Biofuels:
Current and Future

David Kittelson
Center for Diesel Research
Department of Mechanical Engineering
University of Minnesota

2008 BioEconomy Conference
Iowa State University
Ames, Iowa
September 7-9, 2008

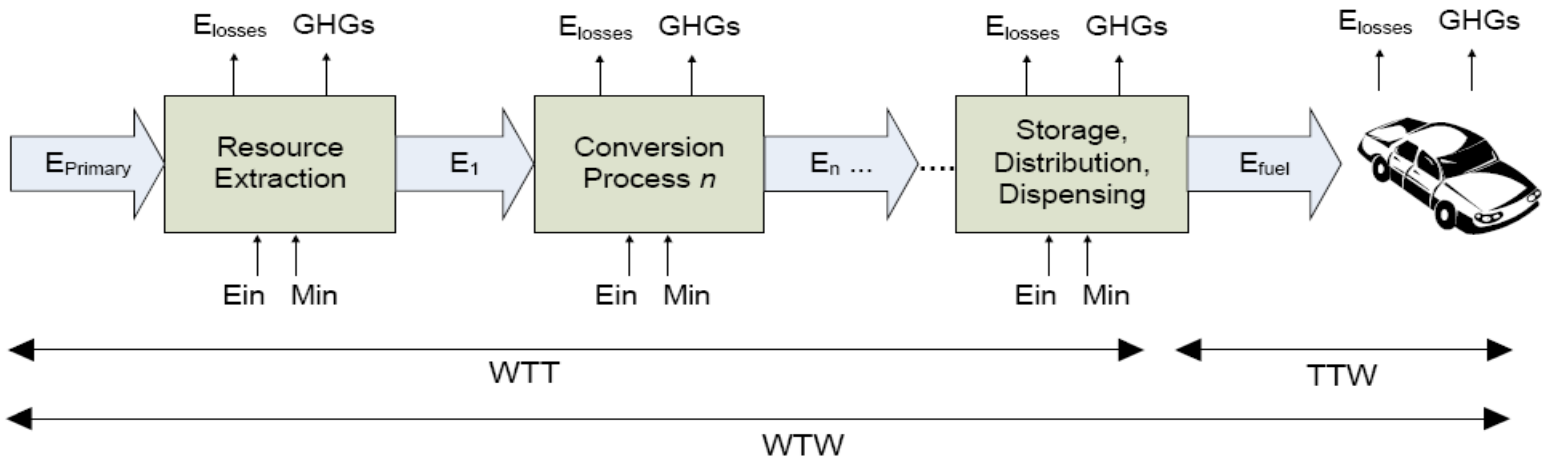
Outline

- Background, fuels, LCA
- Ethanol
- Biodiesel
- DME

Alternative transportation fuels

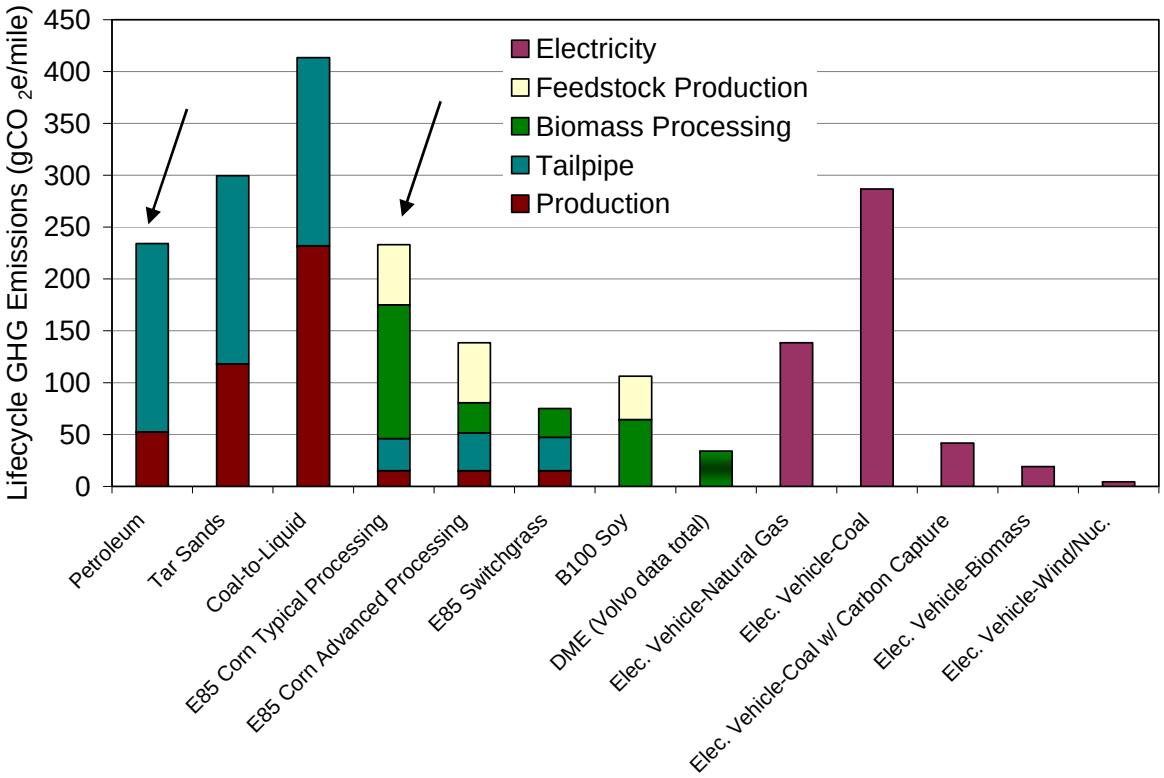
- Non petroleum fossil fuels
  - CNG
  - LPG
  - Coal and natural gas based synthetic fuels (Fischer-Tropsch)
- Biofuels
  - Near term
    - Ethanol (corn, sugar, wheat)
    - Biodiesel (soy, animal fat, canola, rapeseed, palm)
    - Biogas
  - Longer term –biological processes
    - Ethanol (cellulose, sorghum, cassava)
    - Biodiesel (camelina, algae, jatropha, castor)
    - Butanol (beet sugar, corn, cellulose)
  - Longer term – thermochemical processes (biomass feedstocks)
    - Renewable Diesel
    - Dimethyl Ether
    - Fischer-Tropsch liquids
    - Methanol
    - Mixed alcohols
- Energy carriers
  - Electricity (high grade, already work)
  - Hydrogen (low grade, must be converted to work)

Fuel Carbon Footprint Strategies



- Fuel carbon content must be calculated on a lifecycle basis
  - Life cycle analysis in flux as processes and assumptions change
  - Impact of land use changes are an area of uncertainty not included here
- To reduce carbon fuel footprint over the long-term requires
  - Improved production methods
  - Second generation fuels and feedstocks

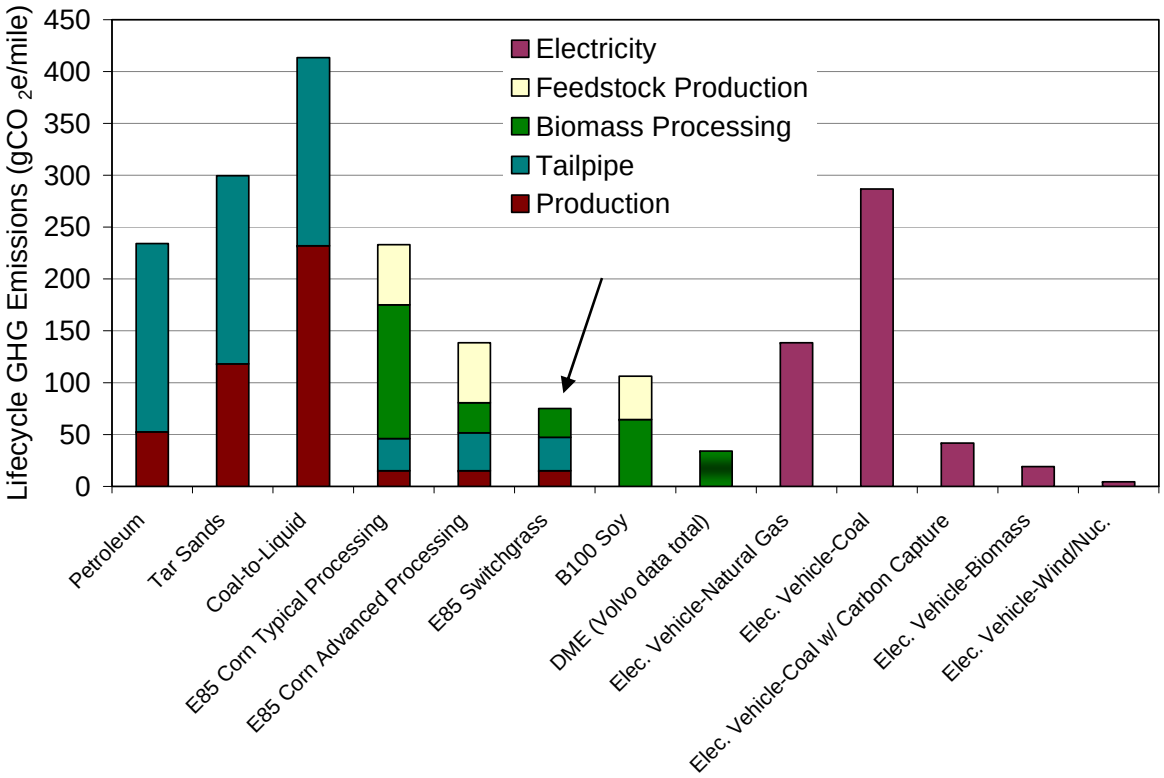
Fuel Carbon Footprint



•Current ethanol is no better than petroleum

Adapted from: Farrell and Sperling, 2007

Fuel Carbon Footprint



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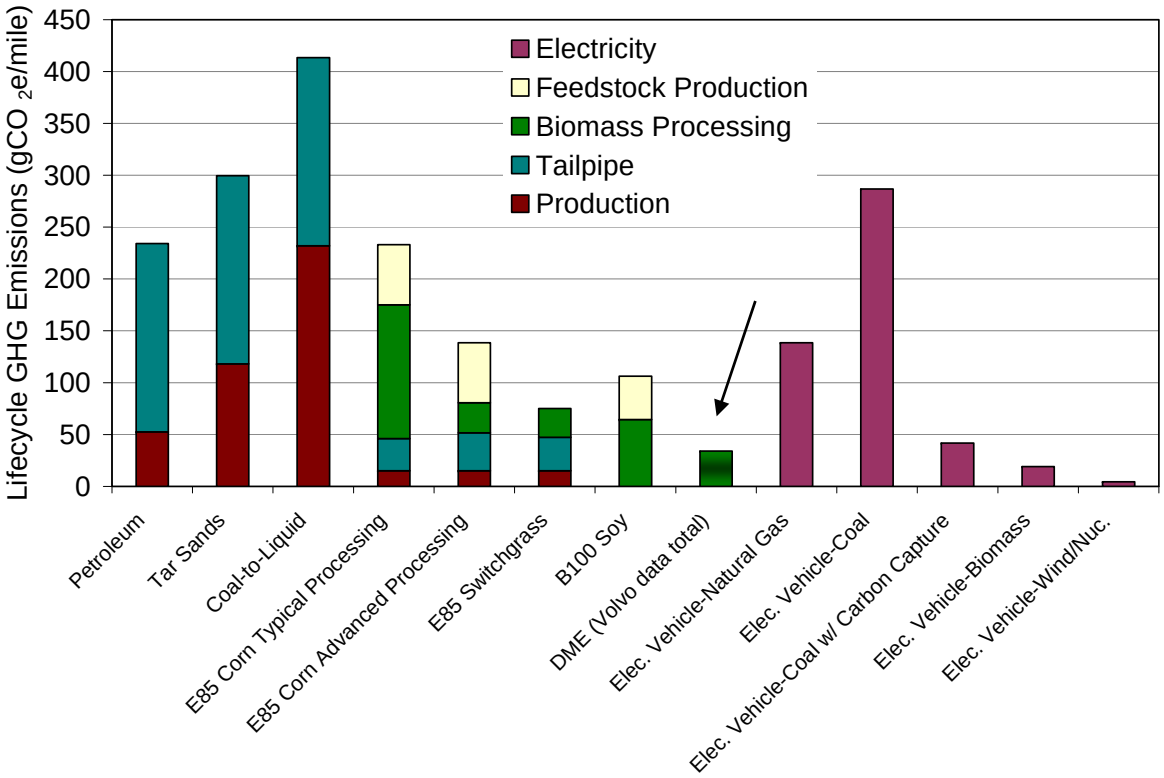

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- DME has the best footprint of any other portable fuel

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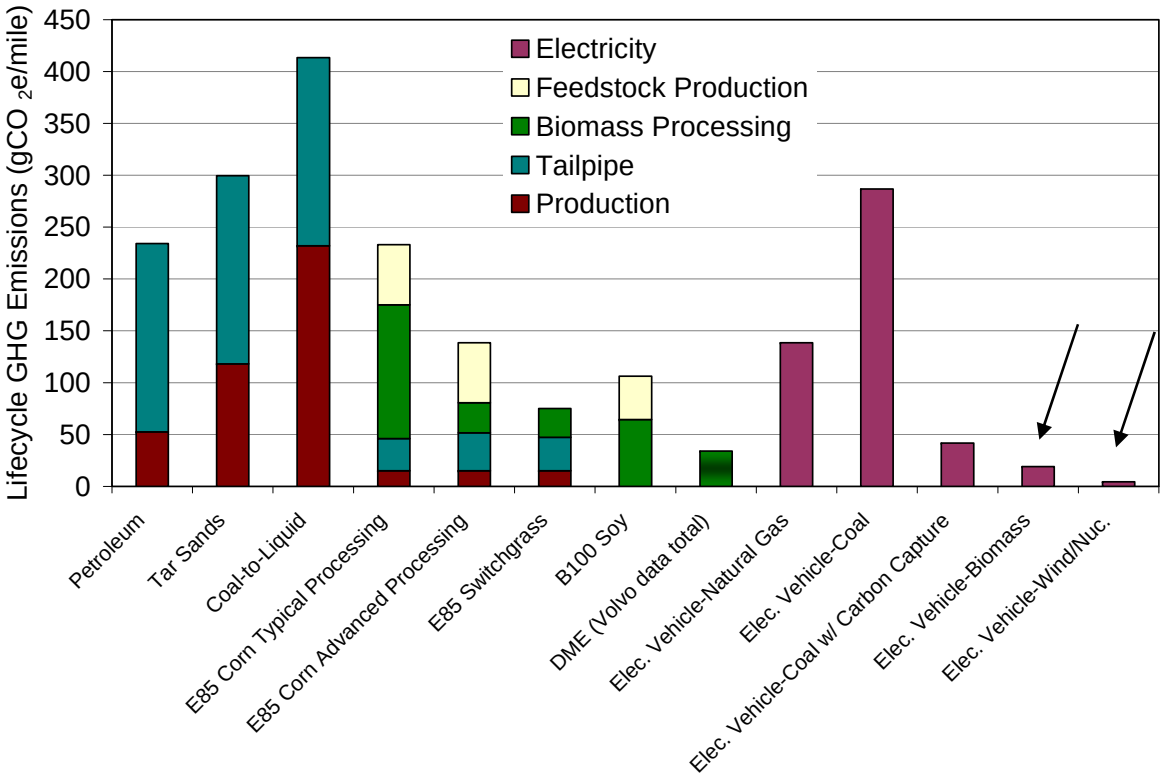


- Current ethanol is no better than petroleum – cellulosic is the hope
- DME has the best footprint of any other portable fuel
- Electric vehicles with electricity from biomass or wind may be best for urban vehicles

Adapted from: Farrell and Sperling, 2007

Status of Minnesota Fuel Policies

- State Policy on Ethanol
  - Current Standard: E10, 10% ethanol in gasoline
  - Future Goal: E20, 20% blend mandated for 2013 with 5% from cellulosic sources
  - The Next Generation Energy Initiative increases E85 gas stations from 300 to 1800 by the year 2010
- State Policy on Biodiesel
  - Current Standard: E2, 2% biodiesel in petroleum Diesel
  - Future Goal: E20, 20% biodiesel in petroleum Diesel mandated for 2015 (methyl ester fuels)

Center for Diesel Research: Ethanol Research

- **Ethanol (E20) spark ignition fleet tests – to help support 2013 E20 mandate in Minnesota**
- **Ethanol (E10 - E85) particle emissions from Otto cycle (gasoline) engine**
- Hydrogen from reformed ethanol as a combustion modifier
- Ethanol (E100) combustion in Diesel engine enhanced with hydrogen injection
- Ethanol (E100) as fuel in homogeneous charge compression ignition (HCCI) engine

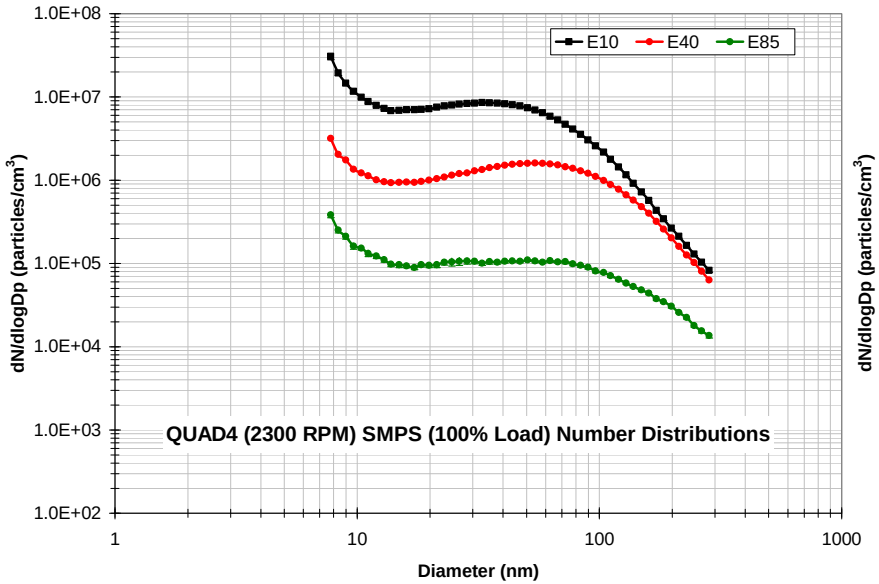
Minnesota's E20 Program

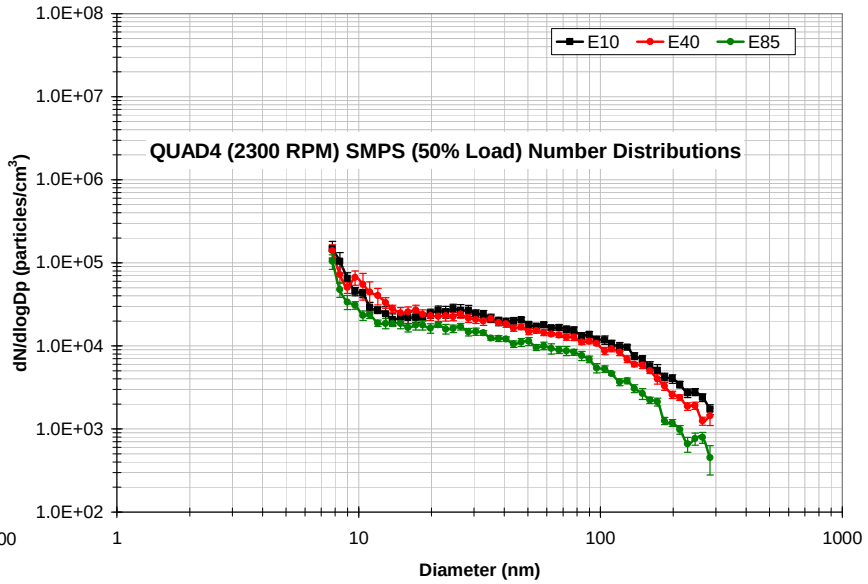
- MN now requires gasoline contain 10% ethanol
- Under the new language 20% ethanol will be required on 8/30/2013 unless by 12/30/2010:
  - 1. 20% of MN gasoline is ethanol (E10 plus E85?)
  - -or-
  - 2. EPA does not approve a 211 (f)(4) waiver application to certify E20 as "gasoline"

E20 research program – data in support of EPA waiver

- UM driveability program - One year field test
  - Matched fleet of UM vehicles, 2000-2006 models
    - 40 running E0
    - 40 running E20
  - Test data
    - Daily driveability survey
    - Tests by driveability raters
    - Maintenance, fuel economy records
  - Results
    - No statistically significant change in driveability
    - No fuel related maintenance problems
    - No statistically significant decrease in fuel economy (1.4% ± 6.6%)
  - Issues
    - Limited fleet size
    - No long term durability
    - Limited to modern, relatively low mileage, passenger cars and light / medium trucks
    - No off road, marine, small engines, etc.
- Material compatibility at Automotive Engineering Technology department in Mankato showed no significant fuel system issues
- Emissions testing of a small fleet of vehicles by Renewable Fuels Association underway

Influence of ethanol blends on ultrafine emissions from port fuel injection gasoline engine*





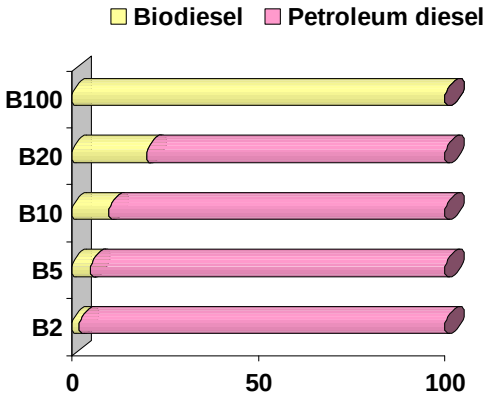
- At high loads the particle emissions are strongly dependent upon the ethanol content of the fuel with 1 to 2 orders of magnitude decrease with E85
- At lighter loads the effect is much smaller, but this doesn't matter because nearly all emissions are at high load
  - E10 emissions go up by two orders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

*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.

Center for Diesel Research and Combustion Lab: Current Biodiesel Research

- Biodiesel (methyl esters: soy, tallow, rapeseed, canola,…new program on palm, jatropha, algae?)
  - **Emphasis on regulated emissions and particle characterization – size, number, etc.**
    - Automotive engines
    - NIOSH underground mine studies
    - Backup power generation
    - Marine engines
  - Soot oxidation kinetics, impact on exhaust filters
- Raw seed oils
  - Atomization
  - Combustion properties
  - Fundamental particle characterizations
- Biodiesel and raw seed oils in gas turbines

Biodiesel Blends and Emissions



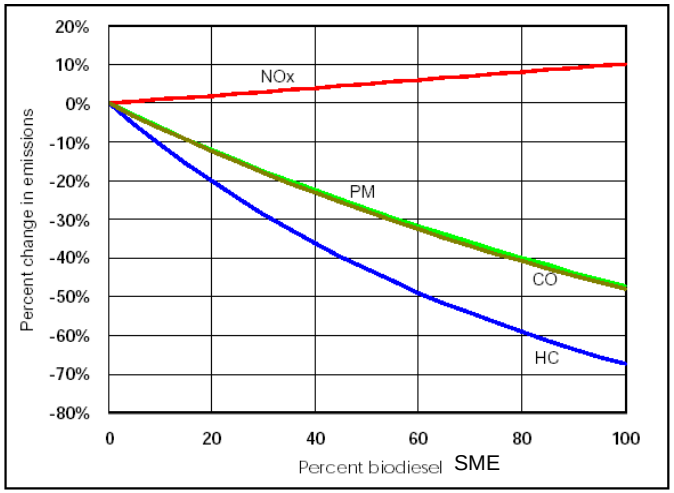
B100 = 100% biodiesel

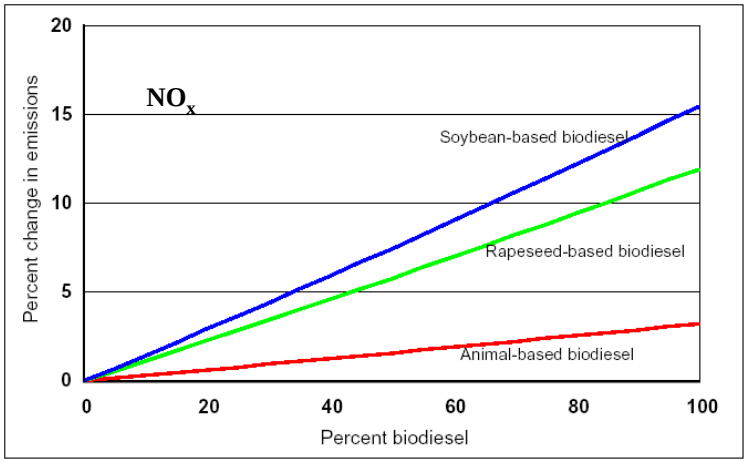
B20 = 20% biodiesel + 80% petroleum diesel

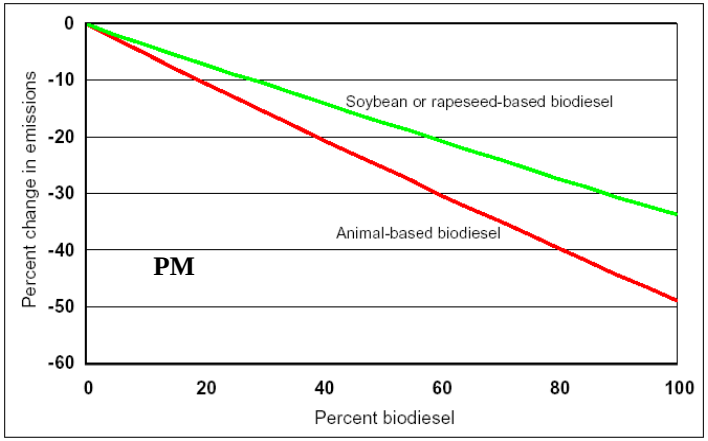
B10 = 10% biodiesel + 90% petroleum diesel

B5 = 5% biodiesel + 95% petroleum diesel

B2 = 2% biodiesel + 98% petroleum diesel

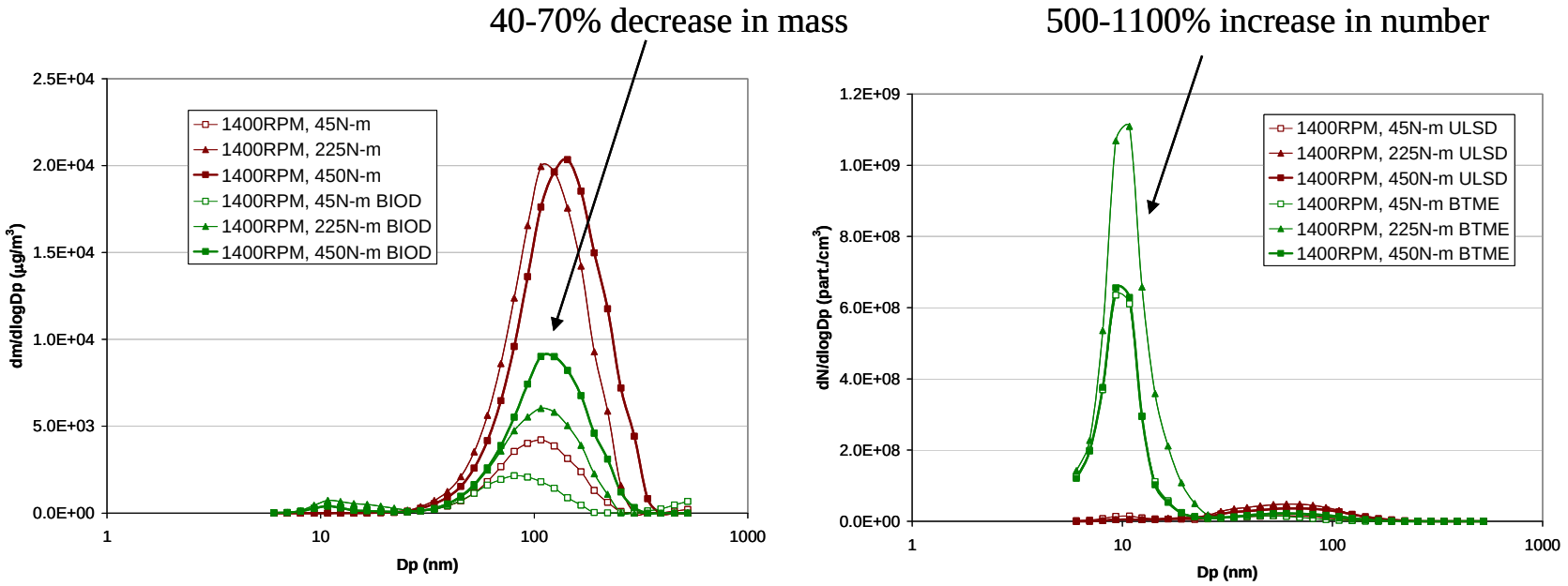






Data from USEPA 2002

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



- The reduction in particle mass is due to reductions in soot emissions
  - Soot is a potent greenhouse agent
  - Soot reduction is common to oxygenated fuels, alcohols, esters, ethers
- The increase in number emissions in the nucleation range (nanoparticles) is a potential concern

Comparison between biodiesel and petroleum particles

- Engine to engine variation
- Biodiesel particles are
  - Smaller – increase in tiny nanoparticles
  - Contain more volatile material, especially in the smallest size range
  - Contain much less soot – less greenhouse forcing
  - Lower mass emissions, higher number emissions
- Much of this volatile material is partially burned fuel
- A well designed oxidizing catalyst removes most of this volatile material
- Biodiesel soot is more readily oxidized, more reactive
- Slight NO_x increases often observed, likely due to higher adiabatic flame temperature

Dimethyl Ether (DME)

- May be produced from natural gas or biomass including wood waste, corn stover, prairie grass
- Physical properties similar to propane – LP gas
  - Nontoxic
  - Gas at ambient conditions and unlike MTBE is not a groundwater pollution threat
- Uses
  - Aerosol propellant in the cosmetic industry to replace CFC propellants
  - Propane replacement
  - Diesel fuel
    - High efficiency
    - Soot free combustion
    - Fuel system modifications required
- Volvo, Nissan, and Isuzu have advanced DME engines ready for production
- EPA, Ann Arbor has active DME / methanol programs

DME emissions

- Soot free combustion allows DME engines to operate without exhaust particle filters and still meet current and future PM mass emission standards
- Absence of soot allows engine to be optimized for low NO_x
- It is likely that the only aftertreatment necessary will be an oxidizing catalyst for hydrocarbon and CO control
- Little is known about unregulated emissions from DME engines
- Nanoparticles from the lubricating oil may be an issue

Minnesota DME/Methanol Production Potential

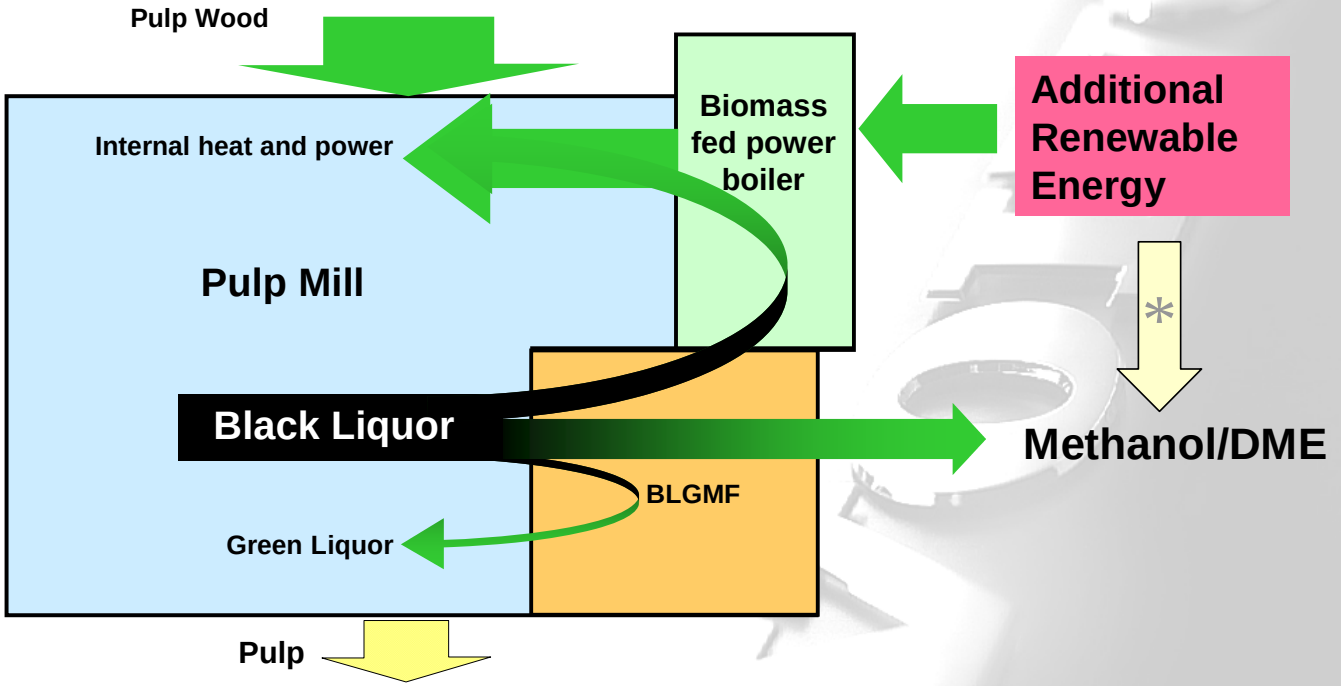
- Rational Bioenergy, Inc. is seeking funding to build a DME plant using corn stover as feedstock
  - ½ to corn stover from 12-15 mile radius
  - 15 million gallons year (Diesel equivalent)
  - Priced below current Diesel fuel
- Using ½ the corn stover statewide
  - Would produce 800 million gallon per year Diesel equivalent
  - Current on-highway Diesel fuel use is about 700 million gallon per year.
- A likely path to DME introduction will be initial use as a propane replacement followed by gradual introduction of DME vehicles
- Production of “green methanol” for use in biodiesel production and for fuel cells may also play a role
- Black liquor gasification in pulp mills offers easy initial path to DME

Conclusions

- Ethanol
  - corn based ethanol as currently produced does little to reduce greenhouse gases but cellulosic ethanol offers substantial reductions
  - E20 blends have shown no issues in modern cars and trucks
  - Ethanol blends reduce PM emissions across entire size range
- Biodiesel
  - SME has lower greenhouse emissions than current ethanol
  - Biodiesel significantly reduces EC, CO, and HC emissions
  - Biodiesel increases emissions of volatile nucleation mode particles and, often, NOx
- DME has the best greenhouse emissions of any portable fuel
  - Requires significant fuel system modifications
  - Essentially eliminates the need for Diesel particulate filters
  - Engine may be optimized for low NOx and high efficiency
  - Unregulated emissions not well understood
- Oxygenated biofuels reduce emissions of soot, a potent greenhouse agent
- Electricity from biomass and other low carbon sources may play and important role in future transportation

Black liquor to engine fuels - Ideal use of low grade biomass

Courtesy - Anders Röj, Volvo Technology Corporation, Fuels and Lubricants



(Source: Chemrec)

$$\text{Production Efficiency} = \frac{\text{Methanol/ DME}}{\text{Additional Renewable Energy}} > 65\%$$

DME/Methanol Production Potential

- From black liquor gasification using existing pulp mills
  - Total use of black liquor in the mill
    - Finland 50% transportation fuels
    - Sweden 30% transportation fuels
    - Minnesota 4 – 7% transportation fuels
  - Adding a small booster plant to existing Minnesota mill
    - 7 million gallons per year DME – enough for about 700 urban buses (MSP metro fleet ~ 900)
    - Or 7 million gallons per year methanol – enough to supply all the methanol needed by all Minnesota's biodiesel plants (6.3 million gallons) with some left over
    - Estimated cost $2.20-2.30 / gallon gasoline equivalent with no subsidies