Biodiesel and Renewable Diesel Research Study

October 5, 2007

California Environmental Protection Agency

Air Resources Board

Introductions

Agenda

- Introduction
- Summary of previous workgroup discussions
  - Fuels
  - Storage
  - Engine selection
- Vehicle selection
- Test design
- Test matrix
- Test schedule
- 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.

Background

- 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
  - 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"

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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

Proposed Fuel Storage

- All fuels will be stored under the same conditions
- Fuels will be stored in barrels with inert liners i.e. epoxy and under nitrogen
- Long term storage will be in-doors
- Long term storage will only be of the finished fuels and fuel blends
- Short term storage will be at CE-CERT and to a lesser extent at the other test facilities

Proposed Fuel Blending

- Gravimetric blending of fuels
  - Totes or barrels
  - Requires multiple batches if barrels are used
  - Ensure proper mixing of feedstocks
- CE-CERT will conduct the blending
- Confirmation of biodiesel blend levels by proposed ASTM 7371-07 mid infrared spectroscopy test method
- Renewable diesel confirmation test method needs to be determined I.e. Specific gravity

Proposed Biodiesel Feedstocks and Fuels

- Feedstock one: soy
- Feedstock two
  - Bracket range of biodiesel feedstock properties
  - NOx: higher in saturated fatty acid esters and higher Cetane than soy I.e. palm oil and animal fat
  - Toxics: animal fats and recycled grease have the potential to have different toxic emissions than vegetable oils
- If possible avoid additives
  - May be difficult to separate the effects of the additives from the fuel
  - No standard additive used

Proposed Biodiesel Diesel Feedstocks and Blends (cont)

- Four blends levels: B5, B20, B50, B100
- ASTM D6751 and BQ9000 compliant

Proposed Storage Stability Criteria

- Revised estimated storage time will be less than one year
  - May allow for one batch of each feedstock to be used for the test
- Use biodiesel feedstocks with high oxidative stability to increase storage life will
  - Minimum Rancimat number of 6 hours
- Only finished fuels will undergo long term storage
- Conduct quarterly stability tests for biodiesel fuels and biannual stability tests for CARB and renewable diesel
- No anti-oxidants will be added

Proposed CARB Diesel

- Commercial fuel with specifications similar to average CARB diesel fuel
  - 53 cetane
  - 15 ppm sulfur
  - 20 percent aromatics

Proposed Renewable Diesel

- One renewable diesel feedstock
- Two blend levels: R20 and R50
- Finished blend must meet ASTM D975 specifications
- If possible avoid additives
  - May be difficult to separate the effects of the additives from the fuel
  - No standard additive used

Proposed Test Engines

- Two Engines will be tested
- Engine horsepower rating
  - 400-550 hp is the middle range
  - Cannot exceed 600 hp and 1575 torque due to engine dynamometer limitations
- Engine with the greatest market share
  - Caterpillar, Cummins, Detroit Diesel
- Propose:
  - 2002-2004 engine
  - 2007 engine

Proposed Test Engines

- Process of obtaining diesel engines
  - 2006 diesel engine
  - 2007 14 L Detroit Diesel series 60

Additional Parameters

- Lube oil
- Engine parameters

Toxics Testing Update

- Elements: Filter/XRF or ICP/MS
- Chromium and Chromium (VI)

Discussion

Vehicle Selection Considerations

- Emissions for PM and NOx
  - The pool of test vehicles will cover the range of major diesel emitters in California
  - Mix of heavy-duty and medium duty
- Market Share
- Chassis Dynamometer Limitations
  - Max weight rating of 100,000 lbs and 660 hp

Contribution of NOx and PM Emissions from On-Road Diesel Vehicles by Vehicle Classes

Pollutant	NOx			PM10		
CalYr	2007	2012	2017	2007	2012	2017
HHD	**75.3**	**74.2**	**72.2**	**85.0**	**81.8**	**76.9**
MHD	**13.5**	**13.3**	**12.5**	**9.4**	**11.3**	**13.9**
BUS	**4.6**	**6.0**	**8.1**	**1.7**	**2.2**	**3.1**
LHD2	2.2	2.3	2.5	0.6	0.7	0.8
LHD1	2.9	2.7	3.1	0.6	0.7	0.9
MDV	0.1	0.1	0.1	0.1	0.1	0.1
LDT2	0.1	0.1	0.1	0.1	0.1	0.1
LDT1	0.8	0.8	0.8	0.8	0.7	0.7
LDA	0.2	0.1	0.1	0.5	0.3	0.2
MH	0.3	0.4	0.5	0.2	0.2	0.3

NOx and PM Emissions from On-Road Heavy-Heavy-Duty Diesel Vehicles by Model Year Groups

Pollutant	NOx			PM10		
CalYr	2007	2012	2017	2007	2012	2017
Pre-1994	20	11	5	42	23	10
1994-2001	60	50	34	39	38	28
2002-2006	18	24	22	19	32	35
2007-2009	2	12	15	<1	4	7
2010-2017		4	24		3	20

NOx and PM Emissions from On-Road Medium-Heavy-Duty Diesel Vehicles by Model Year Groups

Pollutant	NOx			PM10		
CalYr	2007	2012	2017	2007	2012	2017
Pre-1994	22	15	11	31	19	11
1994-2001	50	44	36	42	36	25
2002-2006	25	28	28	24	28	25
2007-2009	3	10	13	3	13	16
2010-2017		3	12		4	23

NOx and PM Emissions from On-Road Diesel Buses by Model Year Groups

Pollutant	NOx			PM10		
CalYr	2007	2012	2017	2007	2012	2017
Pre-1994	57	57	53	61	57	52
1994-2001	32	31	33	29	29	30
2002-2006	10	9	10	9	9	9
2007-2009	1	2	2	1	4	4
2010-2017		1	2		1	5

Proposed Test Vehicles

- Propose: Three on-road vehicles
  - 2007 HHD:
    - Will also be tested over engine dynamometer
  - 2002-2006 HHD
  - 1994-2001 MHD or Bus?
    - Will be tested with and without an diesel particulate filter
- Engine horsepower rating
  - 400-550 hp for HHD; 250-400 hp for MHD and Bus
- Engine selection based on market share
  - HHD: Cummins, Detroit Diesel, Caterpillar
  - MHD: International, Cummins, Caterpillar
  - Bus: Detroit Diesel, Cummins, DEER

On-Road Vehicles/Engines

- Engine one: 2002-2006 HHD
- Engine two: 2007 HHD
- Vehicle one: 2007 HHD
- Vehicle two: 2002-2006 HHD
- Vehicle three: 1994-2001 bus or MHDV
  - Tested in two configurations with and without a diesel particulate filter

Off-Road Vehicle/Engines

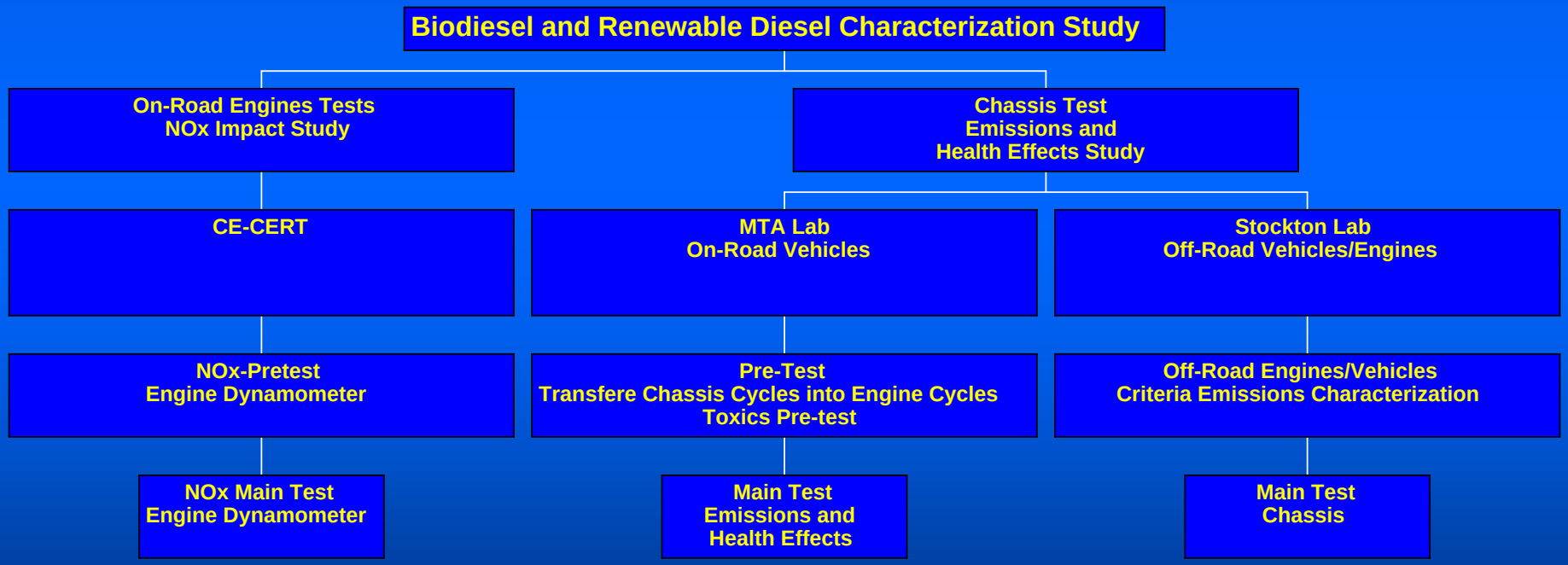
- Discussed at the next Biodiesel and Renewable Diesel Advisory Meeting

Discussion

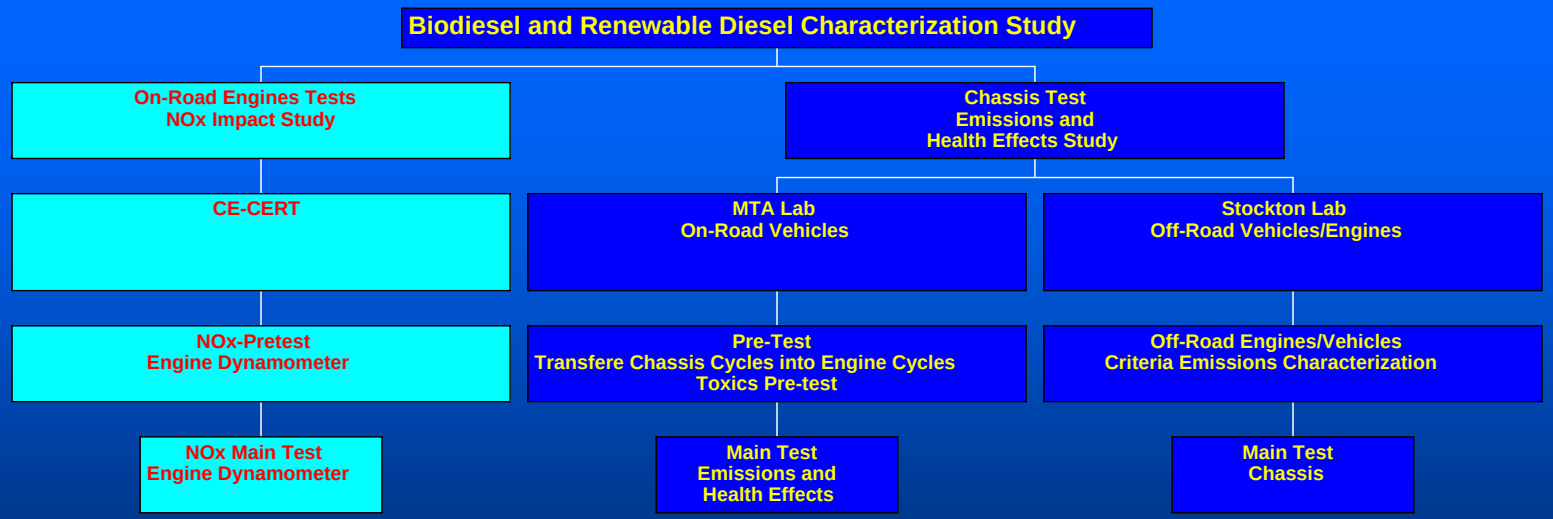
Test Design

- Biodiesel and Renewable Diesel Characterization Study
  - NOx Impact
  - Emissions and health effects
- NOx Mitigation Study
  - Phase one
  - Phase two

Test Design: Biodiesel and Renewable Diesel Characterization Study



Biodiesel and Renewable Diesel NOx Impact Study



Test Design Considerations

Possible Biodiesel NOx Impact

- Biodiesel under certain conditions increase NOx
- Evaluate NOx as compare to average test cycle load (US EPA)
- Evaluate NOx as compared to blend level

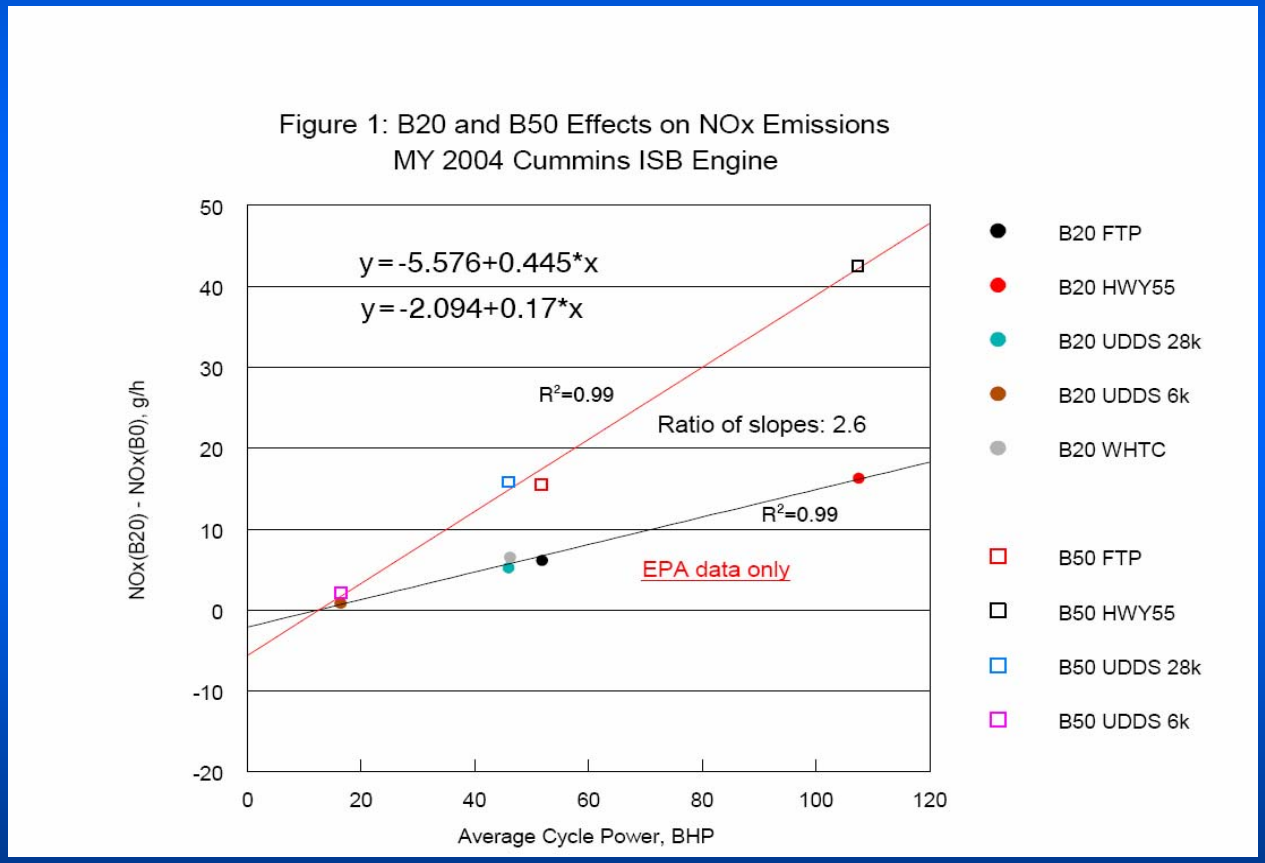
US EPA Biodiesel NOx Evaluation

- Conducted tests on an Cummins ISB engine
- Average cycle load and fuel consumption can explain differences in NOx emissions from biodiesel and diesel fuel
- Engine recalibration may be factor at high average loads
- Reconciles chassis and engine differences
- Need to expand engine sample size

Other Considerations

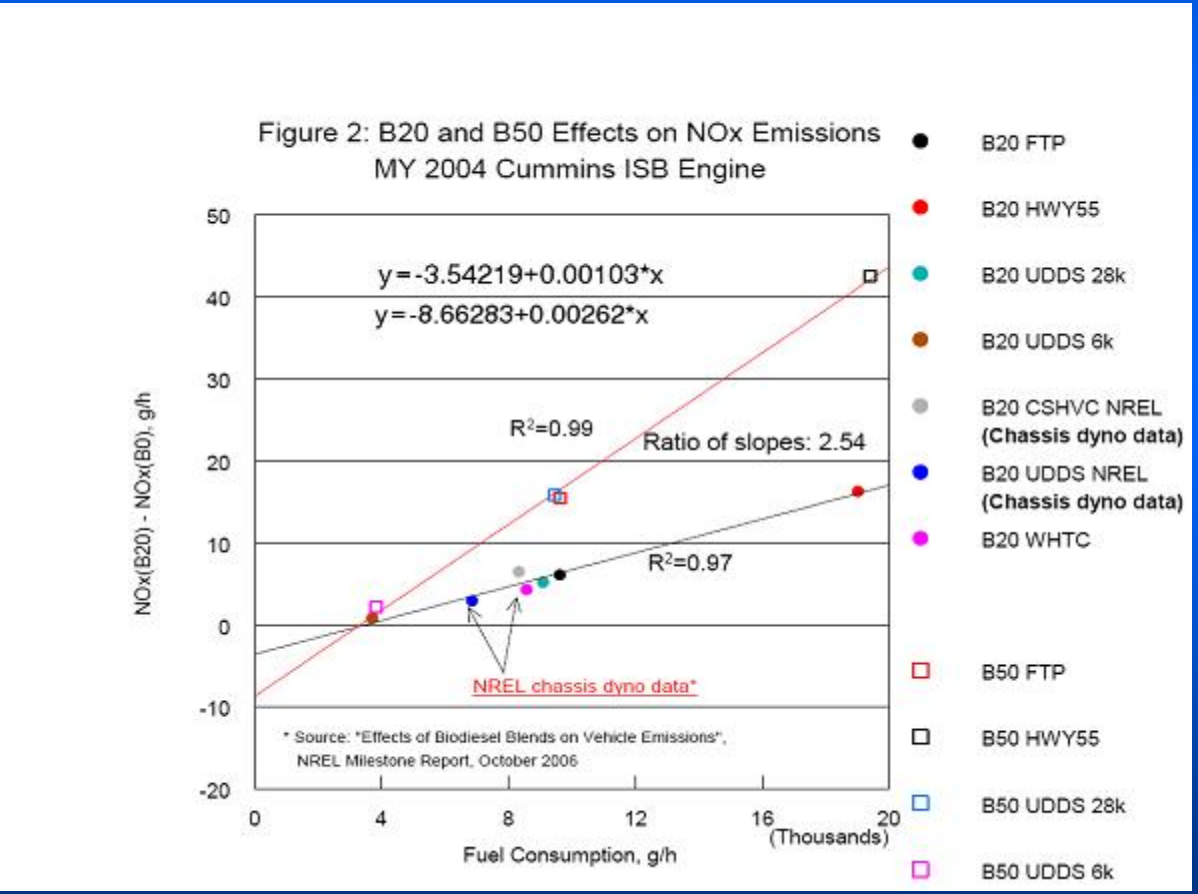
- Meaningful measurement at low biodiesel blend levels
- Random and paired sampling

Biodiesel NOx Effect-Average Cycle Power



- EPA CBET Program

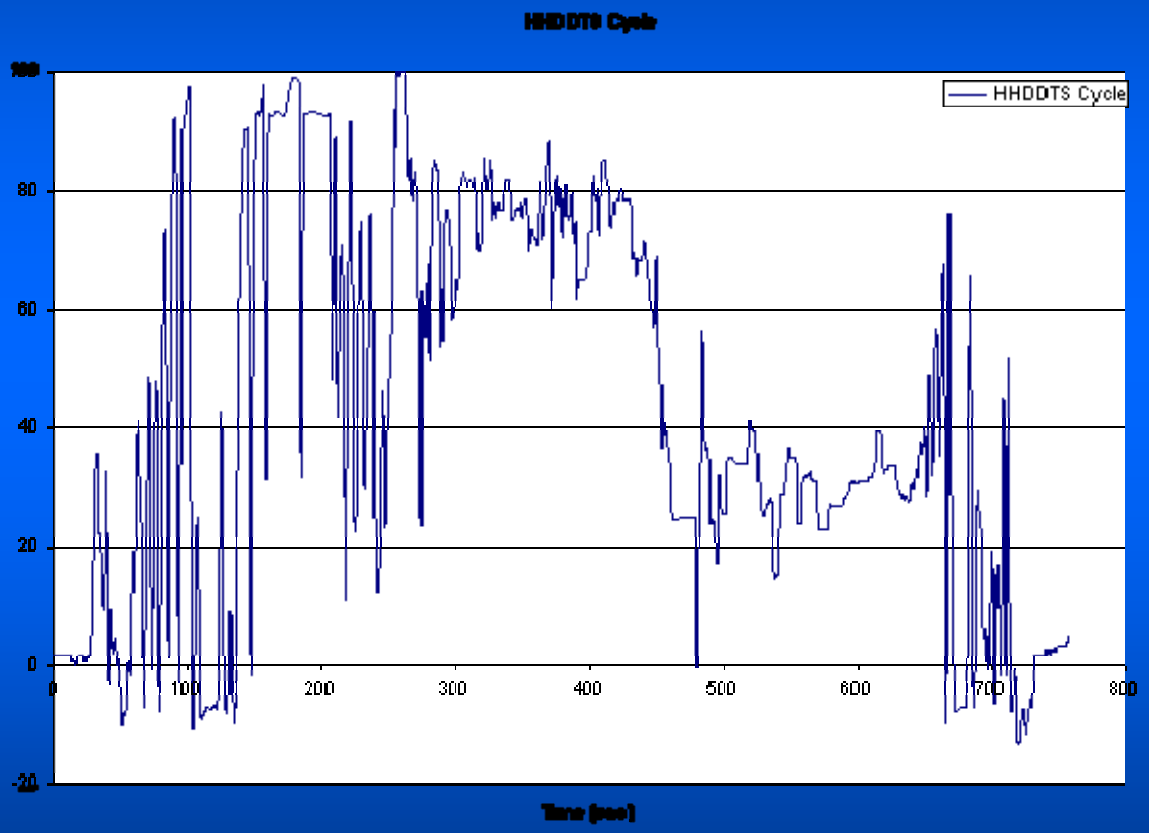
Biodiesel NOx Effect-Fuel Consumption



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 study
  - Provides precision necessary to distinguish small differences in NOx I.e. 2% change at B20
- Engines
  - 2002-2006 and 2007 engine
- Test cycles
  - FTP, UDDS light, HHDDT cruise

50 mph HHDDT Cruise Cycle



CE-CERT Main Test

- Fuels:
  - Biodiesel: two feedstocks at four blend levels
  - Renewable diesel at two levels: R20 and R50
- Toxics and other species:
  - Limited number of unregulated emissions conducted
  - VOCs, 1,3-butadiene, and carbonyls
  - Limited ultra-fines

CE-CERT Main Test (cont)

- Six replicates of each test cycle
- CARB fuel run on days one, four, seven…
- Test fuel blends run days two, three, five, six…
  - Allows for paired testing
  - Minimizes engine drift

CE-CERT NOx Pre-Test

- Scheduled for October-November
- Purpose: Estimate engine drift over a day
  - Needed to determine if the proposed test pattern will meet the precision criteria to measure differences in NOx emissions due to fuel effects
  - Precision criteria used were obtained from the US EPA

  Test intercooler to determine if more replicates can be run in a day
  - Test on DDCs60 help link emissions results to other studies

CE-CERT NOx Pre-test (cont)

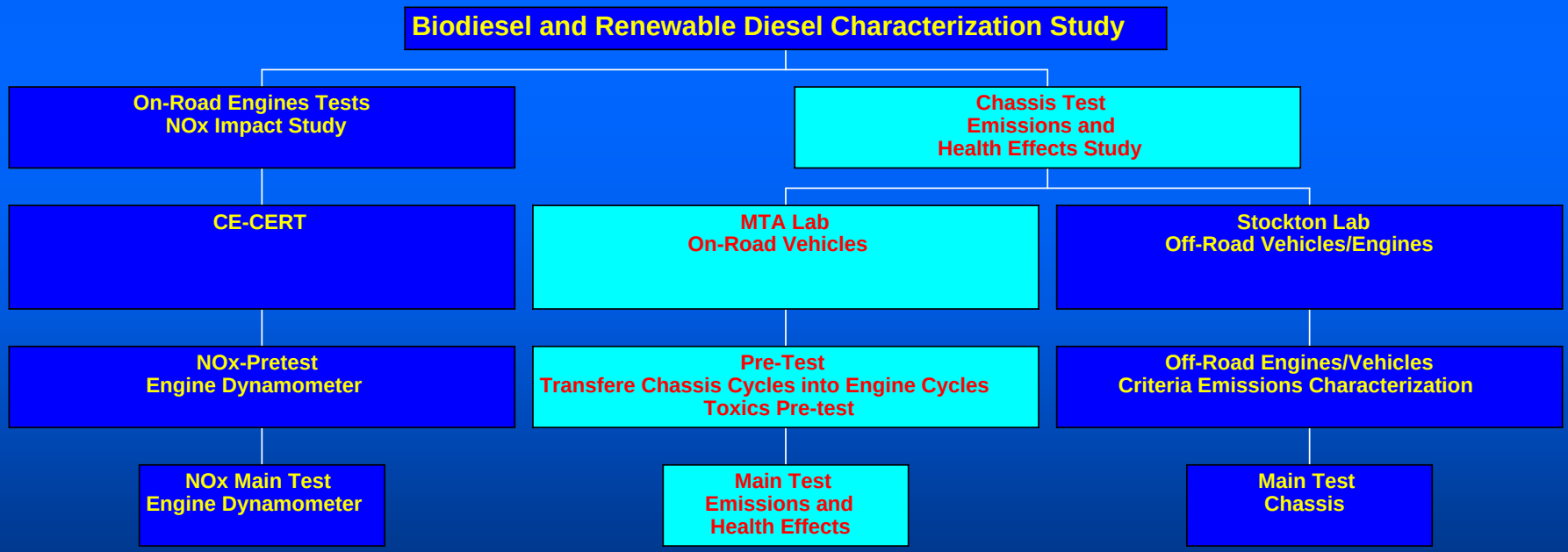
- Test cycle and replicates:
  - Minimum of 9 FTP replicates of CARB diesel on day one and 9 replicates of biodiesel on day two
  - Additional test days may be required
- Test Pattern:
  - Minimum of 9 FTP replicates of CARB diesel on day one and 9 replicates of biodiesel on day two

Discussion

Cal Hodges

"Avoid Data that Hides Behind Error Band"

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

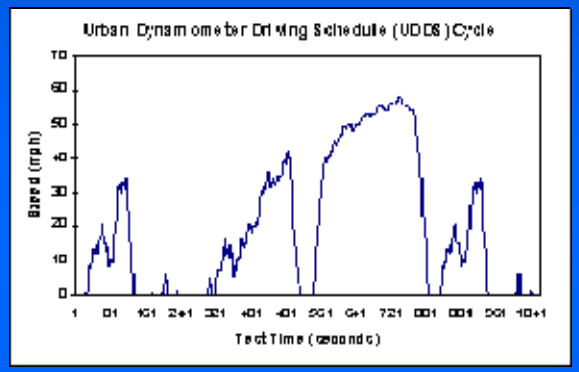
Vehicle Testing

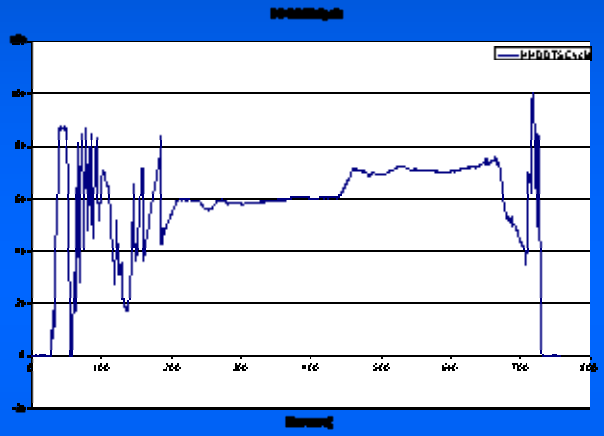
- Advantages:
  - Compliments engine testing
  - Vehicle emissions tests can provide a more real world emissions profile than engine emissions tests
- Disadvantage:
  - Less precision

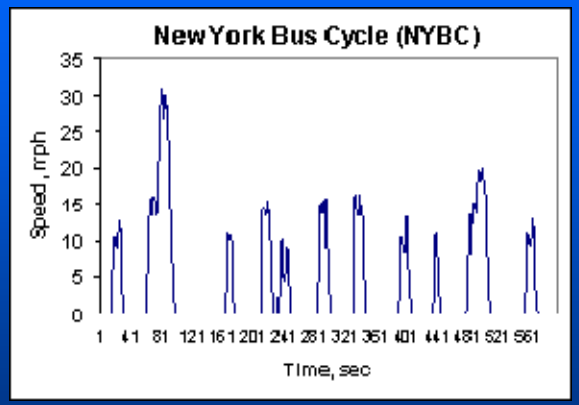
On-Road Biodiesel and Renewable Diesel Characterization Study (On-Road Characterization Study)-Vehicles

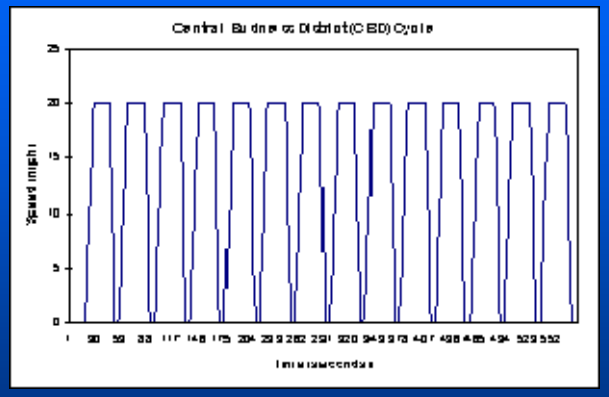
- Three vehicles
  - One of the vehicles will be tested in two configurations-with and without aftertreatment
  - One engine used in the NOx impact study will be installed in one of the vehicles
- Compare two biodiesel feedstocks and four blend levels to CARB diesel
- Compare one renewable diesel at two blend levels to CARB diesel
- Two test cycles-low load and high load
  - Test cycles selection depend on vehicle

Examples of Test Cycles Used for Vehicle Tests









Linking Engine and Chassis Dynamometer Emission Tests Results

- In the US EPA biodiesel test program found a good correlation between chassis and engine dynamometer tests
- 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

On-Road Characterization Study- Emissions Characterization

- Characterize criteria, toxic, greenhouse gas, ultrafine particulates, and other pollutants
- Needed to fill data gaps and evaluate health effects

Un-regulated On-Road Characterization Study - Emissions Characterization

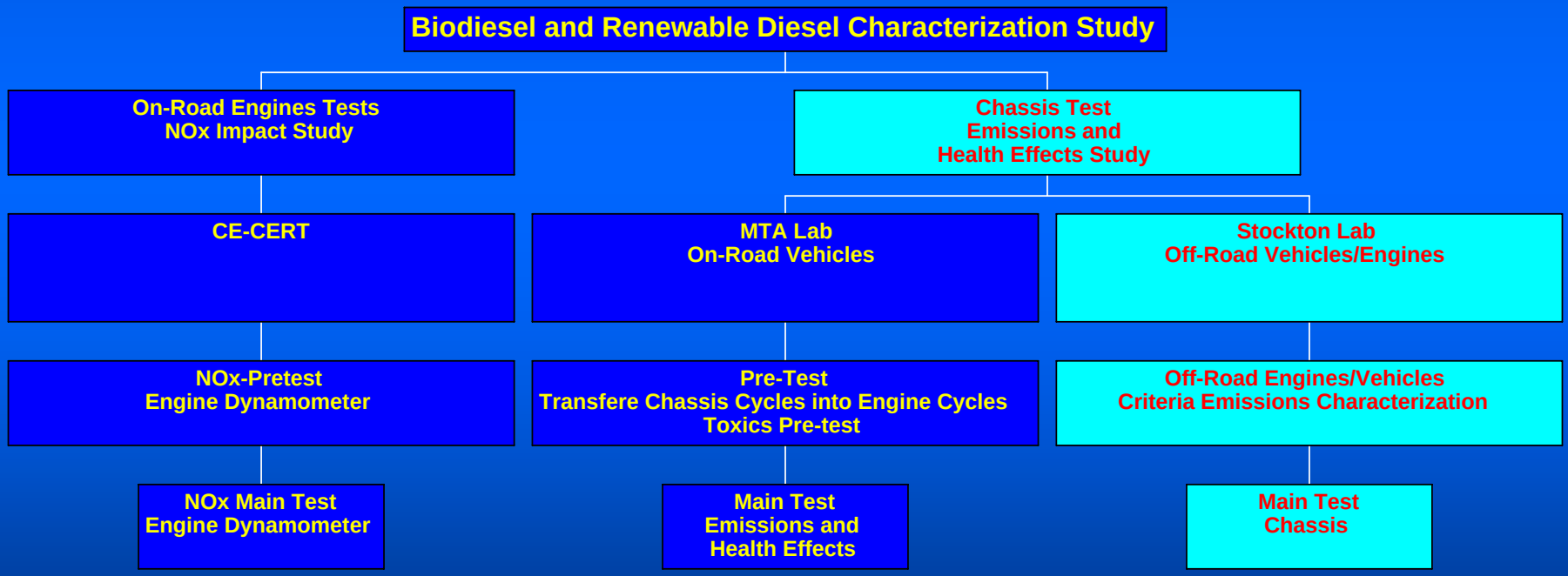
- Toxics evaluated over all test vehicles and fuels, but not all blend levels
  - EC/OC, VOCs, 1,3-butadiene, carbonyls, ions
- In-depth toxics evaluated over two vehicles
  - PAHs, nitro-PAHs, unsaturated carbonyls, elements, and biological tests
  - Conducted on two test vehicles and all fuels but not all blend levels
  - Fewer blends levels
- A proposed test matrix will be given at the next meeting

Characterization Study: Toxics Pre-Tests

- Completed an unsaturated carbonyls pre-test at the Stockton Emissions Test Lab in August
- November MTA pretest
  - Range finding
  - Test sampling systems
  - Obtain chassis test cycle parameters to program into engine dynamometer

Discussion

Off-Road Characterization Study- Emissions Characterization

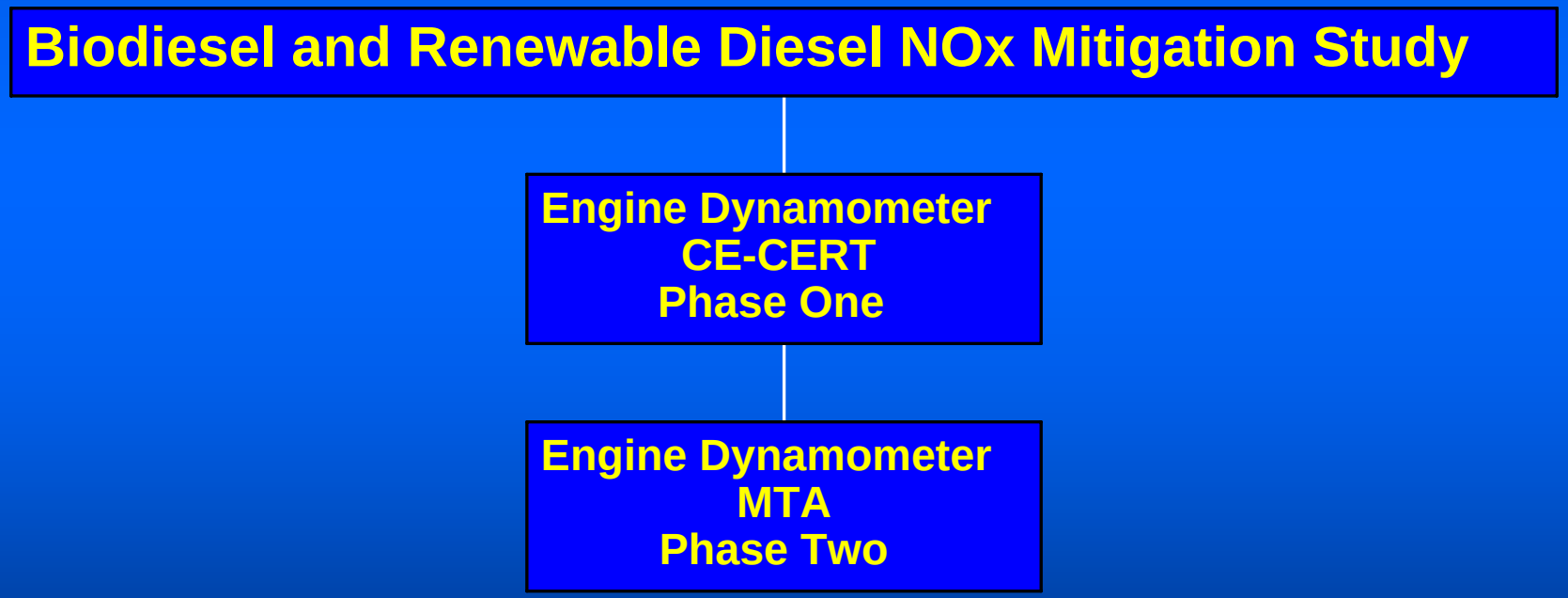


Off-Road Characterization Study- Emissions Characterization

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

Discussion

Test Design: Diesel NOx Mitigation Study



NOx Mitigation Study – Phase One

- Conducted at CE-CERT
- Evaluate four strategies
- Blends from selection
  - Data supporting the effectiveness of strategy
  - Feasibility to be commercially relevant
  - Compatibility with exact infrastructure

NOx Mitigation Study – Phase One

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

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

Test Schedule-Test Plan

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

Test Schedule-Logistics

- Fall 2007
  - Fuels
    - Fuel specifications
    - Obtain fuels, deliver fuels, blend fuels, test fuels, store fuels
  - Engines/vehicles:
    - Criteria and specifications
    - Logistics: obtain engines/vehicles and verify suitability

Test Schedule-Pretests

- CE-CERT NOx Impact pretest, November 2007
- MTA emissions characterization pretest, November 2007
- CE-CERT engine shakedown, December 2007

Test Schedule-Main Tests

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

Discussion

In Kind Contributions

- Fuels
  - CARB diesel fuel
  - US EPA diesel fuel
  - Biodiesel and biodiesel blends
  - Renewable diesel
  - Storage
  - Fuel analysis
- Engines
- Vehicles
- Other

Other Research

- Light-duty vehicles
- Durability Study
- Will be discussed in detail in upcoming meetings

Biodiesel and Renewable Diesel Advisory Group

- Next meeting in November

Presentation by Others

Open Discussion