

# **Biodiesel and Renewable Diesel Research Study**

**March 12, 2009  
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**California Environmental Protection Agency**

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**Air Resources Board**

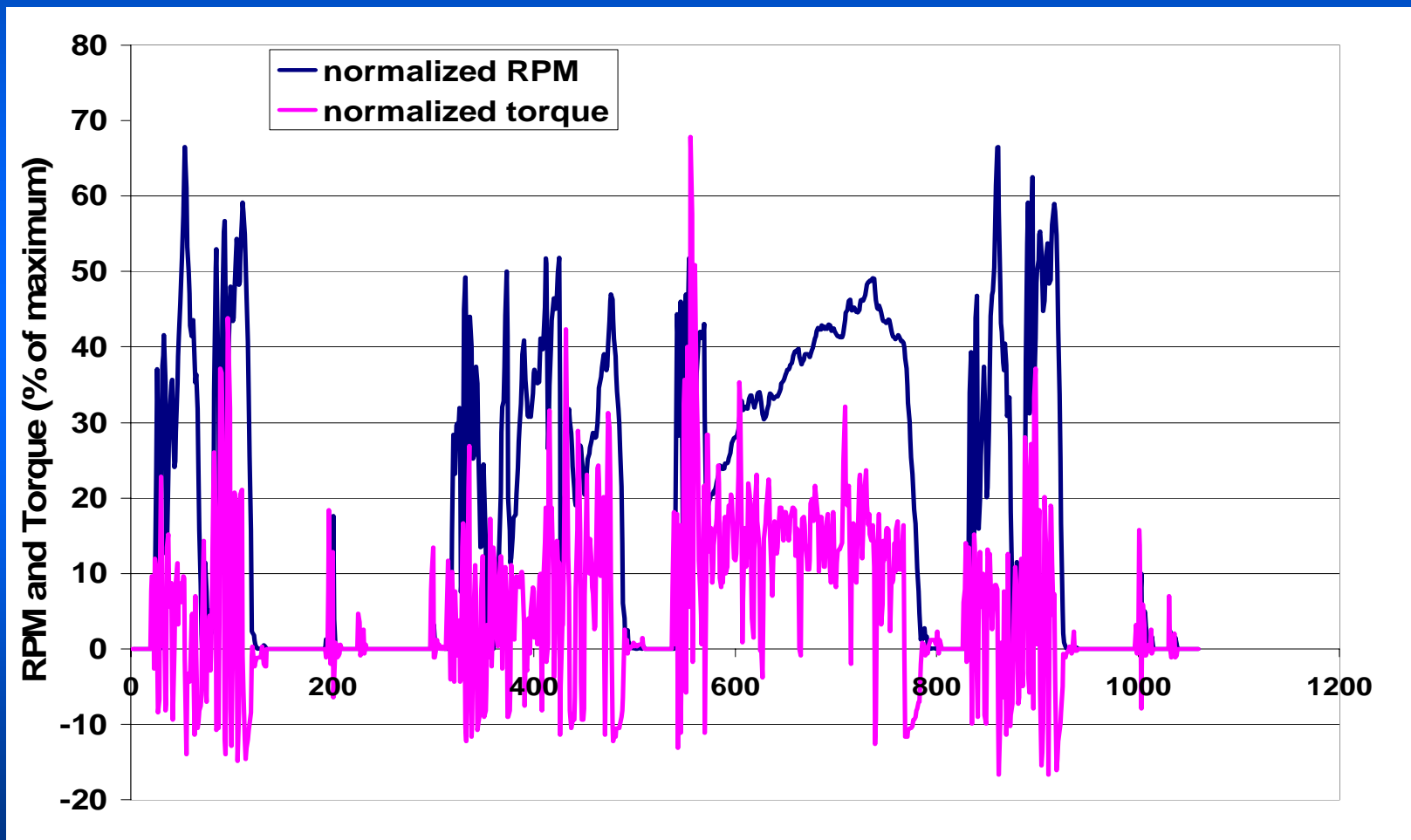
# Engine Dynamometer Cycle Development

- 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<sub>x</sub> 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

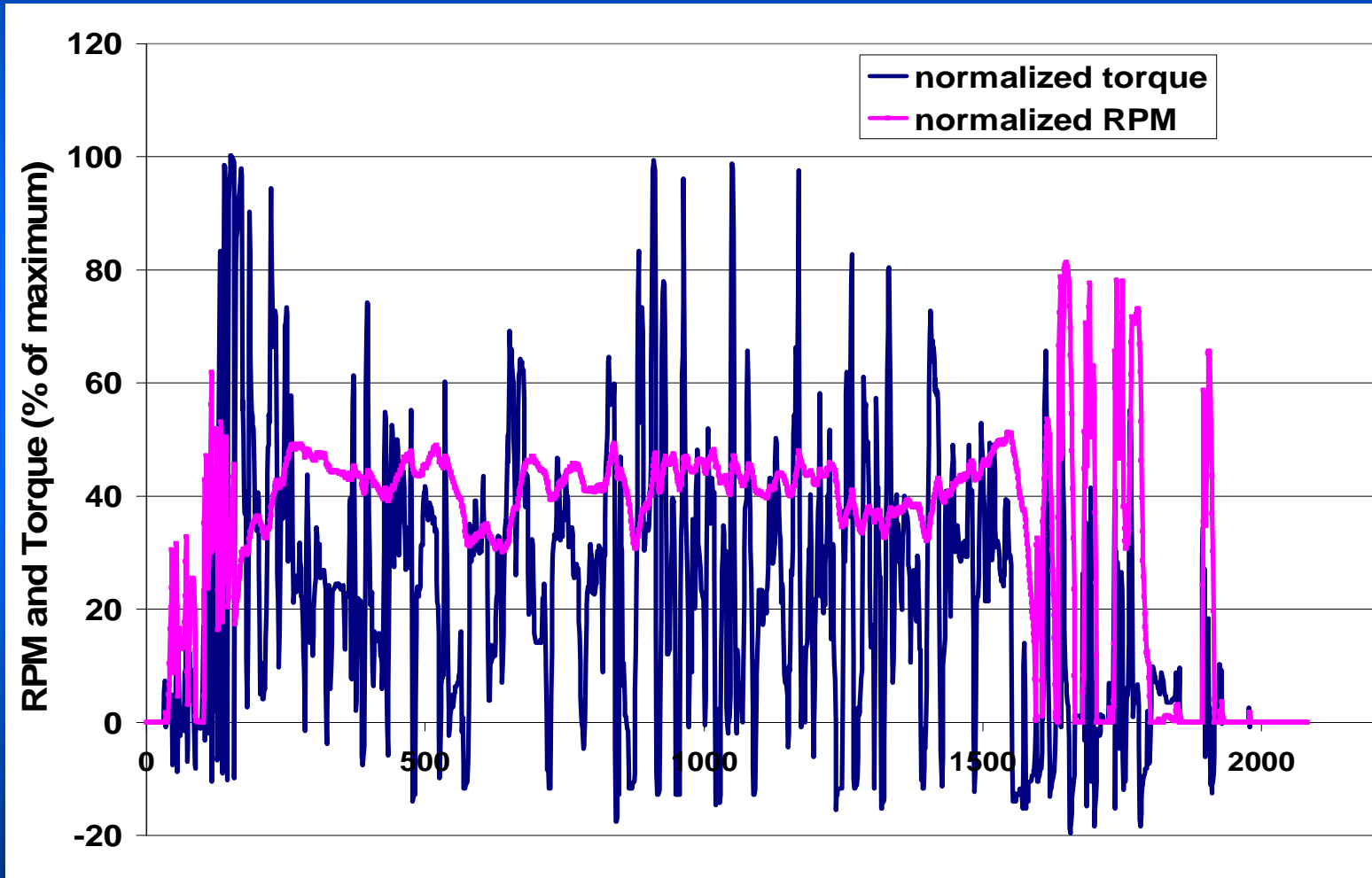
# Engine Parameters

- 2006 Cummins ISM 370
- In-line, 6 cylinder, 4-stroke, 10.8 L engine
- 385 @ 1800 rpm
- Turbo charged with EGR

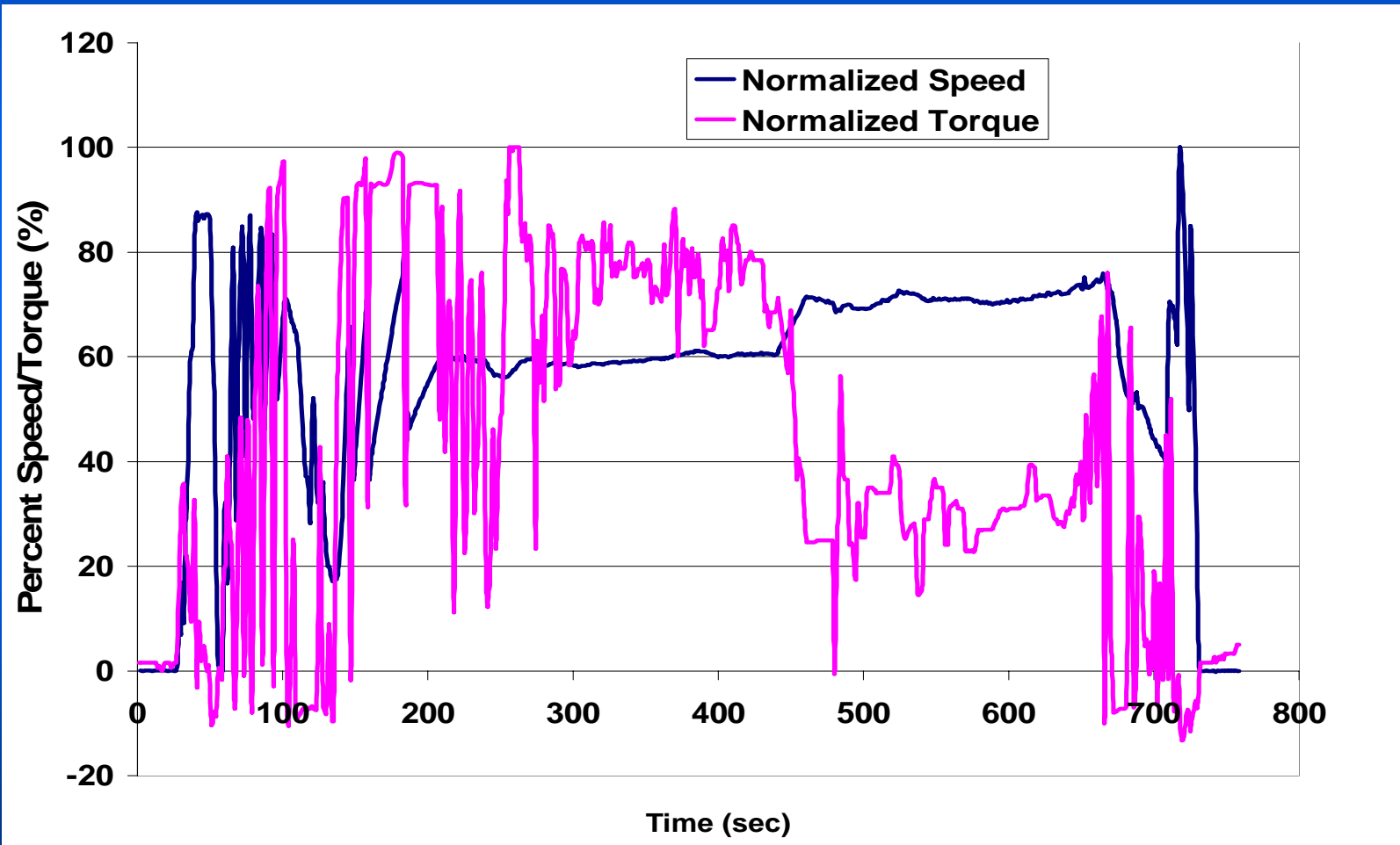
# UDDS Engine Dynamometer Cycle



# Cruise-1 Engine Dynamometer Cycle



# Cruise-2 Engine Dynamometer Cycle



# Engine 1 Test Runs

- Testing completed
  - Soy-based biodiesel
  - Animal-based biodiesel
  - Renewable diesel
  - Initial round of mitigation testing with additives and renewable blends
- Biodiesel Results show trends consistent with expectations
  - Increasing NO<sub>x</sub> for the biodiesel blends
  - Decreasing PM for the biodiesel blends
  - Decreasing THC for the biodiesel blends
- Renewable diesel results show reductions in NO<sub>x</sub> and PM
- Complications due to outliers

# Biodiesel/Renewable Diesel Study

# Soy Feedstock Test Matrix

A Lght. UDDS B FTP C1 ARB 40 mph Cruise C ARB 50 mph Cruise

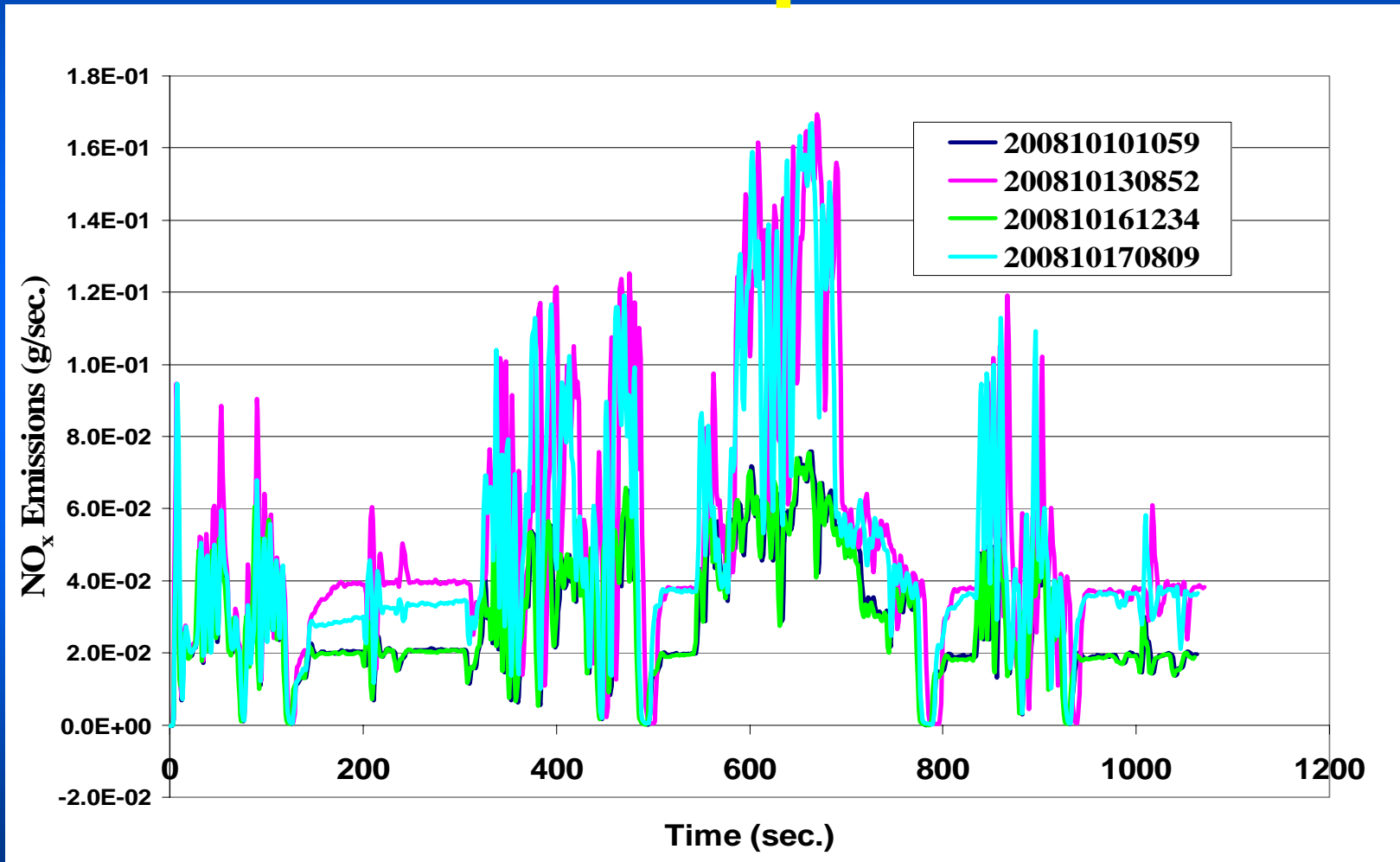
**Engine 1-2006 cummins ISM**

*Soy based biodiesel*

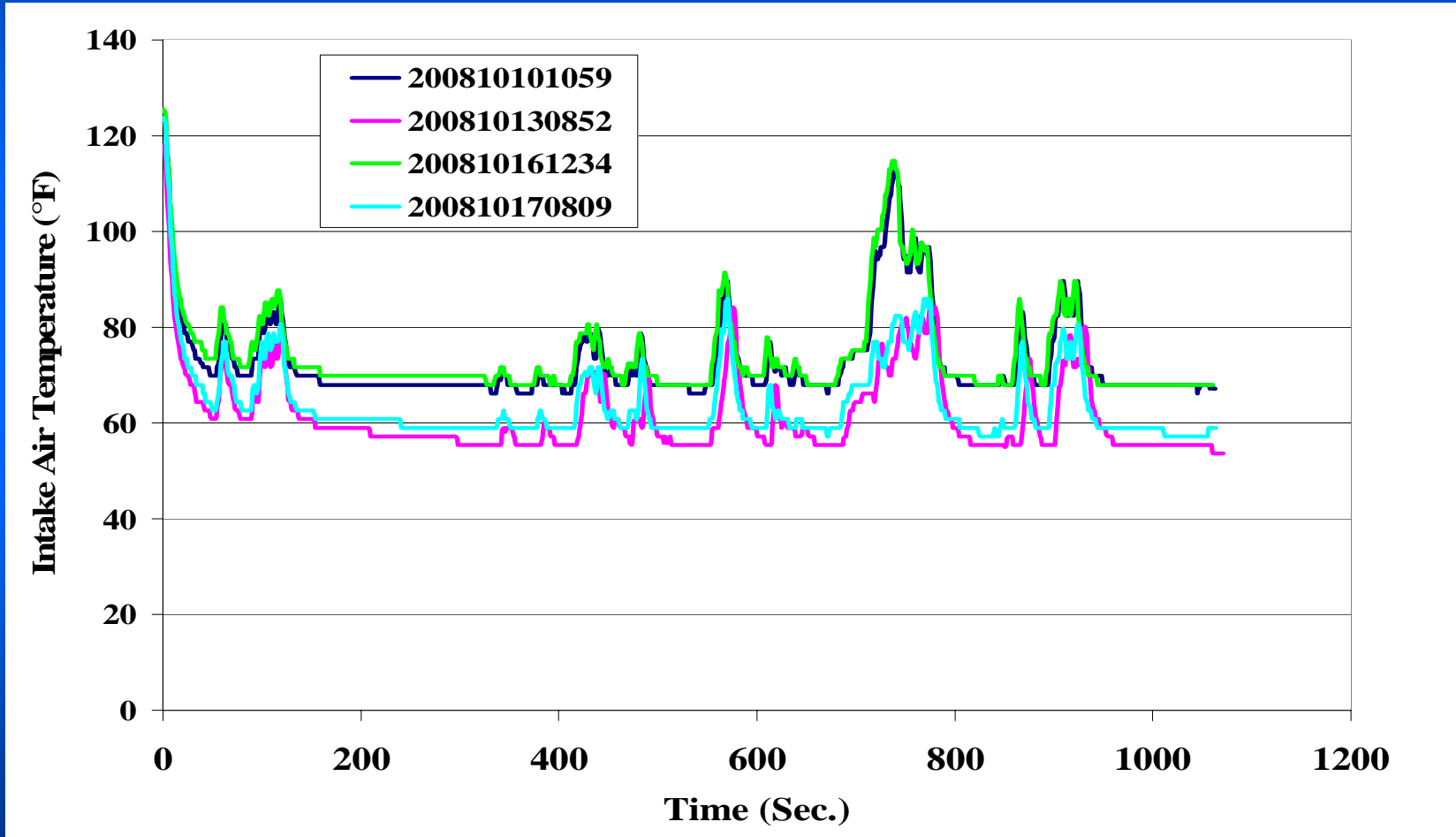
Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7		Day 8		Day 9		Day 10		Day 11		Day 12		Day 13		Day 14		Day 15			
Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle
CARB	A	B20	B	B50	A	CARB	C1	B100	B	B20	C1	CARB	B	B50	A	B100	A	CARB	A	B20	B	B50	A	B100	C1	CARB	C1	CARB	C1	B5	C1
	C1		A		B		A		C1		B		A		B		C1		C1		A		B		A		B		C1		C1
	B		C1		C1		B		A		A		C1		B		B		B		C1		C1		B		C1		C1		C1
B20	C1	B50	B	CARB	C1	B100	A	B20	B	CARB	A	B50	B	B100	C1	CARB	B	B20	A	B50	C1	B100	B	CARB	C1	B5	C1	CARB	C1		C1
	B		C1		A		B		A		C1		A		A		C1		B		B		C1		A		C1		C1		C1
	A		A		B		C1		C1		B		C1		B		A		C1		A		A		B		C1		C1		C1
Day 16		Day 17		Day 18		Day 19		Day 20		Day 21																					
Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle																				
CARB	C	CARB	A	CARB	A	CARB	C	CARB	C	B50	A																				
	A		C		B		C		C		B																				
	B		B		C		C		C		A																				
B20	A	B50	C	B100	B	B5	C		C		B																				
	C		A		A		C	B20	C	B100	C																				
	B		B		C		C		C		C																				
	B		C		A		C		C		C																				
B20	B	B50	C	B100	A	B5	C		C		C																				
	A		B		C		C		C		C																				
	C		A		B		C	B50	C	CARB	C																				
CARB	C	CARB	A	CARB	B	CARB	C		C		C																				
	B		C		C		C		C		C																				
	A		B		A		C		C		C																				



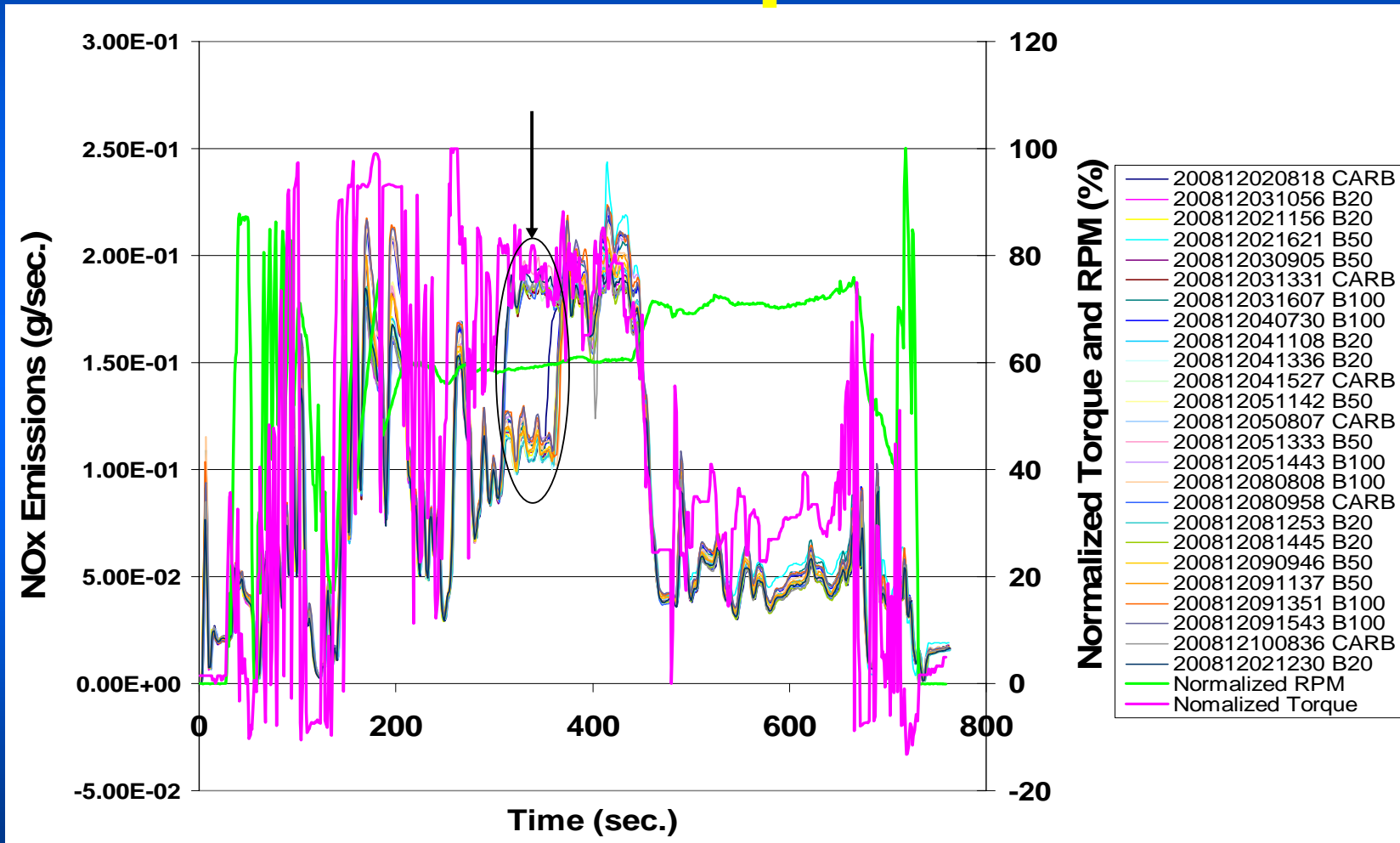
# Outlier Complications



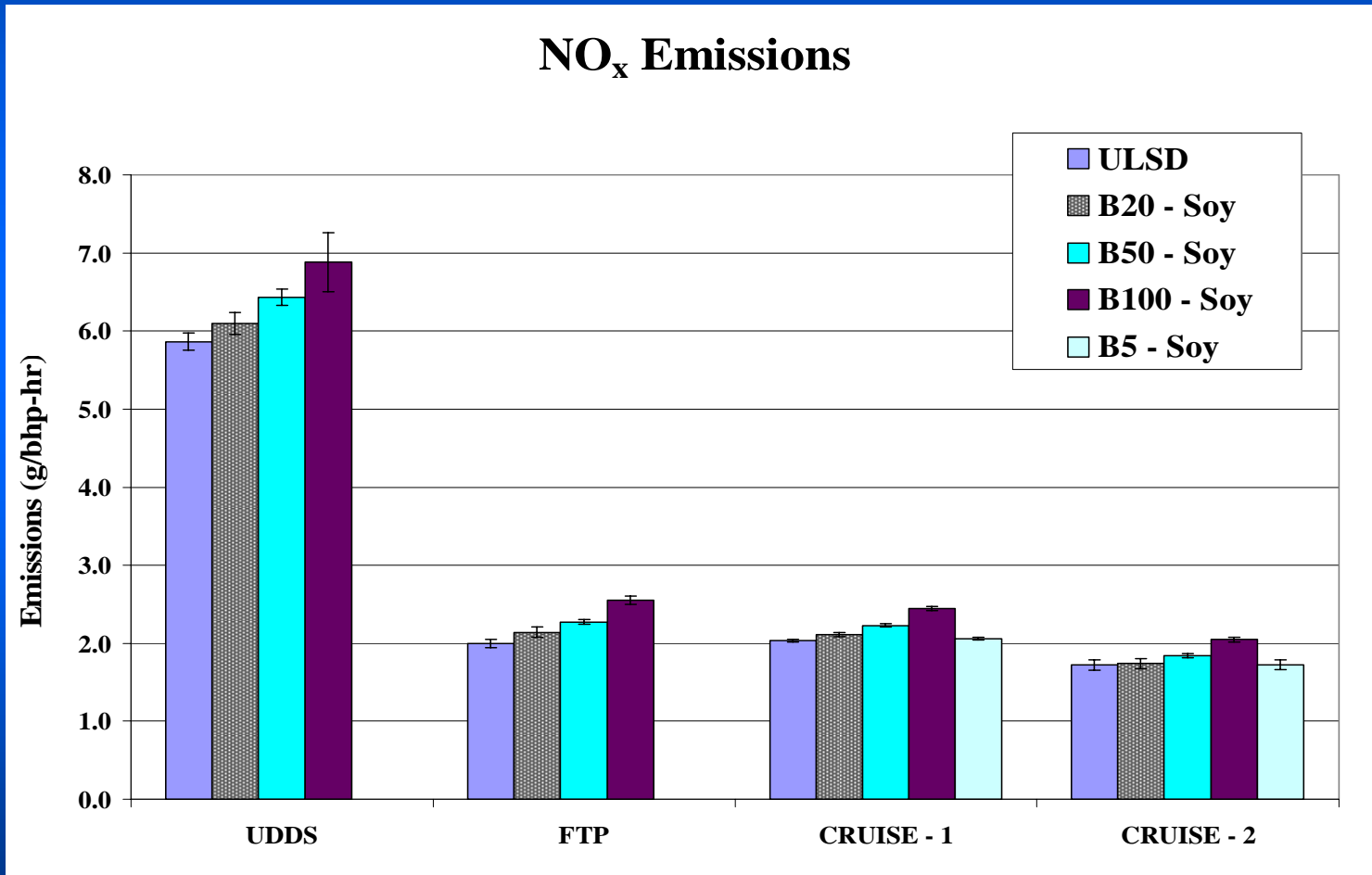
# Outlier Complications



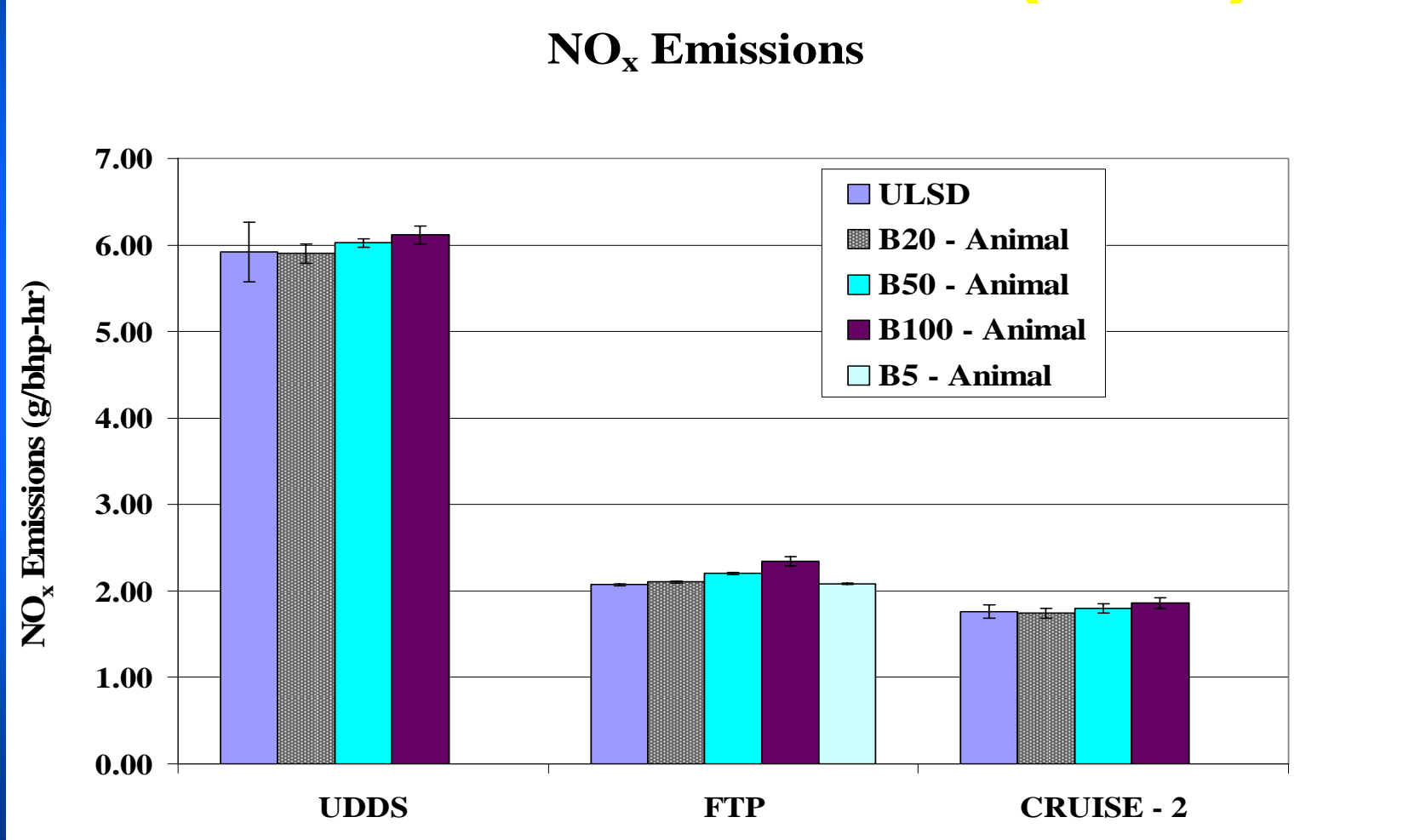
# Outlier Complications



# Draft Test Results (NO<sub>x</sub>)



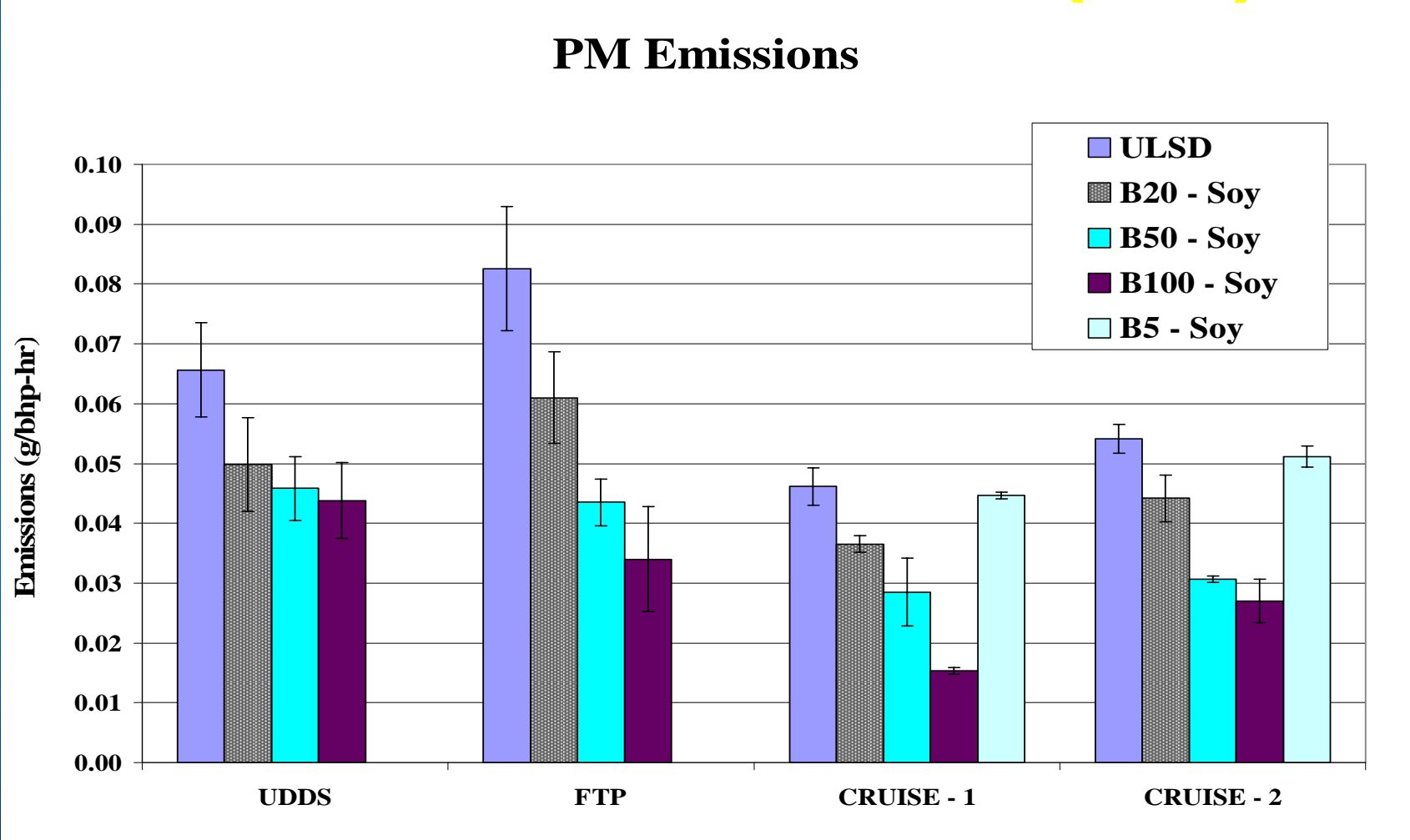
# Draft Test Results (NO<sub>x</sub>)



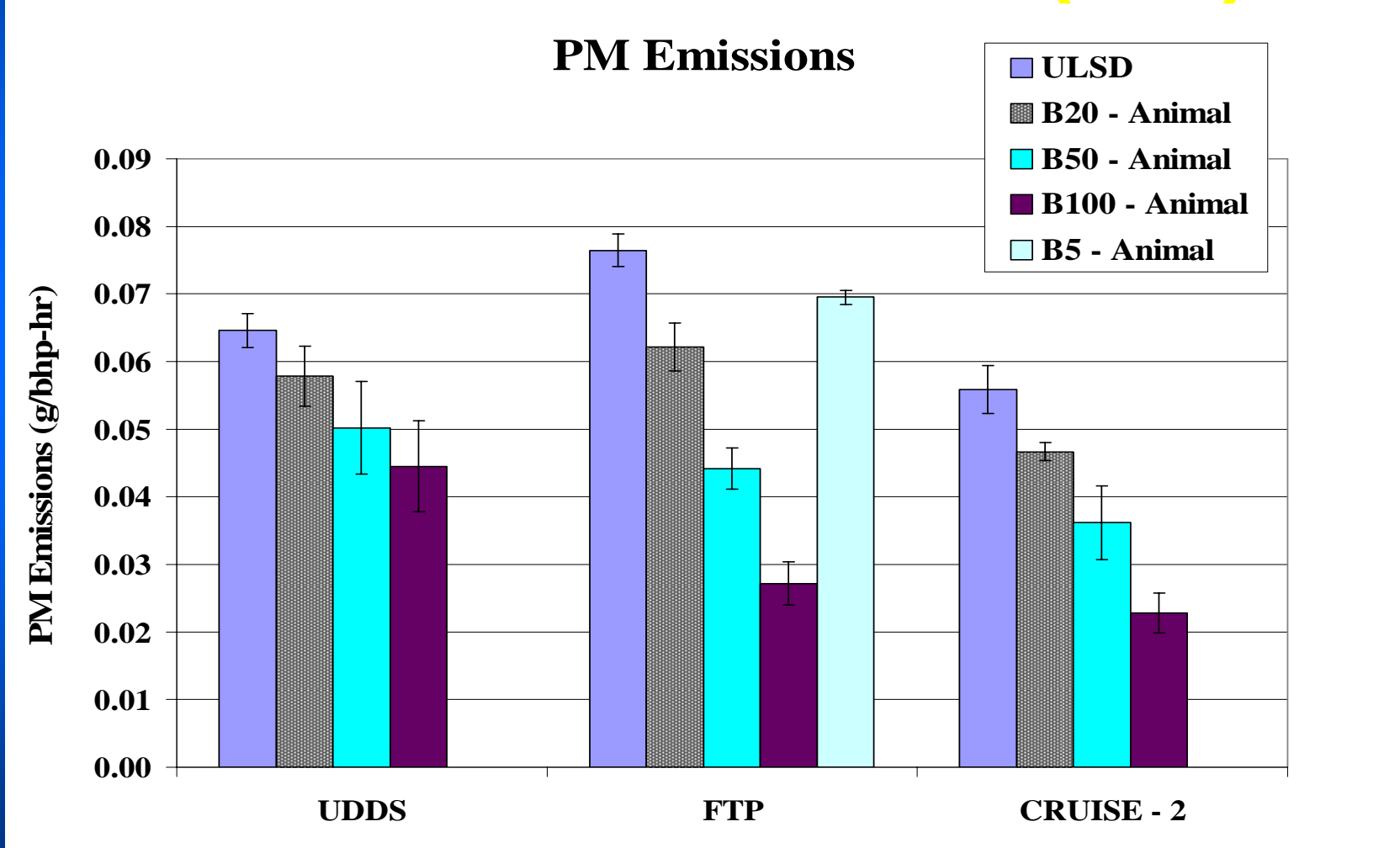
# Draft Test Results (NO<sub>x</sub>)

	CARB vs.	Soy -based		Animal - based	
		Difference	%	P-values	Difference
UDDS	B20	3.9%	0.004	-0.3%	0.952
	B50	9.7%	0.000	1.8%	0.564
	B100	17.3%	0.000	3.3%	0.211
FTP	B5	1.6% (Mit)	0.081	0.2%	0.324
	B10	2.5% (Mit)	0.009		
	B20	7.1%	0.000	1.4%	0.000
	B50	13.7%	0.000	6.3%	0.000
Cruise - 1	B100	27.5%	0.000	13.1%	0.000
	B5	1.9%	0.054		
	B20	3.7%	0.000		
	B50	9.6%	0.000		
Cruise - 2	B100	20.4%	0.000		
	B5	-1.1%	0.838		
	B20	0.9%	0.792	-0.9%	0.671
	B50	6.7%	0.001	2.1%	0.317
	B100	18.7%	0.000	5.8%	0.023

# Draft Test Results (PM)



# Draft Test Results (PM)





# Draft Test Results (PM)

	CARB vs.	Soy -based		Animal - based	
		% Difference	P-values	% Difference	P-values
UDDS	B20	-24%	0.003	-11%	0.009
	B50	-30%	0.000	-22%	0.001
	B100	-33%	0.000	-31%	0.000
FTP	B5	-6% (Mit)	0.000	-9%	0.000
	B10	-17% (Mit)	0.000		
	B20	-26%	0.000	-19%	0.000
	B50	-47%	0.000	-42%	0.000
	B100	-59%	0.000	-64%	0.000
Cruise - 1	B5	-6%	0.033		
	B20	-21%	0.000		
	B50	-38%	0.000		
	B100	-67%	0.000		
Cruise - 2	B5	-5%	0.020		
	B20	-18%	0.000	-16%	0.000
	B50	-43%	0.000	-35%	0.000
	B100	-50%	0.000	-59%	0.000

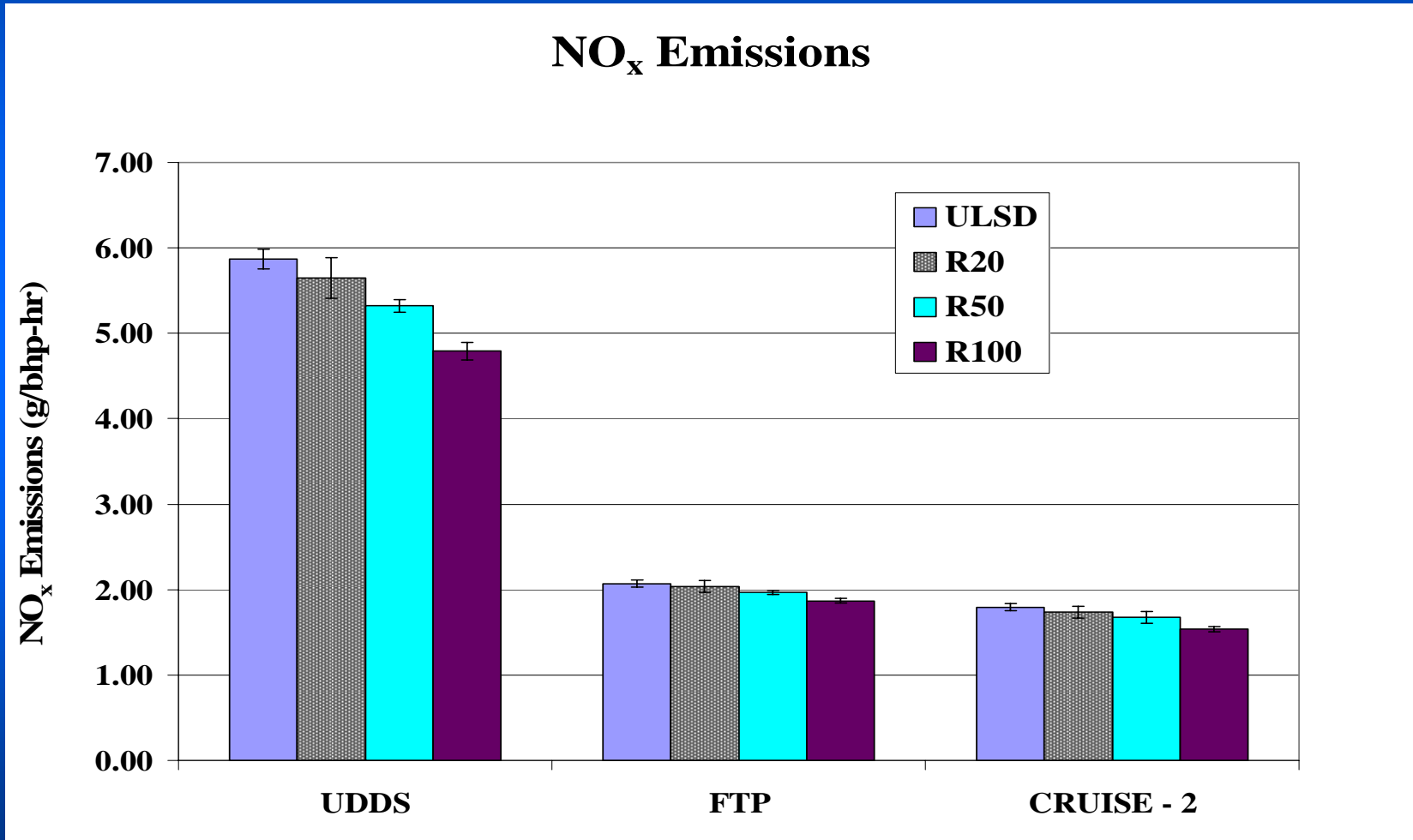
# Draft Test Results (THC)

	CARB vs.	Soy -based		Animal - based	
		Difference	% P-values	Difference	% P-values
UDDS	B20	-12%	0.000	-16%	0.000
	B50	-28%	0.000	-38%	0.000
	B100	-55%	0.000	-73%	0.000
FTP	B5	-2% (Mit)	0.136	-3%	0.011
	B10	-6% (Mit)	0.000		
	B20	-11%	0.000	-14%	0.000
	B50	-29%	0.000	-36%	0.000
Cruise - 1	B100	-63%	0.000	-71%	0.000
	B5	-2%	0.307		
	B20	-15%	0.000		
	B50	-35%	0.000		
Cruise - 2	B100	-69%	0.000		
	B5	-2%	0.224		
	B20	-12%	0.000	-14%	0.000
	B50	-31%	0.000	-37%	0.000
	B100	-68%	0.000	-73%	0.000

# Draft Test Results (CO)

	CARB vs.	Soy -based		Animal - based	
		% Difference	P-values	% Difference	P-values
UDDS	B20	4%	0.157	-10%	0.000
	B50	26%	0.000	-12%	0.000
	B100	61%	0.000	-20%	0.000
FTP	B5	-1% (Mit)	0.405	-4%	0.008
	B10	-2% (Mit)	0.151		
	B20	-4%	0.083	-7%	0.000
	B50	-5%	0.059	-14%	0.000
	B100	2%	0.452	-27%	0.000
Cruise - 1	B5	2%	0.339		
	B20	-1%	0.729		
	B50	1%	0.534		
	B100	2%	0.388		
Cruise - 2	B5	1%	0.465		
	B20	-2%	0.330	-7%	0.003
	B50	-6%	0.002	-9%	0.066
	B100	-15%	0.000	-25%	0.000

# Draft Test Results (NO<sub>x</sub>)



# Draft Test Results (NO<sub>x</sub>)

	CARB vs.	Renewable % Difference	P-values
UDDS	R20	-3.8%	0.051
	R50	-9.4%	0.000
	R100	-18.4%	0.000
FTP	R20	-1.6%	0.291
	R50	-5.0%	0.000
	R100	-9.7%	0.000
Cruise - 2	R20	-3.1%	0.107
	R50	-6.5%	0.003
	R100	-14.4%	0.000

# Strategies for NO<sub>x</sub> Mitigation

- Additives
- Renewable/biodiesel blends
- GTL
- Match blending – subsequent testing??

# Additive Testing

- 2- ethyl-hexyl-nitrate (EHN)
  - 1% level in B5, B10, and B20
- Di-tert-butyl-peroxide (DTBP)
  - 1% level in B10 and B20
- Both additives have been studied by NREL and SwRI
- Use B20-soy with highest NO<sub>x</sub> disbenefit
- All testing on FTP
- DTBP successful at 1% level with B10
- 2-EHN unsuccessful at 1% level with B5
- Additional testing as needed to look at cycle effects and higher blend levels

# Renewable/Biodiesel Blend Testing

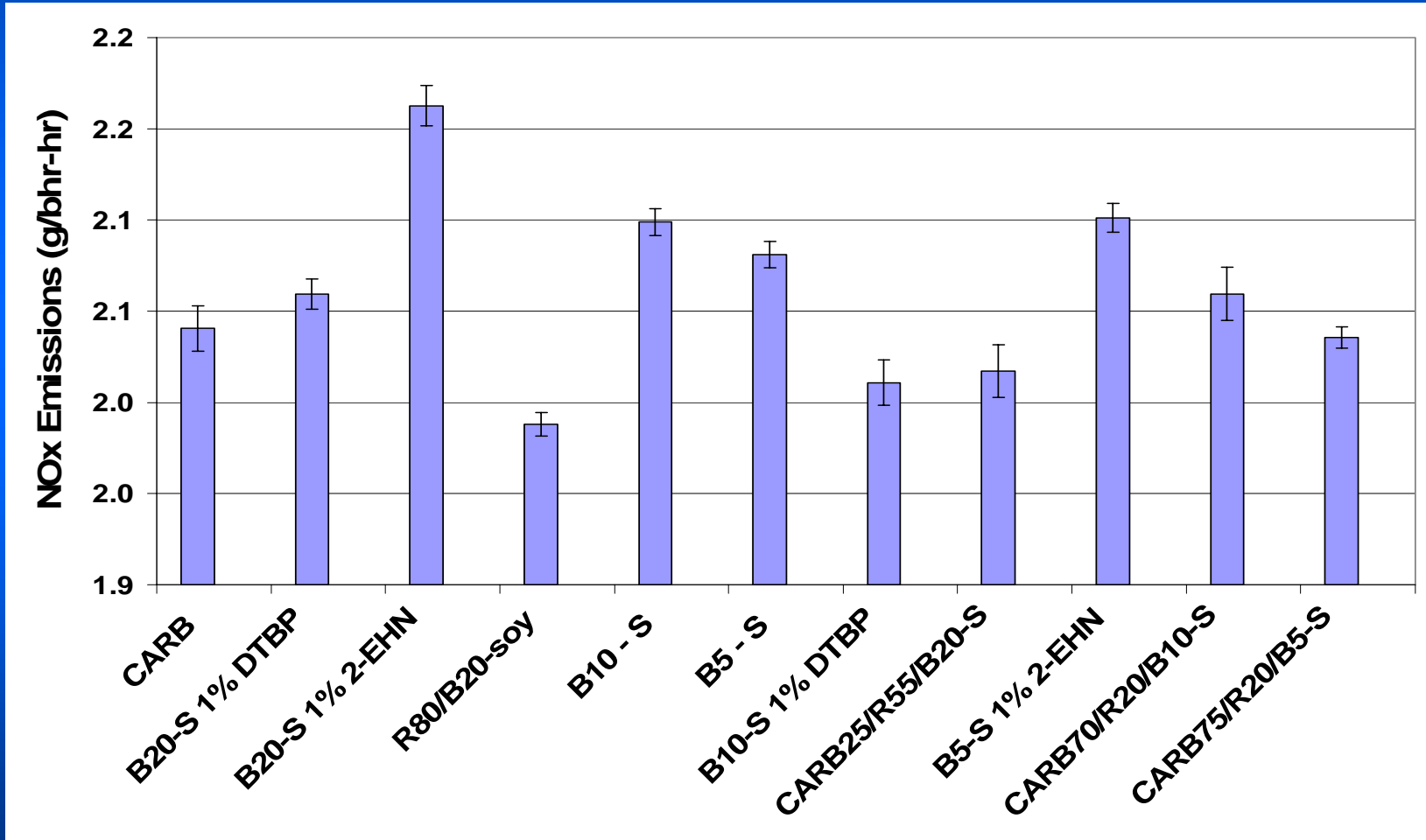
- R80/B20 - successful
- R55/CARB25/B20 - successful
- CARB70/R20/B10 - unsuccessful
- CARB75/R20/B5 - successful



# Text Matrix - Mitigation

CARB	B20-S 1% 2-EHN	R80 B20-S	CARB	B10-S 1% DTBP	C25/R55/B20-S	CARB	CARB
B20-S 1% DTBP	CARB	B10-S	B5 - S	CARB	B5-S 1% 2-EHN	C70/R20/B10-S	C75/R20/B5-S
B20-S 1% DTBP	CARB	B10-S	B5 - S	CARB	B5-S 1% 2-EHN	C70/R20/B10-S	C75/R20/B5-S
B20-S 1% 2-EHN	R80 B20-S	CARB	B10-S 1% DTBP	C25/R55/B20-S	CARB	CARB	CARB

# First Round Results - Draft



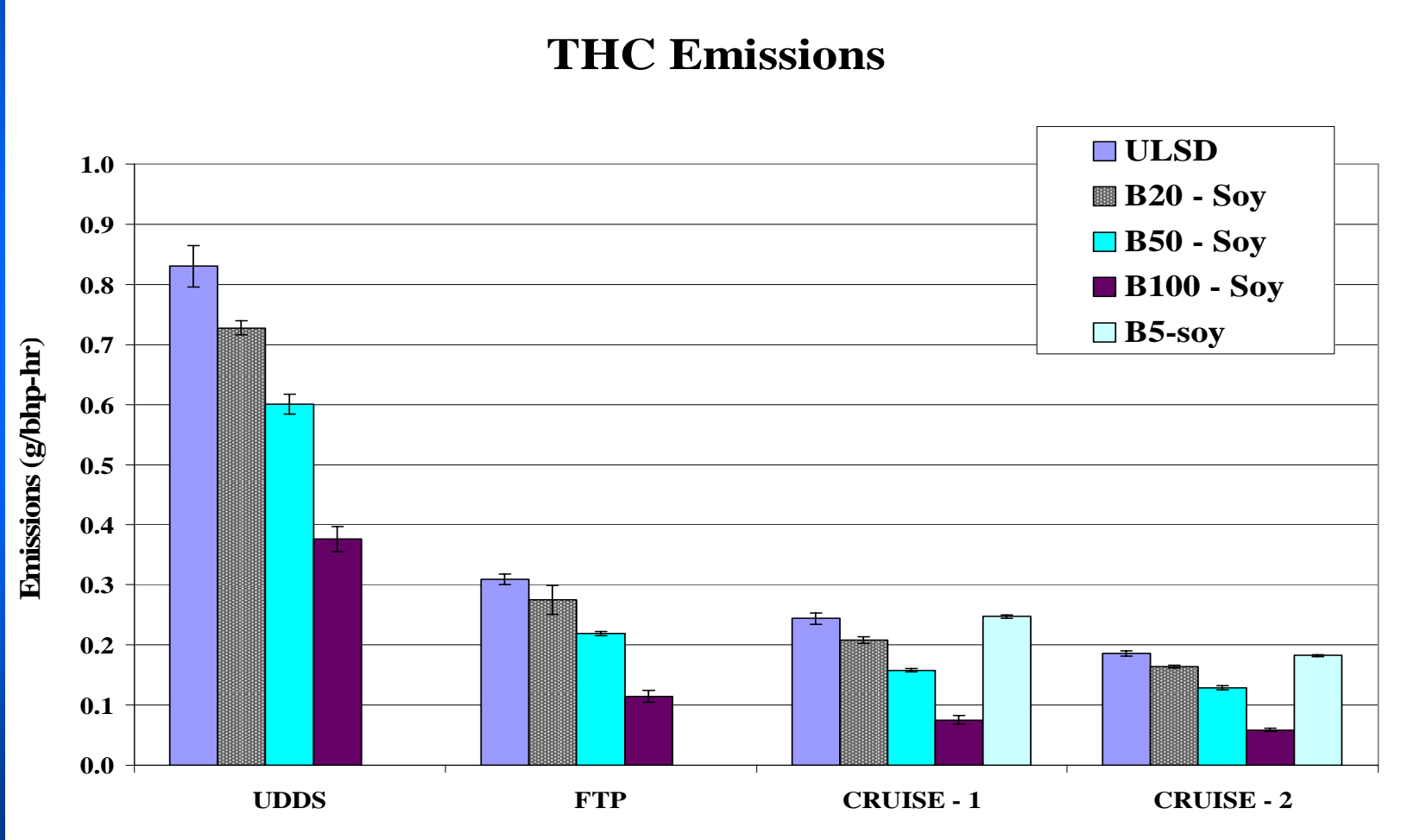
# Draft Test Results (NO<sub>x</sub>)

CARB vs.	% Difference	P-values
B20-S 1% DTBP	0.9%	0.000
B20-S 1% 2-EHN	6.0%	0.001
R80/B20-soy	-2.6%	0.000
B10-S 1% DTBP	-1.5%	0.000
CARB25/R55/B20-S	-1.1%	0.000
B5-S 1% 2-EHN	3.0%	0.000
CARB70/R20/B10-S	0.9%	0.002
CARB75/R20/B5-S	-0.2%	0.511
B5 - S	2.0%	0.000
B10 - S	2.9%	0.000

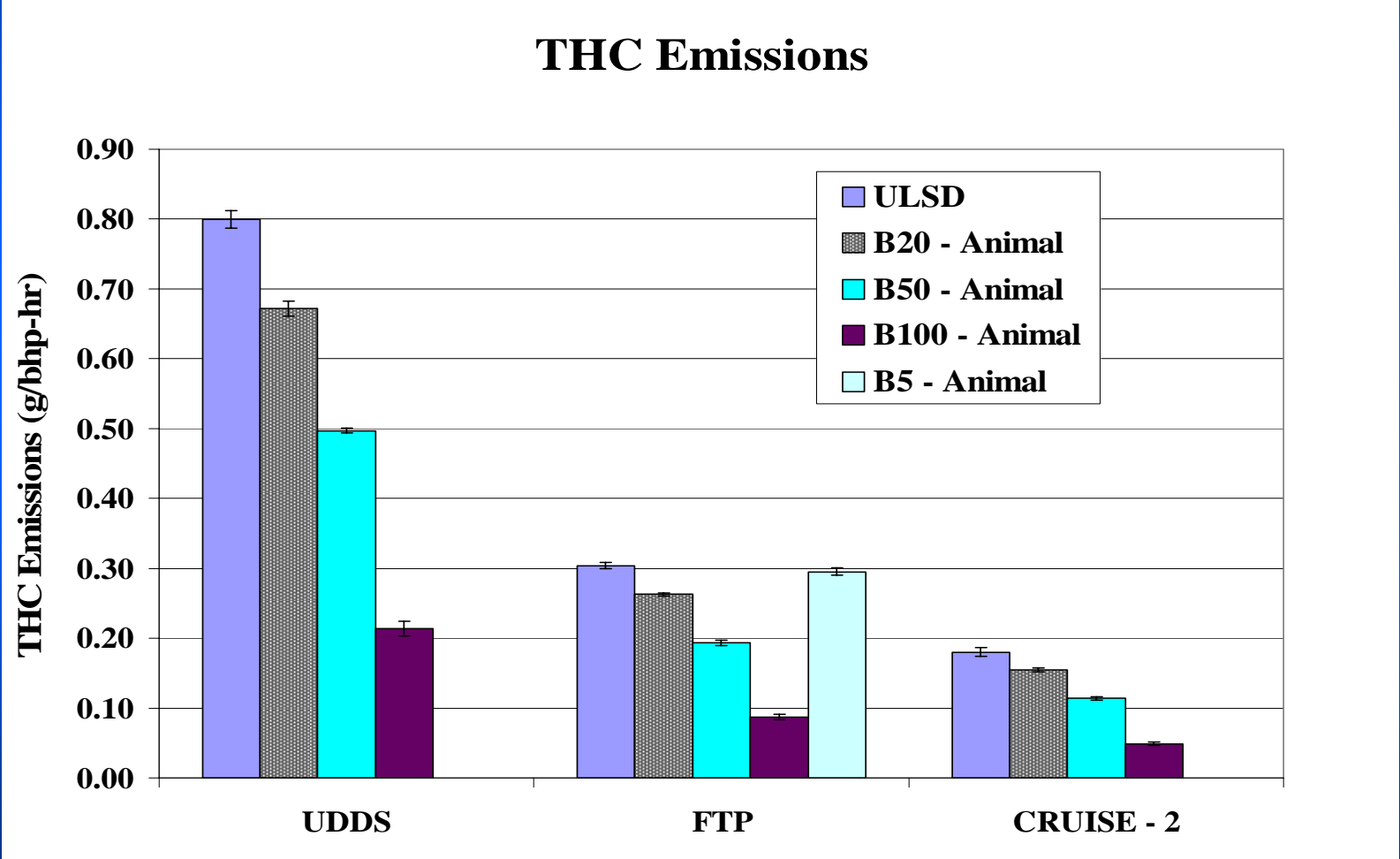
# Additional Mitigation Testing

- Testing with a GTL fuel planned shortly
- Additional testing of Additives, etc. possible

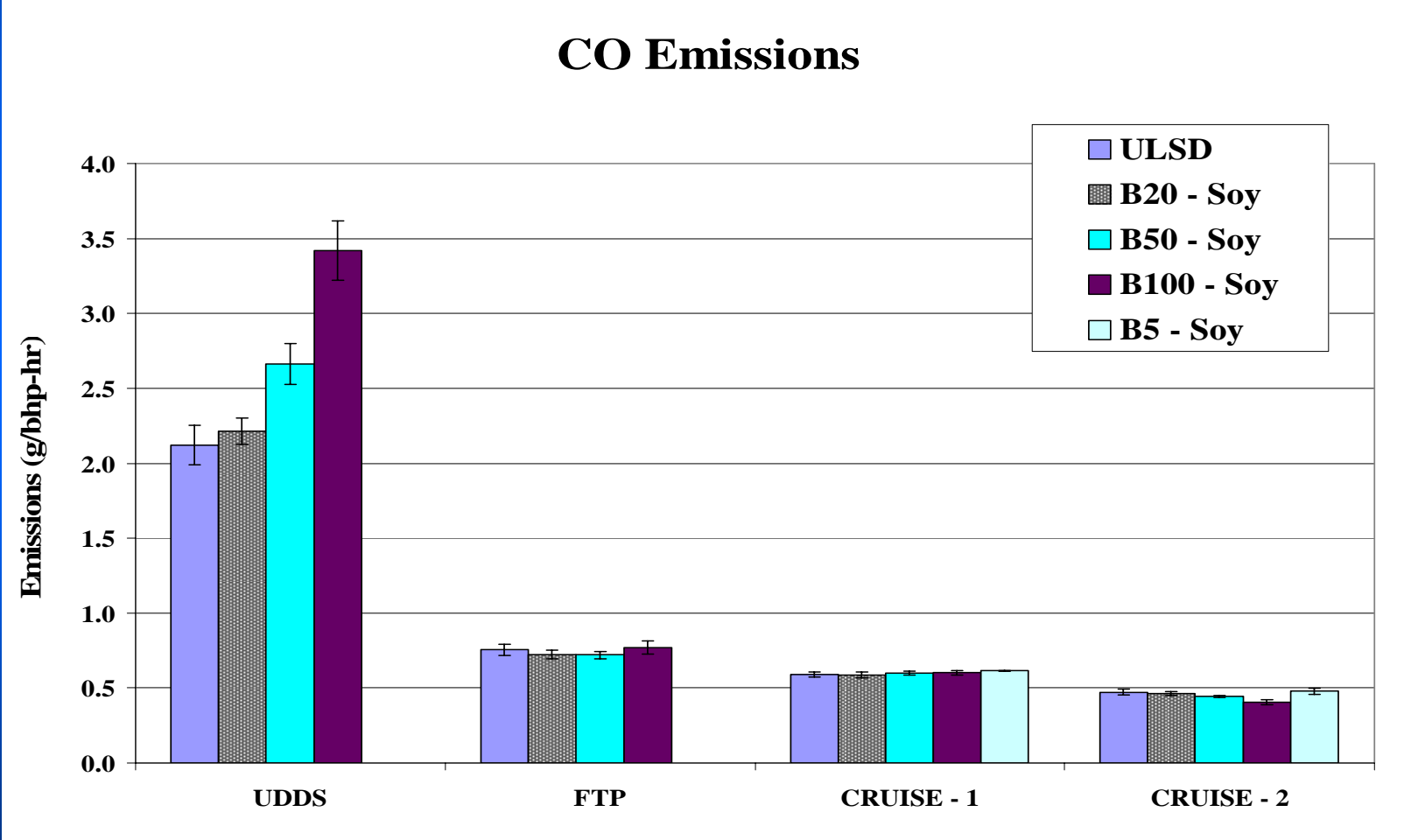
# Additional Slides - Draft



# Additional Slides - Draft



# Additional Slides - Draft



# Additional Slides - Draft

