

Biodiesel and Renewable Diesel Research Study

December 5, 2007

California Environmental Protection Agency



Air Resources Board

Introductions

Agenda

- Introduction
- Summary of previous workgroup discussions
 - Fuels
 - storage, blending, biodiesel and renewable diesel
 - Engine selection
- Engine test matrix-CECERT
 - On-road vehicle test matrix-MTA
 - Detailed description of unregulated emissions tests
- Test schedule
 - Others
- NOx mitigation
 - Selection of NOx mitigation strategies
- Presentation by others
- Open discussion

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.

- Low Carbon Fuels Standard
 - Biofuels Specifications adopted by the first quarter of 2009
 - Biodiesel and renewable diesel research study is needed

Biodiesel and Renewable Diesel Research Study

- Biodiesel and renewable diesel emissions evaluation
- NOx formation and mitigation evaluation
- Multi-Media evaluation

Funded Research Update

- Biodiesel and Renewable Diesel Research Study
 - Biodiesel and renewable diesel characterization and NOx mitigation study-\$1,689,000
 - Biodiesel and renewable diesel multimedia study-\$400,000
 - Total cost **\$2,189,000**
- Other contributors
 - South Coast Air Quality Management District-\$50,000
 - National Biodiesel Board-\$50,000
 - WSPA will provide CARB diesel
 - Innerstate Oil will provide transportation and short term storage of fuels
 - Tentative agreement on renewable diesel
 - Discussions on-going with other contributors

Duration of Contracts and Grants

- Initial biodiesel characterization study: 6/06-6/08
- Biodiesel and renewable diesel characterization and NOx mitigation study: 6/07-6/09
- Biodiesel and renewable diesel multimedia: 6/07-6/09

Biodiesel and Renewable Diesel Emissions Characterization and NOx Mitigation Research

“Assessment of the Emissions from the Use of Biodiesel as a Motor Vehicle Fuel in California- Biodiesel Characterization and NOx Formation and Mitigation Study”

Principal Investigators: Thomas D. Durbin (UCR) and J. Wayne Miller (UCR)

University California Riverside-CE-CERT

University California Davis

Scope of Work

Task 1: Biodiesel and Renewable Diesel Emissions Evaluation Study

- Evaluate emissions and health effects
- Evaluate NOx impact

Task 2: NOx Formation and Mitigation Study

- Investigate the mechanism of NOx formation and evaluate possible NOx mitigation options
 - Changes in fuel specifications-match blending
 - Refinery process
 - Additives
 - Engine recalibration

Summary of previous workgroup discussions

Fuel Storage Update

- Long term storage
 - Difficulty in finding temperature controlled storage facility
 - Options:
 - Possibility of a non-temperature controlled cinder block storage facility
 - Also looking at non-temperature controlled storage facility on the coast where there is smaller temperature swings

Fuel Blending

- No updates-still need to resolve how, when, and where to do fuel blending

Biodiesel Feedstocks and Fuels Update

- Original proposal was to avoid additives
 - May need to consider anti-oxidants and anti-microbial
 - Which anti-oxidants and anti-microbial?

Fuel Specification Analysis

- CARB diesel fuel-D975
- Renewable diesel fuel and blends-D975
- Biodiesel feedstocks-D6751
- Biodiesel blends
 - D975
 - D6751
- All analyses conducted in triplicate

Storage Stability Criteria Update

- Conduct quarterly stability tests for biodiesel fuels and biannual stability tests for CARB and renewable diesel
 - EN14112 Rancimat 6 hrs
 - D664 Acid number 0.5
 - D2274 Gums ?
 - D3703 Peroxide ?

CARB Diesel Update

- No update

Renewable Diesel Update

- Original proposal was to test R20 and R50
- Add additional blend level: R100

Test Engine Update

- Engine secured for testing
 - 2006 11 L Cummins ISM purchased
- Other engines under consideration
 - 2007 14 L Detroit Diesel series 60
 - 2007 International

Additional Parameters Update

- Lube oil-APICJ4-OL
- Engine parameters-J1939

Toxics Testing Update

- Elements: Filter/XRF or ICP/MS
- No Chromium (VI) sampling and analysis will be conducted

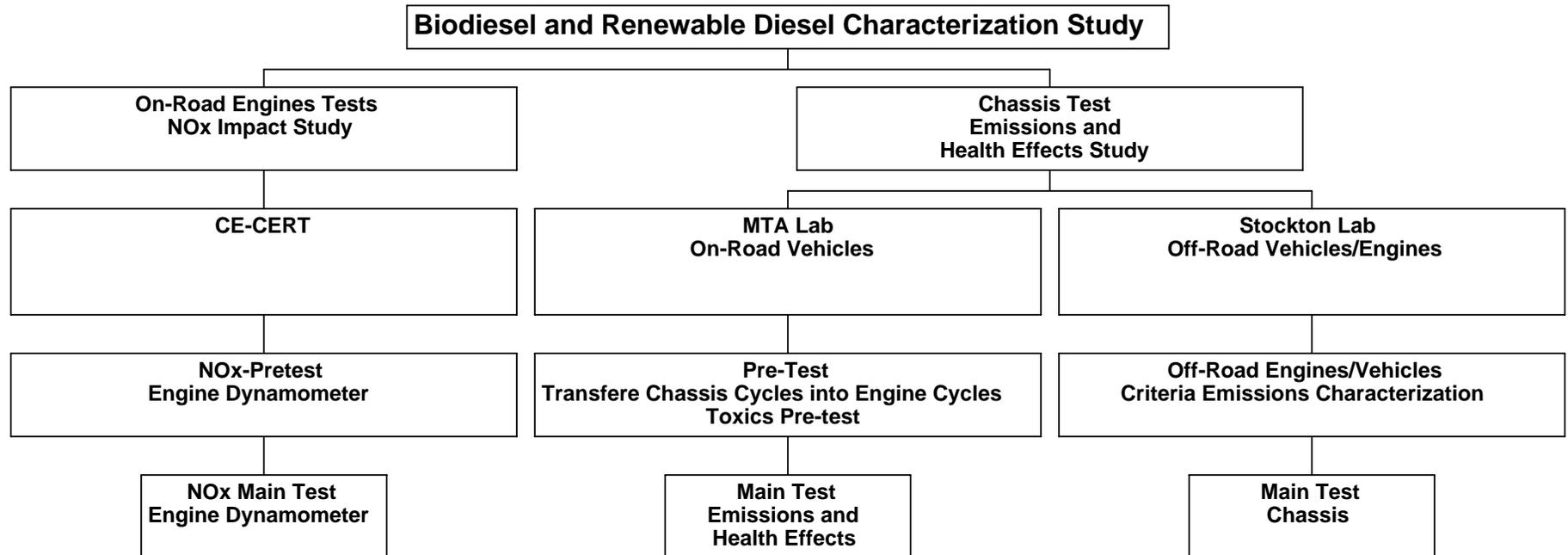
Discussion

Test Design

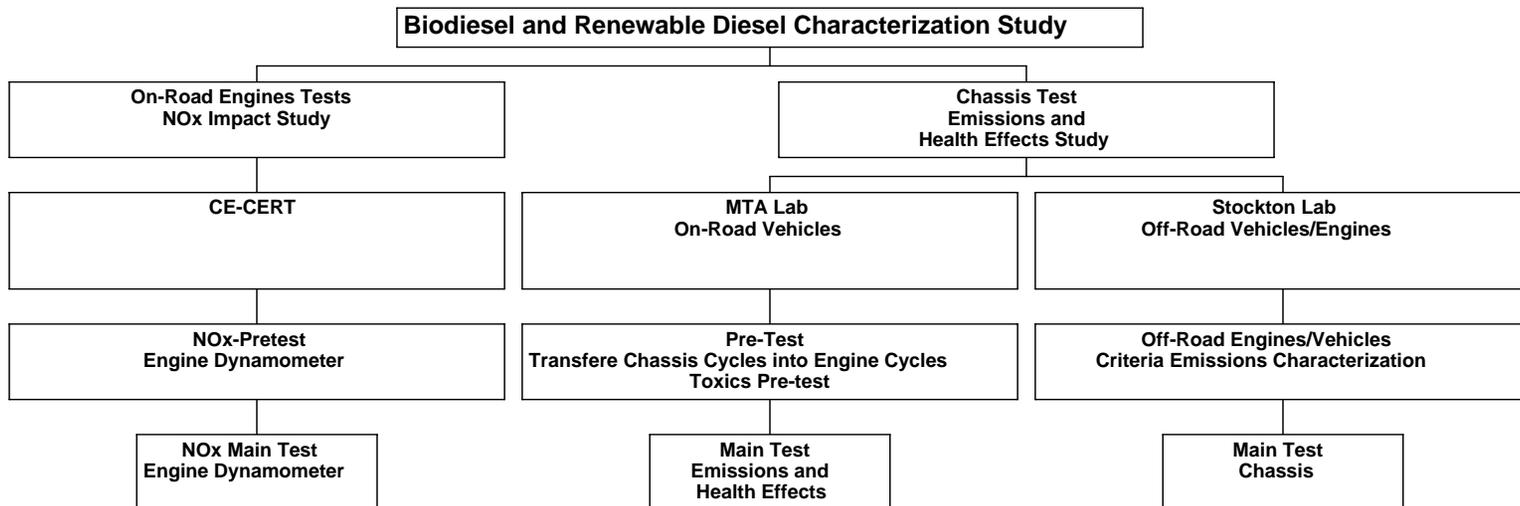
- Task 1: Biodiesel and Renewable Diesel Characterization Study
 - Unregulated emissions and health effects
 - NOx Impact
- Task 2: NOx Mitigation Study
 - Phase one
 - Phase two

Biodiesel/Renewable Diesel Research Study

Test Design: Biodiesel and Renewable Diesel Characterization Study



Biodiesel and Renewable Diesel NOx Impact Study



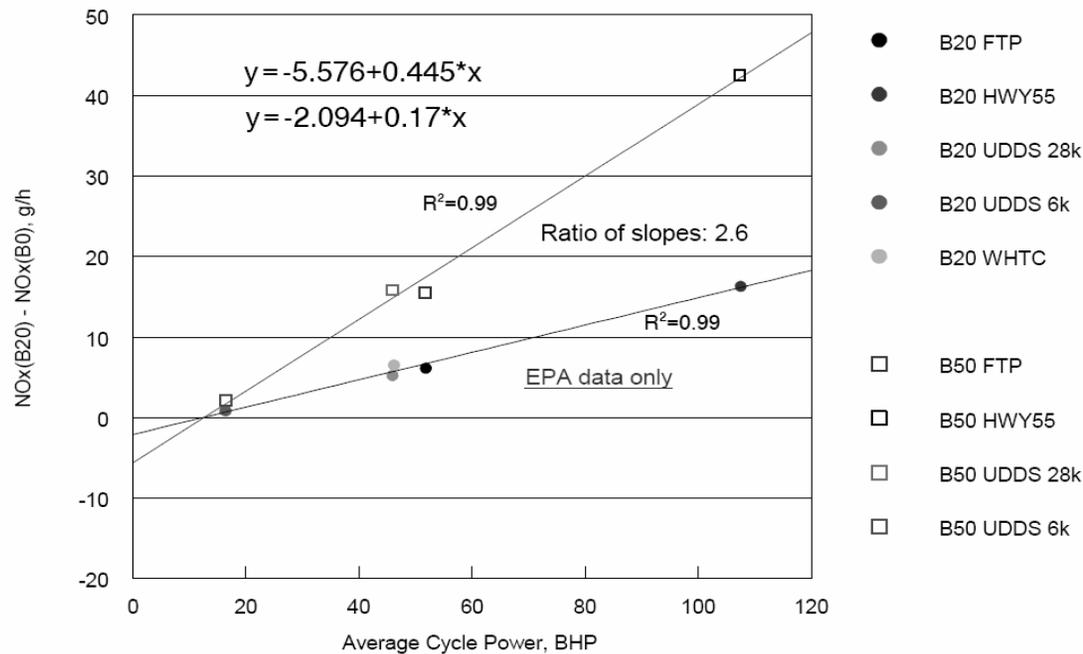
Test Design Considerations

Possible Biodiesel NOx Impacts

- Evaluate test cycle load effects on NOx
- Evaluate biodiesel level effects on NOx

Biodiesel NOx Effect-Average Cycle Power

Figure 1: B20 and B50 Effects on NOx Emissions
MY 2004 Cummins ISB Engine



- EPA CBET Program

CE-CERT NOx Pre-test

- Test cycle and replicates:
 - Minimum of 9 FTP replicates of CARB diesel on day one and 9 replicates of biodiesel on day two
 - Additional test days may be required
- Test Pattern:
 - Minimum of 9 FTP replicates of CARB diesel on day one and 9 replicates of biodiesel on day two
 - Additional tests maybe run on UDDS and HHDT cycles

CE-CERT NOx Impact Study: Main Test

- Build upon USEPA and NREL studies
- Test conducted on an engine dynamometer
 - Engine dynamometer is suited to conduct the NOx impact study
 - Provides precision necessary to distinguish small differences in NOx i.e. 2% change at B20
- Engines
 - 2006 Cummins ISM and 2007 engine
- Test cycles
 - FTP, UDDS light, HHDDT cruise

CE-CERT Main Test

- Fuels:
 - Biodiesel: two feedstocks at four blend levels: B5, B20, B50, and B100
 - Renewable diesel at three levels: R20, R50, and R100
- Optional unregulated emissions testing:
 - VOCs, 1,3-butadiene, and carbonyls
 - Limited ultra-fines

Revised CE-CERT Main Test

- Revised test matrix designed to better measure small differences between CARB and test fuels
 - Closer pairing of CARB fuel and test fuels
 - Account for differences in morning and afternoon testing
 - Testing all three test cycles in one day

Revised CE-CERT Main Test

- Emission differences are expected to be lower for the 2007 engine and lower blend levels especially at the 5% blend level
- Low blends and the 2007 engine may require more test replicates
- Test matrix designed to take this into consideration
 - Split out B5 testing
 - Split tests of other fuels into main and supplemental testing
 - Evaluation of main test results will determine if the supplemental tests need to be conducted

Emissions Characterization

Chemical species	Sampling method	Sampling schedule	Vehicle test cycle
Nitrogen Oxides	Direct Chemilumescence (CLM)	All tests	UDDS, FTP, ARB Hwy
NO:NO ₂	Direct Duel CLM	All tests	UDDS, FTP, ARB Hwy
Total hydrocarbons	Direct/Tedlar Bag FID	All tests	UDDS, FTP, ARB Hwy
Carbon monoxide	Direct/Tedlar Bags NDIR	All tests	UDDS, FTP, ARB Hwy
Carbon Dioxide	Direct NDIR	All tests	UDDS, FTP, ARB Hwy
Particulate matter	Filters	All tests	UDDS, FTP, ARB Hwy
Ultra-fines	Direct	TBD	UDDS, FTP, ARB Hwy

CE-CERT Main Test (Revised)

- Test pattern for both biodiesel feedstocks and engines

Main program

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

Supplemental

Day 1		Day 2		Day 3		Day 4		B5 Day 1		Day 2	
Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle
CARB	A	B20	A	B50	A	B100	A	CARB	C	B20	C
	B		B		B		B		C		C
	C		C		C		C		C		C
B20	A	B50	A	B100	A	CARB	A	B5	C	CARB	C
	B		B		B		B		C		C
	C		C		C		C		C		C

CE-CERT Main Test (Revised)

Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7		Day 8		Day 9			
Fuel	Cycle																		
CARB	A	R20	A	R50	A	CARB	A	R100	A	R20	A	CARB	A	R50	A	R100	A		
	B		B		B		B		B		B		B		B		B	B	B
	C		C		C		C		C		C		C		C		C	C	C
R20	A	R50	A	CARB	A	R100	A	R20	A	CARB	A	R50	A	R100	A	CARB	A		
	B		B		B		B		B		B		B		B		B	B	
	C		C		C		C		C		C		C		C		C	C	C

Day 1		Day 2		Day 3		Day 4	
Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle
CARB	A	R20	A	R50	A	R100	A
	B		B		B		B
	C		C		C		C
R20	A	R50	A	R100	A	CARB	A
	B		B		B		B
	C		C		C		C

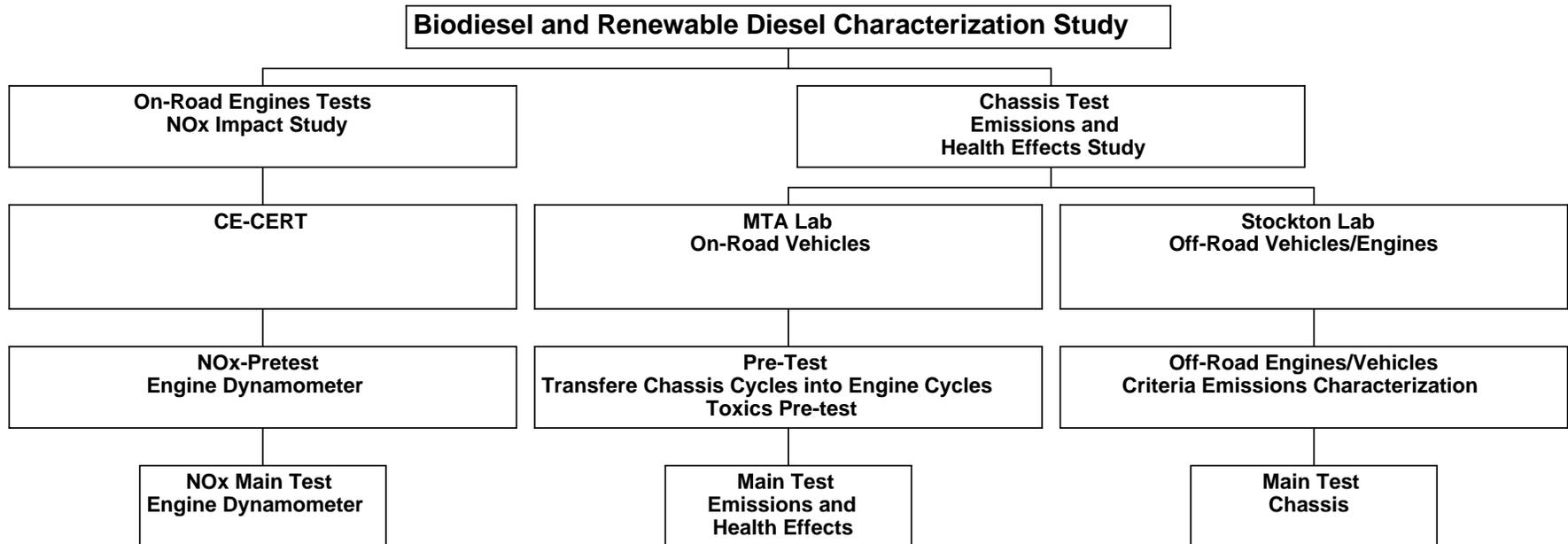
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- No testing on R5
- Renewable diesel tested only on 2006 Cummins ISM engine

Discussion

Biodiesel/Renewable Diesel Research Study

On-Road Biodiesel and Renewable Diesel Characterization Study Conducted at ARB's Heavy Duty Dynamometer Facility's (MTA) Chassis Dynamometer Test Laboratory in Los Angeles



On-Road Biodiesel and Renewable Diesel Characterization Study

- Objective:
 - Test on-road vehicles
 - Emissions and health effects characterization
 - In-depth toxics characterization
 - Greenhouse gas emissions
 - Ultrafines and other species
- Conducted at MTA

Linking Engine and Chassis Dynamometer Emission Tests Results

- Test an engine on a chassis dynamometer and then test the same engine on a engine dynamometer using the same test cycle
- Two of the test cycles will be used on both engine and chassis tests

Update: Un-regulated On-Road Characterization Study - Emissions Characterization

- Eliminate 5% blend level fuels from test matrix
 - Variability much greater in chassis testing making it difficult to discern differences at the 5% blend level

Emissions Characterization

Chemical species	Sampling method	Sampling schedule	Vehicle test cycle
Nitrogen Oxides	Direct Chemilumescence (CLM)	All tests	UDDS, ARB Hwy
NO:NO ₂	Direct Dual CLM	All tests	UDDS, ARB Hwy
Total hydrocarbons	Direct/Tedlar Bag FID	All tests	UDDS, ARB Hwy
Carbon monoxide	Direct/Tedlar Bags NDIR	All tests	UDDS, ARB Hwy
Carbon Dioxide	Direct NDIR	All tests	UDDS, ARB Hwy
Particulate matter	Filters	All tests	UDDS, ARB Hwy
Ultra-fines	Direct	All tests	UDDS, ARB Hwy

Emissions Characterization

Chemical species	Sampling method/Analytical method	Sampling schedule	Vehicle test cycle
Carbonyls	DNPH coated cartridges HPLC/LCMS	General	UDDS, ARB Hwy
VOCs	Tedlar Bags GC/FID	General	UDDS, ARB Hwy
1,3-butadiene	Tedlar Bags GC/FID	in-depth	UDDS
Nitrous Oxide	Tedlar Bags/FTIR	in-depth	UDDS
EC/OC	Quartz filters Thermo-optical analyzer	in-depth	UDDS
Ions	Teflon filters Ion chromatography	in-depth	UDDS
Elements	Filters TBD	in-depth	UDDS
PAHs	Filters/PUF/XAD GC/MS	in-depth	UDDS
nitro-PAHs	Filters/PUF/XAD GC/NCIMS	in-depth	UDDS
Unsaturated Carbonyls	Bisulfite mist chamber GC/NCIMS	in-depth	UDDS

Emissions Characterization

Biological Test	Sampling method	Bioassay/biological endpoints	Sampling schedule	Vehicle test cycle
Mutagenicity	Filters/PUF	TA98 +/-S9 TA100 +/-S9 TA102 (selected samples) TA104 (selected samples)	in-depth	UDDS
DNA damage	Filters	Comet assay	in-depth	UDDS
Oxidative stress and inflammation	Filters	Human lung and macrophage assays: Inflammatory cytokines: IL-8 & TNF Prostaglandin synthase COX-2 Heme oxygenase-1 HO-1 C reactive protein	in-depth	UDDS

In-Depth Emissions Characterization

In -depth		A	B
Vehicle 1			
TB		1	
CARB		3	0
SoyB20		3	0
SoyB50		3	0
SoyB100		3	0
TB		1	
CARB		3	0
AnB20		3	0
AnB50		3	0
AnB100		3	0
TB		1	
CARB		3	0
R20		3	0
R50		3	0
R100		3	0
TB			
Totals		39	0
Vehicle 2			
TB		1	
CARB		3	0
SoyB20		3	0
SoyB50		3	0
SoyB100		3	0
TB			
Totals		13	0

- Test only UDDS (A)
- Applies to all chemical species and biological assays except carbonyls, VOCs, and ultrafines
- Vehicle one equipped with 2006 ISM
 - Test all blend levels-CARB, 20, 50, and 100 percent
 - Test all feedstocks
- Vehicle two equipped with 2007
 - Test all blend levels
 - Test only soy feedstock

Emissions Characterization of Carbonyls and VOCs

General		Vehicle 1		Vehicle 2		Vehicle 3		Vehicle 3r	
		A	B	A	B	A	B	A	B
TB		1	1	1	1	1	1	1	1
CARB		3	3	3	3	3	3	3	3
SoyB20		3	3	3	3	3	3	3	3
SoyB50		3	3	3	3	0	0	3	3
SoyB100		3	3	3	3	3	3	3	3
TB		1	1	1	1	1	1	1	1
CARB		3	3	3	3	3	3	3	3
AnB20		3	3	3	3	3	3	3	3
AnB50		3	3	0	0	0	0	0	0
AnB100		3	3	3	3	3	3	3	3
TB		1	1	1	1	1	1	1	1
CARB		3	3	3	3	3	3	3	3
R20		3	3	3	3				
R50		3	3	3	3				
R100		3	3	3	3				
TB									
Totals		39	39					21	21

- Vehicle one (2006 ISM): Test UDDS (A) and ARB Hwy (B) cycles
 - Test all blend levels and feedstocks
- Vehicle two (2007)
 - Test all blend levels
 - Test only biodiesel feedstocks
- Vehicle three with and without aftertreatment
 - Test A and B cycles
 - Test only biodiesel feedstocks
 - Test only CARB, B20, and B100

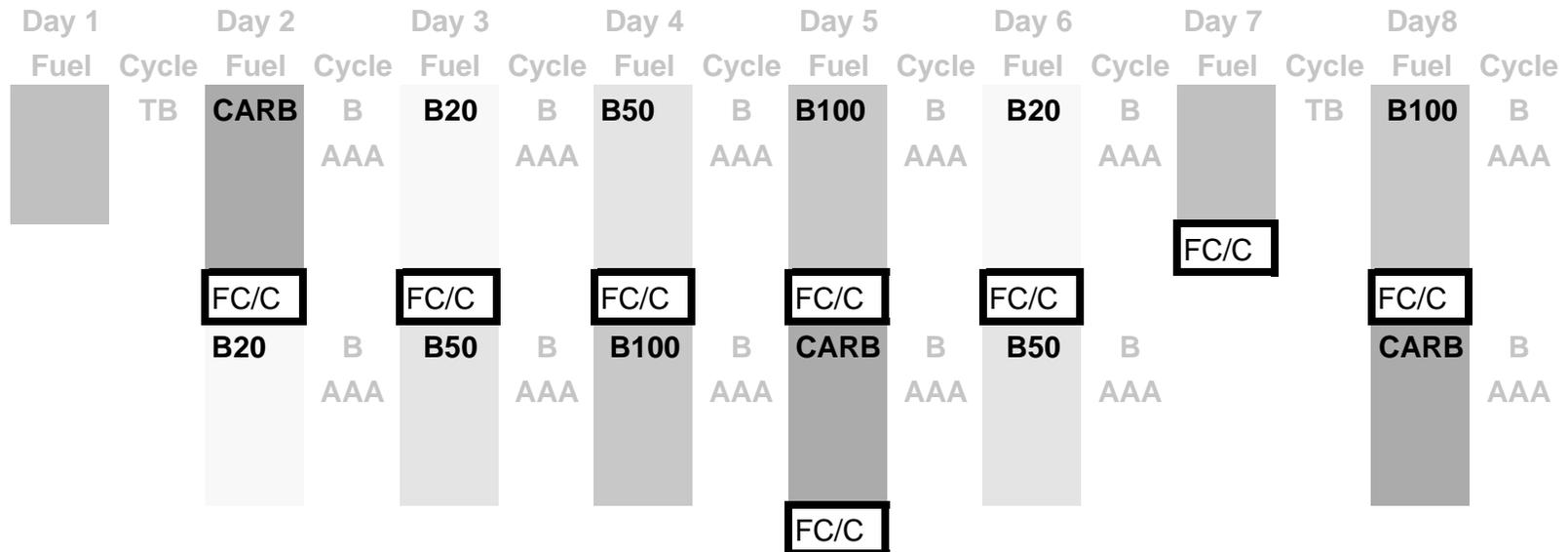
Un-regulated On-Road Characterization Study - Emissions Characterization

- Vehicle one: 2006 Cummins ISM engine
- Test matrix soy feedstock
- Applies to second biodiesel feedstock and renewable diesel

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
Fuel							
	CARB	B20	B50	B100	B20		B100
TB	B	B	B	B	B		B
	AA	AA	AA	AA	AA		AA
	FC/C						
	B20	B50	B100	CARB	B50		CARB
	B	B	B	B	B		B
	AA	AA	AA	AA	AA		AA
				FC/C			

Un-regulated On-Road Characterization Study - Emissions Characterization

- Vehicle 2 equipped with 2007 engine
- Soybased biodiesel
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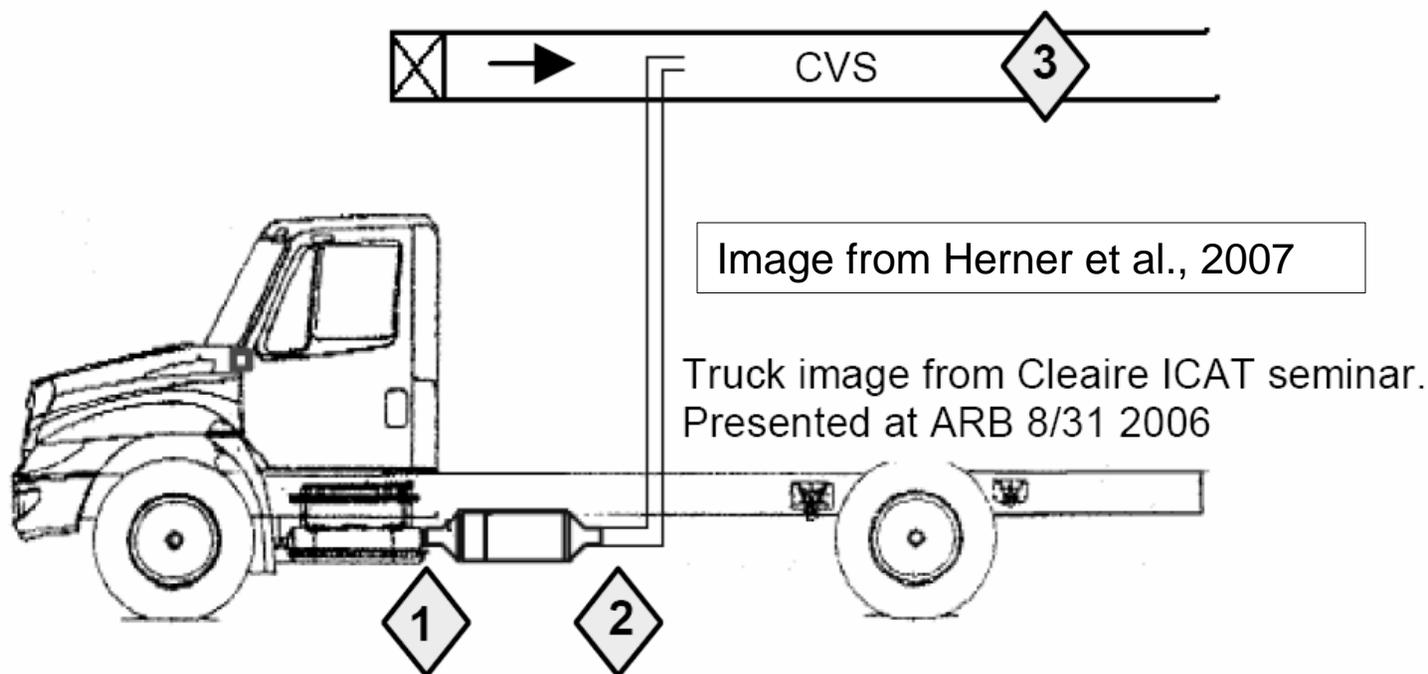
Other Issues

- Discussed in detail at a later meeting
- QA/QC
 - QA samples
 - Dilution tunnel considerations
 - Sampling and analytical
 - Data review and tracking
- Data Reduction

Ultrafine Particles Measurements

- Will be mainly conducted during vehicle testing
 - Particle Number
 - Particle Size Distribution
 - Real-time Mass
 - Surface Area
- European PMP protocol will be considered
- Sampling from CVS dilution tunnel for all three vehicles
- Pre-trap and post-trap partial flow sampling will also be conducted for vehicle 3 w/ aftertreatment configuration

Ultrafine Particles Sampling Locations



- 1: Pre-trap partial flow sampling: vehicle 3 w/ aftertreatment only
- 2: Post trap partial flow sampling: vehicle 3 w/ aftertreatment only
- 3: Full flow sampling (post trap): all vehicles

Recommended PMP Sampling System

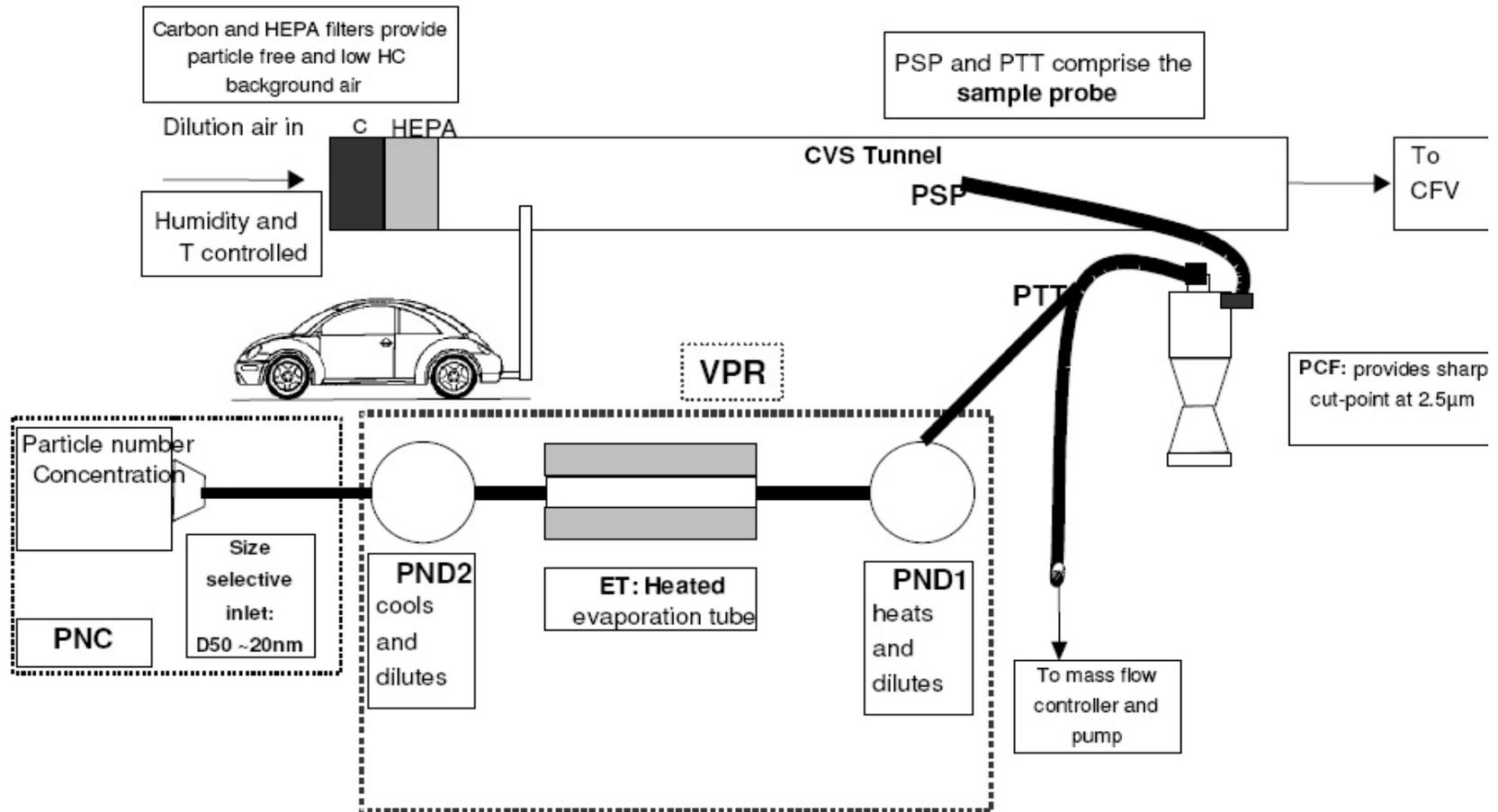
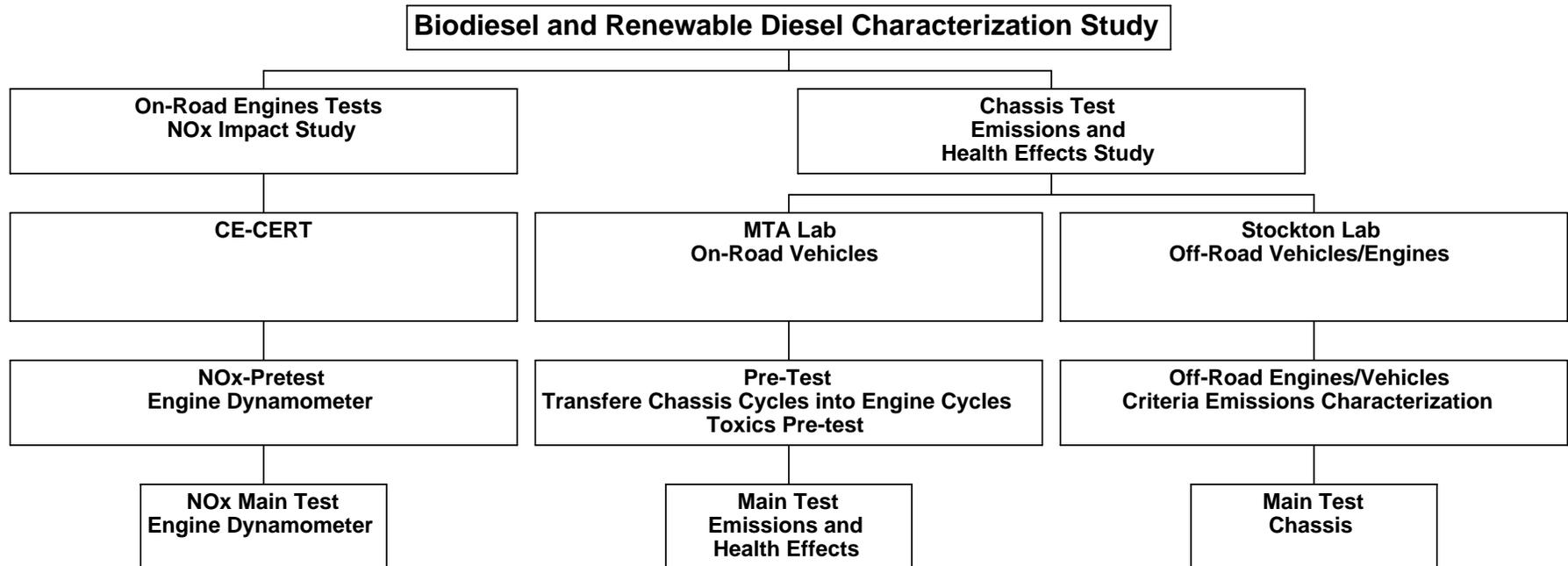


Image from OICA, 2007

Discussion

Off-Road Characterization Study- Emissions Characterization



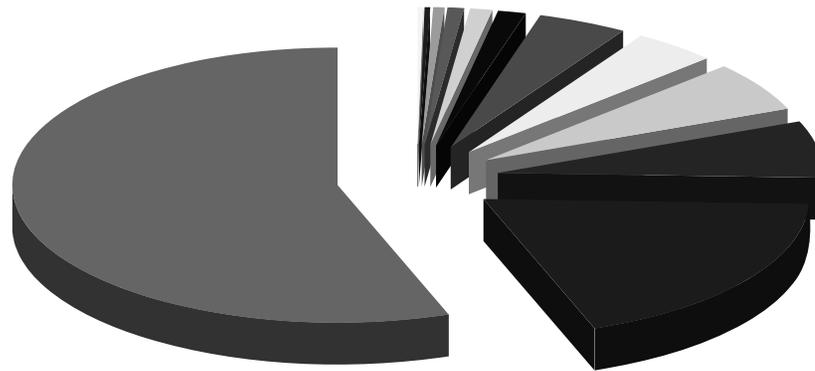
Off-Road Characterization Study- Emissions Characterization

- ARB's emissions test facility in Stockton
- Propose test design
 - Two Vehicles/Engines-TBD
 - Criteria emissions only
 - Two biodiesel feedstocks and four blend levels B5, B20, B50, B100 compared to CARB diesel
 - Three renewable diesel blends R20, R50, and R100 compared to CARB diesel
 - Eight mode steady state
- Detailed test matrix presented at next meeting

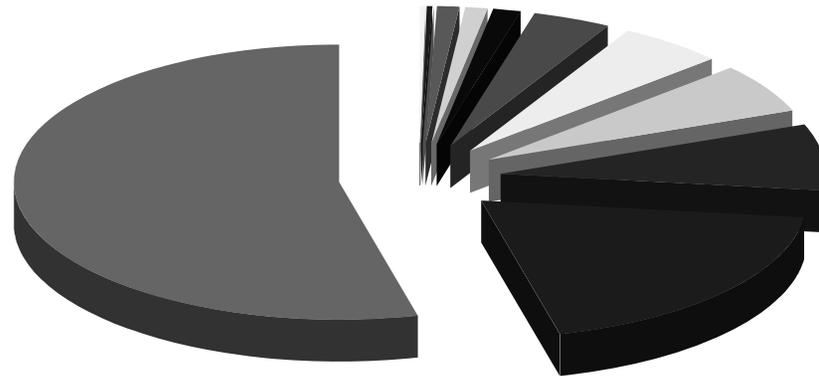
Off-Road Equipment

- Top Emission Contributors
 - Construction & mining equipment (~55%)
 - Agriculture equipment (~20%)
- Issues:
 - Speed limitation of Stockton Chassis Dyno: 25 mph
 - Most construction and agriculture equipment cannot run higher than 25 mph

Off-Road Diesel NOx Emission Inventory (2007)



Off-Road Diesel PM Emission Inventory (2007)



Discussion

Test Schedule-Test Plan

- Fall 2007
 - Test design
 - Biodiesel/renewable diesel advisory group, stakeholders
 - Collaborators: working with stakeholders in obtaining in-kind contribution and funding for the study
 - Test protocol

Test Schedule-Logistics

Fuels

- Estimated time line
 - Delivery of CARB and biodiesel fuels in December
 - Delivery of renewable diesel fuel in January-February
 - Blend fuels biodiesels in December-January
 - Blend renewable diesel fuels in January-February
 - Fuel specifications conducted by independent laboratory

Test Schedule-Logistics

- Engines/vehicles
 - Purchased truck equipped with a 2006 Cummins ISM engine in November
 - Truck equipped with a 2007 C15 Caterpillar engine will be available in February for testing
 - Discussions on second engine is ongoing
 - Other vehicles are also being considered

Test Schedule-Pretests

- MTA emissions characterization pretest, December 2007-January 2008
- CE-CERT pre-test-January 2008

Test Schedule-Main Tests

- Biodiesel and renewable diesel characterization study
 - NOx impact study (CE-CERT)
 - Engine one-January-February
 - Engine two-March-April
 - Phase one NOx mitigation study Summer 2008
 - On-road vehicle characterization study (MTA)
 - Feb-May 2008
 - Stockton-off-road vehicle study
 - Start in 2008
 - NOx Mitigation Study
 - CE-CERT Phase one
 - MTA Phase two

Discussion

Test Design: Diesel NOx Mitigation Study

Biodiesel and Renewable Diesel NOx Mitigation Study

**Engine Dynamometer
CE-CERT
Phase One**

**Engine Dynamometer
MTA
Phase Two**

NOx Mitigation Study – Phase One

- Conducted at CE-CERT
- Collaborate with CRC
- Evaluate four strategies
- Selection Considerations
 - Data supporting the effectiveness of strategy
 - Feasibility to be commercially relevant
 - Compatibility with existing infrastructure

NOx Mitigation Study – Phase One

- Additives
- Match blending properties
- Biodiesel/renewable diesel blends
- Renewable diesel
- Engine re-calibration

Stakeholders Suggested NOx Mitigation Strategies

- Water/biodiesel/diesel emulsified fuels
- Viscon additive

NOx Mitigation Study - Phase Two

- Conducted at MTA
- Select most successful NOx mitigation strategies
 - Confirmation engine
 - Conduct more in-depth study
 - Needs to be fleshed out
 - Limited toxics tests
- Evaluate other strategies if necessary

Discussion

Light-Duty Diesel Vehicle Testing

- To be collaborated with Research Division Light-Duty Test Program
- Two vehicles
 - One passenger car
 - One pick-up truck/SUV/minivan
- Plan to start test in August 2008

Other Research

- Durability Study
- Will be discussed in detail in upcoming meetings

In Kind Contributions

- Fuels
 - US EPA diesel fuel
 - Biodiesel and biodiesel blends
 - Storage (long term)
 - Fuel analysis
- Engines
- Vehicles
- Other

Future Discussion Topics

- UL certification of biodiesel pumps
- Guidelines for converting a diesel engine to biodiesel

Biodiesel and Renewable Diesel Advisory Group

- Next meeting in January/February