Verifying Real-World Emission Impacts of Sustainable Transport Technologies

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Presented at:
Sustainable Fleet Technology Conference
Durham, NC

August 22, 2018

Federal Programs

- Vehicle tailpipe exhaust standards
- National Energy Policy Act
- Renewable Fuel Standards
- Diesel emission reductions

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Motivation

- Programs to promote alternative fuels/vehicles typically assume benefits based on limited surrogate data – e.g., reduced fuel use and lower emissions
- However, there are few efforts to validate these assumptions with real-world data

Key Questions

- How can we measure the ***real-world*** energy use and emissions of the alternative fuels/vehicles?
- How effective are alternative fuels or technologies in reducing energy use and emissions?

Objective

To demonstrate the use of real-world measurements as a basis for comparing ethanol-gasoline blends, biodiesel versus petroleum diesel, and CNG versus diesel vehicles

Using Portable Emission Measurement System (PEMS) to Measure Real-World Vehicle Activity, Fuel Use and Emissions

- **Infrastructure Data**: Vehicle location (GPS), road grade (via altimeter and GPS, if applicable)
- **Vehicle Technology and Fuels**: Engine size, fuel properties
- **Behavior** (Vehicle Dynamics): Speed, Acceleration, Engine RPM
- **Ambient conditions**: temperature, humidity, pressure
- **Vehicle Fuel Use and Emissions**: Gas analyzers for NO, HC, CO, CO_2 and surrogates for PM (e.g., opacity, black carbon)

Frey, H.C., A. Unal, N.M. Rouphail, and J.D. Colyar, "On-Road Measurement of Vehicle Tailpipe Emissions Using a Portable Instrument," *Journal of Air & Waste Manage. Assoc*., 53(8):992-1002 (August 2003).

Frey, H.C., K. Zhang, and N.M. Rouphail, "Fuel Use and Emissions Comparisons for Alternative Routes, Time of Day, Road Grade, and Vehicles Based on In-Use Measurements," *Environmental Science and Technology*, 42(7):2483–2489 (April 2008).

Sandhu, G.S., and H.C. Frey, "Effects of Errors on Vehicle Emission Rates from Portable Emissions Measurement Systems," *Transportation Research Record*, 2340:10-19 (2013).

Yazdani, B., and H.C. Frey, "Road Grade Quantification Based on Global Positioning System Data Obtained from Real-World Vehicle Fuel Use and Emission Measurements," *Atmospheric Environment*, 85:179-186 (March 2014)

PEMS Variations: Examples

SEMTECH-DS
CFR 1065 Compliant
NDIR: CO_2, CO, HC
FID: THC
NDUV: NO, NO_2
Heated Sample Line
Heavy (~50 lbs)
High Power Demand

ParSYNC
“micro-PEMS”
Electrochemical:
CO_2, NO, NO_2
PM: light-scattering, opacity, ionization
Water separation
Portable (~10 lbs)
Low Power Demand

Axion
NDIR: CO_2, CO, HC
Electrochemical: NO, O_2
Light-scattering: PM
Water separation bowl
Portable (~30 lbs)
Low Power Demand

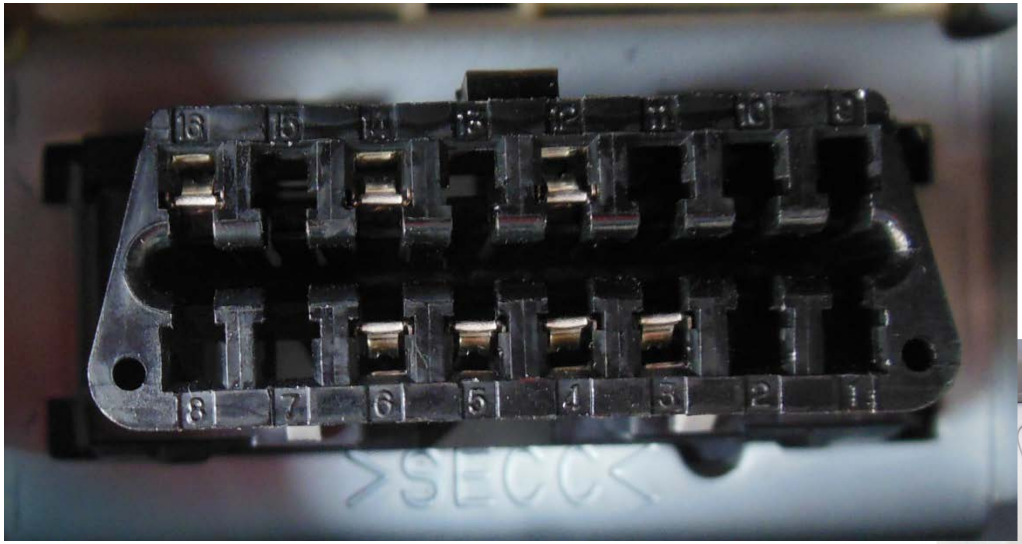
Exhaust Sample Probe

Portable Emission Measurement System

Global Postioning System (GPS) Receivers with Barometric Altimeters

Yazdani, B., and H.C. Frey, "Road Grade Quantification Based on Global Positioning System Data Obtained from Real-World Vehicle Fuel Use and Emission Measurements," *Atmospheric Environment*, 85:179-186 (March 2014).

On-Board Diagnostic Data Logging



Alternatively, can use an exhaust flow meter

Instrumented Vehicle

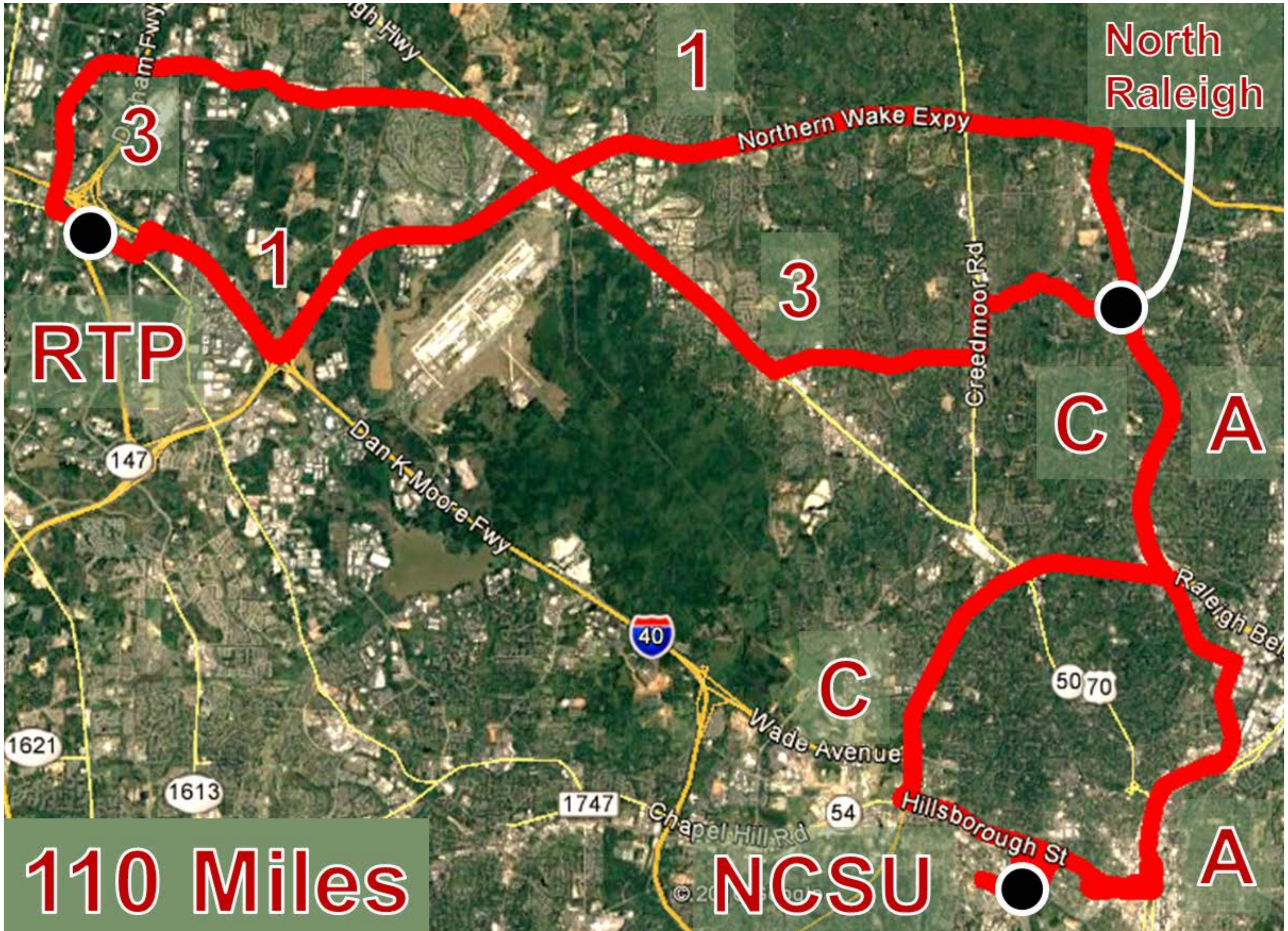
Overview of Measurements at NC State

- Over 200 light duty vehicles (on RTP routes)
  - 2/3 passenger car
  - 1/3 passenger truck
- 50 heavy duty vehicles (observed routes)
  - 12 dump trucks
  - 8 concrete mixers
  - 6 combination trucks
  - 24 refuse trucks
- Over 40 construction vehicles
- 7 diesel-electric railroad locomotives

Examples of Completed Studies

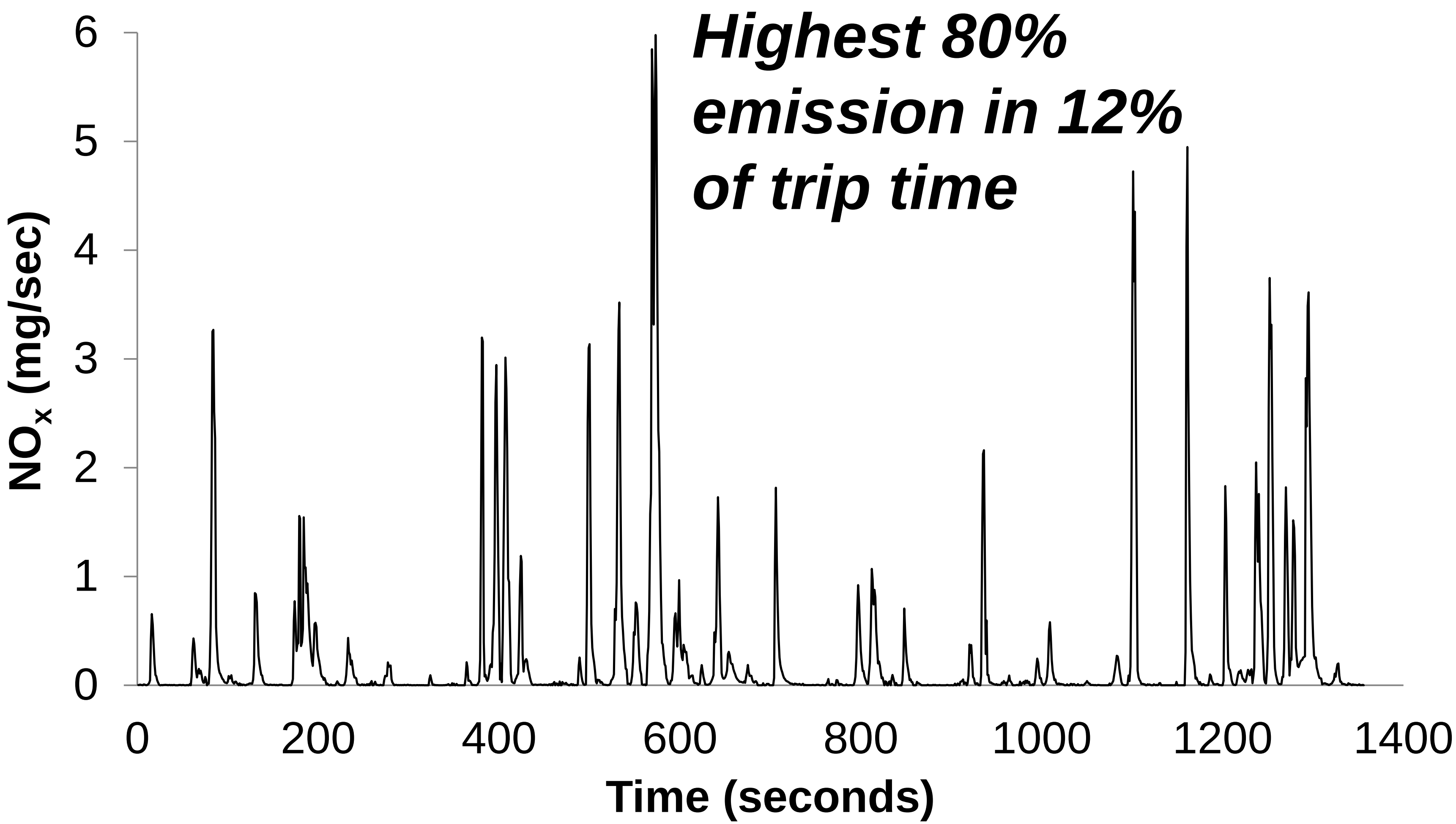
- Real-world effectiveness of
  - Emission standards
  - Emissions controls (e.g., TWC, SCR, DPF)
- Trends over time (e.g., model years, standards)
- Vehicle classes
- Vehicle technology (e.g., HEV, PHEV, FFV, GDI)
- Diesel vs. gasoline fuels
- Alternative vs. conventional fuels
- Cold starts
- Road functional class
- Level of service, congestion
- Effect of road grade
- Identification of emissions hotspots
- Roundabout vs. signalized intersections
- Signal timing and coordination
- Idle reduction
- Driver behavior and driving cycles
- Alternative routes for an Origin/Destination pair
- Siting of remote sensing locations
- Comparison of transport modes (e.g., rail vs. passenger car)

Selected Routes in Raleigh and Research Triangle Park



Frey, H.C., K. Zhang, and N.M. Rouphail, "Fuel Use and Emissions Comparisons for Alternative Routes, Time of Day, Road Grade, and Vehicles Based on In-Use Measurements," *Environmental Science and Technology*, 42(7):2483–2489 (April 2008).

Identifying and Managing Emissions Hotspots



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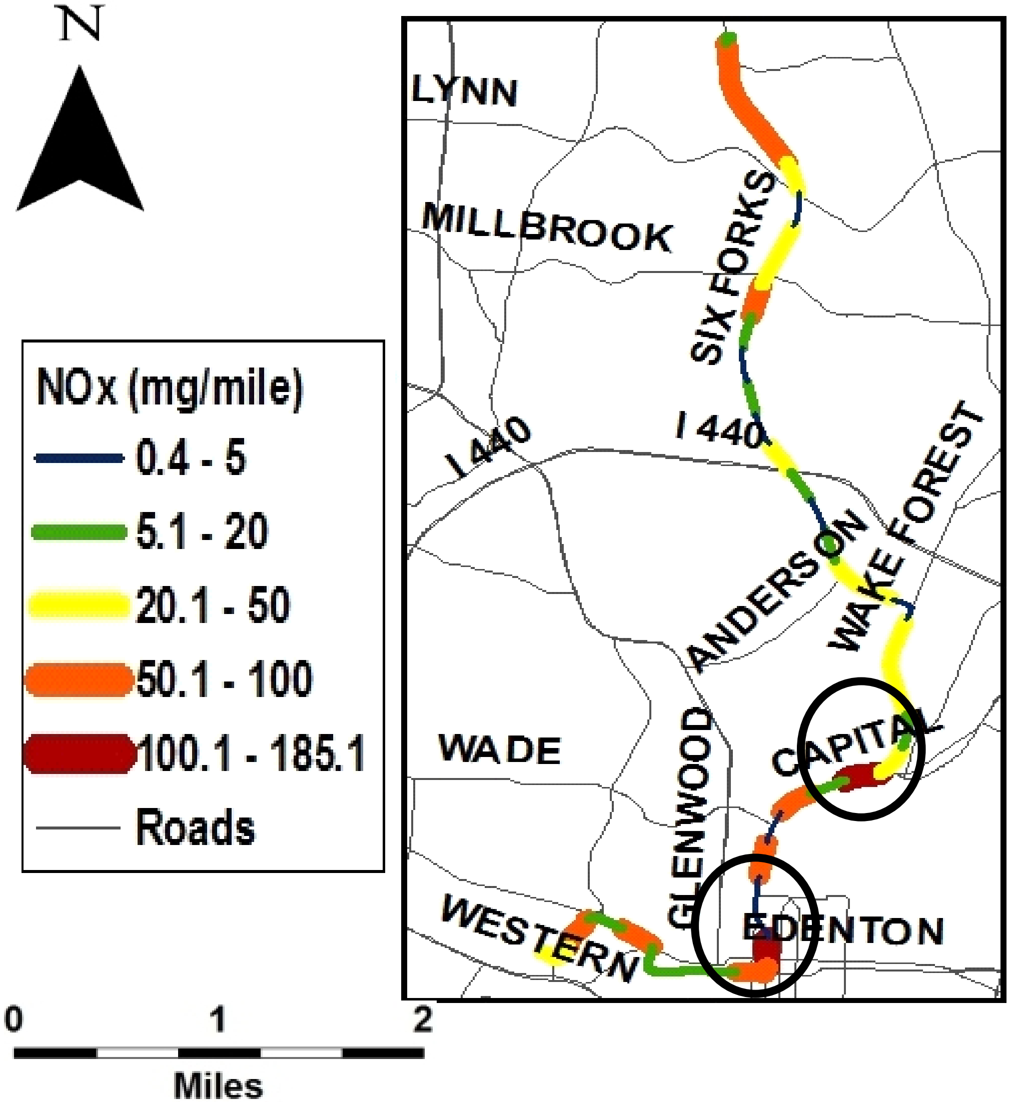
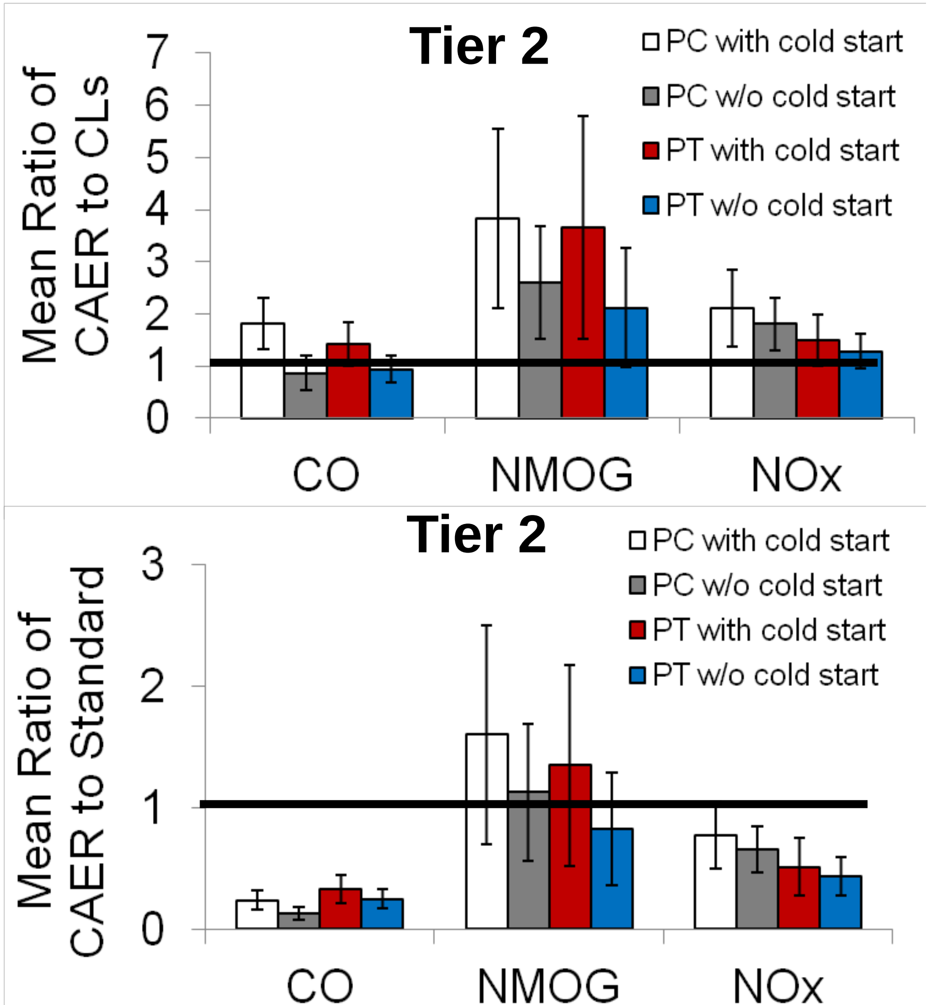
Spatial Distribution: Measured Segment Average NO_x Emission Rates (mg/mile)



Fine spatial resolution to help locate NO_x emission hotspot

Comparison of Route A Cycle Average Emission Rates to Certification Level and to Standard



Real-world rates typically higher than the certification level…

… but less than or equal to the level of the standard

Khan, T., and H.C. Frey, “Comparison of Real-world Versus Certification Emission Rates for Light Duty Gasoline Vehicles,” *Science of the Total Environment*, 2017.

Vehicles Measured on E0, E10R, E10P, and E25

2017 Chevrolet Equinox

2017 Chevrolet Cruze

2018 Toyota Camry

2016 Nissan Quest

2016 Ford Focus

Fuels

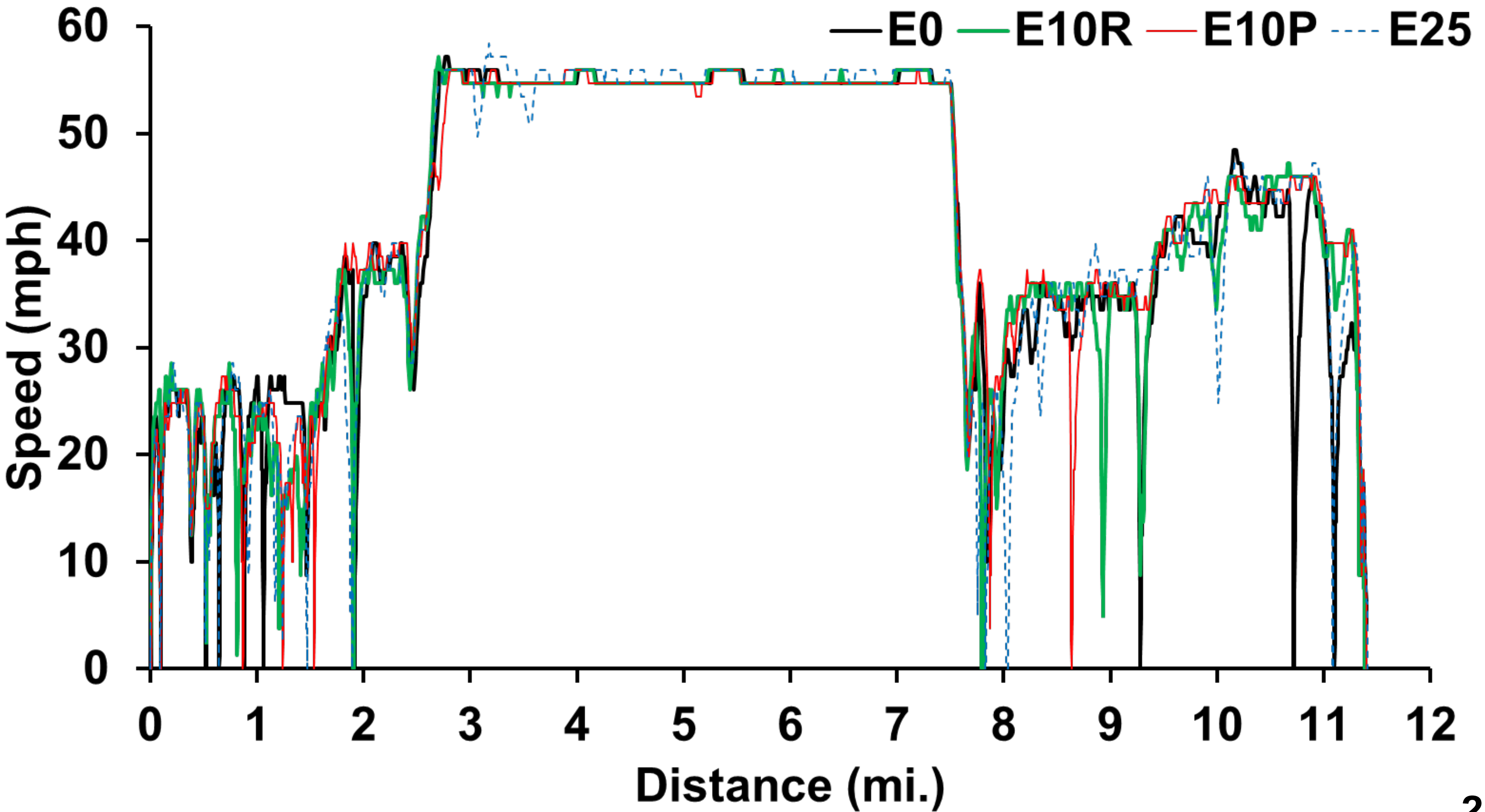
- E0 (neat gasoline)
- E10R (10% ethanol by volume “regular”)
- E10P (10% ethanol by volume “premium”)
- E25 (25% ethanol by volume)

Fuel Properties

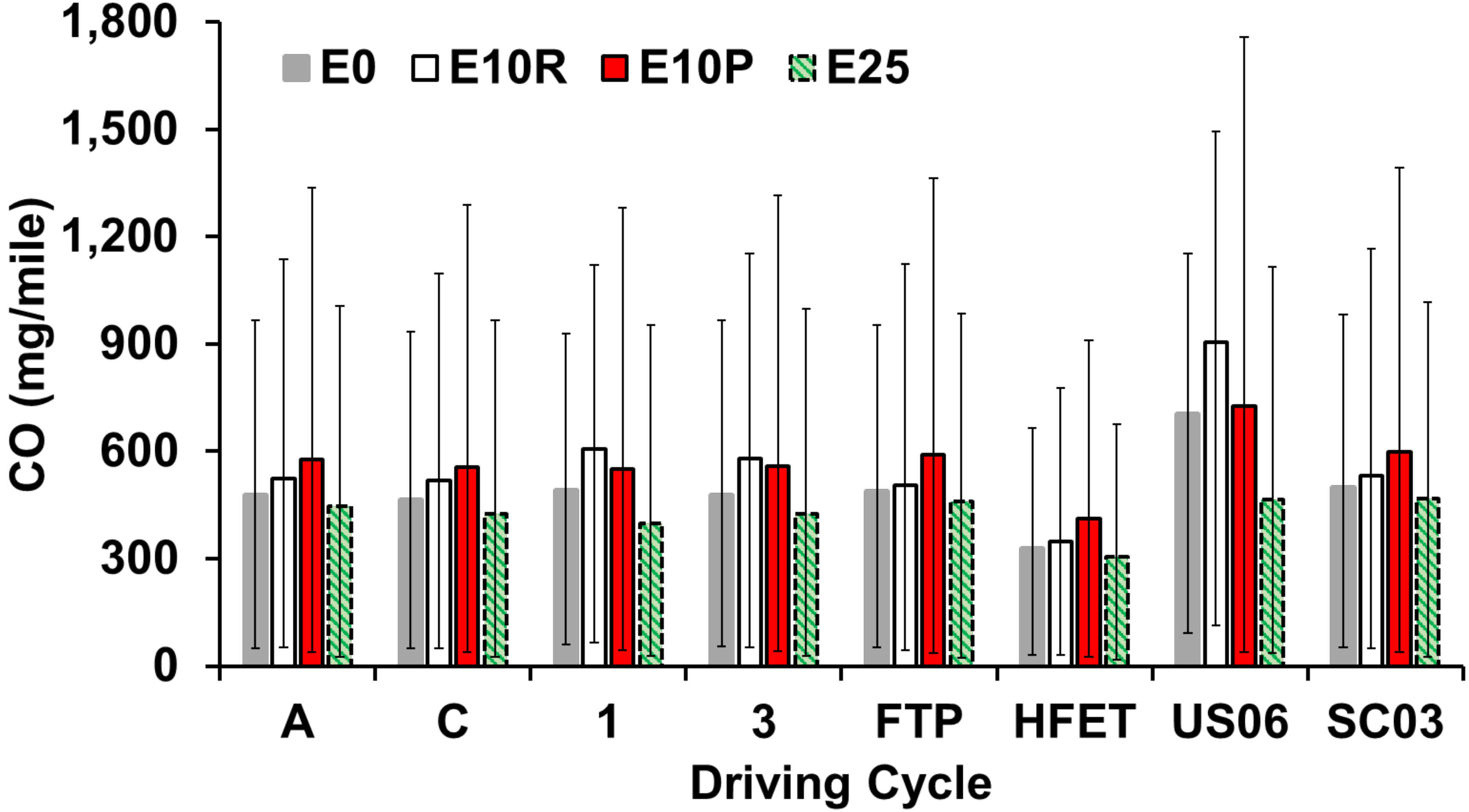
Fuel	Density (g/gal)	Energy (BTU/lb)	Composition		Distillation		Octane		
			O (wt%)	Aromatics (wt%)	T_{50} (°F)	T_{90} (°F)	RON	MON	AKI
E0	2,820	18,610	0.0	41	226	322	94	85	90
E10R	2,790	17,900	4.1	28	155	321	92	84	88
E10P	2,840	17,670	3.8	39	198	316	99	88	93
E25	2,830	16,630	10.5	22	163	307	99	86	92

Driving Cycles: Example

Example: 2016 Nissan Quest, Route C-outbound



Cycle Average Analysis – CO



Note: Error bars are 95% confidence intervals (CIs) based on mean cycle-average CO emission rates for 5 vehicles for each driving cycle, and are estimated using bootstrap resampling for negative CIs.

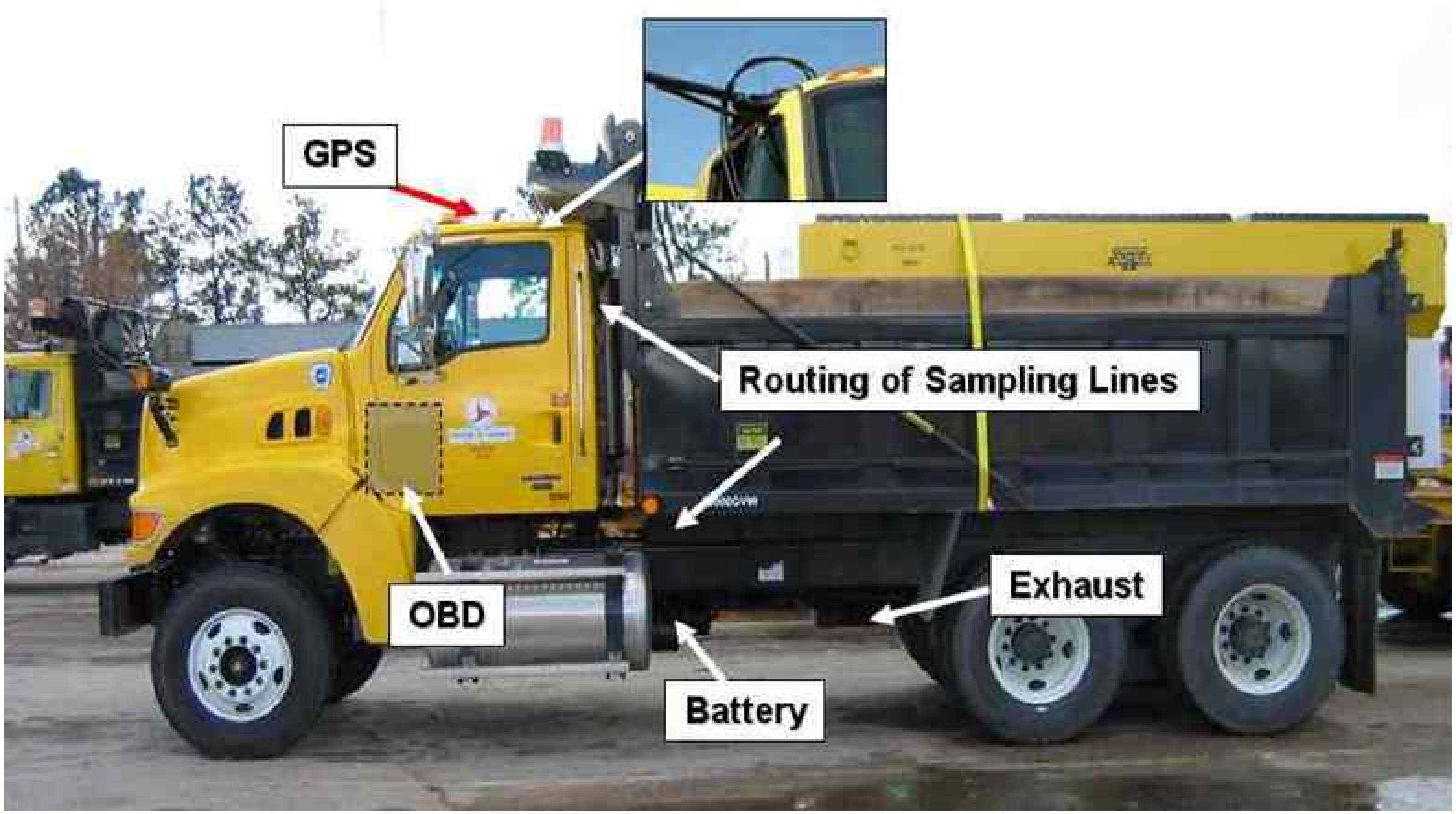
P-values for Paired-t Test – CO

Pairs	Driving Cycles							
	A	C	1	3	FTP	HFET	US06	SC03
E0 < E10R	0.50	0.41	0.20	0.23	0.85	0.71	0.18	0.69
E10P > E10R	0.54	0.67	0.69	0.84	0.37	0.28	0.59	0.47
E25 < E10R	0.10	0.04	0.09	0.05	0.54	0.28	0.12	0.31
E25 < E0	0.50	0.39	0.22	0.31	0.51	0.33	0.20	0.49
E25 < E10P	0.29	0.28	0.21	0.25	0.37	0.21	0.23	0.36
E0 < E10P	0.52	0.54	0.72	0.60	0.55	0.41	0.95	0.56

Ethanol-Gasoline Blend Findings

- E25 has lower tailpipe CO_2 emission rates than the other three fuels due to its lower carbon content
- The CO emission for E25 is significantly lower than for E10R for two cycles (C and 3), and is, on average, 30% lower than for E0 due to higher oxygenation for E25
- HC emissions tend to be lowest for E25
- NO_x emissions not significantly different among fuels
- PM emission rates are (not significantly) lower for E25 for most of the cycles
- Bottom line: E25 has lower emission rates for some pollutants, and no significant difference for others.

Comparison of Biodiesel and Ultra-Low Sulfur Diesel



Field Measurement of 8 Cement Mixers: B20 vs. Petroleum Diesel

- Four cement mixers measured in Atlanta, GA
- Four measured in Vancouver, British Columbia, Canada

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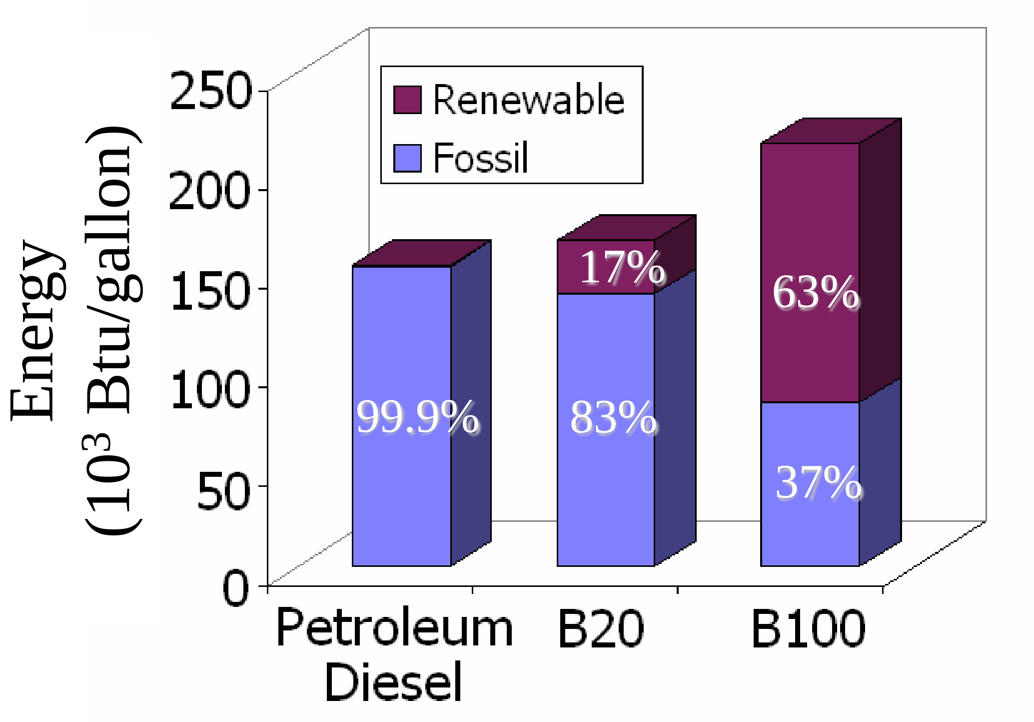
Example: Installation of the PEMS on Construction Vehicles

Biodiesel vs. Diesel: Results from Real-World Tests of 35 Vehicles

Type	Vehicle	NO [a]	Opacity	HC	CO
Onroad	Dump Truck (12)	-10	-10	-21	-11
	Cement Mixer (8)	-0.25	-20	-27	-27
	Average	-5.1	-15	-24	-19
Nonroad	Backhoe (5)	-4.1	-17	-27	-17
	Front-End Loader (4)	-1.0	-19	-35	-42
	Motor Grader (6)	-0.16	-18	-17	-17
	Average	-1.8	-18	-26	-25
Overall (35)		-3.5	-16	-25	-22

[a] NO emissions were corrected based on ambient temperature and humidity

Life Cycle Energy Use



The total energy includes the heating value of fuel itself and process energy.

0.07% of diesel transport fuel is biodiesel.

Reduction in LCI Fossil Energy:

B20: 9.1%

B100: 45.3%

Comparison of CNG versus Diesel Refuse Trucks

Front-Loader: Diesel (6)

Roll-Off: Diesel (6)

Side-Loader: Diesel (6)

Side-Loader: CNG (3)

Front-Loader: CNG (3)

Comparison of CNG to Diesel Refuse Trucks

- Front-Loader:
  - Fuel use rate is 22% lower on diesel equivalent basis
  - NO_x and PM emission rates are lower by over 96 percent
  - Non-methane HC emissions are 28% higher
  - CO emissions are 140% higher
- Side-Loader
  - Fuel use rate is approximately the same
  - NO_x and PM emission rates are over 93 percent lower
  - Non-methane HC emissions are over 300% higher
  - CO emissions are nearly 200% higher

Ongoing work: Characterization of GP40 and F59 Passenger Diesel-Electric Locomotives: Biofuels, Duty Cycles, Emission Controls

Conclusions

- Real-world duty cycles often differ from standard cycles used in laboratory tests or emissions models
- Actual engine load depends on speed, acceleration, and road grade
- Cycle average emission rates depend on highly episodic microscale emissions
- Real-world measurements can lead to more representative assessment of the actual performance of alternative fuels or vehicle technologies

Questions?


GPS
Routing of Sampling Lines
OBD
Exhaust
Battery
Bobcat
PLUG-IN
HYBRID ELECTRIC VEHICL
Advanced ENERGY
advancedenergy.org
SCHOOL BUS
1797
N
C