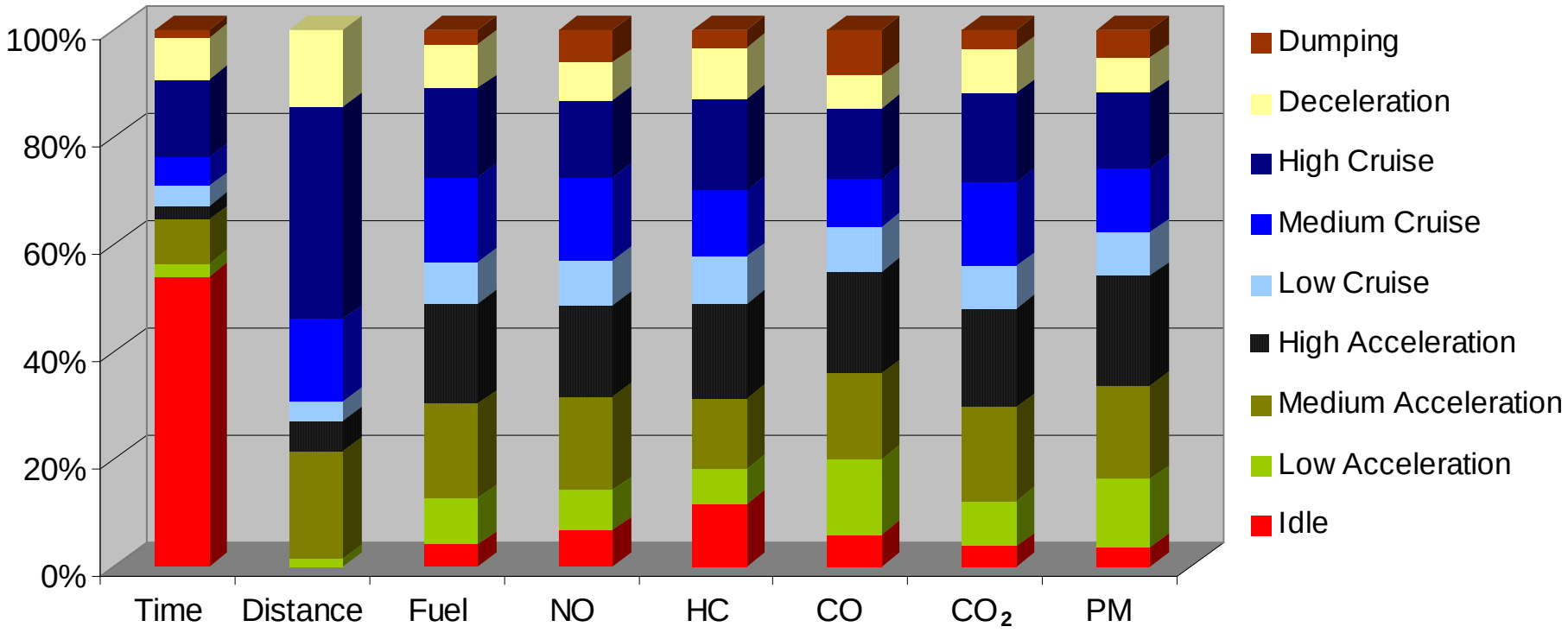
## Distribution of Time, Distance, Fuel Use, and Emissions by Operating Mode




Example for a Loaded Single Rear Axle Tier 1 Dump Truck on B20 Biodiesel

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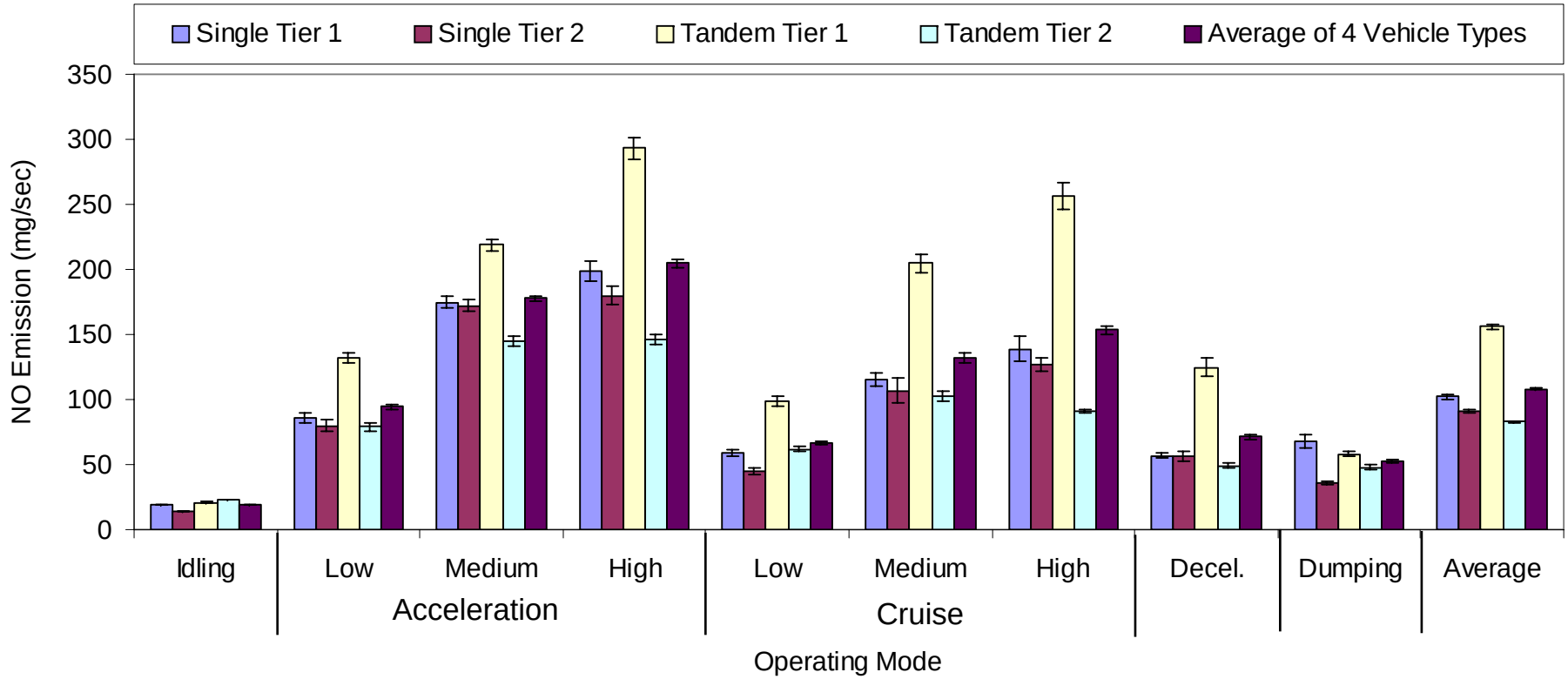
# Comparison of Operating Mode NO Emissions for Loaded Trucks, Petroleum Fuel



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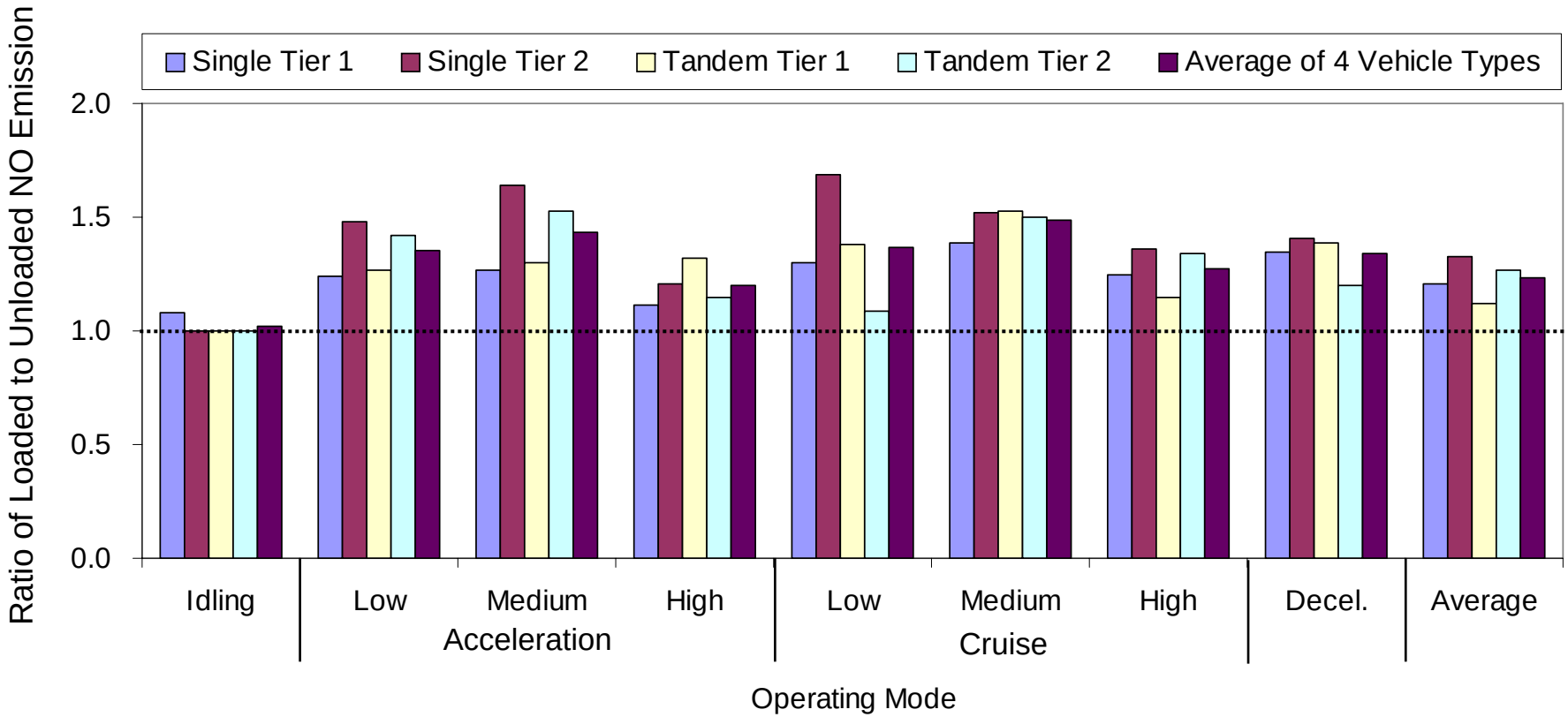
# Comparison of NO Emission for Loaded Vs. Unloaded Trucks by Mode and Vehicle Type, Biodiesel Fuel



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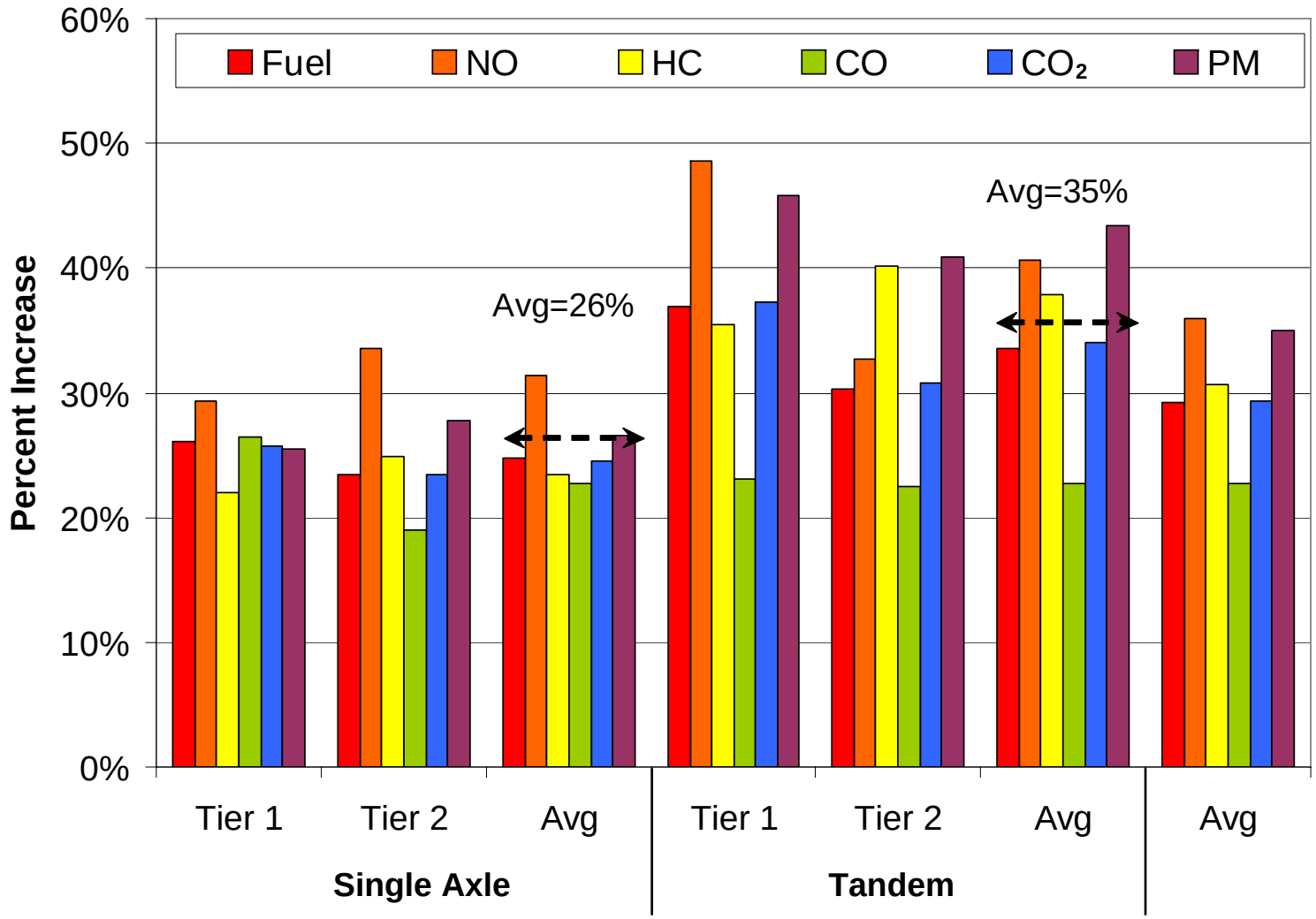
# Overall Comparison of Loaded Versus Unloaded Fuel Use and Emissions: Petroleum Diesel



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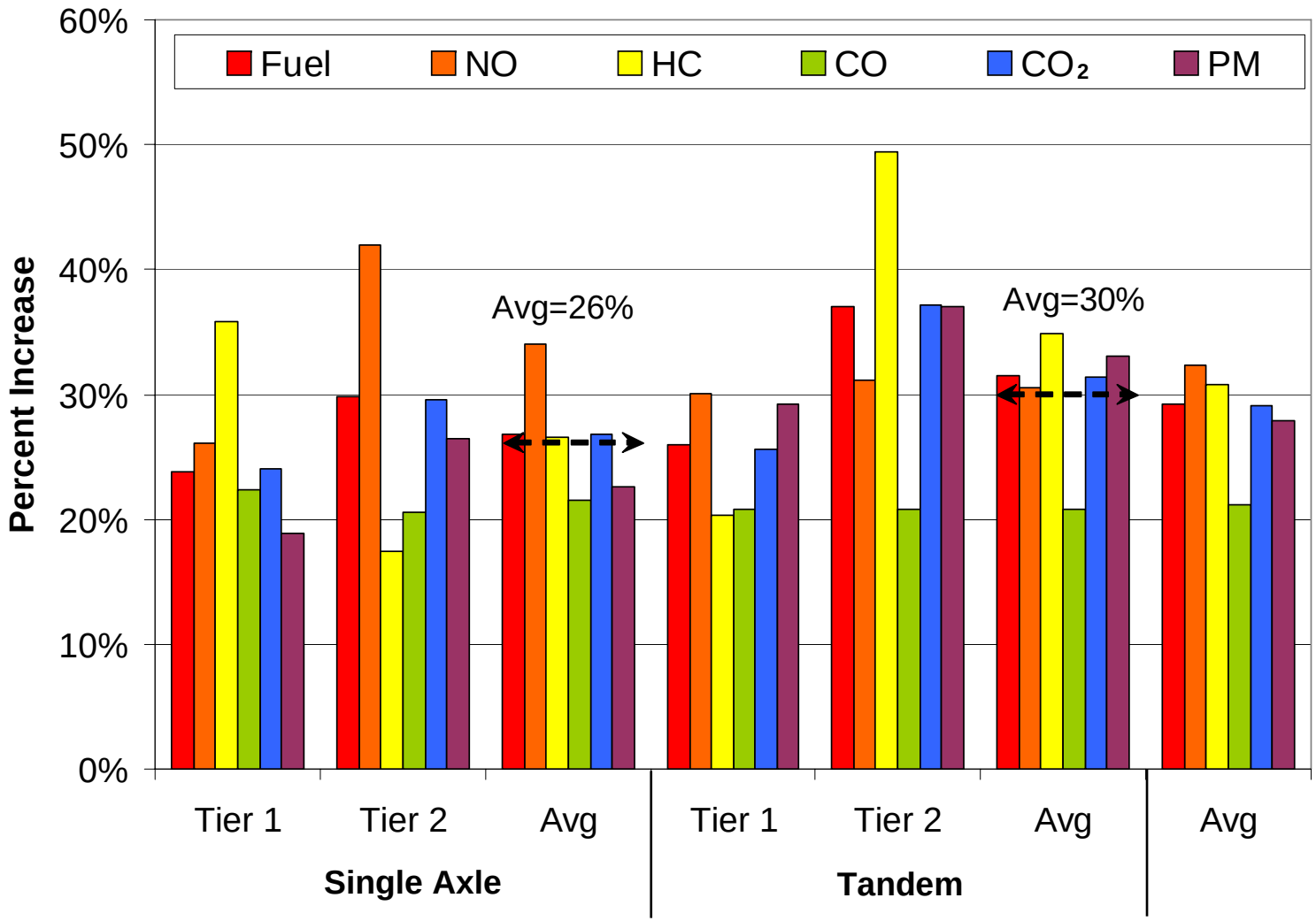
# Overall Comparison of Loaded Versus Unloaded Fuel Use and Emissions: B20 Biodiesel



# Alternatives for Comparing B20 versus Petroleum Diesel

- Comparison of Average Rates per Operating Mode
- Idle, Acceleration, Cruise, and Deceleration Modes are common to loaded and unloaded vehicles
- “Dumping” mode only applies to loaded vehicles
- Comparisons are based upon common modes only
- Weights per mode vary from one vehicle-day to another.
- For comparability, assigned equal weights to all modes
- Other weighting schemes can be explored
- Temperature and humidity may affect $NO_x$ emissions

# Summary of Average Ambient Conditions

| Ambient Condition | Vehicle Type | B20 | Petroleum Diesel |
|---|---|---|---|
| Temperature (°C) | Single Tier 1 | 23 ~ 32 | 16 ~ 24 |
| | Single Tier 2 | 19 ~ 28 | 16 ~ 25 |
| | Tandem Tier 1 | 26 ~ 31 | 17 ~ 21 |
| | Tandem Tier 2 | 14 ~ 22 | 16 |
| Relative Humidity (%) | Single Tier 1 | 37 ~ 59 | 71 ~ 83 |
| | Single Tier 2 | 47 ~ 58 | 64 ~ 90 |
| | Tandem Tier 1 | 50 ~ 74 | 45 ~ 62 |
| | Tandem Tier 2 | 27 ~ 71 | 31 ~ 41 |

*Applied a Humidity Correction for $NO_x$ Emissions in Some Comparisons*

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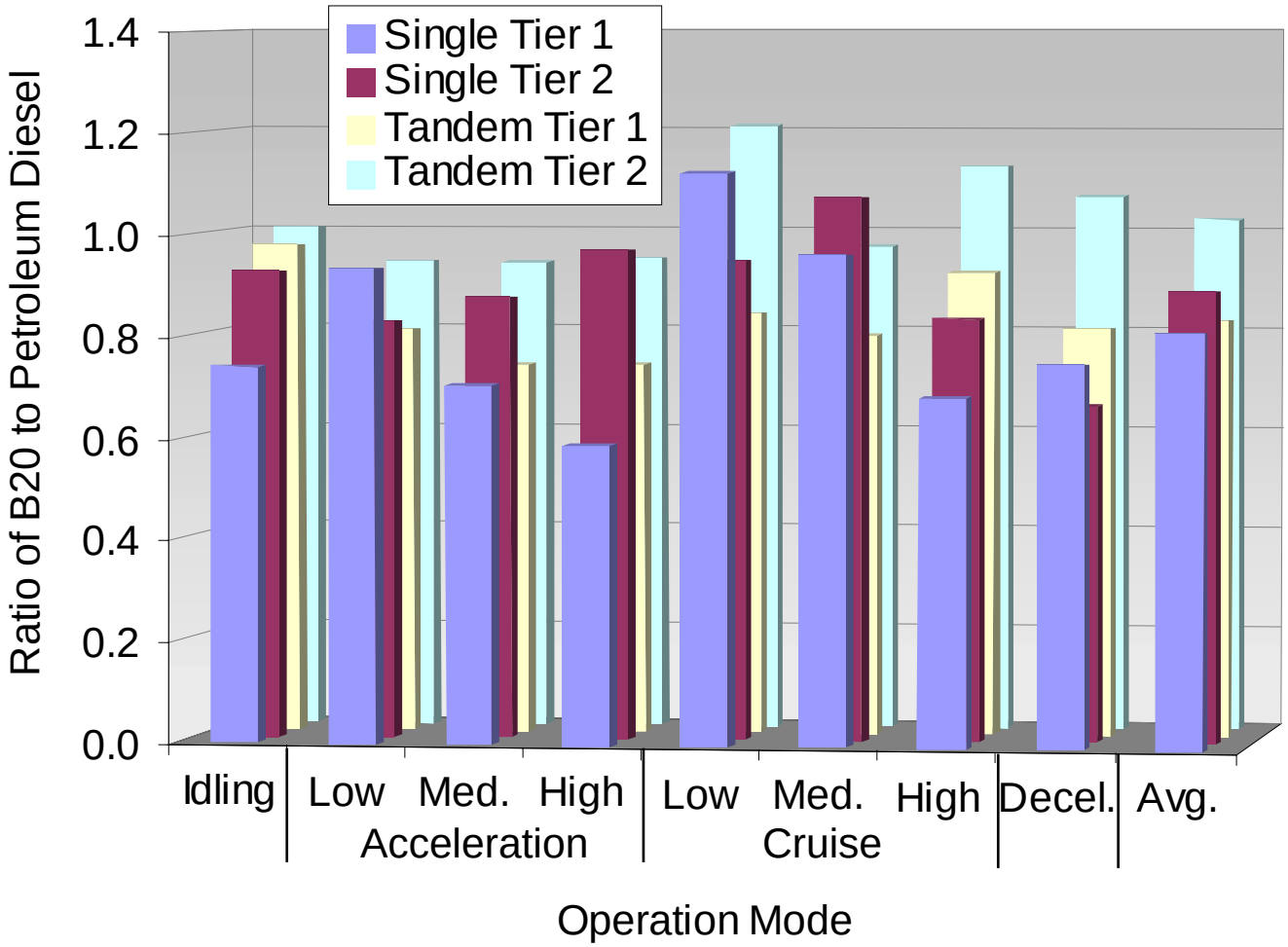
# NO Emissions Uncorrected Ratio of B20 to Petroleum Diesel for Unloaded Trucks




*Average Reduction of 11%*

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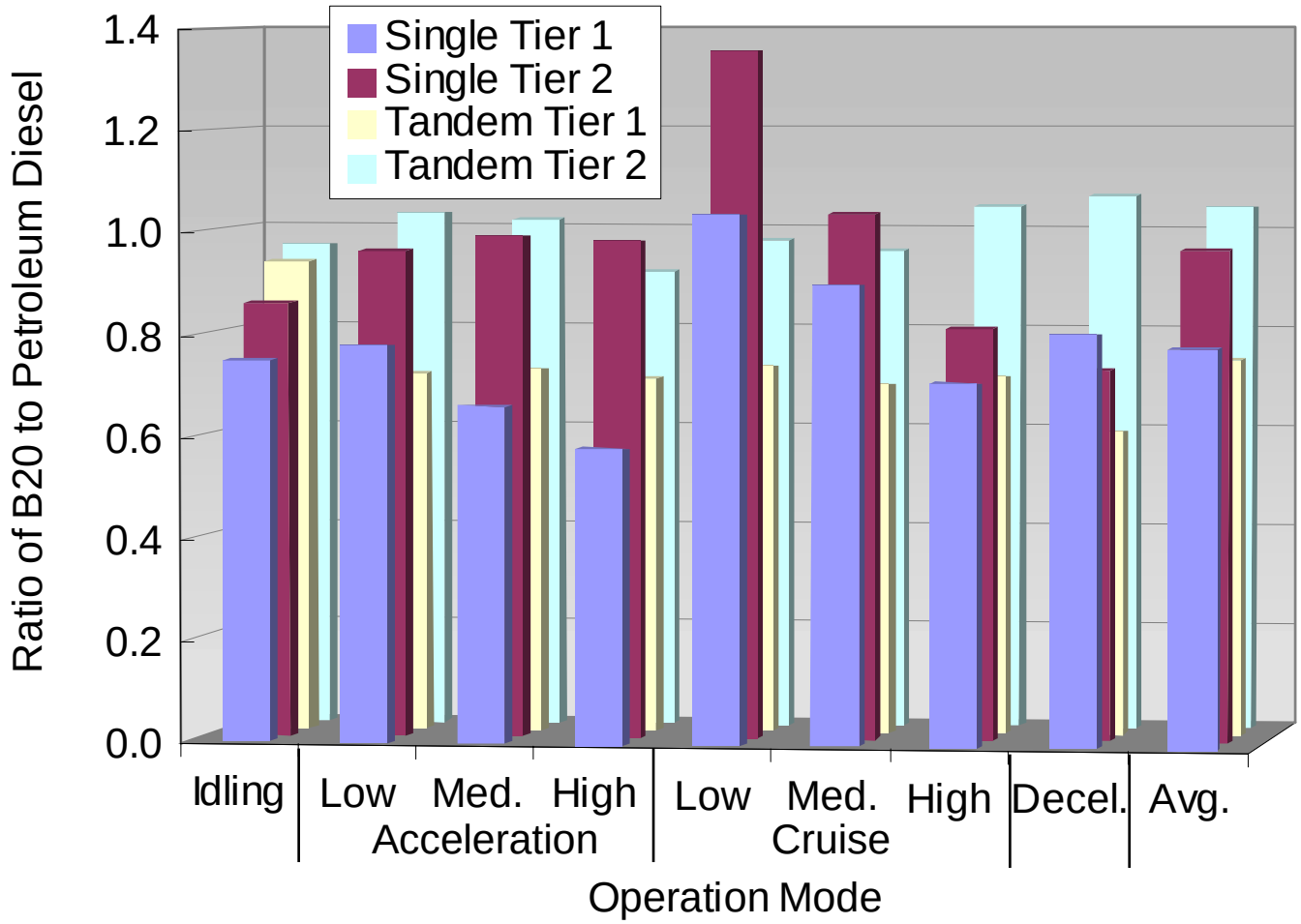
# NO Emissions Uncorrected Ratio of B20 to Petroleum Diesel for Loaded Trucks




*Average Reduction of 12%*

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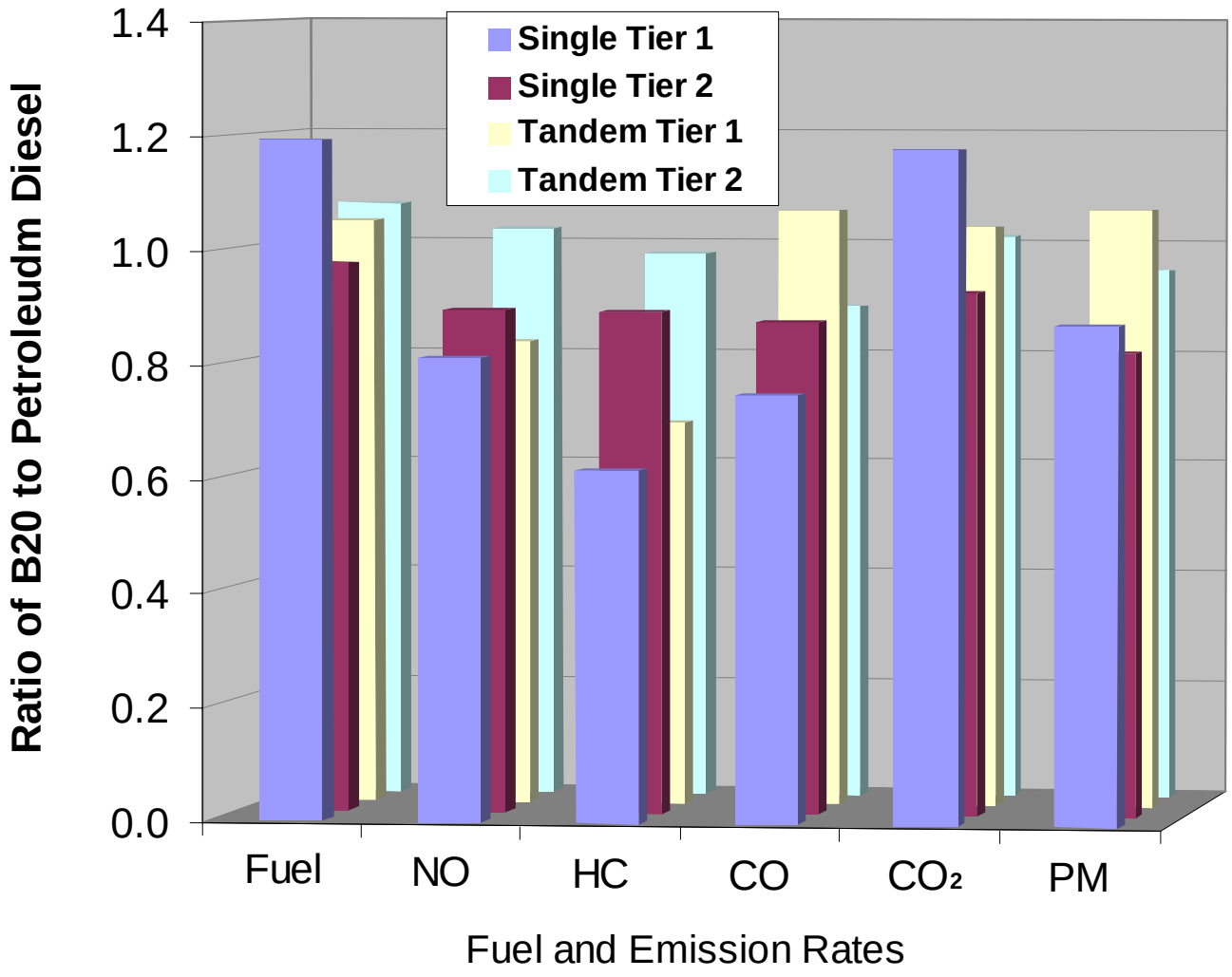
# Comparison of B20 Versus Diesel for Fuel Use and Emissions for Unloaded Trucks



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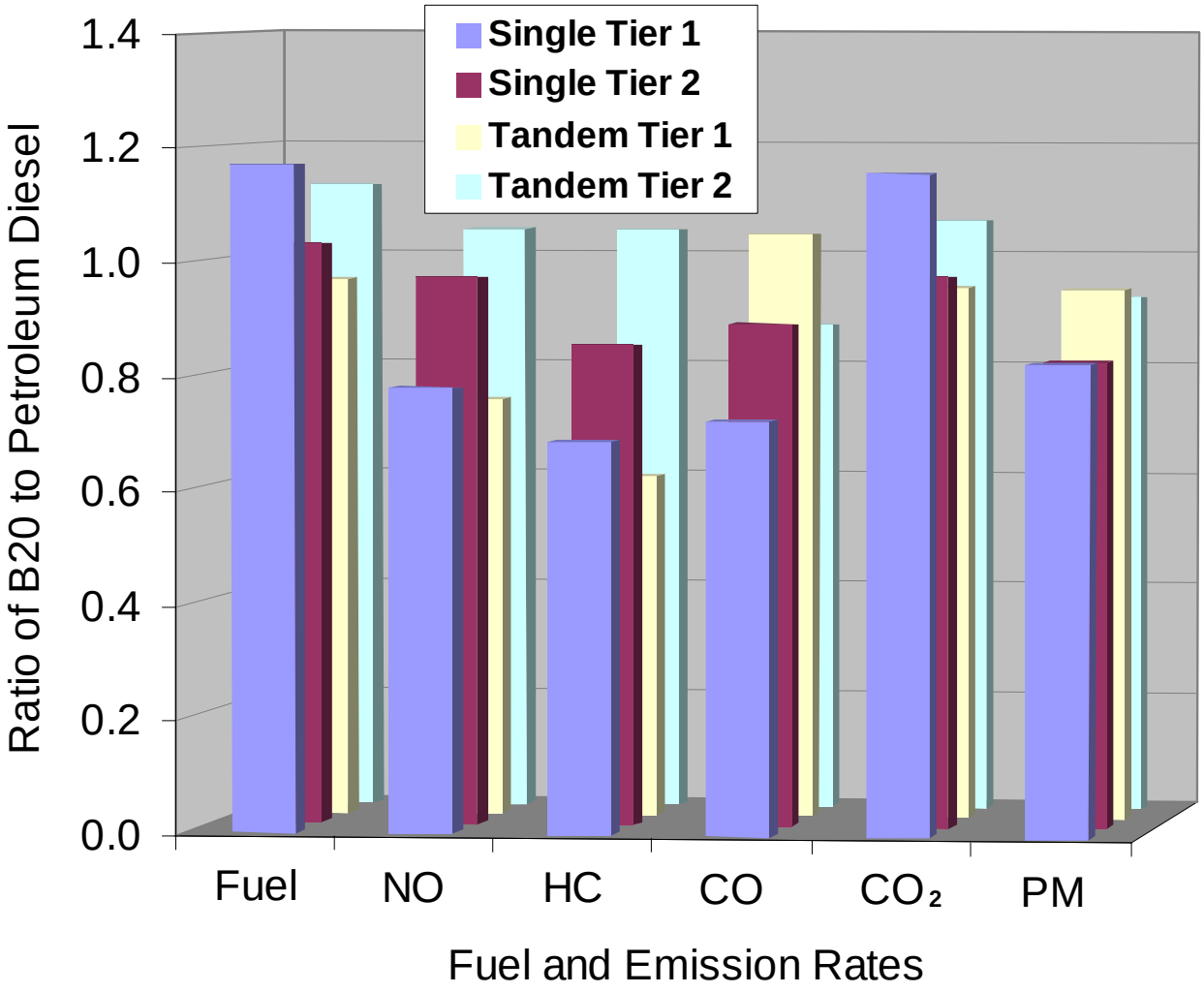
# Comparison of B20 Versus Diesel for Fuel Use and Emissions for Loaded Trucks



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## Overall Average Comparisons:
## Average Percent Difference, B20 vs. Petroleum Diesel

| | Unloaded | Loaded | Combined | Engine Dyno. |
|---|---|---|---|---|
| Fuel | 7 | 7 | 7 | NR |
| NO | -11 (-9)[a] | -12 (-12)[a] | -11 (-10)[a] | 2 |
| HC | -21 | -20 | -21 | -21 |
| CO | -11 | -12 | -11 | -11 |
| $CO_2$ | 4 | 3 | 3 | NR |
| PM | -8 | -12 | -10 | -10 |

[a] *Applied $NO_X$ humidity Correction Factor for diesel engines based on EPA 40 CFR*

# Findings: B20 vs. Diesel

- Although not statistically significant, the mean decrease in fuel economy and mean increase in $CO_2$ emissions are approximately as expected.
- HC, CO, and PM emissions are lower by 10~20%, which is statistically significant and comparable to other estimates.
- Average Corrected NO emissions are lower by about 10%. By comparison, engine dynamometer data imply a slight increase of approximately 2~4%. Emissions for some operating modes are slightly higher.

# Conclusions

- Findings are mostly consistent with other data and expectations.
- The difference in NO results could be attributable to the in-use real-world duty cycles, fuel properties, or focus on NO and not total $NO_2$.
- Fuel use and emissions trends by mode are reasonable.
- Fuel use and emissions increase approximately 30 percent for loaded versus unloaded vehicles; vehicle weight approximately doubles when loaded.

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