Assessing Pollutant Emissions from Natural Gas-Derived FT-Diesel

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Overview

- NREL has reviewed public data on vehicle criteria air pollutant emissions
- Sources include published papers and data submitted by petitioners
- Provide limited data on criteria pollutant emissions, mostly for pre-1998 vehicles and engines
- All existing data is for conventional vehicles and engines rather than AFVs
- In most tests NO_x and PM are reduced significantly relative to conventional No. 2 diesel
- FT fuel meeting certain defined parameter limits will reduce pollutant emissions with a high degree of probability

Example Fuel Properties

Comparison to No. 2 Diesel

Property	Method	Typical No. 2	Direct F-T	PetroSA COD
HHV, MJ/kg	D240	43-48	45-48	45-48
Density, 15°C	D4052	0.8464	0.7695-0.7905	0.8007-0.8042
Distillation, °C	D86			
IBP		174	159-210	230
50%		253	244-300	254
90%		312	327-334	323
FBP		344	338-358	361
Cetane number	D613	44.9	>74	~50
Sulfur, ppm	D5453	300	<1	<1
Total Aromatics	D5186	~30	0.1-2	~10
Hydrogen, wt%	D5291	13-13.5	~15	~14.4
Cloud Point, °C	D2500	-15	0	-15
Lubricity		good to poor	poor	poor

←Similar energy content but lower density

←Higher Cetane Number

←Ultra-low sulfur

←Near zero or low aromatic

←High hydrogen content

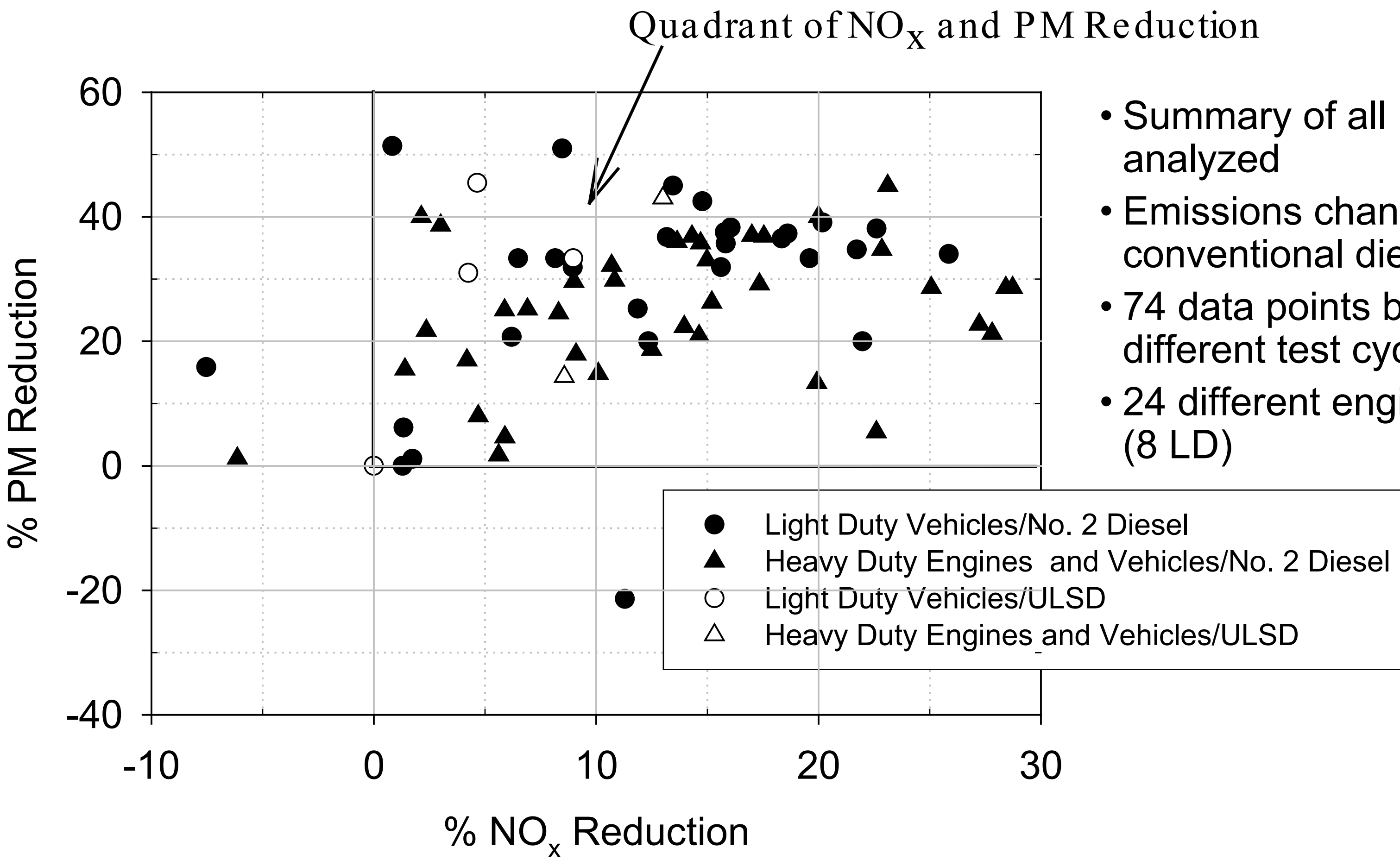
←Lubricity and cold flow

- Direct FT=FT distillate produced directly through FT reaction and subsequent refining
- PetroSA (formerly Mossgas) COD=Blend of FT fuel and oligomerized olefins

Uncertainty in Fuel Properties

- Tested fuels are not representative of what will actually be produced:
  - Many fuels produced at pilot scale, fuel properties may change with scale up
  - Post-processing (distillation, isomerization, cracking,…) will likely be required to meet customer requirements and ASTM D975
- Many studies do not present detailed properties of both FT-diesel and base fuel used for comparison

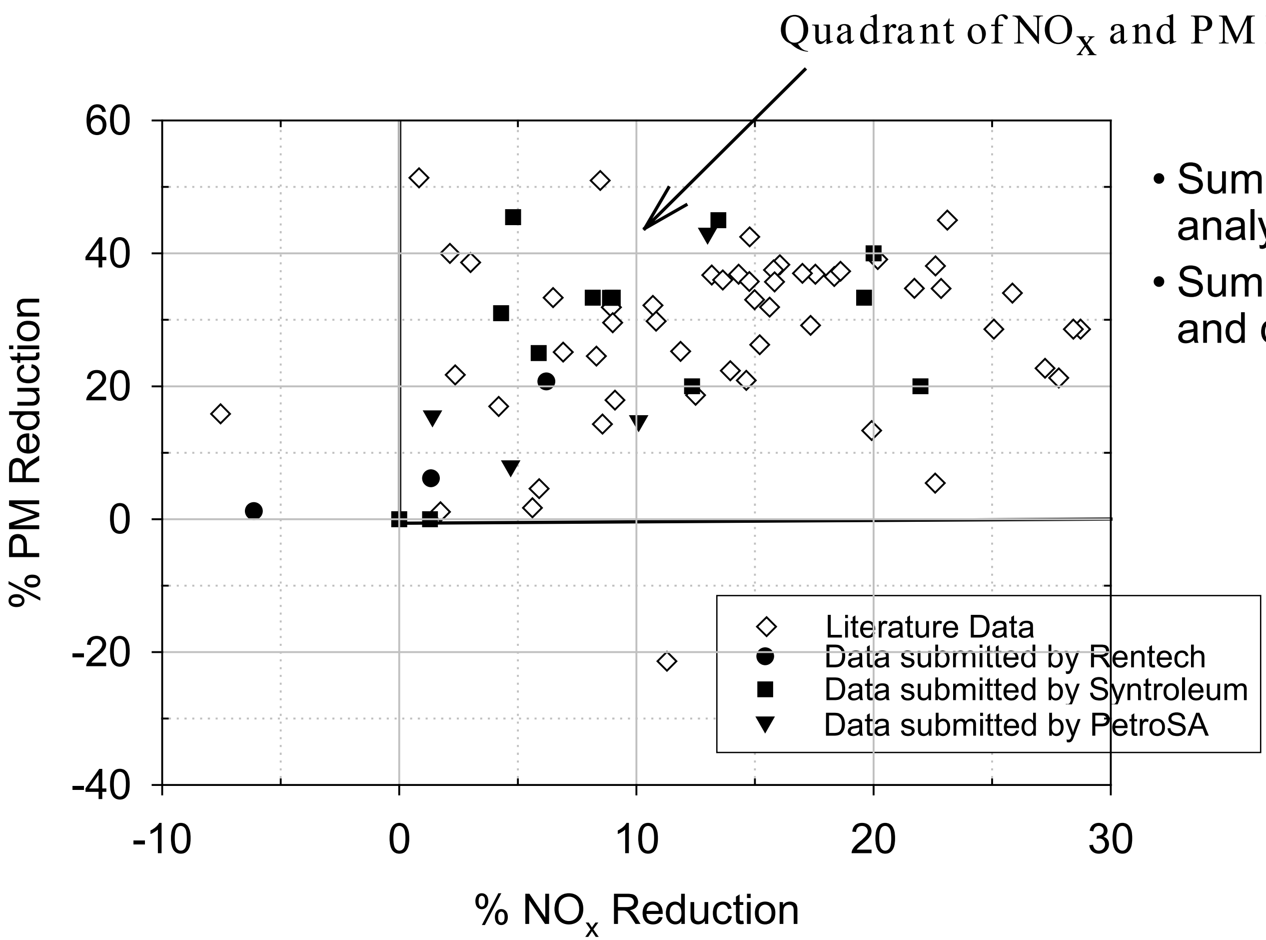
NO_x and PM Summary-HD/LD



- Summary of all FTD data NREL analyzed
- Emissions changes relative to conventional diesel and ULSD
- 74 data points based on several different test cycles
- 24 different engines and vehicles (8 LD)

- Few data points relative to ULSD also show reductions
- Higher scatter in LD PM data because of generally lower emission levels (smaller engines)
- LD are over-represented as ~95% of diesel use is HD

NO_x and PM Summary-Petitioner Data



- Summary of all FTD data NREL analyzed
- Summary showing literature data and data submitted by petitioners

- Most tests show a reduction in emissions
- On average NO_x reduced by 12%, PM by 27%
- Petitioners' data falls within the range of literature data, has similar level of scatter

Limitations of FT-Emissions Data

- Fuels tested may not be representative of what will actually be produced
- Experimental error not quantified in all studies, significance difficult to determine
- Data exists for limited range of model years, engine sizes, and engine technology
- Emissions data not available for a representative sample of diesel vehicle fleet
- Data may not be adequate to show substantial environmental benefit across entire diesel vehicle fleet

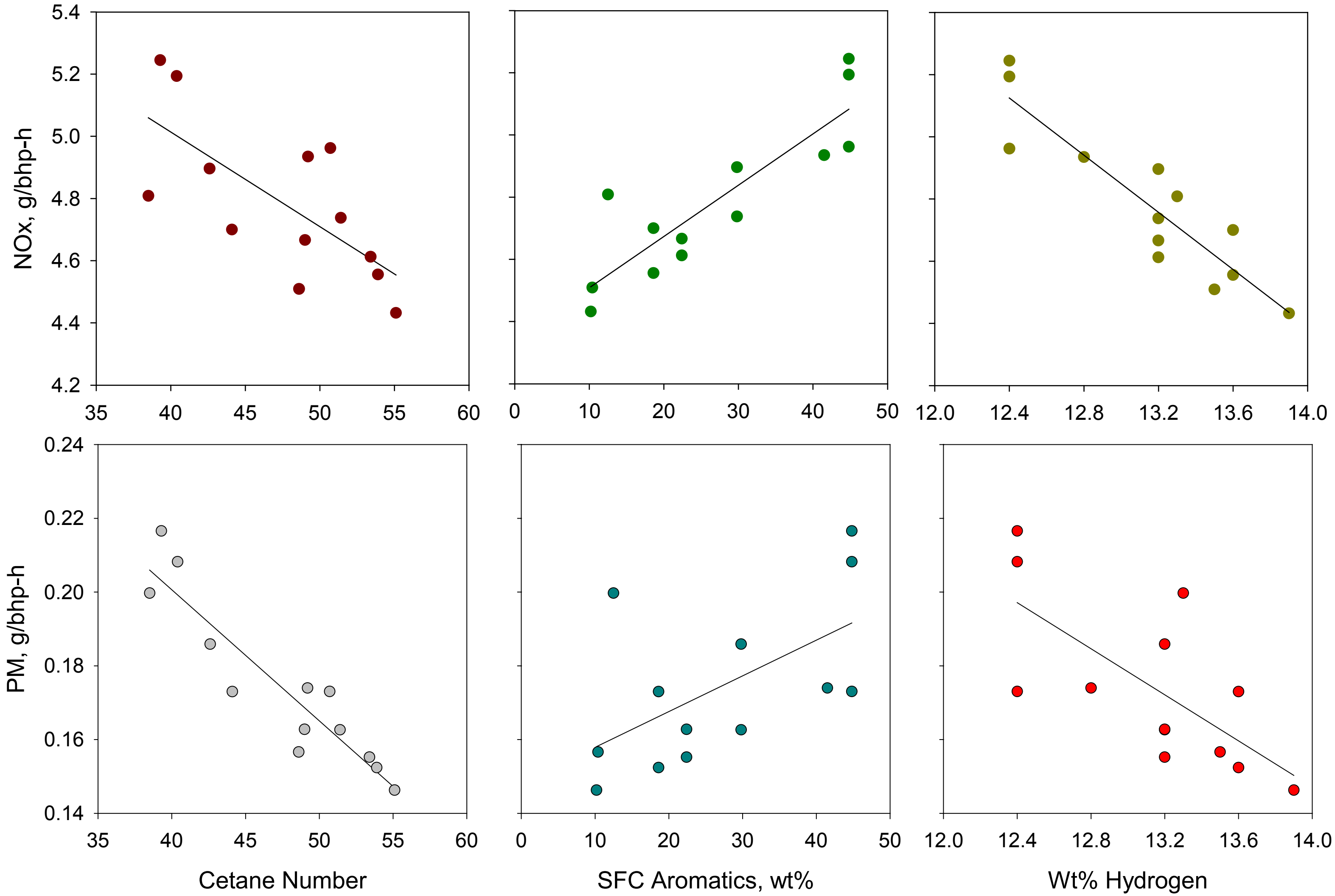
Fuel Property Effects on Emissions

Well known fuel property impacts on emissions

- Low sulfur content
  - Reduces PM
  - Enables exhaust catalyst and trap systems
- Increasing cetane number
  - Can reduce NO_x, 2-5% for an increase of 10 CN in some engines
  - But has no effect on NO_x for other engines
  - Effect on PM is also engine dependent
  - Can assist in cold starting and reduce white smoke
- Reducing aromatic content
  - Can reduce NO_x by 0-5% for a reduction from 30 to 10%
  - Reduction in polyaromatics may account for most of this effect
  - Magnitude of NO_x reduction is engine dependent
  - PM reductions observed in some engines

Fuel Effects in 1991 Engine

- CRC VE-1 Study: 1991 DDC Series 60 (5 g/bhp-h NO_x, 0.25 g/bhp-h PM)
- HD-FTP



- Increasing CN and/or lowering aromatics lowers NO_x and PM
- Wt% Hydrogen correlates well with NO_x and PM

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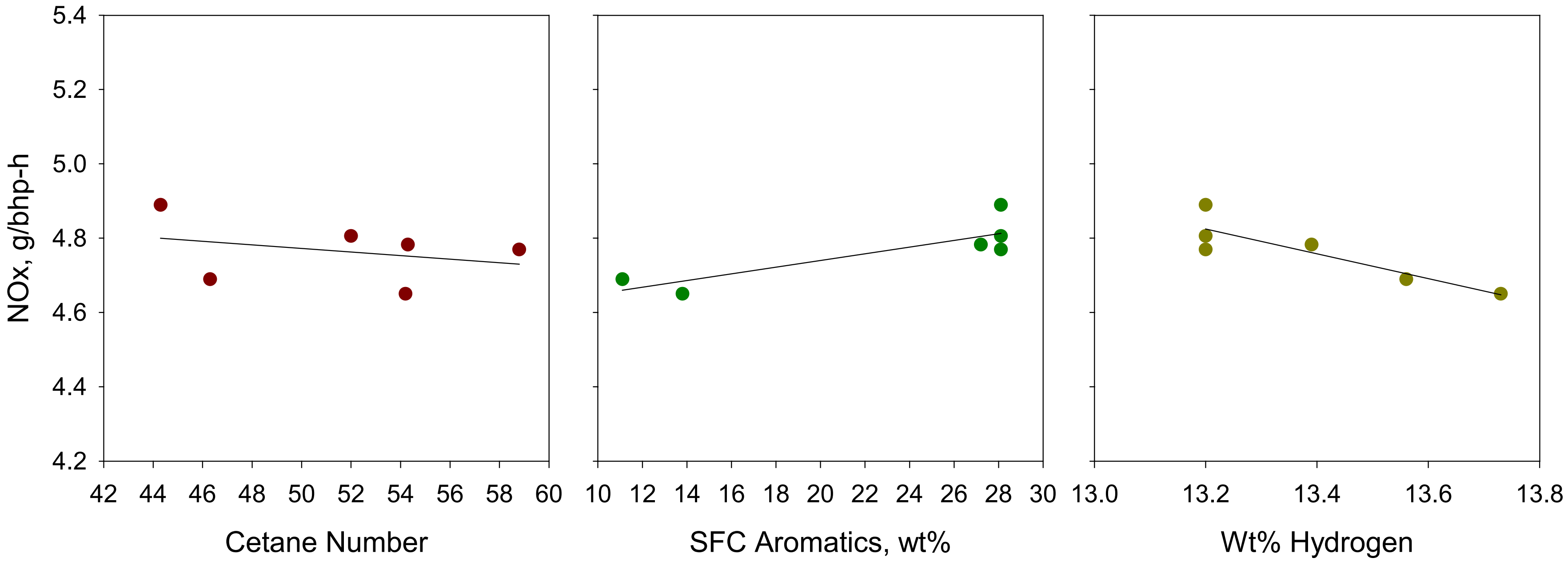
Fuel Effects in 1994 Engine

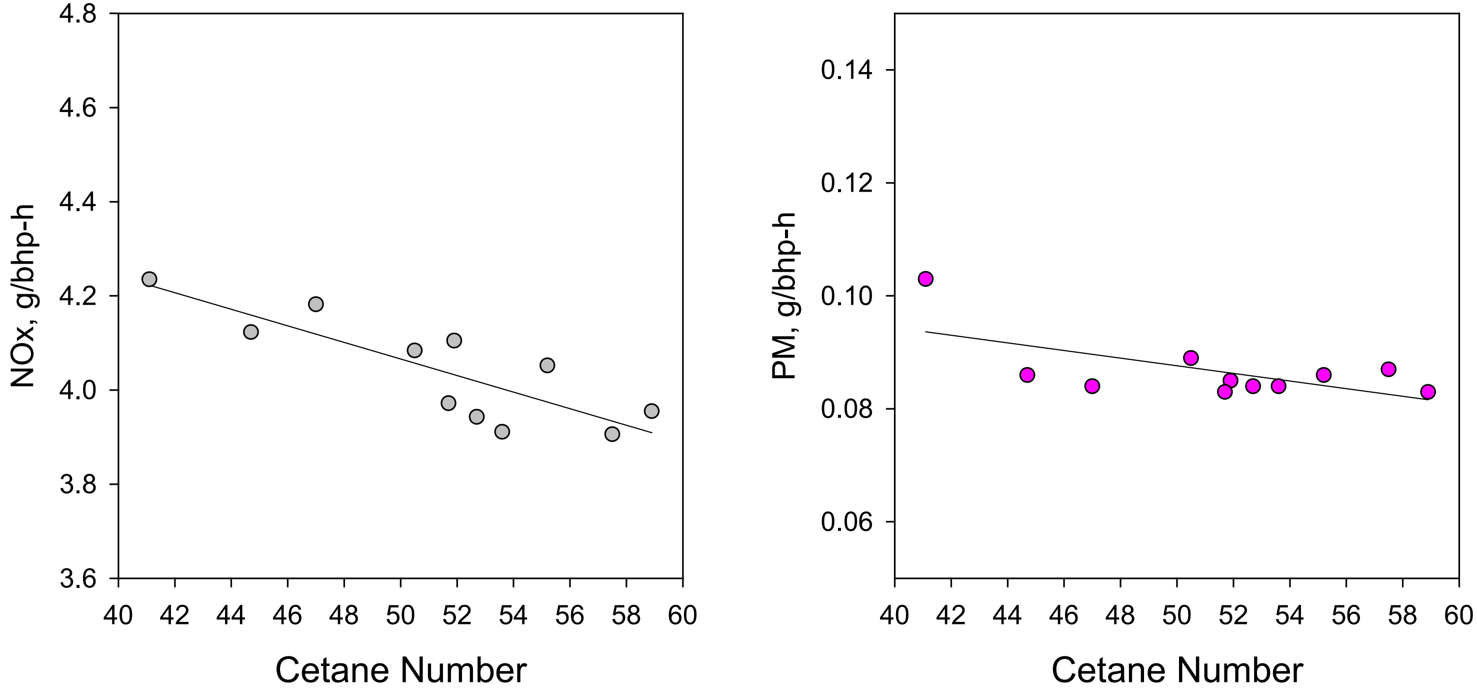
- CRC VE-10 Study: 1994 DDC Series 60 (5 g/bhp-h NO_x, 0.1 g/bhp-h PM)
- HD-FTP
- All fuel effects on NO_x are much less significant



- No fuel effect on PM emissions

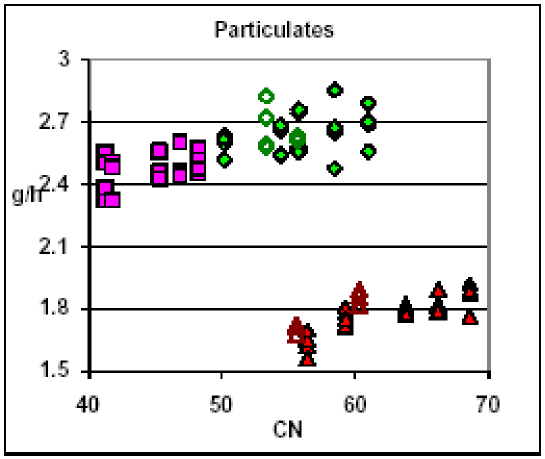
Fuel Effects in 1998 Engine

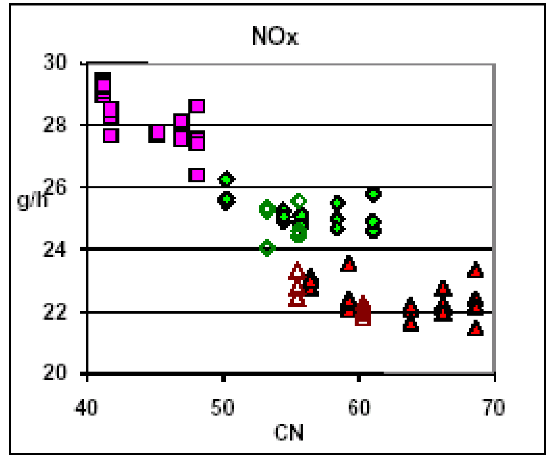
- CRC VE-10 Study: 1998 DDC Series 60 (4 g/bhp-h NO_x, 0.1 g/bhp-h PM)
- HD-FTP, CN varied only
- CN correlates well with NO_x but not PM



Fuel Effects in Engines with EGR (2004)

SAE 2001-01-3522, Rover L LD engine, 4-mode SS test:

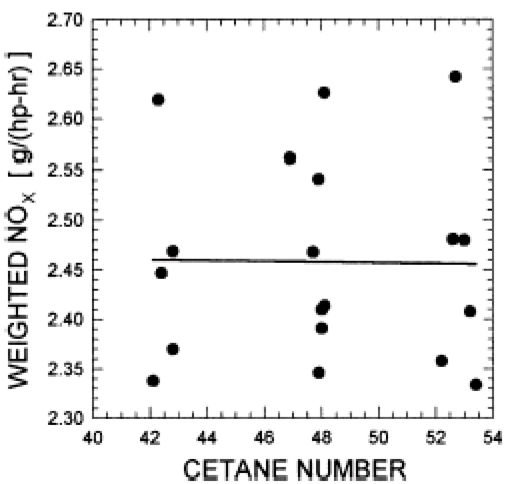


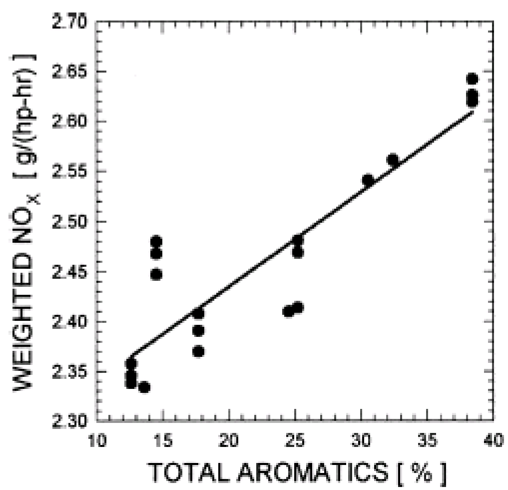


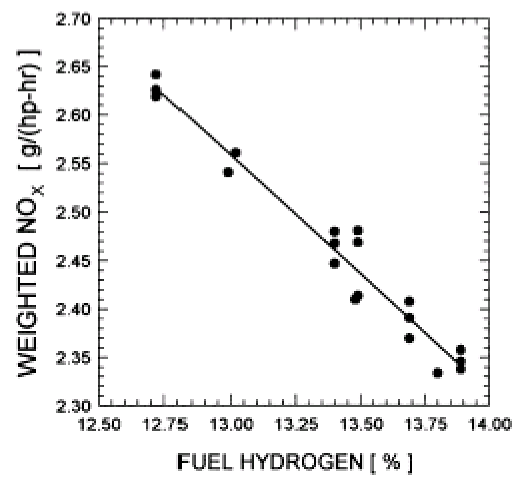
2.5 g/bhp-h NOx+HC
0.1 g/bhp-h PM

- Increasing CN lowers NO_x
- May increase PM

SAE 2000-01-1858, Cat 3176 HD Engine, 8-mode SS tests:







- No effect of CN on NO_x
- Lowering aromatics or increasing hydrogen content lowers NO_x
- PM not reported

Fuel Effects Overview

- Effect of fuel properties is not the same for engines of different emissions levels and different technology:
  - 1991 calibration: Δ10CN$\rightarrow$4% NO_x, Δ15%aro $\rightarrow$4% NO_x
  - 1994 calibration: Δ10CN$\rightarrow$1% NO_x, Δ15%aro $\rightarrow$2% NO_x
  - 1998 calibration: Δ10CN$\rightarrow$2% NO_x
  - Engines with EGR: Δ10CN$\rightarrow$0-4% NO_x, Δ15%aro $\rightarrow$4% NO_x

- Cetane Number is not consistently associated with emissions reductions, but high CN has advantages for cold starting and white smoke emissions
- Effect of aromatic and hydrogen content changes with model year but is consistently positive
- Aromatic content, hydrogen content, and density are likely to be highly correlated with one another
- Wt% hydrogen does not capture differences between normal, iso, and cylco-alkanes

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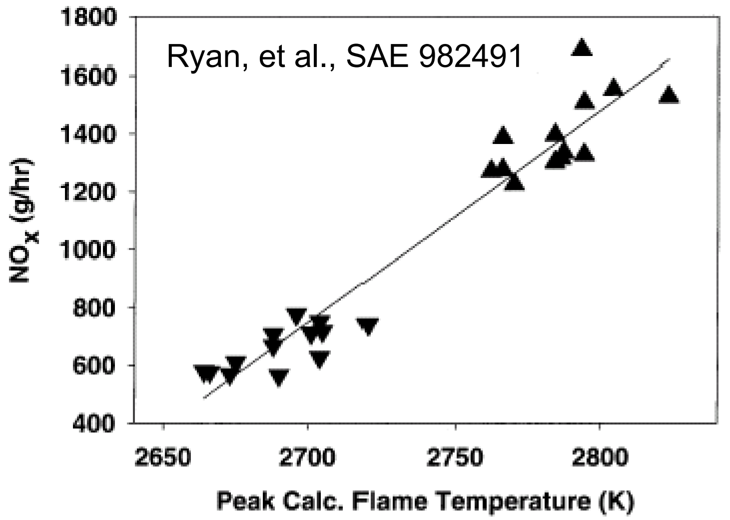
Fuel Effects Conclusion

- Reducing aromatic content is consistently associated with emissions reductions
  - In both old and new engines
  - Likely this is related to reduction in adiabatic flame temperature which is higher for aromatics
  - Poly-aromatics may have a larger effect than mono-aromatics



- *Emissions reductions observed for FT-diesel may be most reliably correlated with the low total and poly-aromatic content*
- *In older engines the high CN may also be important*

Additional Data Needs

- Emissions on a much wider range of engines, including post-2002 engines with EGR and prototype engines with advanced catalytic exhaust treatment
  - In two studies not connected to this rulemaking, NREL plans to conduct tests of FT-diesel in three 2000 MY vehicles and one 2002 MY engine with EGR during FY03
- Emissions studies with detailed fuel composition data
  - Analysis for normal, iso, and cyclo-alkanes as well as for total and polyaromatics
- Speciated emission studies
- Data on durability of fuel systems and potential impacts on engine components associated with emissions

Summary

- Pollutant emissions data available for a limited set of engine models, not fully representative of in-use fleet
- However, available data show significant PM and NO_x reductions for FT relative to conventional diesel in most tests
- Additional data on the emissions impact from newer engines as well as emissions durability is desirable
- It is not clear based on emissions testing data for FT alone that significant emissions reductions will be achieved
- Emissions reductions may be more directly related to fuel properties of FT-diesel

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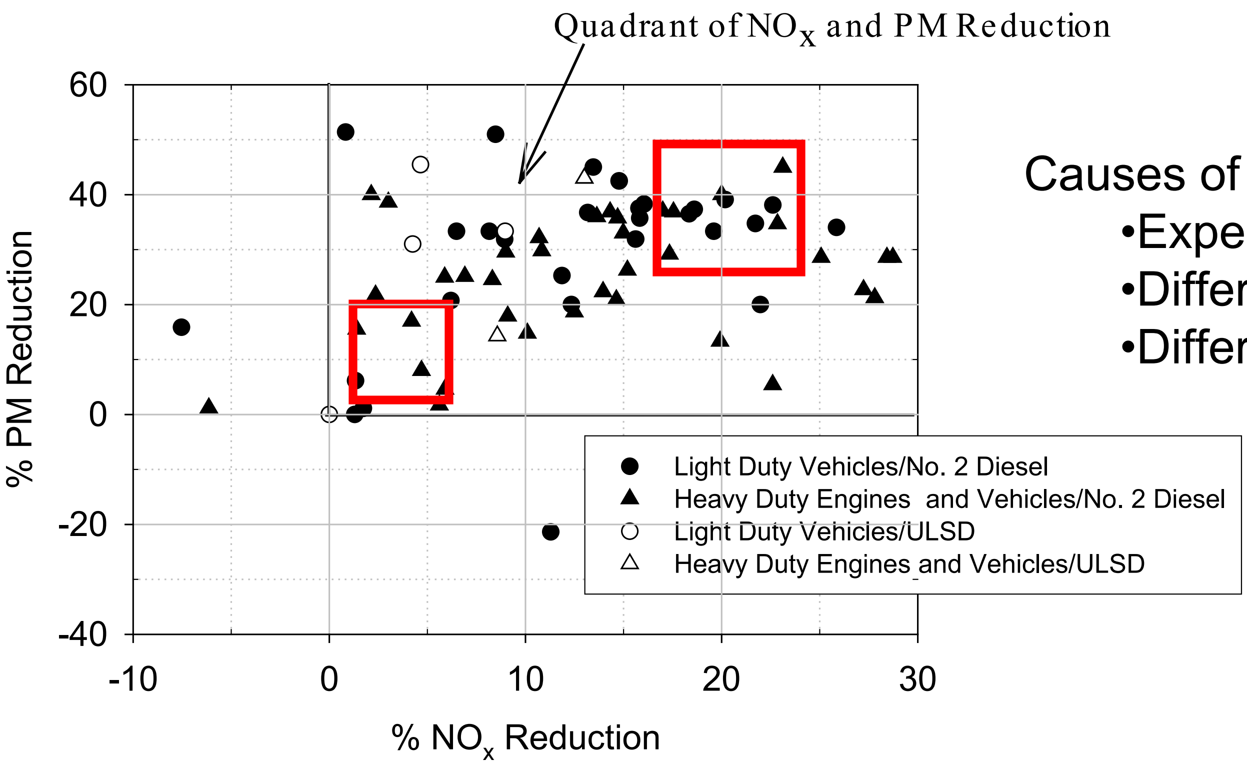
Summary-II



Causes of scatter include:

- Experimental error
- Different engine technologies
- Different base fuel properties

Where will emissions benefits of future FT-fuels and engine technologies fall?

Specification of minimum fuel properties can provide emission benefits across all technologies.

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DOE Seeks Comment on Fuel Parameters for Generic Designation

Examples:

- Maximum aromatics 1-15%?
  - Separate specification on polyaromatics?
- Other hydrocarbon composition limits (n-paraffin?)
- Cetane number
- Sulfur <15ppm?
- Hydrogen content?
- Conformity to ASTM D975-02
- Other properties?