Biofuels Utilization Research at the University of Minnesota Center for Diesel Research

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Engine, Fuel and Nanoparticle Research
Center for Diesel Research

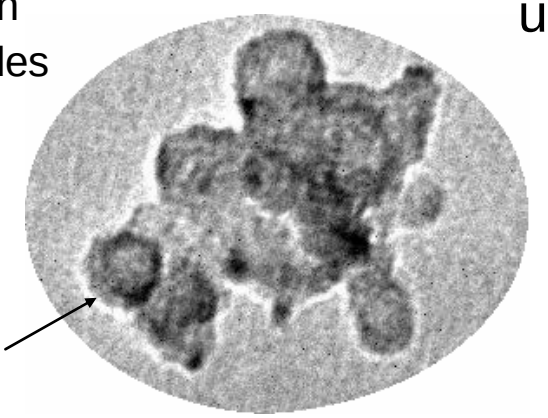
Nanoparticle formation

- In the atmosphere
- In the engine
- sampling artifacts

Sensors for real time control of ultrafine particles and NO_x

Fundamental studies

- Role of fuel and oil composition on nanoparticle formation
- New combustion modes
  - Hydrogen assisted
  - Low temperature



Renewable fuels, biodiesel, ethanol, to reduce CO_2 and ultrafine particles

David B. Kittelson, Professor of Mechanical Engineering
Director, Center for Diesel Research

Outline

- Introduction
- Biodiesel Research
- Ethanol Research
- Butanol Research
- Future Work - DME

Status of Minnesota Fuel Policies

- State Policy on Biodiesel
  - Current Standard: 2% Biodiesel blend
  - Future Goal: 20% blend by 2015

- State Policy on Ethanol
  - Current Standard: 10% Ethanol blend in gasoline
  - Future Goal: 20% blend by 2013 with 5% from cellulosic
  - The Next Generation Energy Initiative increases E85 gas stations from 300 to 1800 by the year 2010

Center for Diesel Research and Combustion Lab
Current Biodiesel Research

- Biodiesel (methyl esters)
  - Backup power generation
  - Marine engines
  - Automotive engines
    - » Emission measurements
    - » Fundamental particle characterizations
- Raw Seed Oils / Straight Vegetable Oils
  - Atomization
  - Combustion properties
  - Fundamental particle characterizations
- Biodiesel and raw seed oils in gas turbines

Soybeans the Main US Biodiesel Feedstock: Soy Methyl Ester (SME) Biodiesel Production

100 lbs. of soybean oil

+

10 lbs. methanol

=

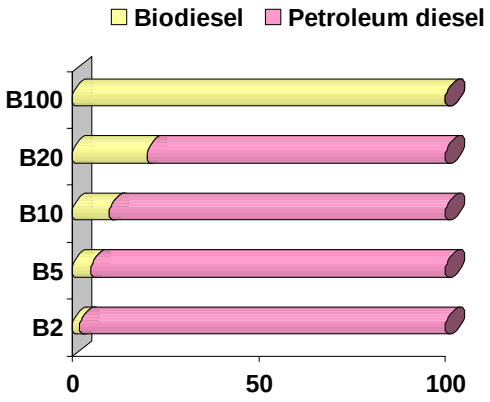
100 lbs. soy biodiesel (B100)

+

10 lbs. of glycerin

Biodiesel may also be made from animal fat, restaurant grease, canola, rapeseed, palm, etc.

Biodiesel Blends and Emissions



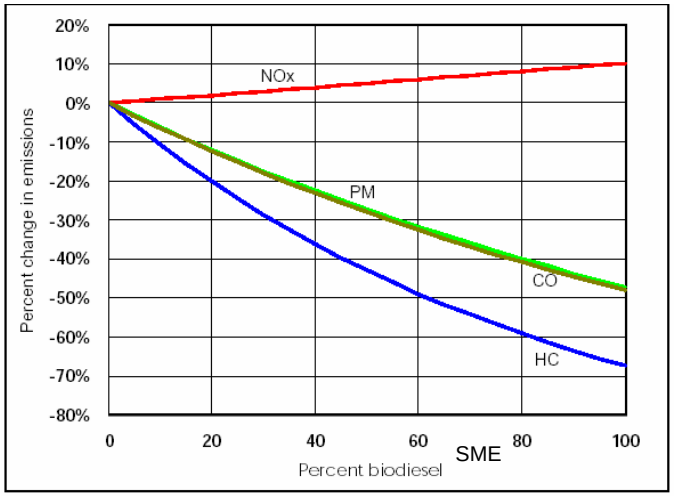
B100 = 100% biodiesel

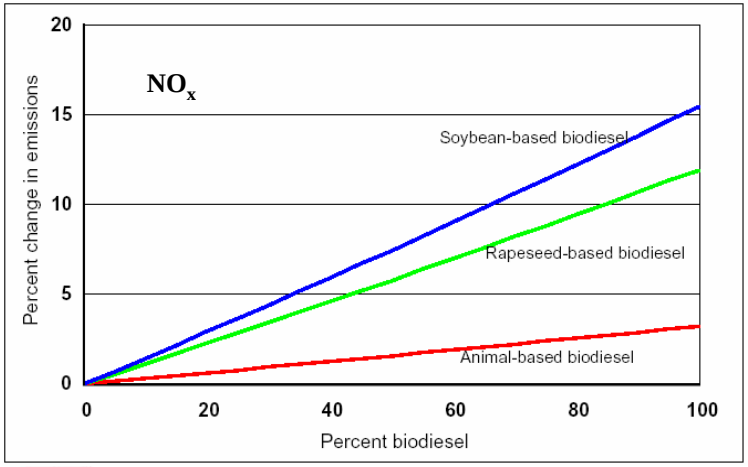
B20 = 20% biodiesel + 80% petroleum diesel

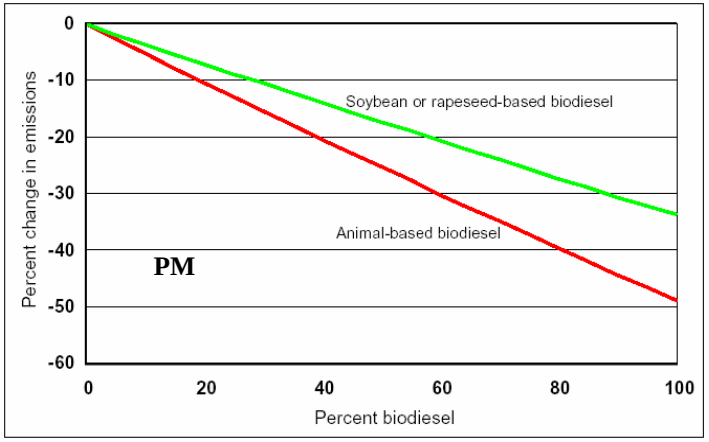
B10 = 10% biodiesel + 90% petroleum diesel

B5 = 5% biodiesel + 95% petroleum diesel

B2 = 2% biodiesel + 98% petroleum diesel

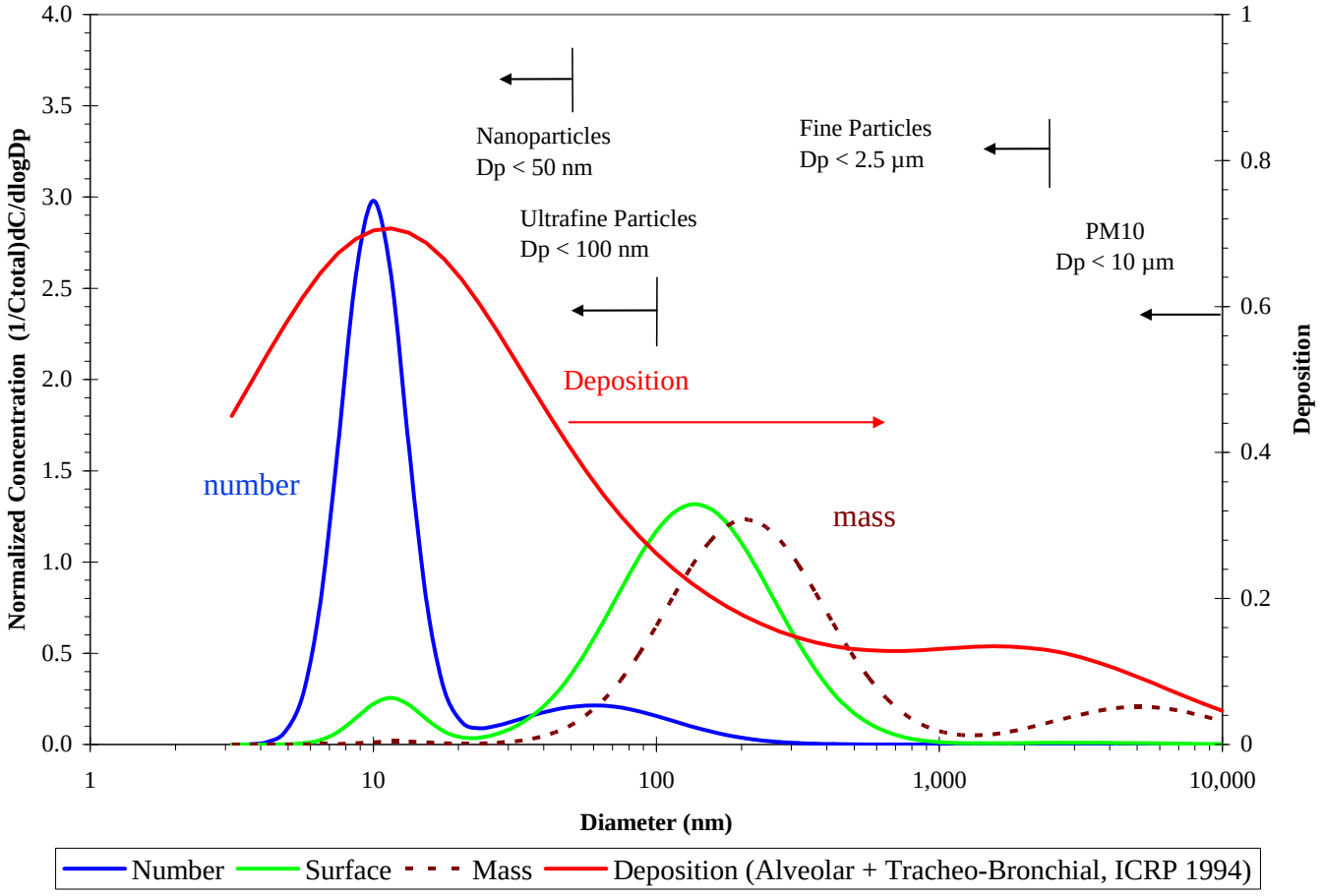






Data from USEPA 2002

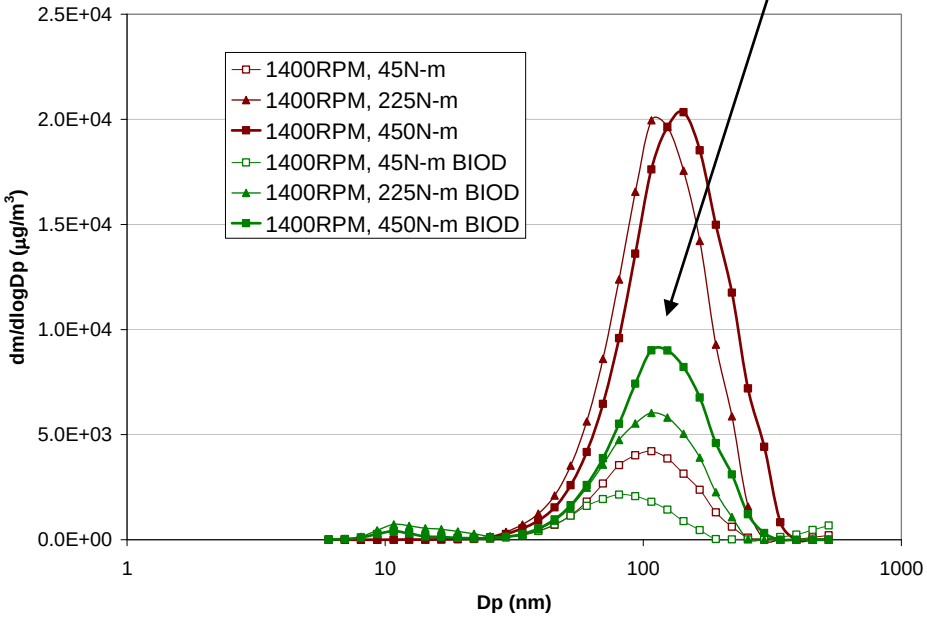
Engine particle size distributions, lung deposition efficiency – biodiesel makes smaller particles



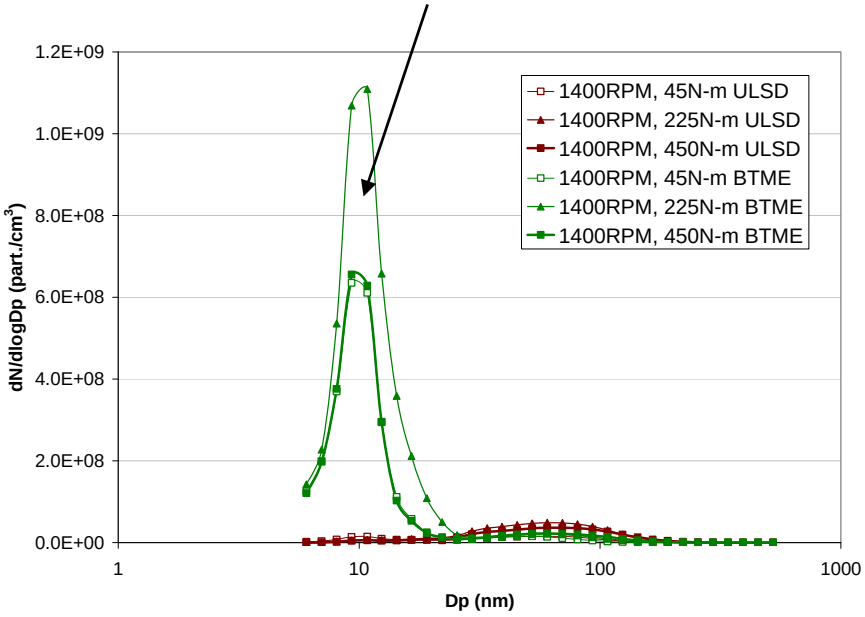
Kittelson, D.B. 1998. "Engines and Nanoparticles: A Review," J. Aerosol Sci., Vol. 29, No. 5/6, pp. 575-588, 1998

Mass & Number distributions, medium-duty engine, ULSD and Beef Tallow Methyl Ester (BTME)

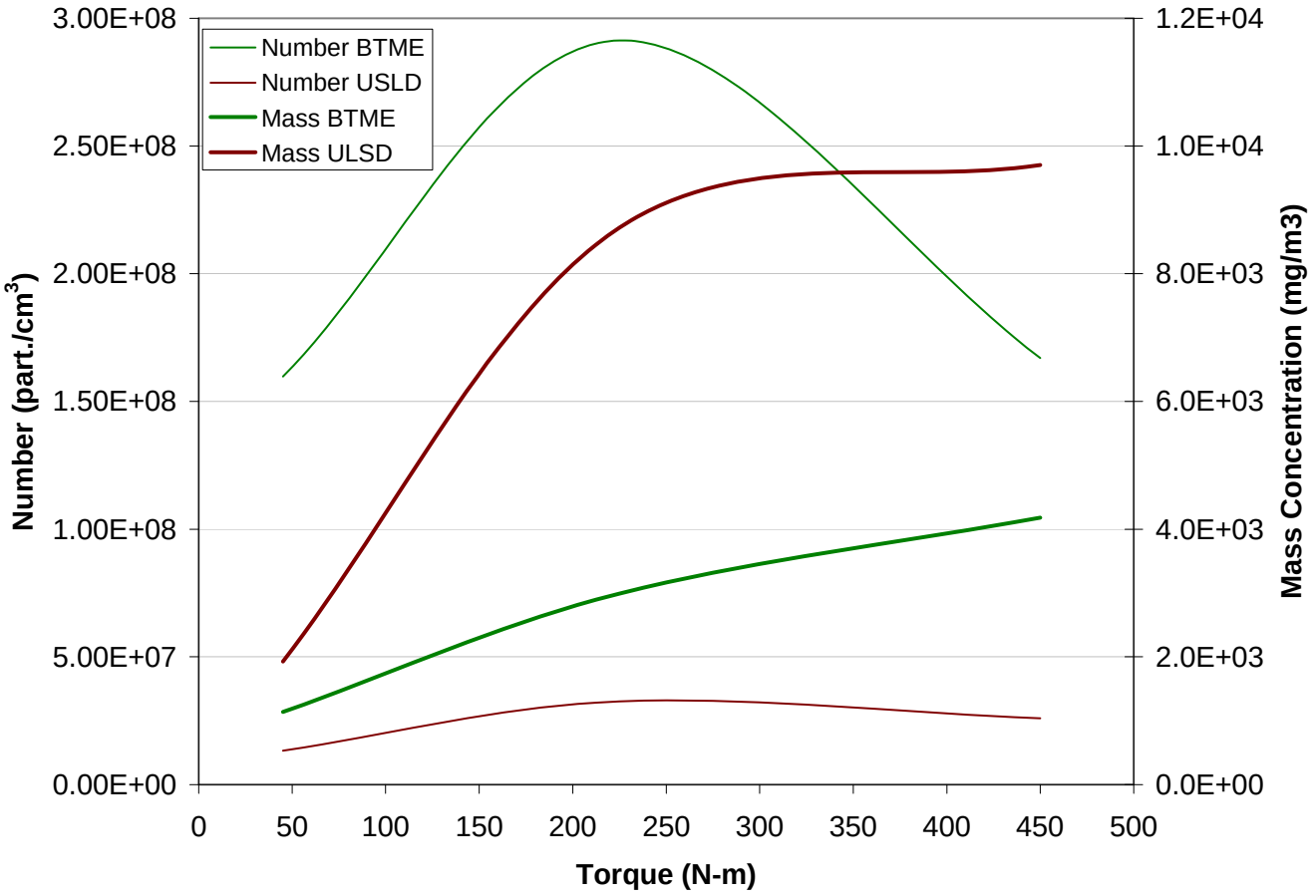
40-70% decrease in mass



500-1100% increase in number

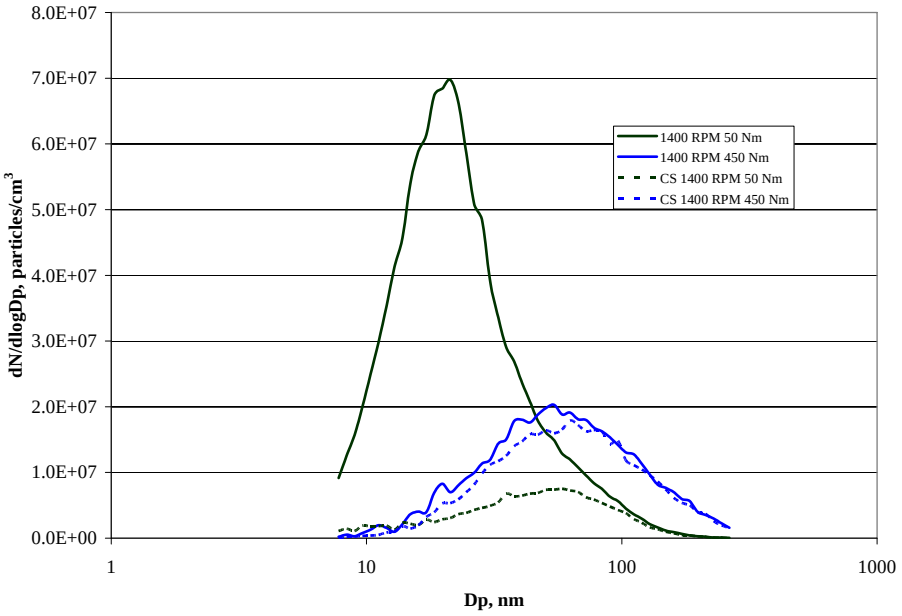


Mass and Number Concentrations, Medium-Duty Engine, ULSD and BTME



Number distributions, medium-duty engine, B50 (SME) with and w/out a Catalytic Stripper

Upstream of DOC



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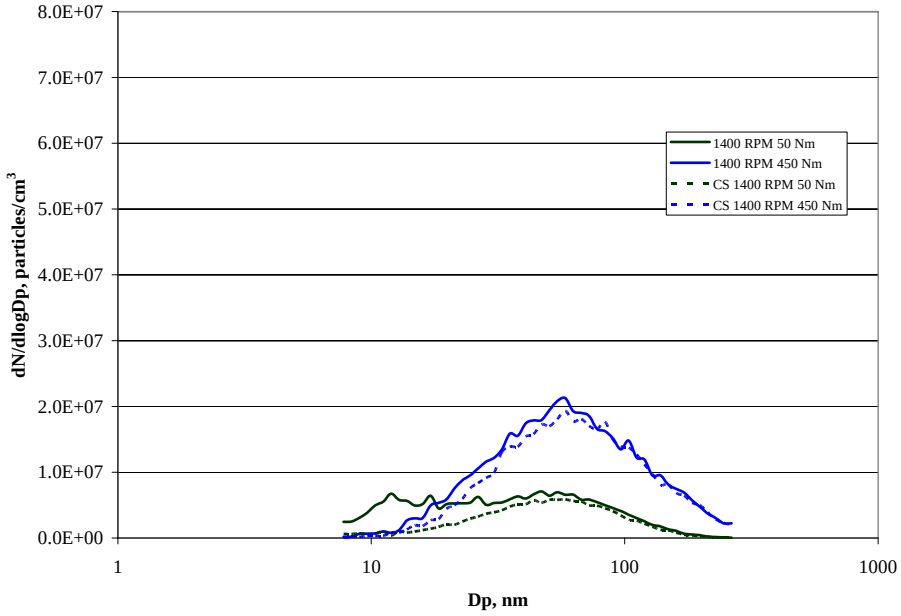


Comparison Between Biodiesel and Petroleum Particles

- Engine to engine variation
- Biodiesel particles are
  - Smaller
  - Contain more volatile material, especially in the smallest size range
  - Contain much less soot
- Much of this volatile material is partially burned fuel
- A well designed oxidizing catalyst removes most of this volatile material
- All this applies to current engines, what about advanced engines with aftertreatment?

Center for Diesel Research and Combustion Lab Ethanol Research

- Ethanol (E85) performance and particle emissions in Otto (gasoline) engine
- Ethanol (E20) spark ignition fleet tests – to help support 2013 E20 mandate in Minnesota
- Ethanol (E100) combustion in Diesel engine enhanced with hydrogen injection
- Ethanol (E100) as fuel in homogeneous charge compression ignition (HCCI) engine
- Hydrogen from reformed ethanol as a Diesel combustion modifier

Fundamental studies of ethanol blends in SI engine (E0 –E85)

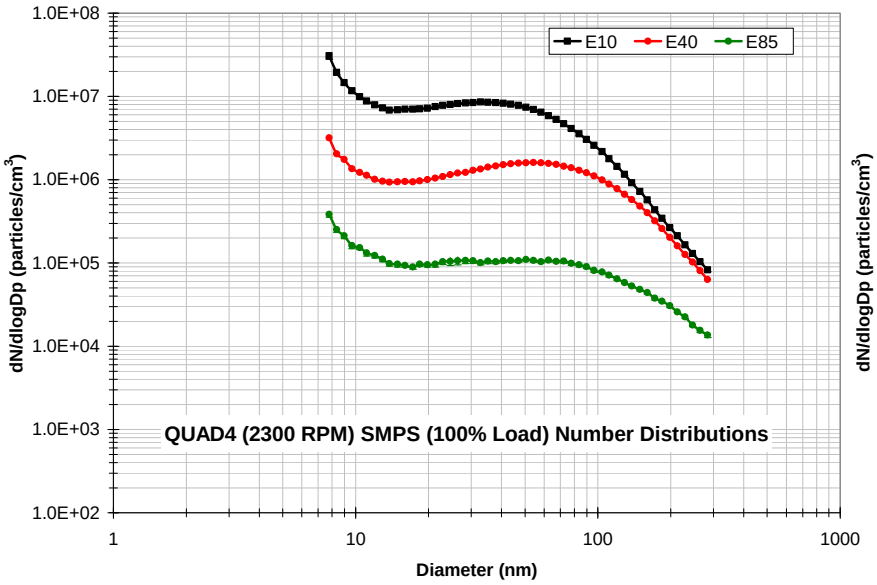
- Overall particle emissions – size and number*
- Optical properties of soot particles – light absorption and scattering characteristics*
- Kinetics of oxidation of ethanol soot**
- Single particle mass spectrometer measurements of unregulated particle emissions***

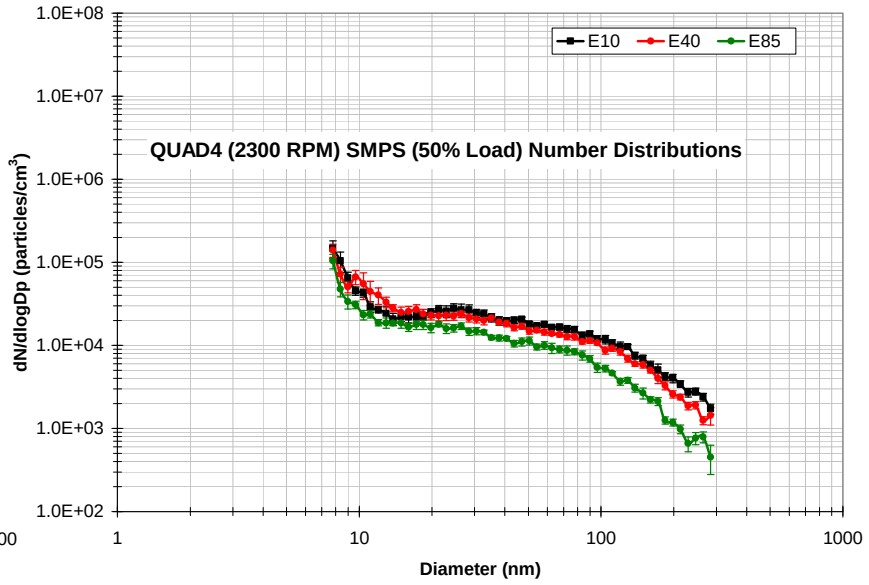
*Drayton, Marcus K.; Henry M. Ajo, Jeffrey T. Roberts, and David B. Kittelson, 2008. "The Influence of Fuel Ethanol Content on Spark Ignition Engine Nano-Particulate Emissions and Black Carbon Composition," in preparation for submission to SAE.

**Ajo, Henry M.; Marcus K. Drayton, David B. Kittelson, and Jeffrey T. Roberts, 2008. "The Effects of Ethanol as an Oxygenate Additive on Soot Nanoparticulate Matter Oxidation Kinetics, in preparation for submission to EST.

***Dutcher, Dabrina D.; Marcus Drayton, Mark R. Stolzenburg, Juan M. Medrano, Deborah S. Gross, David B.Kittelson, and Peter H. McMurry, 2008. "Bio-Fuel Combustion: a Single Particle Perspective, Part 1: Ethanol" submitted to Environmental Science and Technology.

Influence of Ethanol Blends on Ultrafine and Nanoparticle Emissions*





- At high loads the particle emissions are strongly dependent upon the ethanol content of the fuel with 1 to 2 orders of magnitude decrease with E85
- At lighter loads the effect is much smaller, but this doesn't matter because nearly all emissions are at high load – E10 emissions go up by about a factor of 1000 during hard acceleration

*Drayton, Marcus K.; Henry M. Ajo, Jeffrey T. Roberts, and David B. Kittelson, 2008. "The Influence of Fuel Ethanol Content on Spark Ignition Engine Nano-Particulate Emissions and Black Carbon Composition," in preparation for submission to SAE.

E20 Program*

- Thirteen month field test program with matched fleet of UM light and medium duty gasoline vehicles
  - 40 running E0
  - 40 running E20
- Test data
  - Daily driveability survey by lay drivers
  - Quarterly driveability tests by professional raters
  - Maintenance, fuel economy records
  - ***Result – no statistically significant changes***
- Complementary programs
  - Material compatibility at Automotive Center in Mankato
  - Emissions testing of subset of vehicles at end of program by RFA

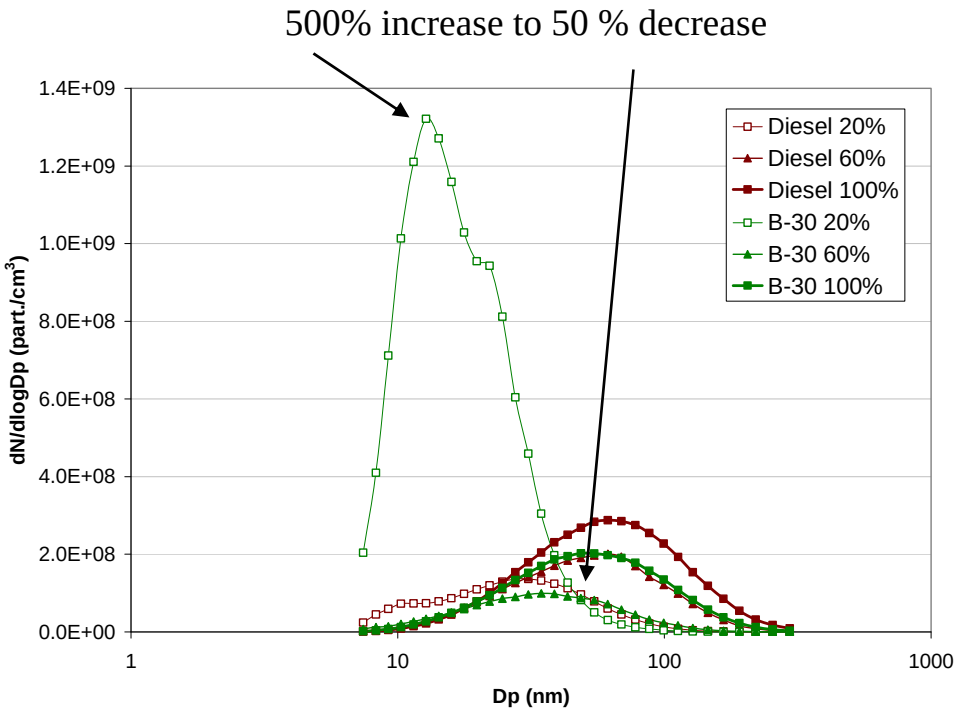
*Kittelson, David; Andy Tan, Darrick Zarling, Beth Evans, and Carlton H. Jewitt, Consultant, 2008. "Demonstration and Driveability Project to Determine the Feasibility of Using E20 as a Motor Fuel," Final Report submitted to Minnesota Department of Agriculture.

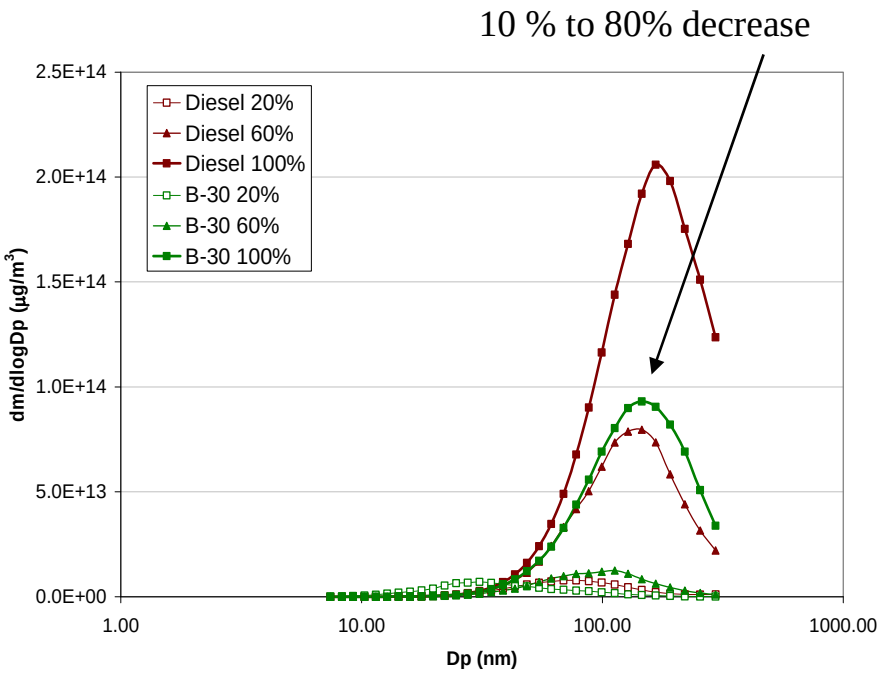
Butanol*

- BP is promoting the use of butanol as a gasoline fuel extender
- We decided to test butanol blends in both gasoline and Diesel engines
- Preliminary Diesel results shown below
- Gasoline test results being processed

*Olson, Andre, M.S. Thesis in preparation, University of Minnesota, 2008.

Number & Mass distributions, small RV generator, ULSD and 30% butanol in ULSD





Butanol*

- Preliminary Diesel tests reported here for 30% butanol blend with ULSD
  - 20 to 50% NO_x reductions
  - Particle results as reported above
  - Number increase at light load, nucleation mode particle formation
  - Number decrease at heavier load
  - Mass decrease across the load range
- Butanol appears to behave somewhat like biodiesel in low blends as a diesel fuel extender but does not have NO_x increase or cold flow issues
- Butanol has a very low Cetane Number which would lead to operability issues at higher blend levels

*Olson, Andre, M.S. Thesis in preparation, University of Minnesota, 2008.

DME
A second generation renewable fuel for Diesel engines

- DME is a strong candidate for a longer term future fuel.
- Fuel Properties
  - Energy dense and liquid at low pressure
  - Non-toxic, biodegradable and harmless to the atmosphere
  - Best well-to-wheel energy efficiency from bio source, 25% better than synthetic diesel (Fischer-Tropsch)
  - Highest efficiency, lowest global warming potential and cost of the biomass to liquid (BTL) fuels
  - Close to CO_2 neutral if produced from biomass
- Engine Behaviour
  - Very low exhaust emissions (soot-free combustion, Euro 5)
    - » Eliminates need for particle traps
    - » Allows low NO_x engine optimization
  - Requires substantial engine modification, mainly to fuel system

DME prospect in Minnesota

- CDR is seeking funding for DME research
  - Seeking guidance from Volvo Technology in obtaining funding
  - We have funding to set up DME fuel storage and distribution in the lab if other funding available
- Minnesota company, Rational Energy, seeking funding to build DME plant
  - 250 ton DME per day from corn stover
  - Initial market propane replacement
  - Negotiating with UM and Metro Transit for engine tests and bus demonstration

Acknowledgements

We would like to thank our many sponsors including:

U of MN Initiative for Renewable Energy and the Environment
Minnesota Department of Agriculture
National Biodiesel Board
MN Soybean Producers
AURI
Xcel Energy
Great Lakes Governors
Volkswagen
Volvo
Deere Power Systems
And many others

Along with U of M Researchers and Graduate Students:

Dr. Win Watts, Jason Johnson, Andy Tan, Marcus Drayton, Andre Olson, and Aaron Collins

? Questions or Comments ?

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