Biodiesel and Renewable Diesel Research Study

October 14, 2008

California Environmental Protection Agency

Air Resources Board

Agenda

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III. NOx Impact Study and NOx Mitigation Study (Dr. Tom Durbin)
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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

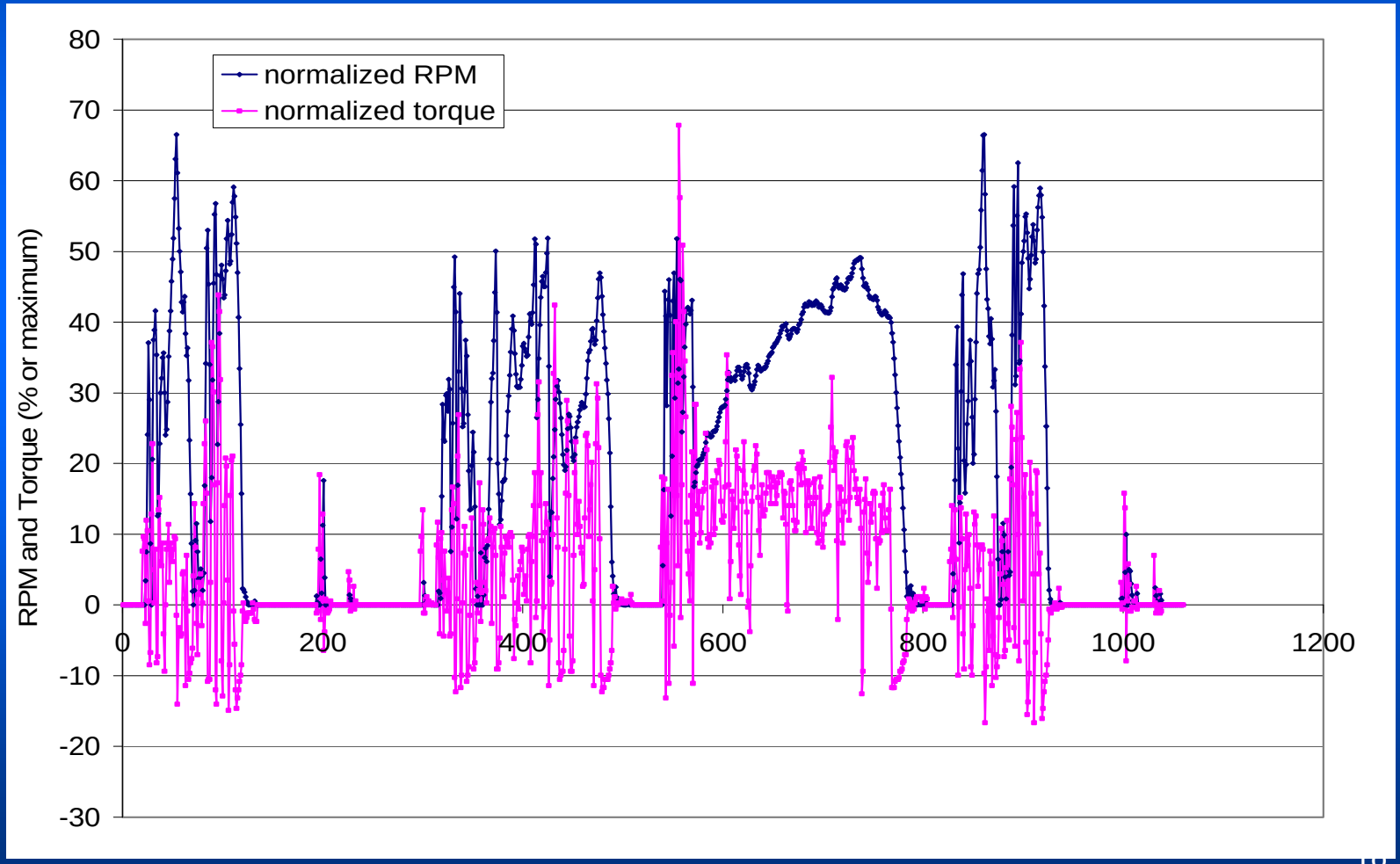
Draft Preliminary Test Results

	THC g/bhp-hr	CO g/bhp-hr	NO_x g/bhp-hr	PM g/bhp-hr	CO_2 g/bhp-hr
CARB ULSD					
ave.	0.289	0.757	2.108	0.078	632.492
st dev.	0.003	0.026	0.022	0.002	4.343
COV	1.1%	3.4%	1.0%	2.8%	0.7%
B20-Animal					
ave.	0.250	0.692	2.146	0.061	637.065
st dev.	0.004	0.013	0.016	0.000	4.056
COV	1.8%	1.9%	0.8%	0.7%	0.6%
% difference (B20 - CARB)	-13.8%	-8.6%	1.8%	-21.2%	0.7%
T-Test	0.000	0.000	0.006	0.000	0.089

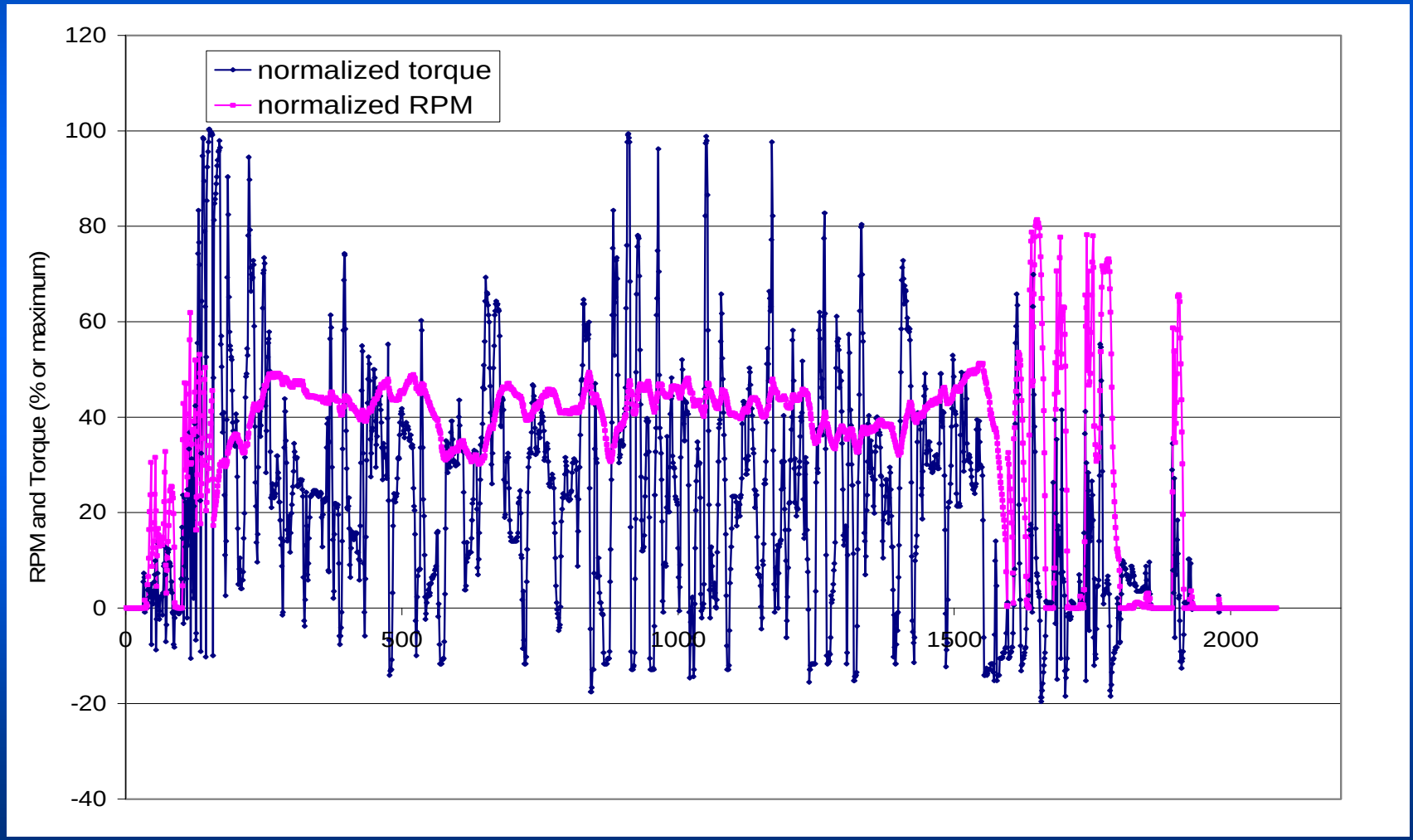
Engine Dynamometer Cycle Development

- 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

Main program

Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7		Day 8		Day 9	
Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle
CARB	A	B20	B	B50	A	CARB	C	B100	B	B20	C	CARB	B	B50	A	B100	A
	C		A		B		A		C		B		A		B		C
	B		C		C		B		A		A		C		C		B
B20	C	B50	B	CARB	C	B100	A	B20	B	CARB	A	B50	B	B100	C	CARB	B
	B		C		A		B		A		C		A		A		C
	A		A		B		C		C		B		C		B		A

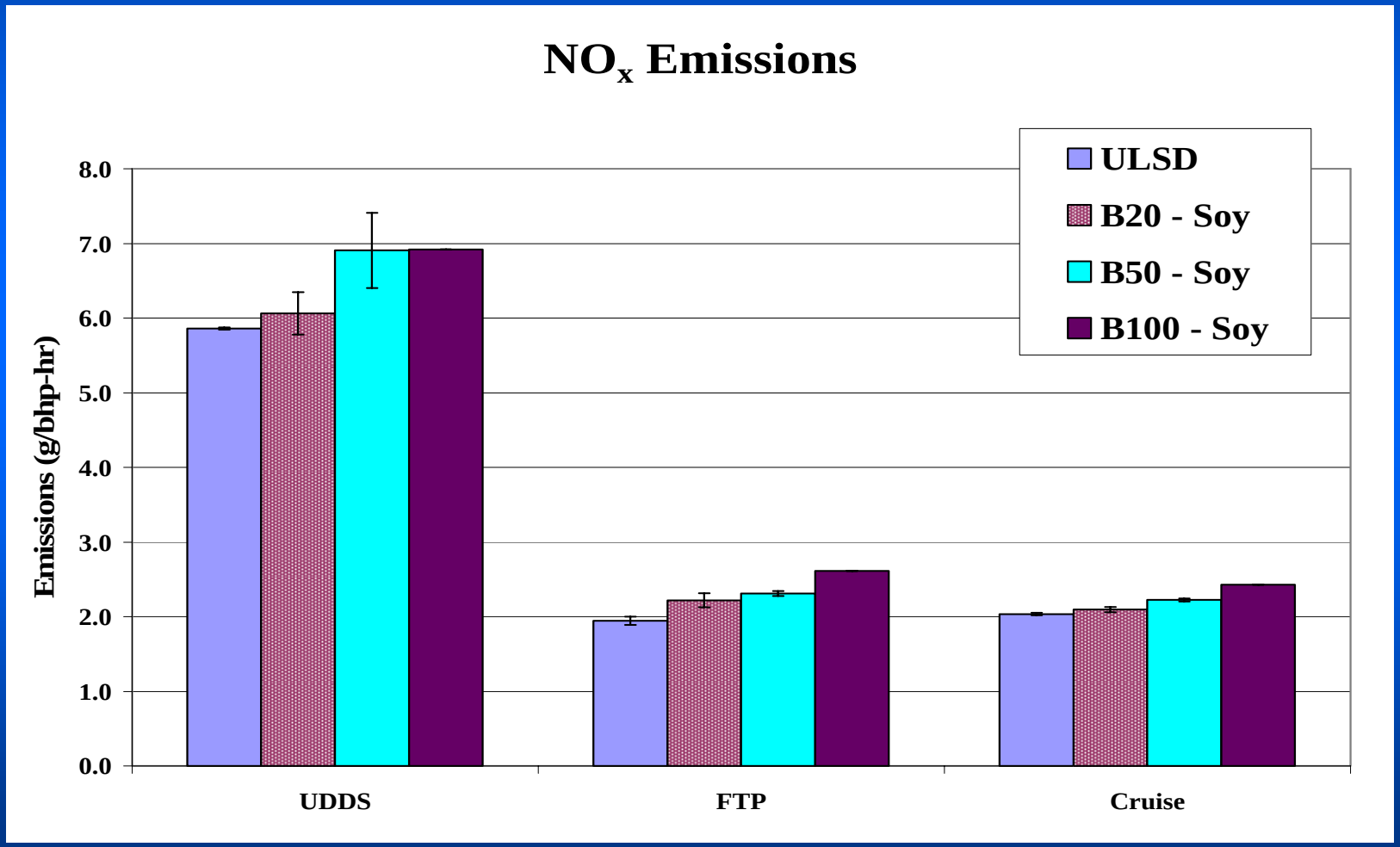
Supplemental

Day 1		Day 2		Day 3		Day 4	
Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle
CARB	A	B20	B	B50	A	B100	C
	C		A		B		A
	B		C		C		B
B20	A	B50	C	B100	B	CARB	C
	B		B		C		A
	C		A		A		B

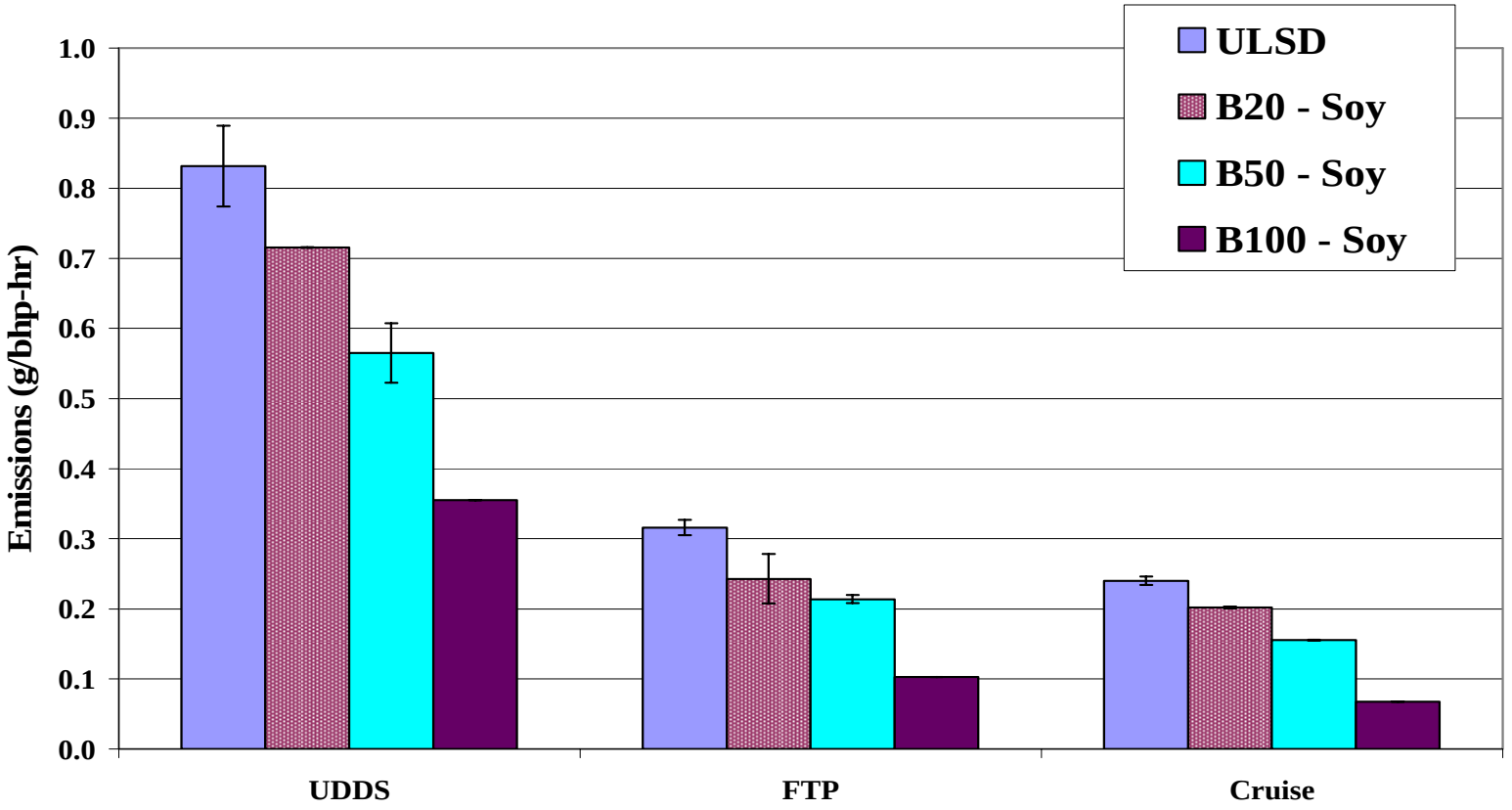
B5

Day 1		Day 2	
Fuel	Cycle	Fuel	Cycle
CARB	C	B5	C
	C		C
	C		C
B5	C	CARB	C
	C		C
	C		C

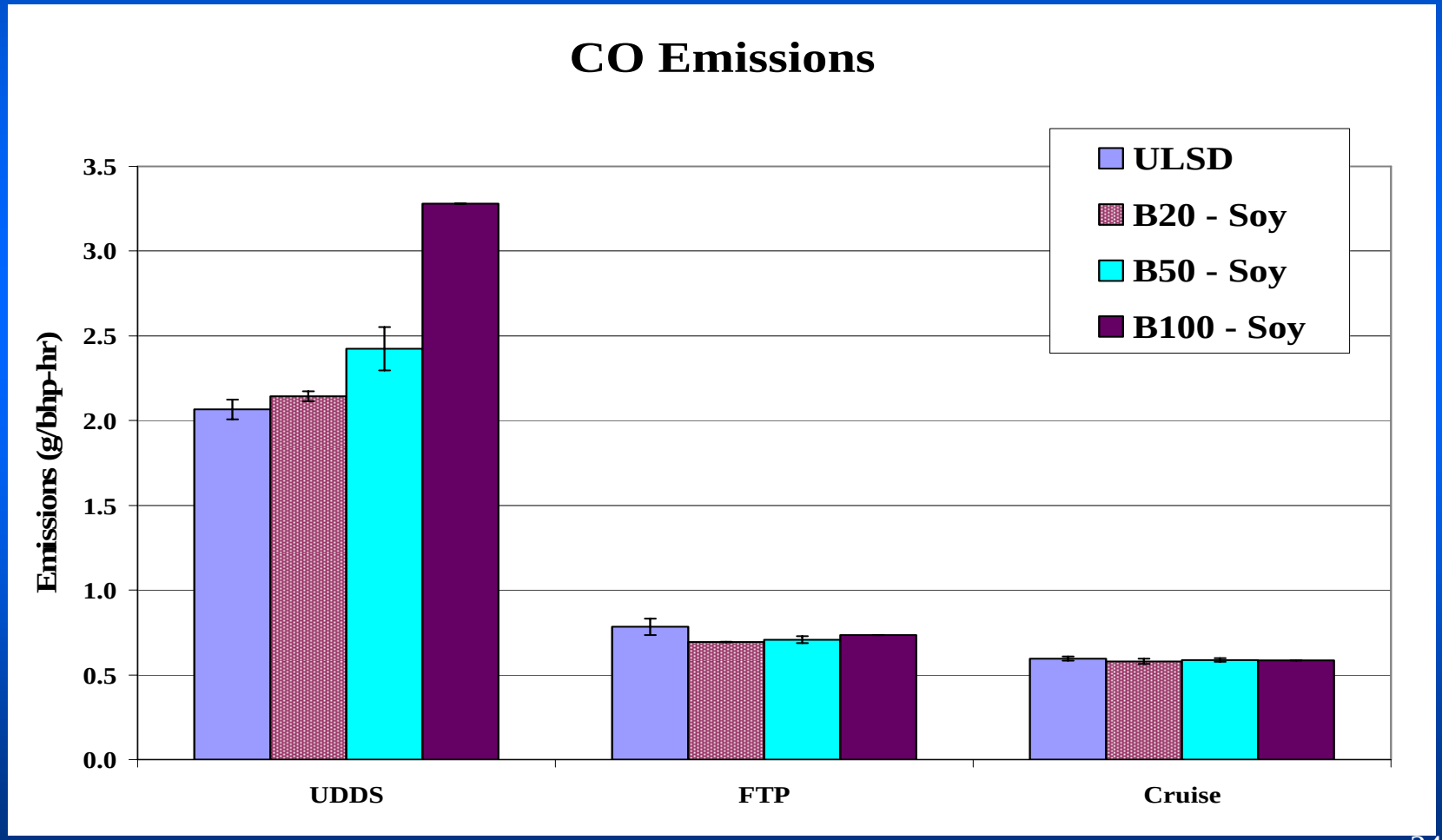
Preliminary Draft Main Test Results



Preliminary Draft Main Test Results

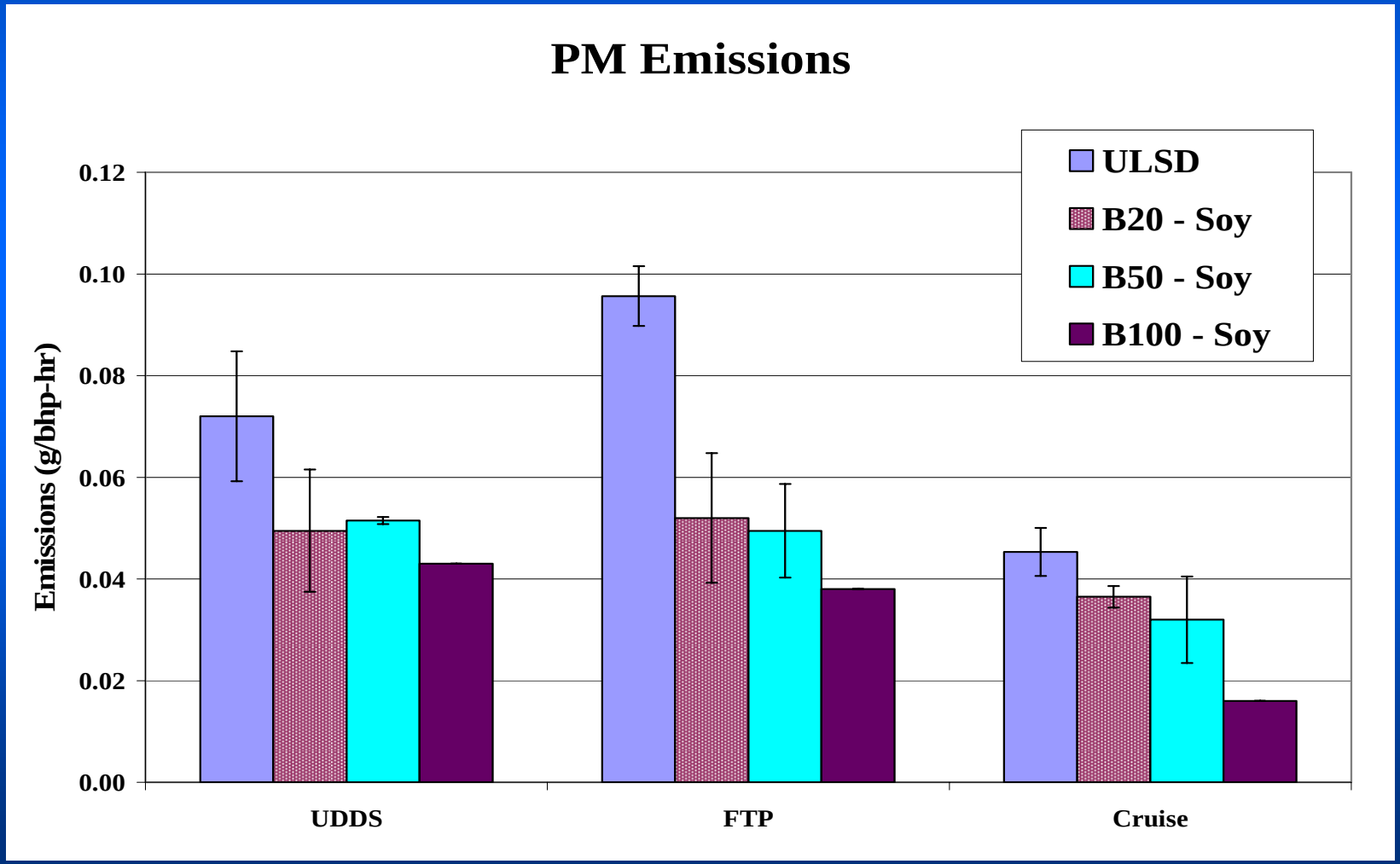


Preliminary Draft Main Test Results



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

Day 1		Day 2		Day 3		Day 4		Day 5		Day 6	
Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle
CARB	FTP	B20	FTP	B20 +	FTP	CARB	FTP	B20 +	FTP	B20 +	FTP
	FTP		FTP	0.5%	FTP		FTP	1.0% DTBP	FTP	1.5% DTBP	FTP
	FTP		FTP	DTBP	FTP		FTP		FTP		FTP
B20	FTP	B20 +	FTP	CARB	FTP	B20 +	FTP	B20 +	FTP	CARB	FTP
	FTP	0.5%	FTP		FTP		FTP		FTP		FTP
	FTP	DTBP	FTP		FTP	1.0% DTBP	FTP	1.5% DTBP	FTP		FTP

Initial Testing EHN

Day 1		Day 2		Day 3		Day 4		Day 5		Day 6	
Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle
CARB	FTP	B20	FTP	B20 +	FTP	CARB	FTP	B20 +	FTP	B20 +	FTP
	FTP		FTP	0.5% EHN	FTP		FTP	1.0% EHN	FTP	1.5% EHN	FTP
	FTP		FTP		FTP		FTP		FTP		FTP
B20	FTP	B20 +	FTP	CARB	FTP	B20 +	FTP	B20 +	FTP	CARB	FTP
	FTP		FTP		FTP		FTP		FTP		FTP
	FTP	0.5% EHN	FTP		FTP	1.0% EHN	FTP	1.5% EHN	FTP		FTP

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

Day 1		Day 2		Day 3		Day 4		Day 5		Day 6	
Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle
CARB	Cruise	B20 +	Cruise	CARB	FTP	B100 +	FTP	CARB	Cruise	B100 +	Cruise
	Cruise	x% DTBP	Cruise		FTP	x% DTBP	FTP		Cruise	x% DTBP	Cruise
	Cruise		Cruise		FTP		FTP		Cruise		Cruise
B20 +	Cruise	CARB	Cruise	B100 +	FTP	CARB	FTP	B100 +	Cruise	CARB	Cruise
	Cruise		Cruise		FTP		FTP		Cruise		Cruise
x% DTBP	Cruise		Cruise	x% DTBP	FTP		FTP	x% DTBP	Cruise		Cruise

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

Day 1		Day 2		Day 3		Day 4		Day 5		Day 6	
Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle
CARB	FTP	B20 Soy	FTP	Bx1 Ry1	FTP	CARB	FTP	Bx2 Ry2	FTP	Bx3 Ry3	FTP
	FTP		FTP		FTP		FTP		FTP		FTP
	FTP		FTP		FTP		FTP		FTP		FTP
B20 Soy	FTP	Bx1 Ry1	FTP	CARB	FTP	Bx2 Ry2	FTP	Bx3 Ry3	FTP	CARB	FTP
	FTP		FTP		FTP		FTP		FTP		FTP
	FTP		FTP		FTP		FTP		FTP		FTP

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