# Biodiesel and Renewable Diesel Research Study

## October 14, 2008

**California Environmental Protection Agency**

**Air Resources Board**

# Agenda

I. Introductions
II. Updates
    a. Fuels
    b. Engine/vehicle tests
III. NOx Impact Study and NOx Mitigation Study (Dr. Tom Durbin)
    a. Preliminary test
    b. Engine dynamometer cycle development
    c. Main test
    d. Additives
    e. Alternative fuel blends
    f. Matched blending
IV. Transportation Refrigeration Unit (TRU) biodiesel test program
V. Open Discussion

# Introductions

# Background

- Executive Order S-1-07 Low Carbon Fuel Standard (LCFS)
  - Reduce at least 10 percent of the carbon intensity of California's transportation fuels by 2020.
  - Early action item with a regulation to be adopted and implemented by 2010.
- Executive Order S-06-06, establishing targets for the use and production of biofuels and biopower
  - Includes biodiesel and ethanol.
  - California shall produce a minimum of 20 percent of its biofuels within California by 2010, 40 percent by 2020, and 75 percent by 2050.

## Background

- Low Carbon Fuels Standard
  - Biofuels specifications by 2009

# Biodiesel and Renewable Diesel Study

- Biodiesel and renewable diesel emissions evaluation
- Oxides of Nitrogen (NOx) formation and mitigation evaluation
- Transportation Refrigeration Units (TRUs)
- Light duty vehicles
- Durability study
- Multi-Media evaluation

# Updates

# Fuels Update-Biodiesel Blend Fuel Specifications

- Oxidative stability EN 14112
  - All blends: 12 hours
- Blend level results (EN14078 IR results)
  - Soy (5%) 5.3, (20%) 20.8, (50%) 52.5
  - Animal (5%) 5.4, (20%) 21.2, (50%) 52.8

# Fuels Update-Renewable Diesel Blends

- CECERT completed the blending in August
- Fuel analysis-in progress

# Test Vehicle Update

- Vehicle one
  - Heavy-duty diesel truck equipped with a 2005 Caterpillar C13 engine
- Vehicle two secured for testing
  - Heavy-duty diesel truck equipped with a 2007 Detroit Diesel MBE 4000 engine
  - Engine/vehicle break in:  minimum 3000 additional miles needed
- Vehicle three
  - Transit bus equipped with a Detroit Diesel 1997 DDCs50 engine and with a Cleaire Longview

# Biodiesel Characterization Vehicle One Chassis Test

- Pretest “dress rehearsal” completed
- Potential issue with vehicle
  - Excessive smoke and liquid oil out of blow by tube
- Plan to address issue
  - Identified vehicle was overfilled with lube oil by six quarts due to miscalibration of dipstick-dipstick recalibrated
  - Taken to dealer for service and diagnostic
    - Identified valve issue which was repaired
    - No other problems were identified
  - Undergoing oil consumption tests to confirm oil consumption is within Caterpillar’s specifications
    - 60 gals of fuel per quart of lube oil
    - Test completed next week
  - Consultation with Caterpillar
- Alternative vehicle a truck equipped with a 2001 C15 Caterpillar engine

# Discussion

# NOx Impact Tests

- Check list
  - Vehicle duty cycle translations
    - Coast down completed
    - Vehicle duty cycle translations
  - Remove engine from 2006 Cummins ISM
  - Tested converted duty cycles on engine dynamometer
  - Preliminary test
  - QA/QC completed
  - Began main engine tests in October

# NOx Impact and NOx Mitigation Study

Dr. Tom Durbin

Principle Investigator

CECERT

# Preliminary Test Runs

- 6 test runs in a single day on CARB ULSD and B20 Animal
- Results show
  - Emission differential B20 to ULSD of ~2% (1.8%) for $NO_x$
  - Coefficients of Variation (COVs) of ~1 %
  - Emissions values comparable to certification values

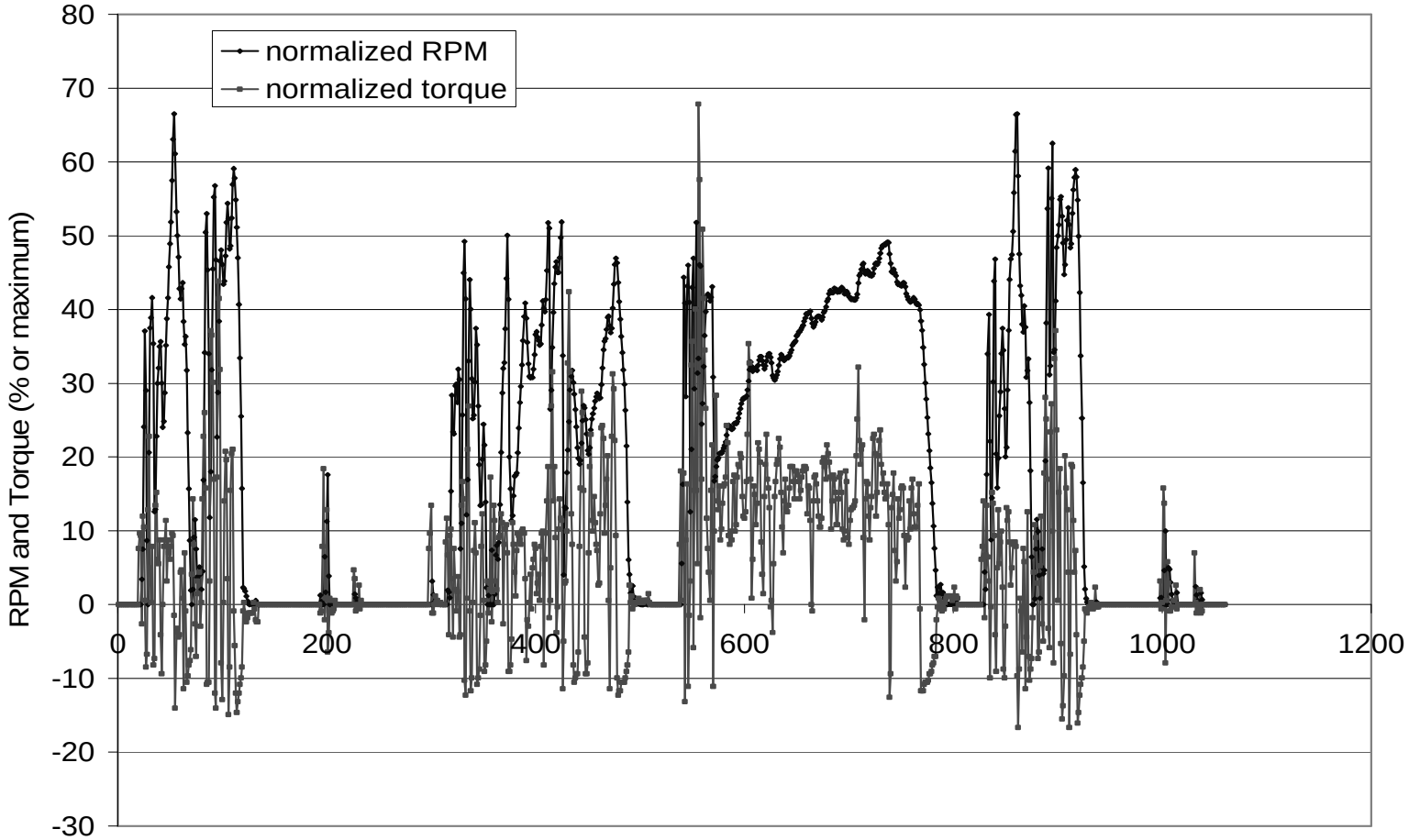
# Draft Preliminary Test Results

| | | | | |
|---|---|---|---|---|
| 0.289 | 0.757 | 2.108 | 0.078 | 632.492 |
| 1.1% | 3.4% | 1.0% | 2.8% | 0.7% |
| 0.250 | 0.692 | 2.146 | 0.061 | 637.065 |
| 1.8% | 1.9% | 0.8% | 0.7% | 0.6% |
| -13.8% | -8.6% | 1.8% | -21.2% | 0.7% |
| 0.000 | 0.000 | 0.006 | 0.000 | 0.089 |

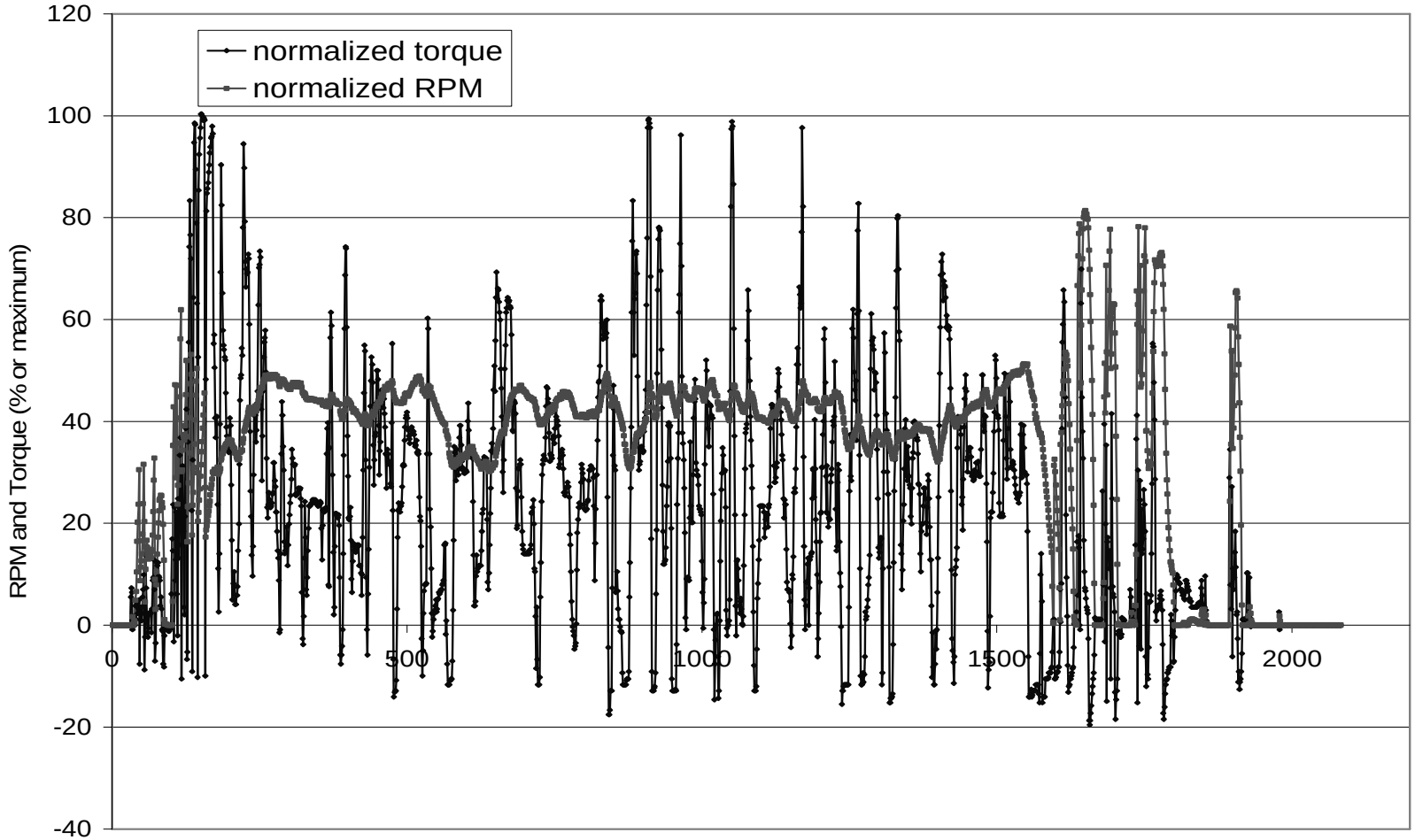
# Engine Dynamometer Cycle Development

- Engine parameters (J1939) obtained from chassis dynamometer runs over the UDDS and Cruise cycles
  - UDDS was loaded at weight of truck cab only
  - Cruise was loaded at the full vehicle GVWR
- A single test run was selected to represent the set of engine parameter data collected
  - Based on $NO_x$ emissions, deviation from the drive cycle, and examination of outliers
- Torque and RPM values normalized
- Cycles were optimized for the engine dyno
- New regression statistics criteria

# UDDS Engine Dynamometer Cycle



# Cruise Engine Dynamometer Cycle



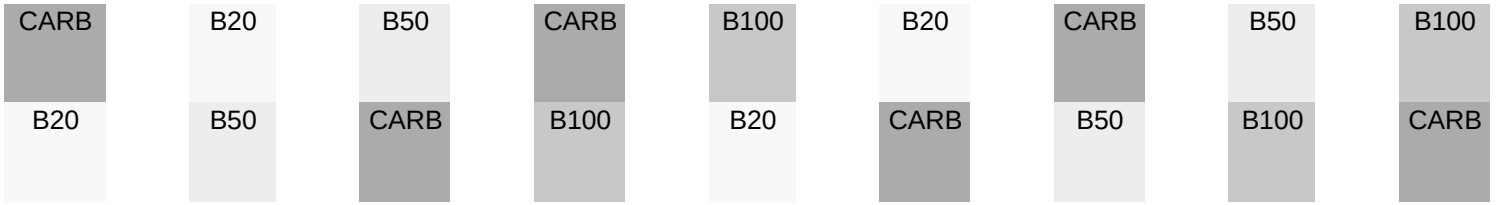
# Initial Main Test Runs

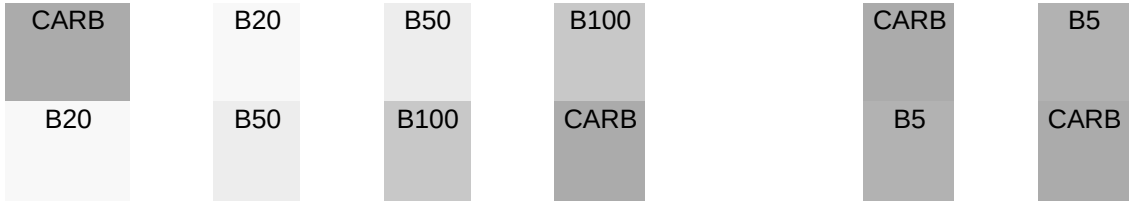
– First round of testing on the soy-based feedstock

– Initial results show trends consistent with expectations

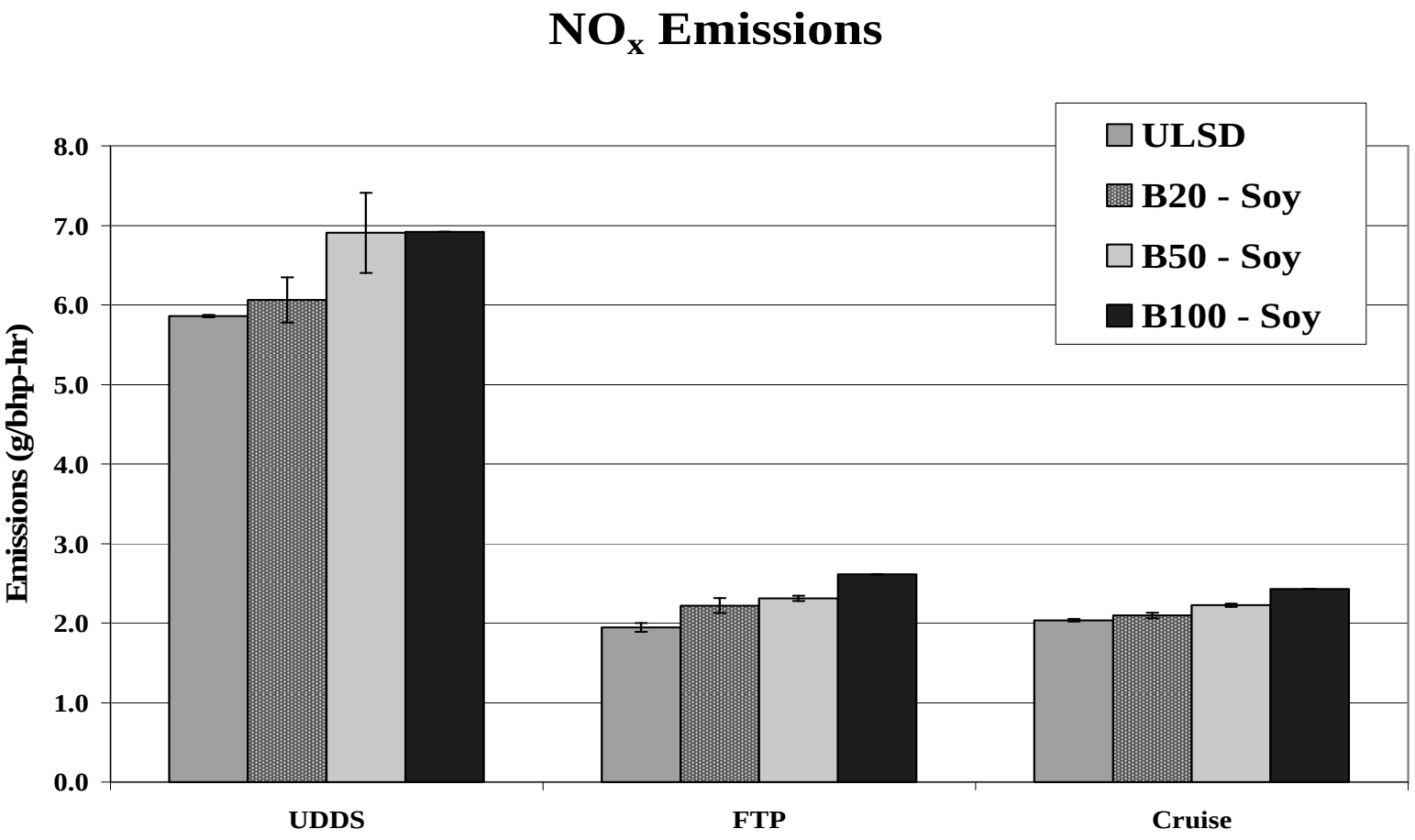
- Increasing $NO_x$ for the biodiesel blends
- Decreasing PM for the biodiesel blends
- Decreasing THC for the biodiesel blends

# Soy Feedstock Test Matrix



# Preliminary Draft Main Test Results



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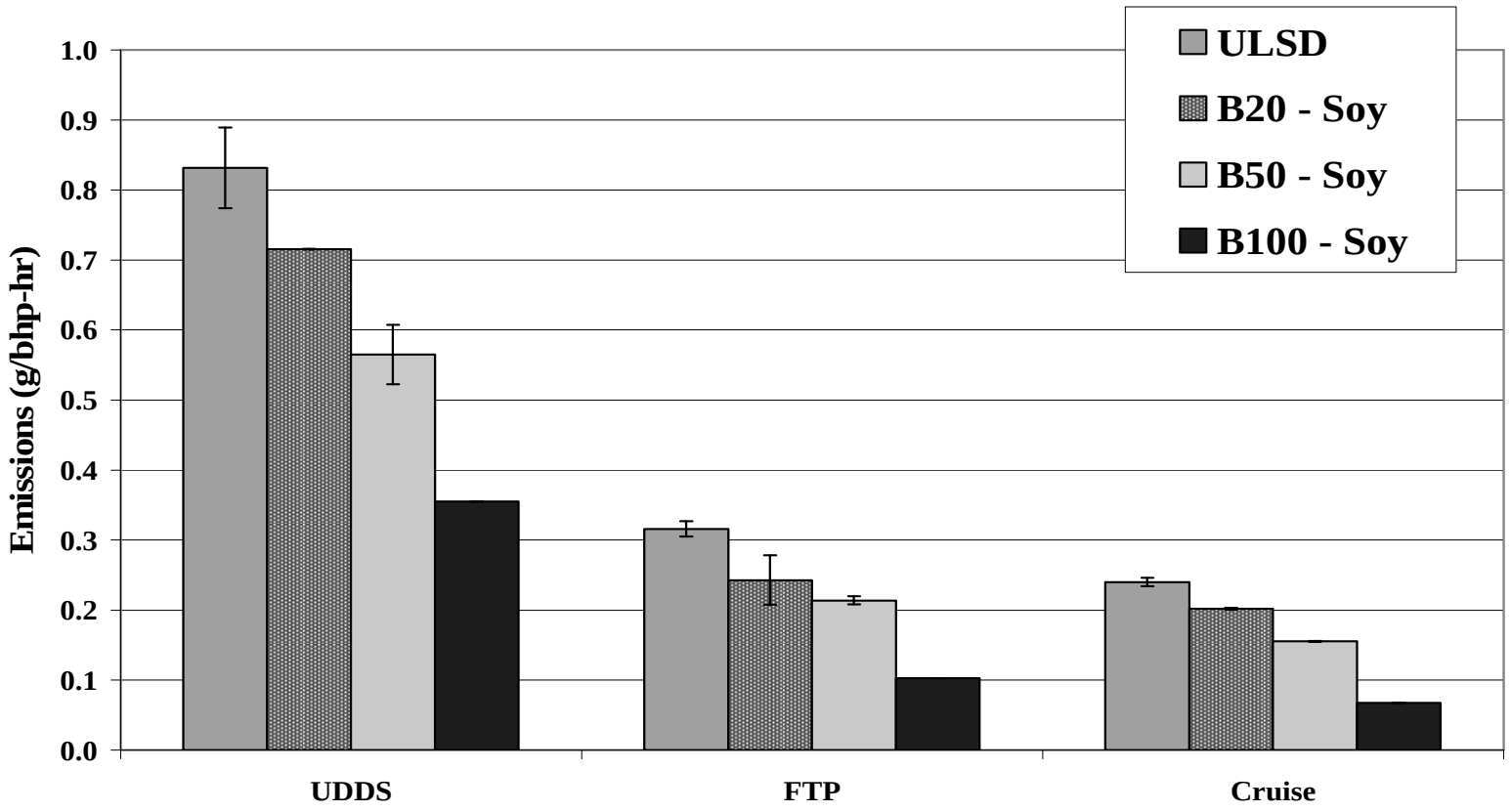

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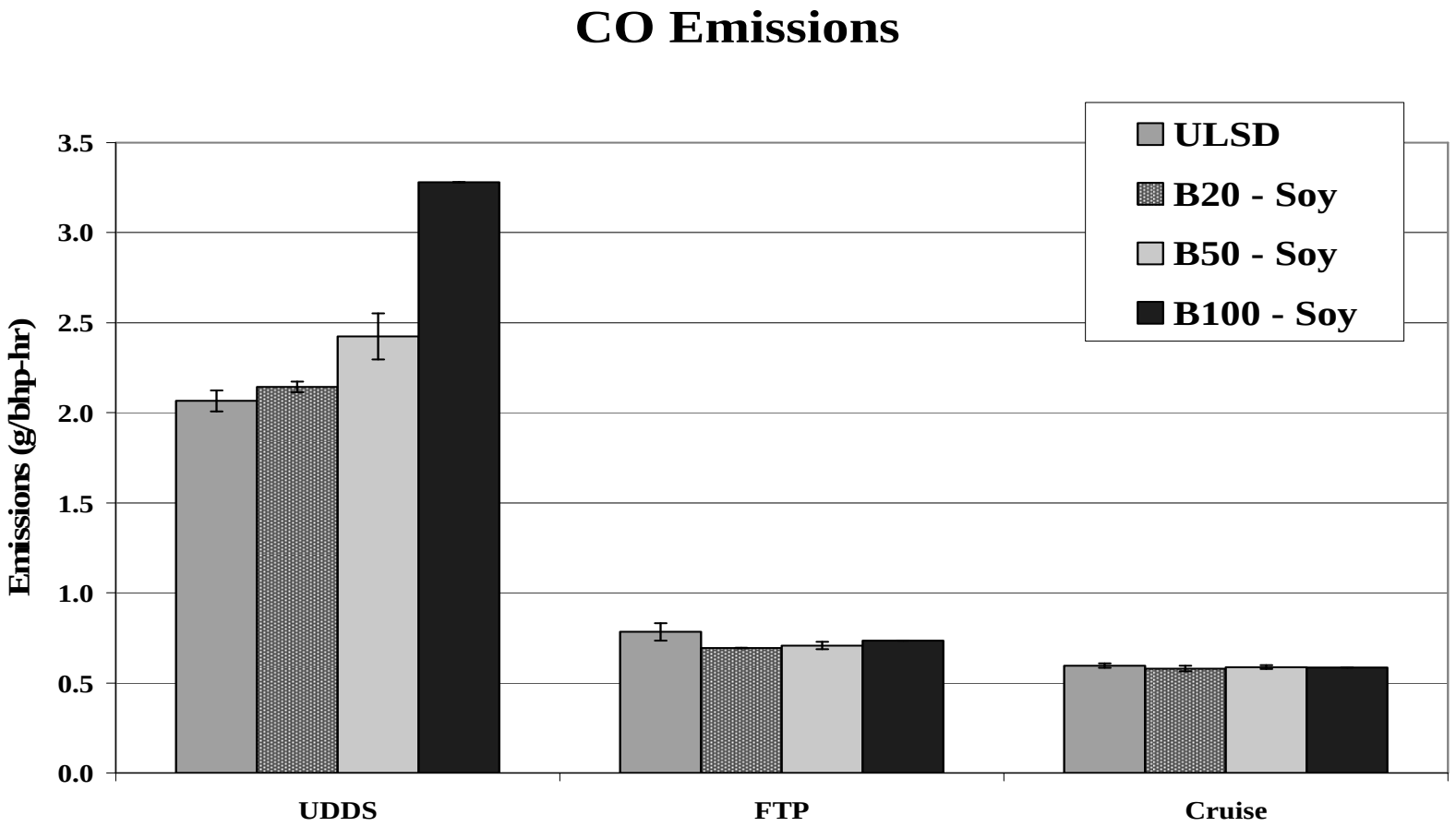
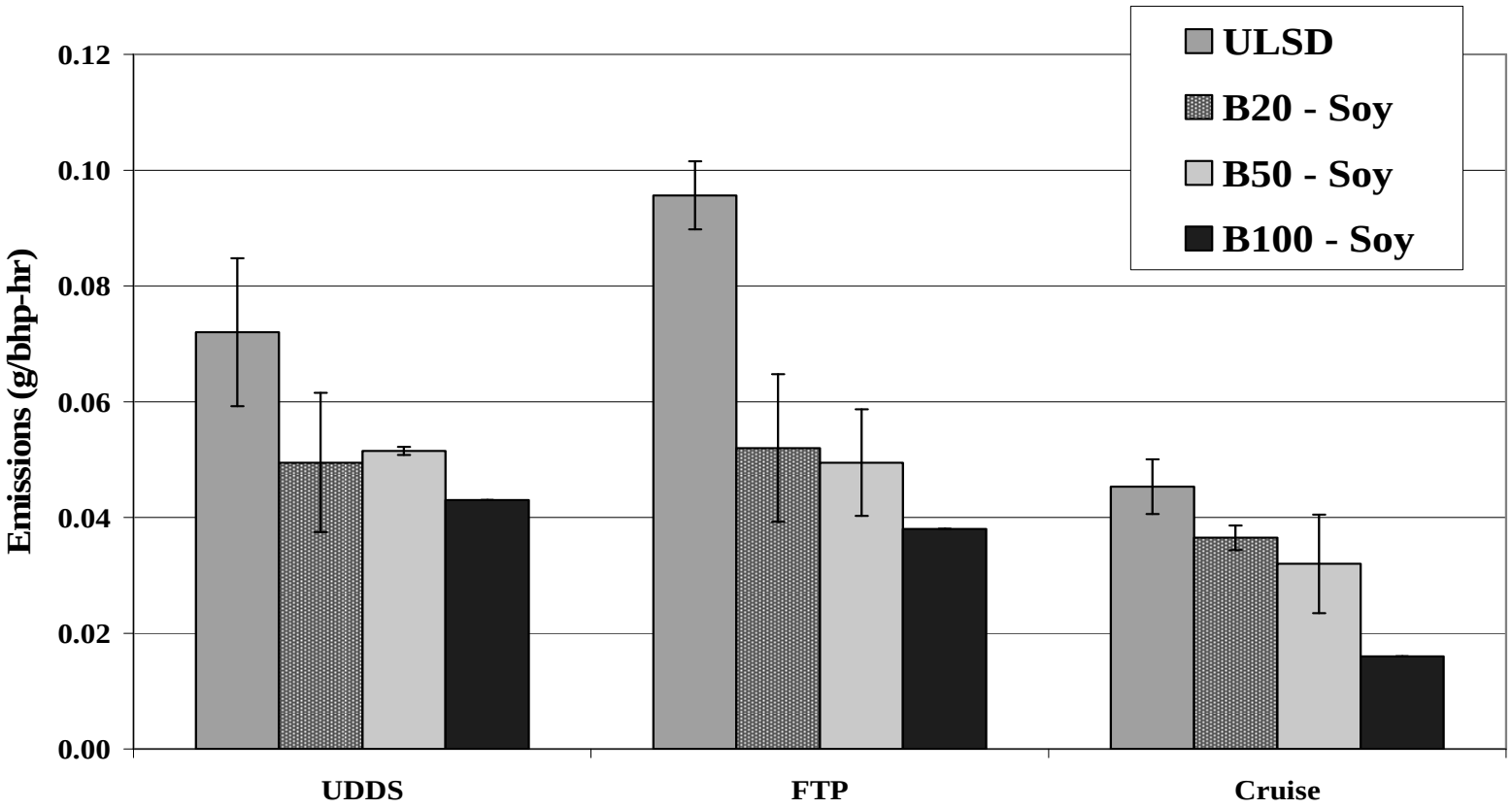


Biodiesel/Renewable Diesel Study

# Very Preliminary Draft Main Test Results



# Discussion

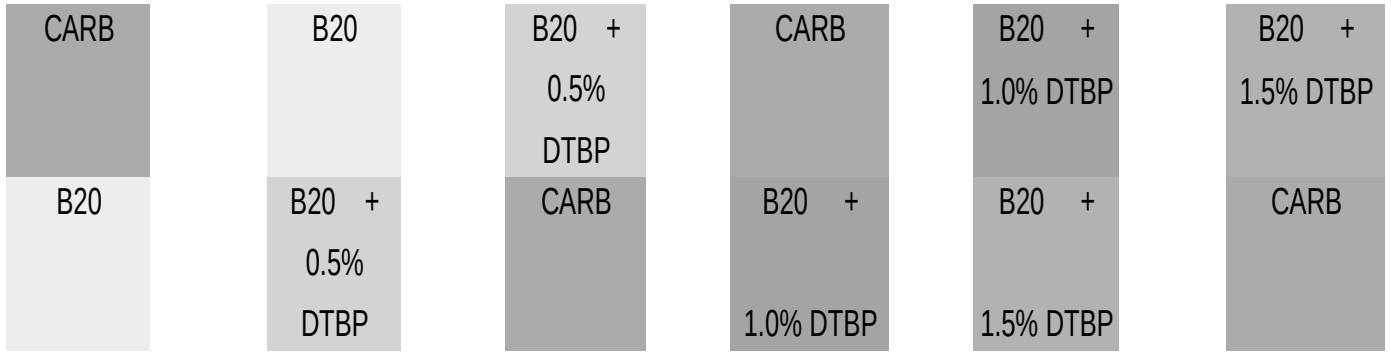
# Strategies for $NO_x$ Mitigation

- Additives
- Renewable/biodiesel blends
- GTL
- Match blending – subsequent testing (phase 2)

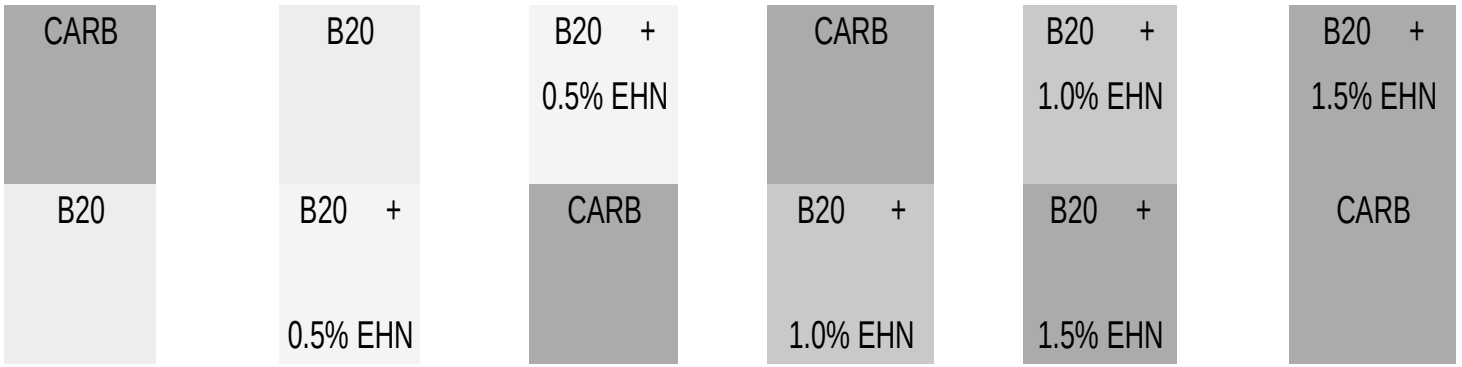
# Additive Testing

- 2- ethyl-hexyl-nitrate (EHN)
- Di-tert-butyl-peroxide (DTBP)
- Both additives have been studied by NREL and SwRI
- Initially explore effectiveness of different blends levels (0.5%, 1.0%, and 1.5%)
- Use B20 with highest $NO_x$ disbenefit
- Additional testing as needed to look at cycle effects and higher blend levels

# Initial Testing on DTBP



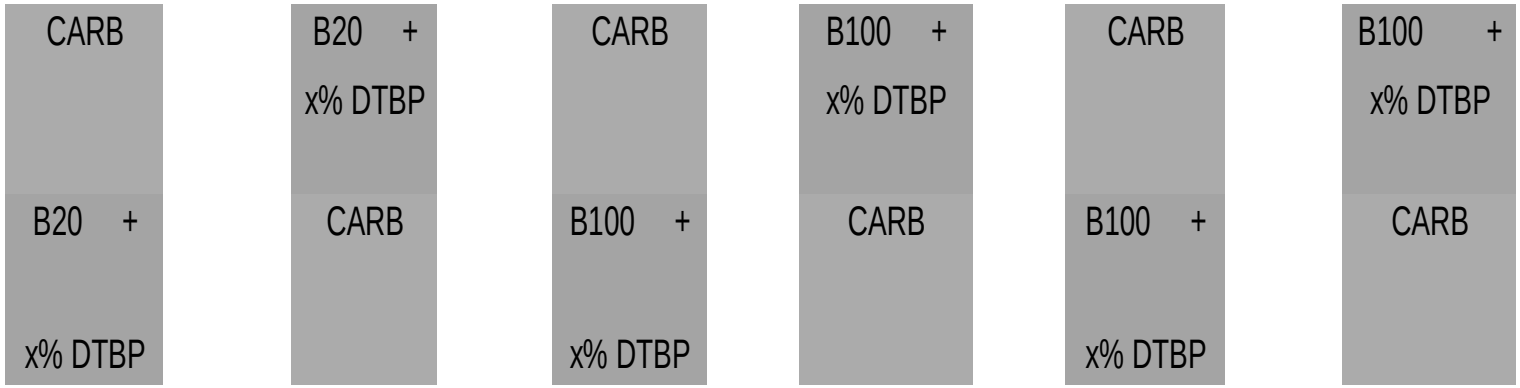
# Initial Testing EHN



# Further Additive Testing

- Look at the effects of additives
  - Utilize blend level that was successful in producing $NO_x$ neutrality for a B20 on the FTP
  - Higher loads (ARB Cruise)
  - Higher levels of biodiesel (B100)

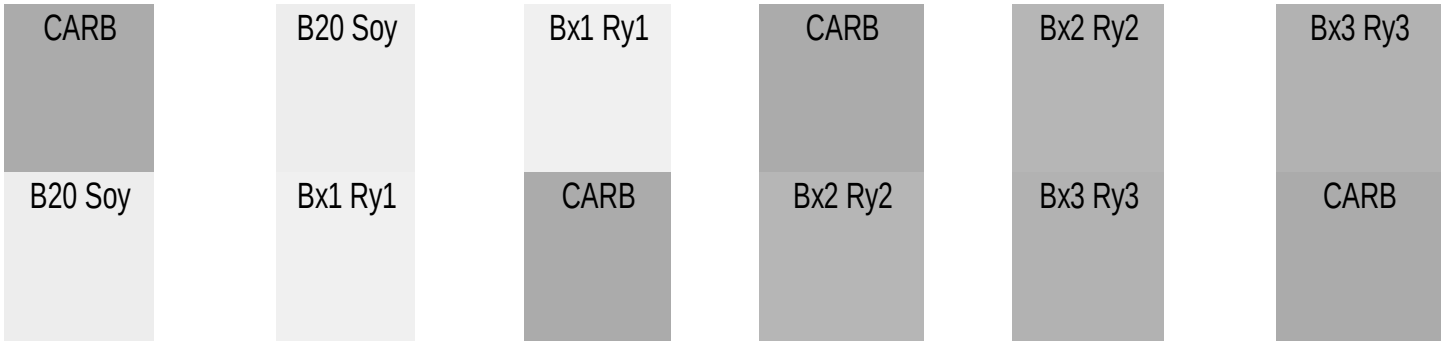
# Further Additive Testing



# Renewable/Biodiesel Blends

- Utilize different percentage of biodiesel and renewable diesel
- Results based on the renewable diesel tested in the biodiesel characterization portion of the study

# Renewable/Biodiesel Testing



# GTL Testing

- An appropriate GTL fuel has been identified for testing
- Test matrix will be developed based on existing test data

# Discussion

# Transportation Refrigeration Unit (TRU) Biodiesel Test Program

# Program Objectives

- Support particulate matter (PM) emission reduction from diesel engines
- Support carbon dioxide ($CO_2$) emission reduction through low carbon fuel standard (LCFS)
- Quantify PM reductions and oxides of nitrogen ($NO_X$) emission increases due to use of biodiesel and biodiesel blends in small diesel engines used in TRUs and off-road applications

# Testing Apparatus

- Dyne Systems Dynamometer
- Horiba Constant Volume Sampling System
- AVL Full Flow Particulate Sampling System
- AVL Exhaust Gas Analyzer System
- AVL Heated Flame Ionization Detector

- Test Cell Ready Mid-November 2008

# ISO 8178, Part 4, section 6.3.1, “Test cycle type C1, ‘Off-road vehicles, industrial and medium/high load.’”

| SPEED | TORQUE | 8-Mode Wt. | 4-Mode Wt. |
|---|---|---|---|
| Rated | 100 % | 0.15 | 0 |
| Rated | 75 % | 0.15 | 0.25 |
| Rated | 50 % | 0.15 | 0.25 |
| Rated | 10 % | 0.10 | 0 |
| Intermediate | 100 % | 0.10 | 0 |
| Intermediate | 75 % | 0.10 | 0.25 |
| Intermediate | 50 % | 0.10 | 0.25 |
| Low-no-load | 0 % | 0.15 | 0 |

# Three Test Engines

- Engine No. 1
  - 1998 Kubota, 37.5 hp, Unregulated (“Tier 0”)
- Engine No. 2
  - 1998 Isuzu, 34.8 hp, Unregulated (“Tier 0”)
- Engine No. 3
  - 1995 Yanmar, 12.5 hp, SORE-II Certified

# Six Test Fuels

- California Diesel Fuel
- Soy-Derived Biodiesel ($B100_S$)
- Animal-Derived Biodiesel ($B100_A$)
- Soy-Derived Biodiesel/California Diesel Fuel Blends
  - 50 percent biodiesel ($B50_S$)
  - 20 percent biodiesel ($B20_S$)
  - 5 percent biodiesel ($B5_S$)

# Test Matrix

| Series | Cycle | Engine | Fuels | | |
|---|---|---|---|---|---|
| 1 | 8-mode | No. 1 | CA | $B100_S$ | |
| 2 | 8-mode | No. 1 | CA | $B100_A$ | |
| 3 | 8-mode | No. 1 | CA | $B20_S$ | $B50_S$ |
| 4 | 8-mode | No. 1 | CA | $B5_S$ | |
| 5 | 4-mode | No. 2 | CA | $B100_S$ | |
| 6 | 4-mode | No. 2 | CA | $B100_A$ | |
| 7 | 4-mode | No. 3 | CA | $B100_S$ | |
| 8 | 4-mode | No. 3 | CA | $B100_A$ | |

# Daily Test Sequence

- Morning
  - Run **one** 8-mode or **two** 4-mode tests on same engine with morning fuel (same fuel as afternoon fuel from the day before)
- Mid-day
  - Switch fuel filter and fuel
  - Run engine to purge morning fuel
- Afternoon
  - Run **one** 8-mode or **two** 4-mode tests on same engine with afternoon fuel (same fuel as morning fuel for next day)

# Procedures

- Change Oil and Oil Filter Before Each New Test Series, Except for Test Series 4 (Series 3 and 4 Test Soy-Derived Blends)
- Use Dedicated Fuel Filters for Each Fuel
  - Engine No. 1
    - CA, $B100_S$, $B100_A$, $B50_S$, $B20_S$, $B5_S$
  - Engine No. 2
    - CA, $B100_S$, $B100_A$
  - Engine No. 3
    - CA, $B100_S$, $B100_A$

# Procedures (Continued)

- Measure Emissions and Work for Each Mode
  - $NO_X$ and nitrous oxide ($N_2O$)
  - PM
  - Hydrocarbons (HC)
  - Carbon Monoxide (CO) and ($CO_2$)
- Run at Least Eight Test Cycles on Each Fuel in Each Test Series, Trying to Determine Differences of Average Weighted $NO_X$ Emissions to 0.5 % with 90 % Confidence

# Discussion

# Open Discussion

# Biodiesel/Renewable Diesel Workgroup Meeting

- Tentatively planned for December 2nd at the CAL/EPA building
- Notice and agenda
- Include Tier one report and Tier two test protocol
- Guest speakers and panel discussion