Literature Review
Historical Perspective

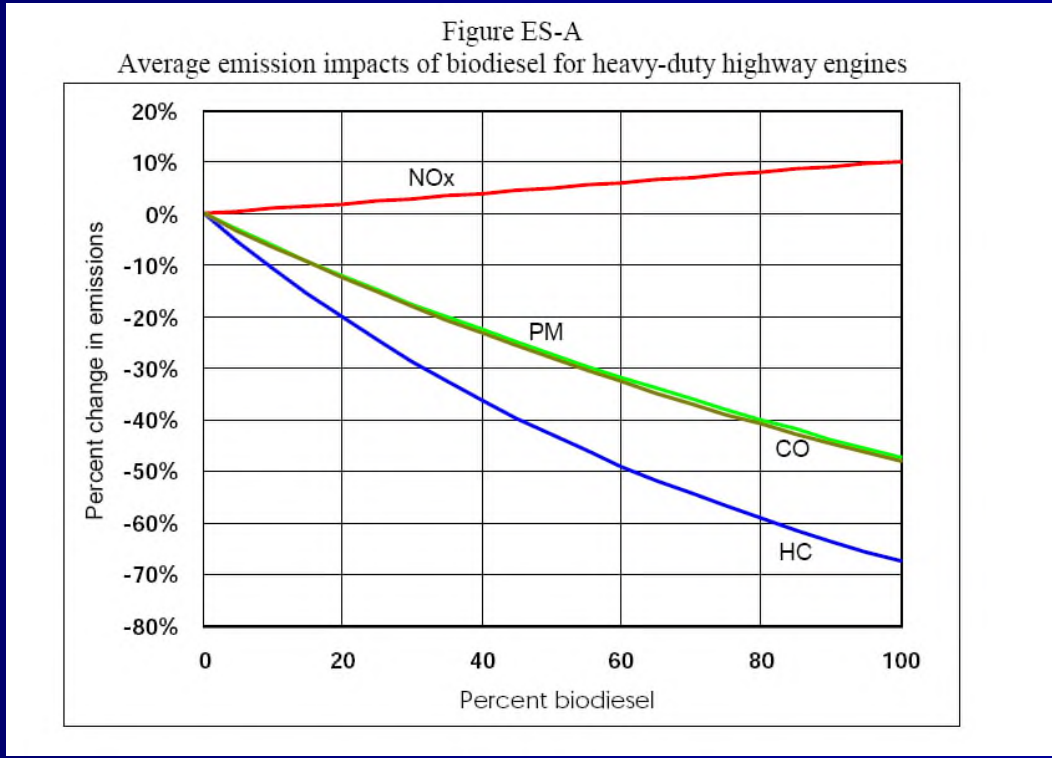
What did we know about the NOx impact of biodiesel use at the start of the biodiesel program?

- Main reference was the EPA Report on the biodiesel impacts on exhaust emissions
  - Comprehensive review of the literature
  - Analysis of impacts based on base fuel, feedstock, engine class, etc.

"A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions" Draft Technical Report EPA420-P-02-001, October 2002 (Draft Technical Report)

Literature Review
Historical Perspective

Figure from Draft Technical Report cited when discussing the NOx impact from biodiesel

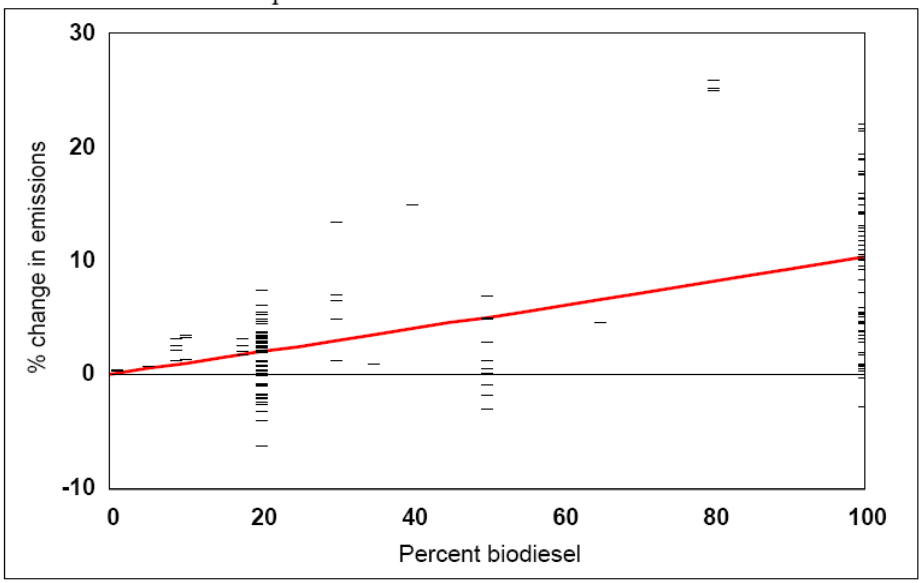


- 2% increase at B20 and 10% increase at B100
- Over all diesel base fuels

Literature Review
Historical Perspective

Not discussed as often is the scatter in the NOx trend line.

Figure IV.A.1-2
Comparison of data to basic NOx correlation



- To explain the range of results, EPA evaluated the effect of various factors such as base fuel and duty-cycle load effects

Literature Review
Historical Perspective

EPA Base Fuel Analysis

Table III.C.2.e-1
Base fuel emission group proposed definitions

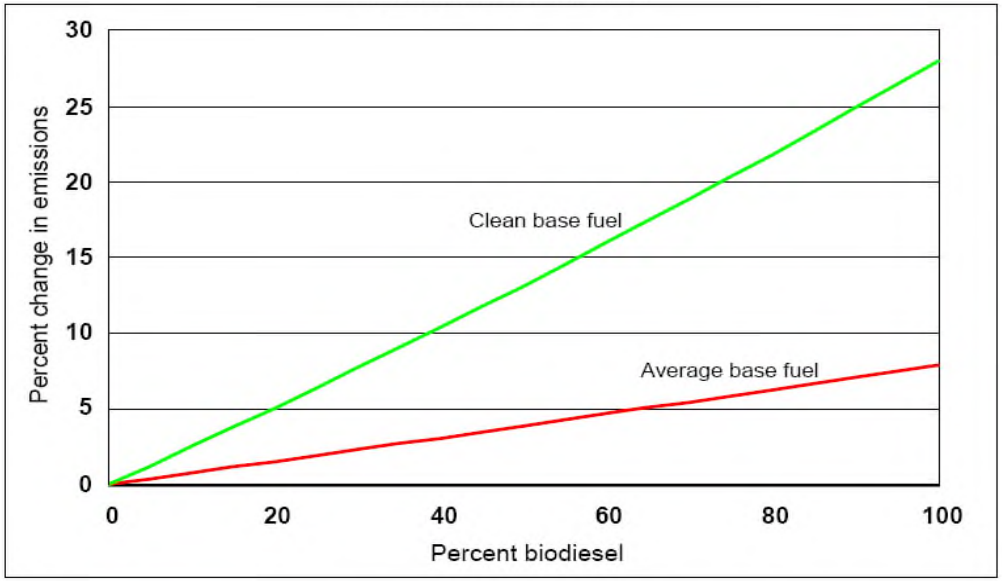
A. All base fuels to which biodiesel is added are assigned to the "average" emission category for the purposes of estimating emission benefits of biodiesel using the correlations in this report, unless
B1. The base fuel in question meets the requirements for highway diesel fuel sold in California or alternative requirements that are substantially similar to those in California, or
B2. The fuel in question meets all of the following conditions: 1. Total cetane number is greater than 52 2. Total aromatics content is less than 25 vol% 3. Specific gravity is less than 0.84 For fuels meeting conditions B1 or B2, the base fuel should be assigned to the "clean" category.

- Selection criteria for base fuel analysis

Literature Review
Historical Perspective

EPA found NOx increases more when biodiesel is blended with clean base fuels (e.g., CARB/CARB-like diesel) than with average base fuels

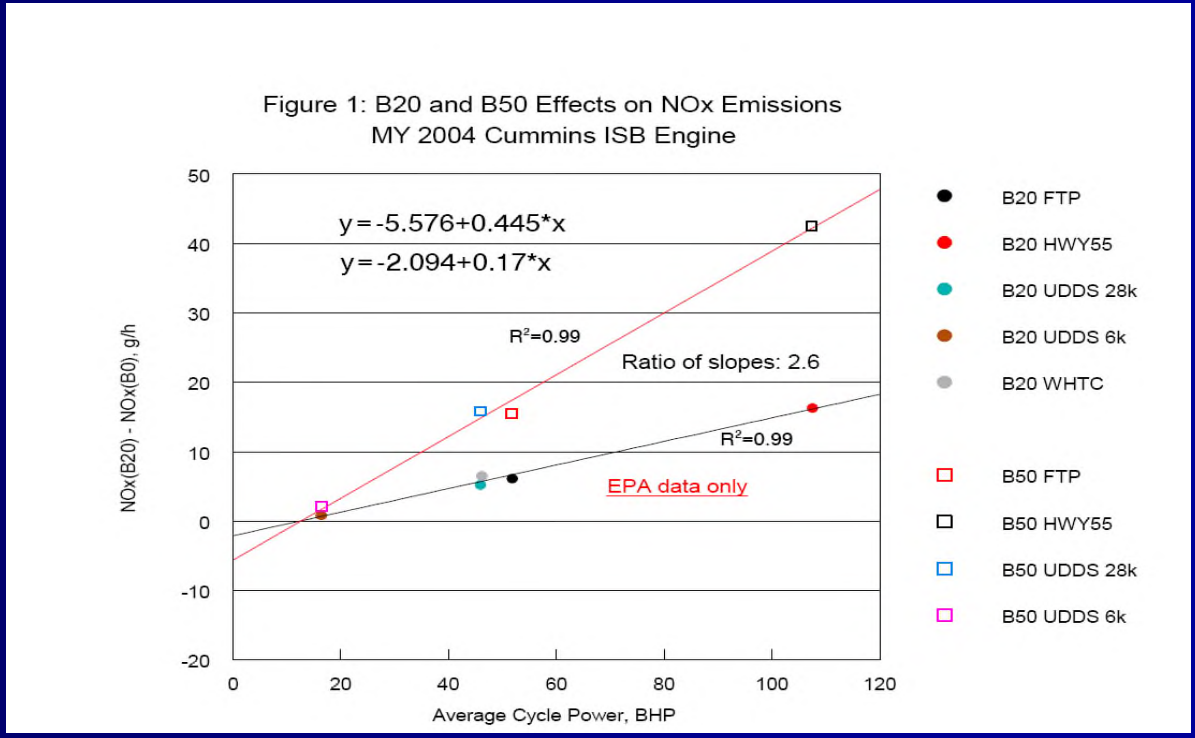
Figure IV.B.4-1
Base fuel effects for NOx



B100: ~27% more NOx than clean diesel, ~7% more NOx than avg. diesel.
B20+clean diesel: ~5% more NOx than clean diesel alone
B20+avg. diesel: ~2% more NOx than avg. diesel alone

Literature Review
Historical Perspective

Another finding by the EPA showed that biodiesel effects on NOx emissions were related to average cycle power



[1]Sze et al, 2007

Literature Review
Historical Perspective

- **Why was CARB Biodiesel/Renewable diesel study initiated?**
  - EPA finding that biodiesel blended with CARB base fuels show a higher percent increase in NOx
  - Expand limited data set especially newer technology engines
  - Expand limited data set on low biodiesel blend levels
  - Need for more robust studies
  - Run duty-cycles of different loads

Literature Review
What do we know now?

- CARB study results
- Literature reviews
- Current literature

Literature Review
What do we know now

- **CARB biodiesel/renewable study results**
  - Study on-going, estimated completion date Sept. 2010
- Preliminary results
  - CARB study also shows higher NOx impact for CARB base fuels
  - Continue to refine the information as the study nears completion
  - Matches with other research showing base fuels have a significant impact

Literature Review
What do we know now?

Literature Reviews

- A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions, EPA report 420-P-02-001, David Korotney, 2002
- NREL Review, "Effects of Biodiesel Blends on Vehicle Emissions", Fiscal Year 2006 Annual Operating plan Milestone 10.4, R. L. McCormick et al., 2006
- Draft Regulatory Impact Analysis: Changes to Renewable Fuel Standard Program, Appendix A, EPA-420-D-09-001, Zoltan Jung, 2009
- CRC Report No. AVFL-17, S. Kent Hoekman, et al., 2009

Literature Review
What do we know now?

- **Reviews Cont**
  - Of the major literature review studies only the 2002 Draft Technical Report evaluated the effect of clean base fuels

Literature Review
Next Steps

- Review current literature for
  - Trends and mechanism
  - Emissions data low biodiesel blend levels
- Conduct an analysis of clean base fuels
  - CARB diesel base fuels
  - High cetane base fuels
  - Analysis criteria
  - How the analysis results will be reported

Literature Review
Next Steps

Review Current Literature

- Key examples
  - Eckerle, 2008
  - Sze, 2007
  - Cheng, 2006
  - Thompson, 2010
  - Others?

Literature Review
Next Steps

Base Fuels Evaluated

- CARB diesel fuels
- High cetane fuels

Literature Review
Next Steps

Analysis results

- Compare biodiesel NOx impact of CARB base fuels with
  - High Cetane base fuels (23 studies)
  - to all diesels base fuels (114)
  - to EPA study results

Literature Review
Next Steps

Comparison to other factors that affect NOx

- If possible will look at other factors; however,
- Limited by small data set which may preclude the following evaluations
  - Feedstock
  - Engine
  - Heavy, Medium, Light duty vehicles
  - On-road and non-road

Literature Review
Next Steps-Criteria for Analysis

Selection of studies

- Heavy duty engines, no test engines
- No duplicate studies
- Published in a peer-reviewed journal, by a research center, or company
- Experimental design, no modeled results.

Literature Review
Next Steps-Criteria for Analysis

Summary of specifications for fuels used for the analysis

- Base fuel, CN ≥ 48, Aromatics ≤ 21
- Blend is B5, B10, B20
- Biodiesel is made from feedstocks that are an agriculture crop, like soy, or waste stream, like beef tallow.

Literature Review
Next Steps-Criteria for Analysis

CARB Baseline Diesel

- Suggested studies?

Literature Review
CARB Diesel Studies

- 114 articles on biodiesel emission effects
- Considered studies on biodiesel produced from currently available feedstocks (generally soy, canola, rapeseed, palm, yellow grease, animal tallow)

Literature Review
Comments Requested

- Specific comments requested on:
  - Methodology of search
  - Selection of CARB representative studies
  - Quality of data

Literature Review
Discussion

- Questions or Comments?

Comments from First Workshop

- Literature Review
  - Clarify and expand NOx impact of biodiesel use.
  - CARB's findings on NOx vs literature (esp. B5)
  - What is the NOx impact at low blend levels?
- ***Fuel Properties***
  - Biodiesel Feedstock Effects
  - Gas To Liquid (GTL) diesel
  - GTL and renewable diesel properties
- Certification

Fuel Properties
Overview

- Two components contribute to NOx emissions
  - Biodiesel Feedstocks and Blendstocks
  - Hydrocarbon Diesel
- Goal: specify properties of each component that are predictors of NOx

Fuel Properties
Biodiesel Feedstocks and Blendstocks

- Biodiesel blends have different emissions effects based upon feedstock
  - ARB testing found soy biodiesel increased NOx more than animal tallow biodiesel
  - This result is generally supported in literature

Fuel Properties
Biodiesel Feedstocks and Blendstocks

- Problems associated with use of feedstock to predict NOx effects:
  - Biodiesel feedstocks are frequently mixed
  - Multiple feedstock properties account for differences in emissions, including saturation, chain length and branching

Fuel Properties
Biodiesel Feedstocks and Blendstocks

- Can blendstock properties predict feedstock based variation in emissions?
  - Properties of interest:
    - Iodine Number EN 14111
    - H, C and O content ASTM D5291
  - Properties are indicators of saturation, chain length and branching

Fuel Properties
Hydrocarbon Diesel

- Properties of base fuel affect NOx emissions of the blend
- Higher cetane, lower aromatics and lower density base fuels can reduce or eliminate NOx increase

Fuel Properties
Hydrocarbon Diesel

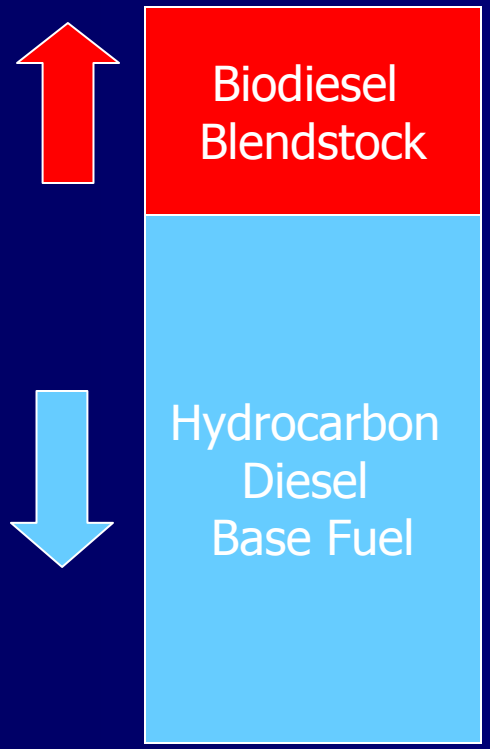
- Specifications for the base fuel:
  - Predictive Model:
    - Used by regulated party for compliance; or
    - Used by ARB to determine compliant specifications

Fuel Properties
Hydrocarbon Diesel

- U.S. EPA Unified NOx Model
  - Strategies and Issues in Correlating Diesel Fuel Properties with Emissions
  - http://www.epa.gov/otaq/models/analysis/p01001.pdf

Fuel Properties
Hydrocarbon Diesel

NOx Trend



NOx Predictors

- Iodine Number
- C, H, and O content

Predictive Model:
- Cetane Number
- Aromatics Content
- Density or API Gravity

Fuel Properties
Hydrocarbon Diesel

- High Cetane hydrocarbon fuels:
  - Renewable Diesel
    - Simple mixture of hydrocarbons derived from:
      - Hydrotreatment of biological feedstocks
      - Enzymatic reactions of biological feedstocks
  - GTL & BTL
    - Complex mixture of hydrocarbons derived from syngas from fossil or biological sources

Fuel Properties
Comments Requested

- Specific comments requested on:
  - Biodiesel blendstock properties
  - Hydrocarbon diesel properties
  - Model and specifications

Comments from First Workshop

- Literature Review
  - Clarify and expand NOx impact of biodiesel use.
  - CARB's findings on NOx vs literature (esp. B5)
  - What is the NOx impact at low blend levels?
- Fuel Properties
  - Biodiesel Feedstock Effects
  - Gas To Liquid (GTL) diesel
  - GTL and renewable diesel properties
- ***Certification***

Certification
Concept

- Emissions equivalent certification based upon certification in diesel rules (13 CCR 2282 g)
  - Issues

Certification
Concept

- Current process uses 1991 DDC Series 60 for testing
- Two primary problems:
  - Engine becoming harder to find in serviceable condition
  - Engine becoming less representative of on-road fleet

Certification
Concept

- Possible modifications:
  - Newer engine for biodiesel certification program
  - 2006 Cummins ISM

Certification
Concept

- Support for 2006 Cummins ISM:
  - No DPF means accurate PM measurement
  - Cummins is largest engine model in California fleet
  - Biodiesel testing conducted on this engine, large amount of data available

Certification
Planned Testing

- Post-rulemaking:
  - Additional testing on mitigation options after rulemaking
  - Testing done to meet requirements of certification, consideration as a certified option

Certification
Comments Requested

- Specific comments requested on:
  - Engine choice
  - Framework

Overview

- Background
- Biodiesel Studies Update
- Comments from First Workshop
  - Literature Review
  - Fuel Properties
  - Certification
- ***Next Steps***
- Contacts
- Discussion

Next Steps

- Comments requested Monday, June 21
- Next Workshop (tentatively mid-July)
- Additional Workshops as needed
- Proposal late August
- Board meeting October 2010

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http://www.arb.ca.gov/fuels/diesel/altdiesel/biodiesel.htm

Questions & Discussion