Vehicle/ Fuel Technologies Issues in the Use of Biofuels in the US and their Measures

Matthew Thornton

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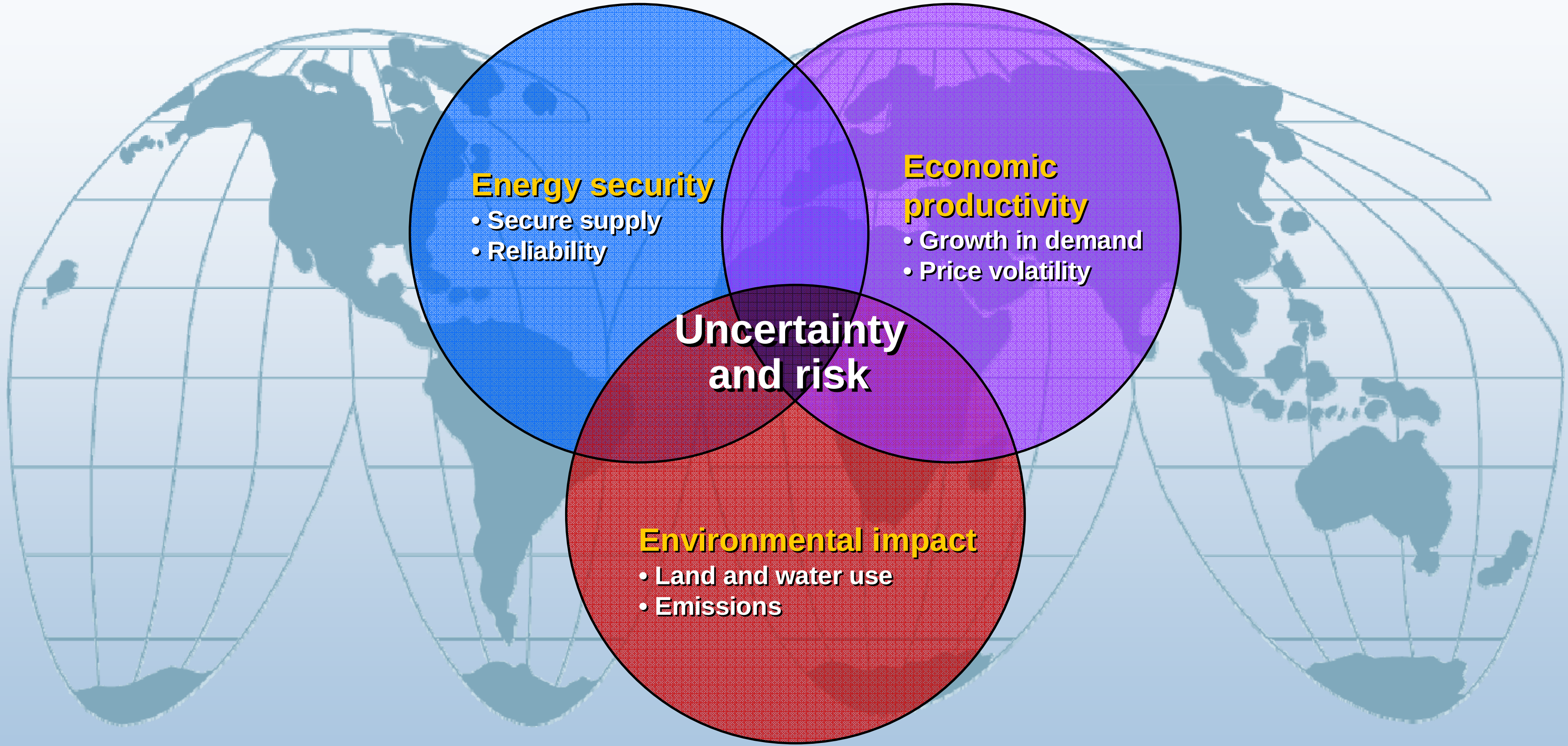
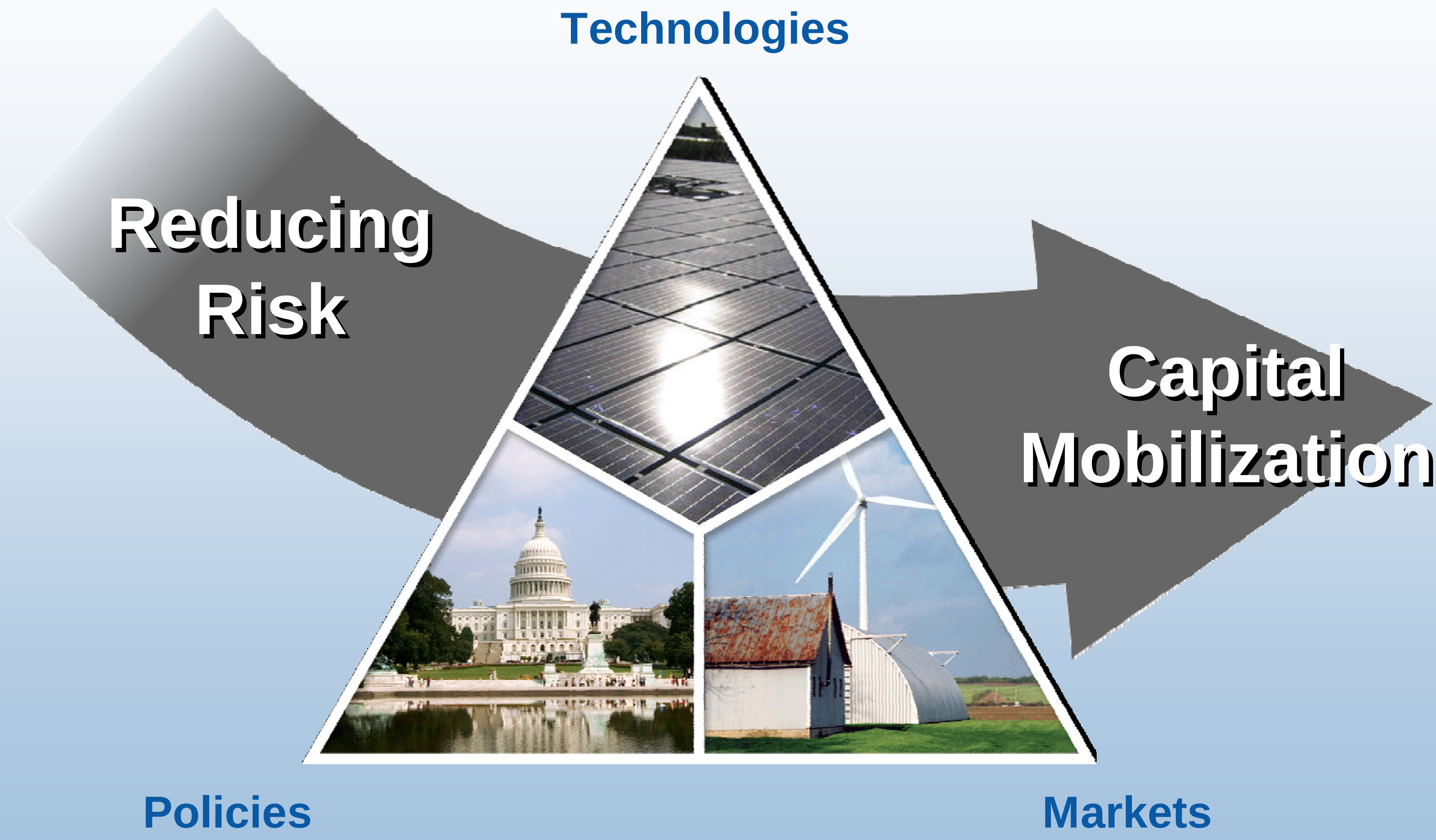
U.S. Department of Energy
Office of FreedomCAR and Vehicle Technologies and Biomass Program

Energy Solutions are Enormously Challenging



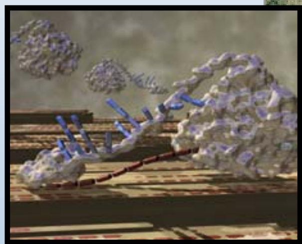
We need a balanced portfolio of options

Getting There Involves…



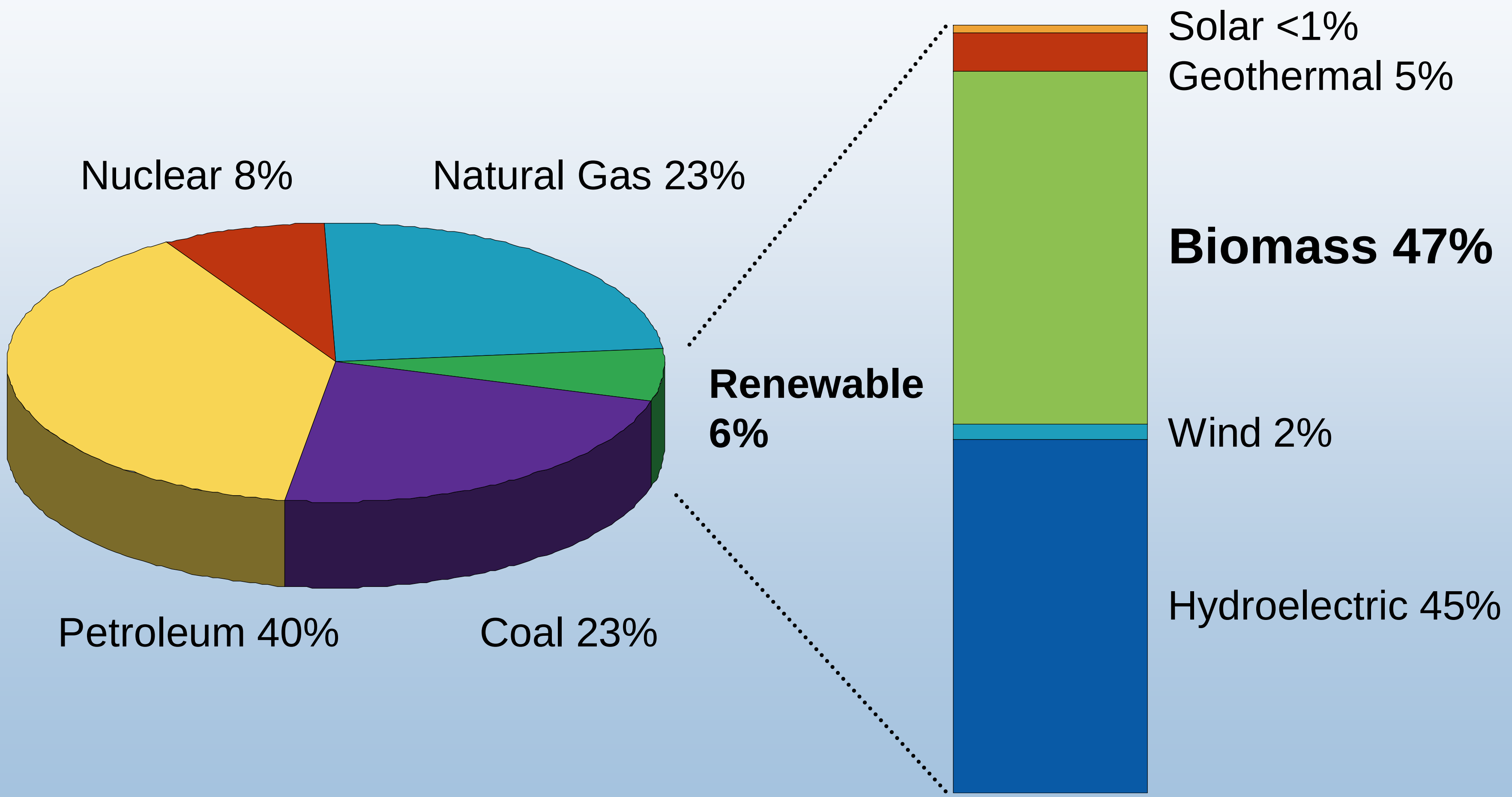
NREL Biofuels Research

- Two Main Research Focus Areas
  - Fuel Production
    - Feedstock Supply and Resources
    - Conversion Process
    - CO_2 Emissions
  - Fuel Utilization
    - Performance and Pollutant Emissions
    - Distribution
    - Vehicle Compatibility



Ethanol Production Research

Biomass Share of U.S. Energy Supply (2004 data)



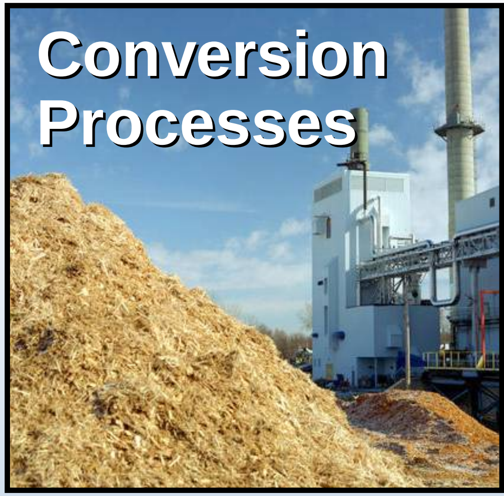
Source: Renewable Energy Trends 2004; Energy Information Administration, August 2005.
Note: Total U.S. Energy Supply is 100.278 QBtu; Energy Information Administration, August 2005.

Biomass Strengths

- Biomass is:
  - Abundant
  - Renewable
  - Carbon-neutral
  - The only sustainable source of hydrocarbons.
- Biomass can:
  - Fill the gap between energy demand and petroleum availability in the near term.
  - Be a renewable source of hydrogen in the long term.

Range of Biorefinery Concepts

- Trees
- Grasses
- Agricultural Crops
- Residues
- Animal Wastes
- Municipal Solid Waste
- Algae
- Food Oils

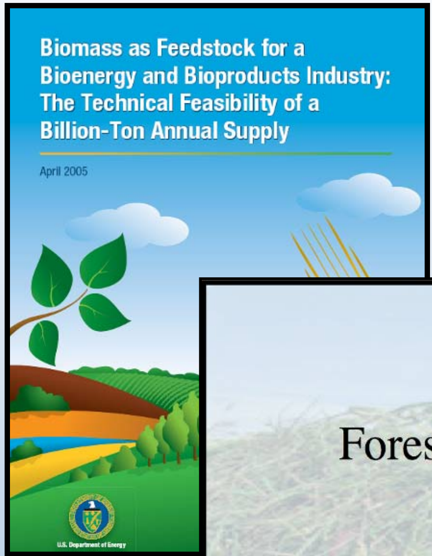


- Enzymatic Fermentation
- Gas/liquid Fermentation
- Acid Hydrolysis/ Fermentation
- Gasification
- Combustion
- Co-firing
- Trans-esterification

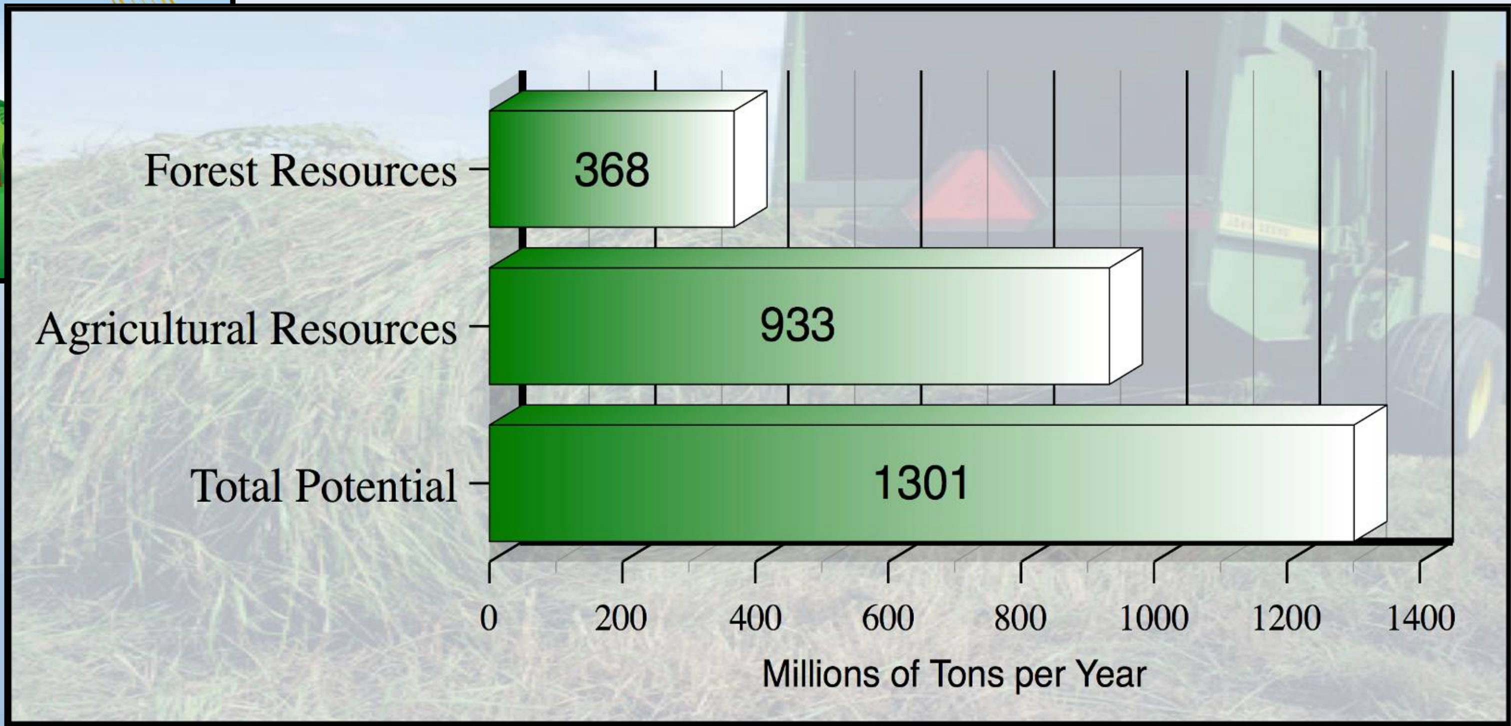
§ Products

- § **Fuels**
  - Ethanol
  - Biodiesel
  - "Green" Gasoline & Diesel
- § **Power**
  - Electricity
  - Heat
- § **Chemicals**
  - Plastics
  - Solvents
  - Chemical Intermediates
  - Phenolics
  - Adhesives
  - Furfural
  - Fatty Acids
  - Acetic Acid
  - Carbon Black
  - Paints
  - Dyes, Pigments, and Ink
  - Detergents
  - Etc.
- **Food and Feed**

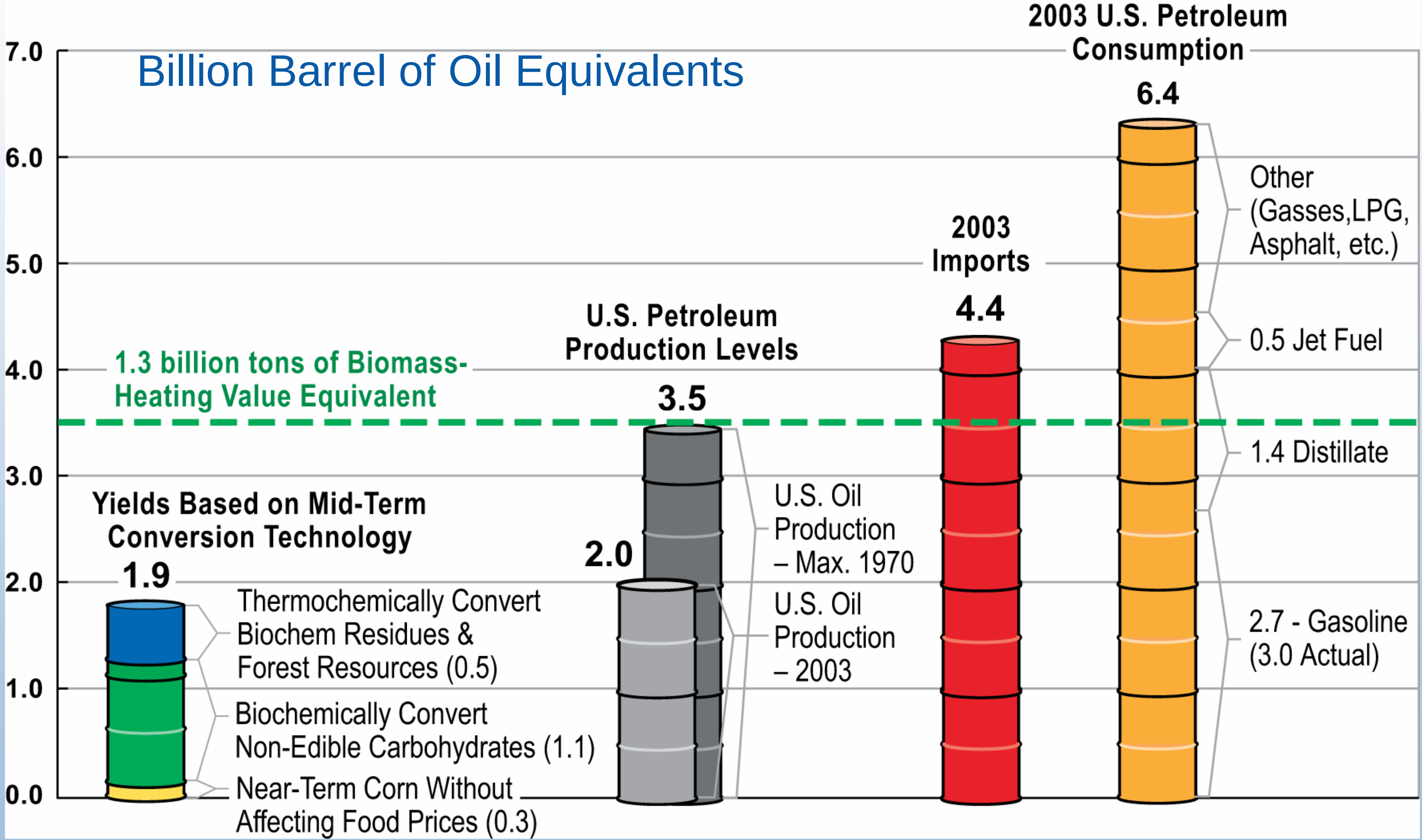
U.S. Biomass Resource Assessment



- Updated resource assessment - April 2005
- Jointly developed by U.S. DOE and USDA
- Referred to as the “Billion Ton Study”

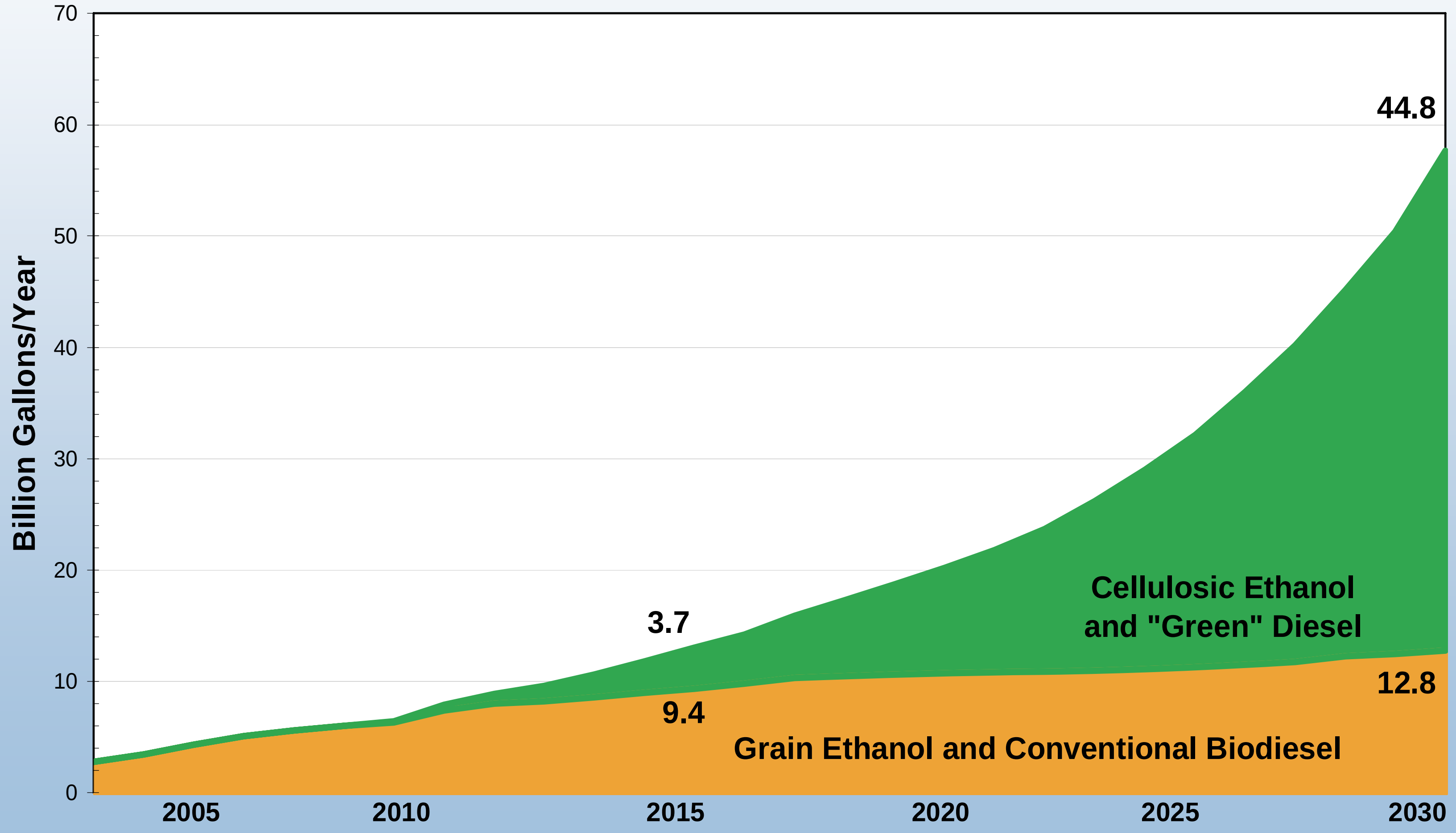


The 1.3 Billion Ton Biomass Scenario

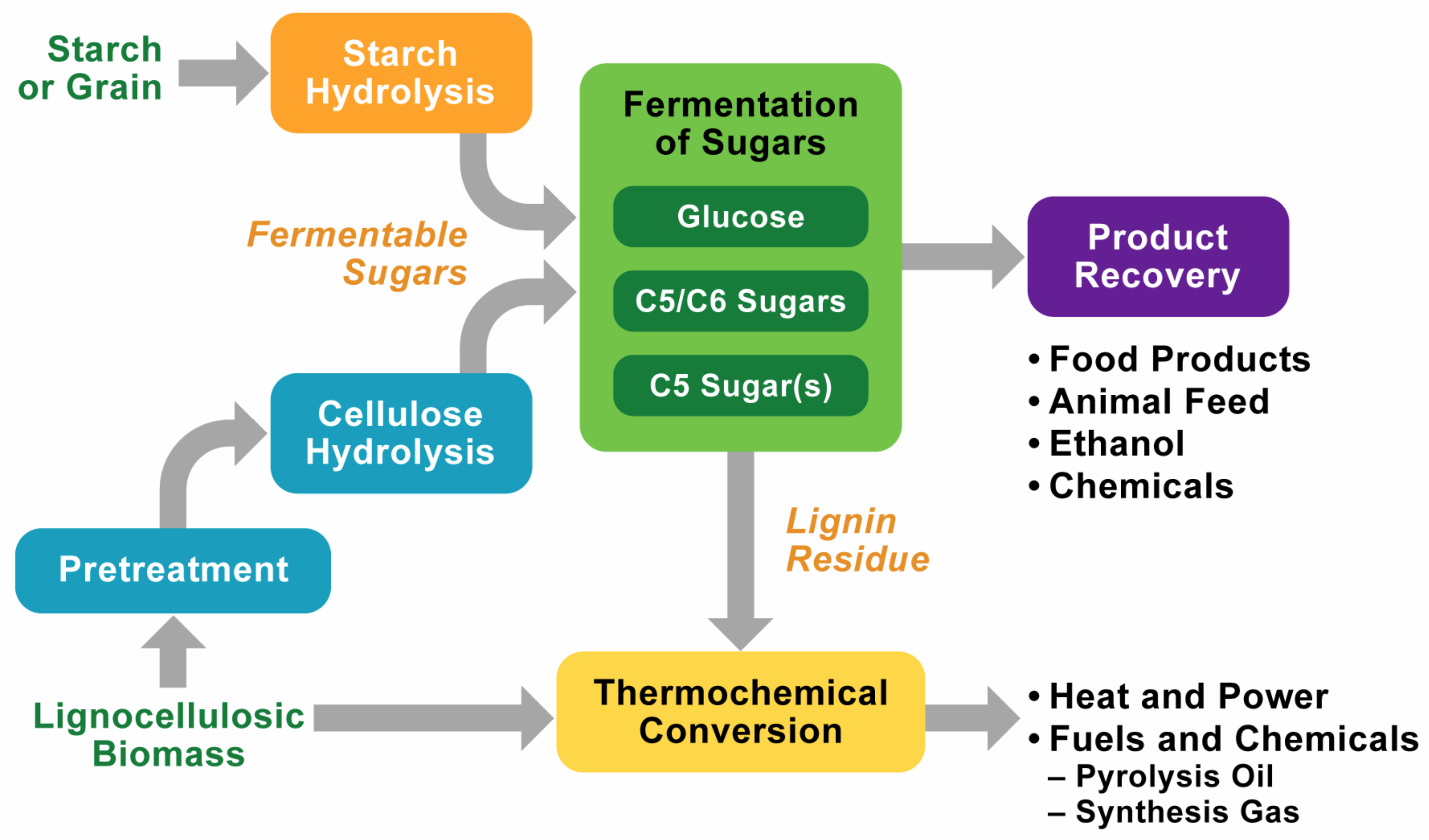


Based on ORNL & USDA Resource Assessment Study by Perlach et.al. (April 2005)
http://www.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf

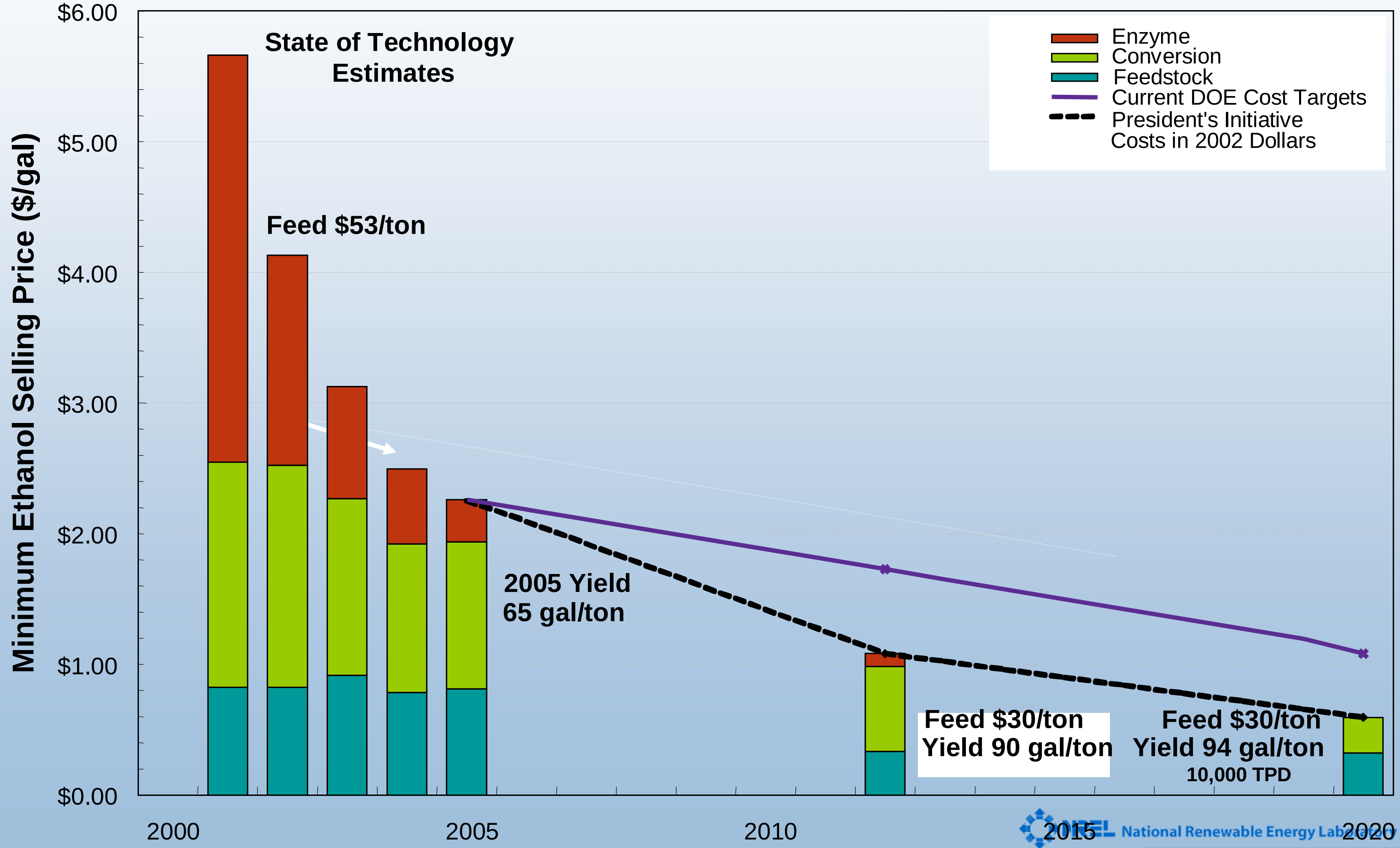
Required Growth of Cellulosic Ethanol to Supply 30% of U.S. Gasoline Demand by 2030



Integrated Biorefinery Elements



Reducing the Cost of Ethanol From Stover

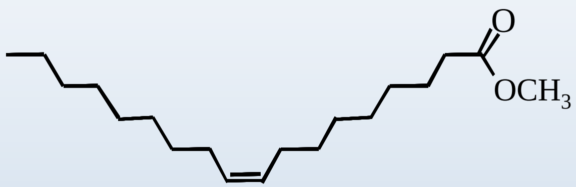


NREL National Renewable Energy Laboratory

Biodiesel Utilization Research Activities

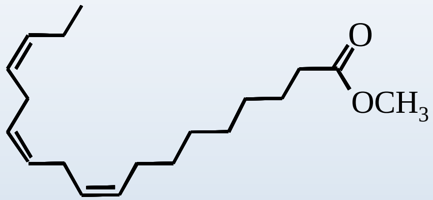
What is biodiesel?

- Mono-alkyl esters of fatty acids (i.e. methyl or ethyl esters)



Methyl Oleate

Methyl Linoleate

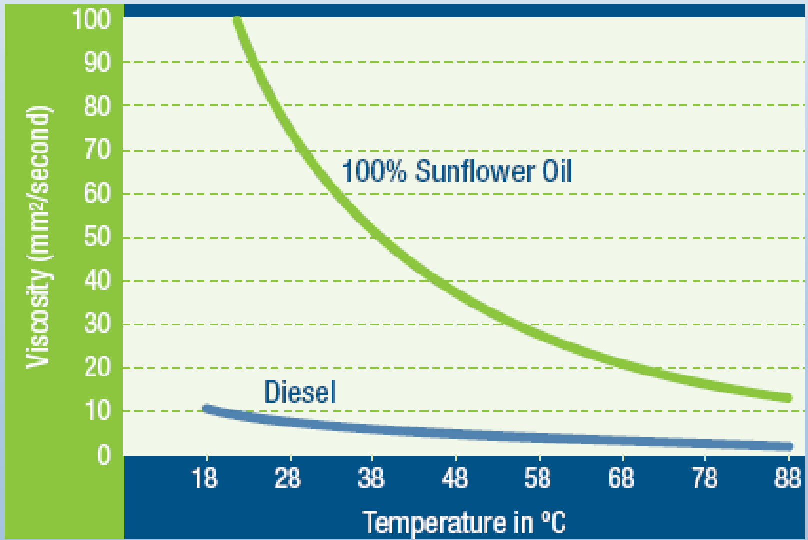


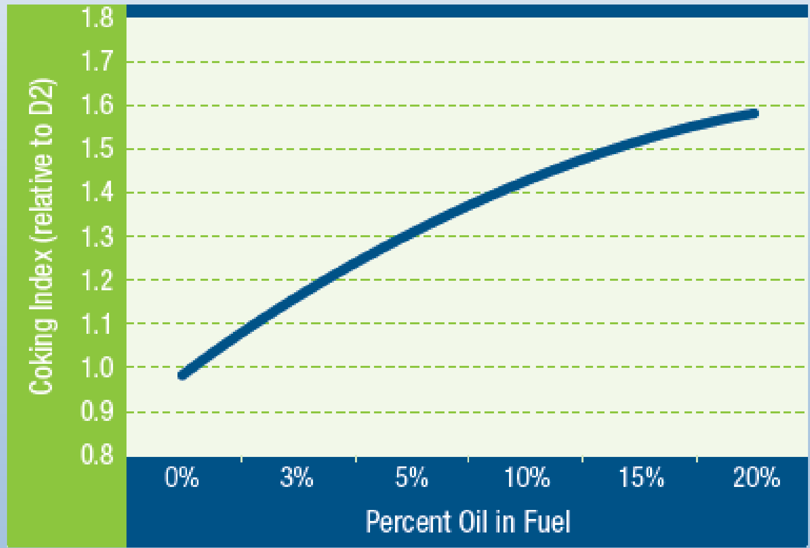
Methyl Linolenate

- Must meet the quality requirements of ASTM D6751
- Typically used as blend with petrodiesel (up to 20%)
- Price similar to petroleum diesel
- Agri-biodiesel (not recycled oil) is eligible for $1/gal blenders tax credit

What is not biodiesel?

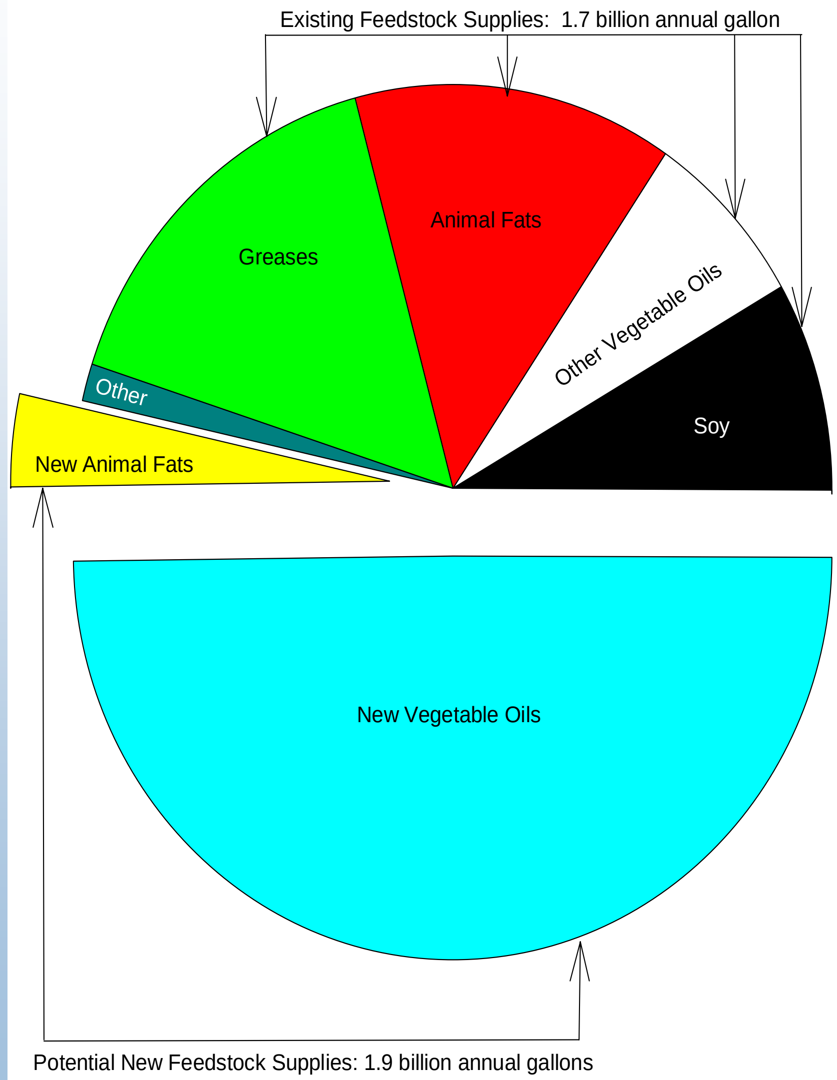
- Biodiesel is NOT unrefined vegetable oil or used cooking oil
- The much higher boiling point and viscosity of straight vegetable oil leads to engine carbon deposits, reducing engine life or increasing maintenance costs
- Fact sheet can be found here http://www.nrel.gov/docs/fy06osti/39733.pdf





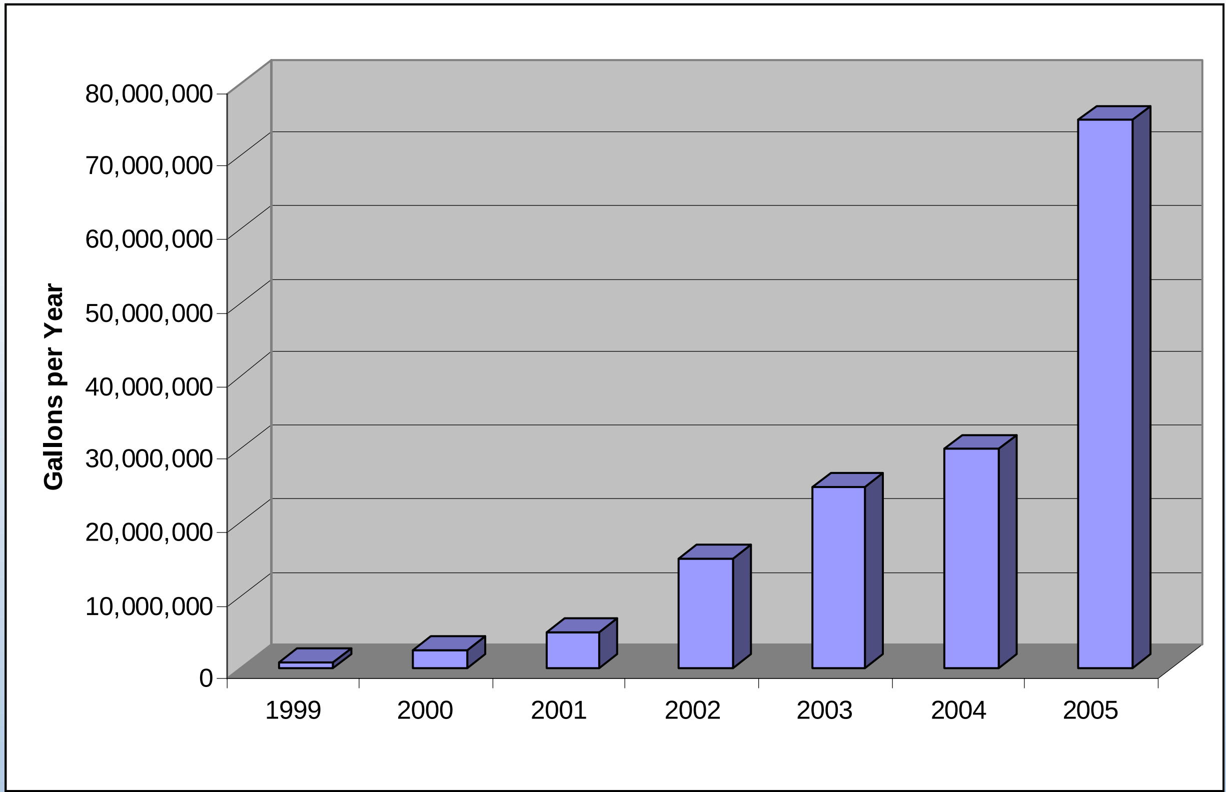
There is Enough to Make a Difference

- 1.7+ billion annual gallon resource today (~40 billion gallon on-road diesel market)
- 3.6 billion annual gallons by 2015
- Long-Term Potential: 10 billion annual gallons by 2030
- Other scenarios such as use of micro-algae could produce even higher levels
- Positive life-cycle energy balance (FER~3.2)



Feedstock analysis from NREL/TP-510-34796, June 2004

Biodiesel Production



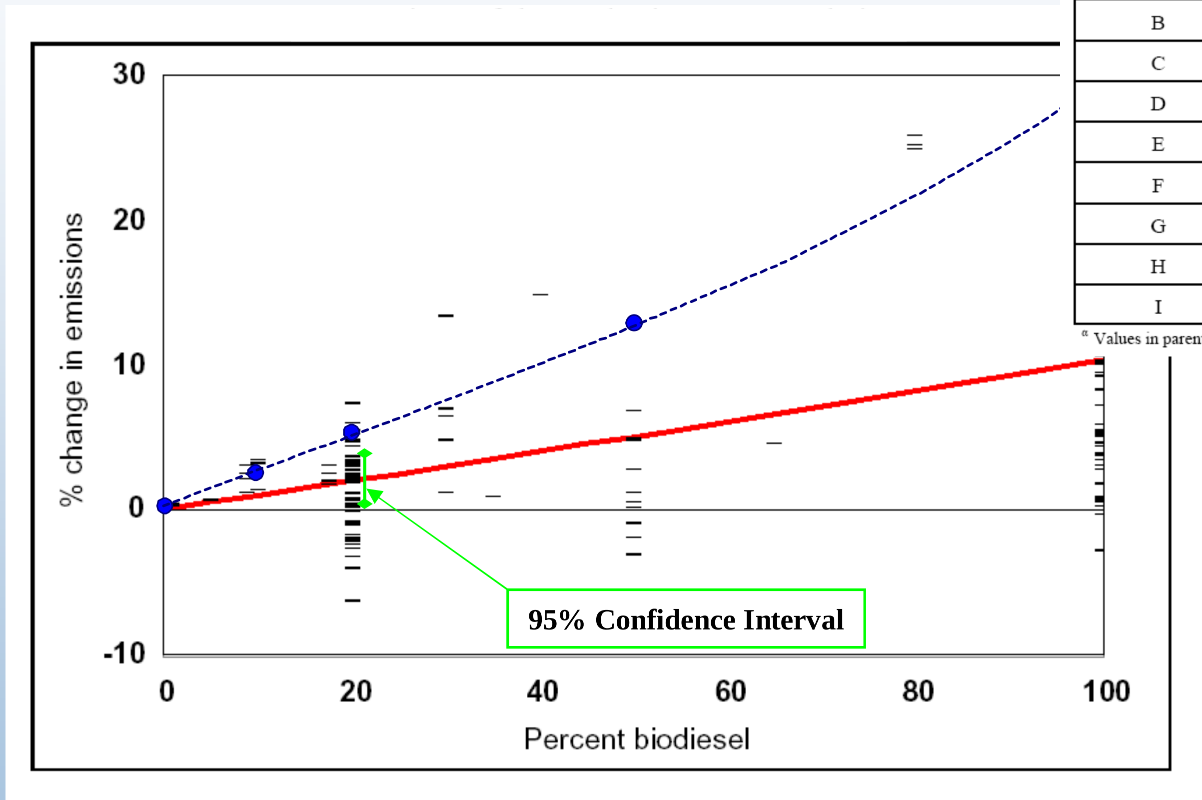
- *NBB predicting 150 million gallons for 2006*
- *Current production capacity is more than 290 million annual gallons*
- *More than 570 million annual gallons under construction or planned*

Biodiesel and NO_x Emissions

Biodiesel's Effect on NO_x Emissions -Engine Data

Typical Older Engines (thru 1997): B20 = +2%, B100 = +10%

Newer Engines (2004 compliant): B20 = +4%, B100 = +30%



Standards group	Model years	HD highway engines	NOx observations
B	2002 - 2006	0	0
C	1998 - 2001	2	14 (2)[a]
D	1994 - 1997	10	152 (19)
E	1991 - 1993	16	394 (50)
F	1990	3	87 (11)
G	1988 - 1989	8	112 (14)
H	1984 - 1987	2	16 (2)
I	- 1983	2	10 (1)

[a] Values in parentheses are percent of total observations

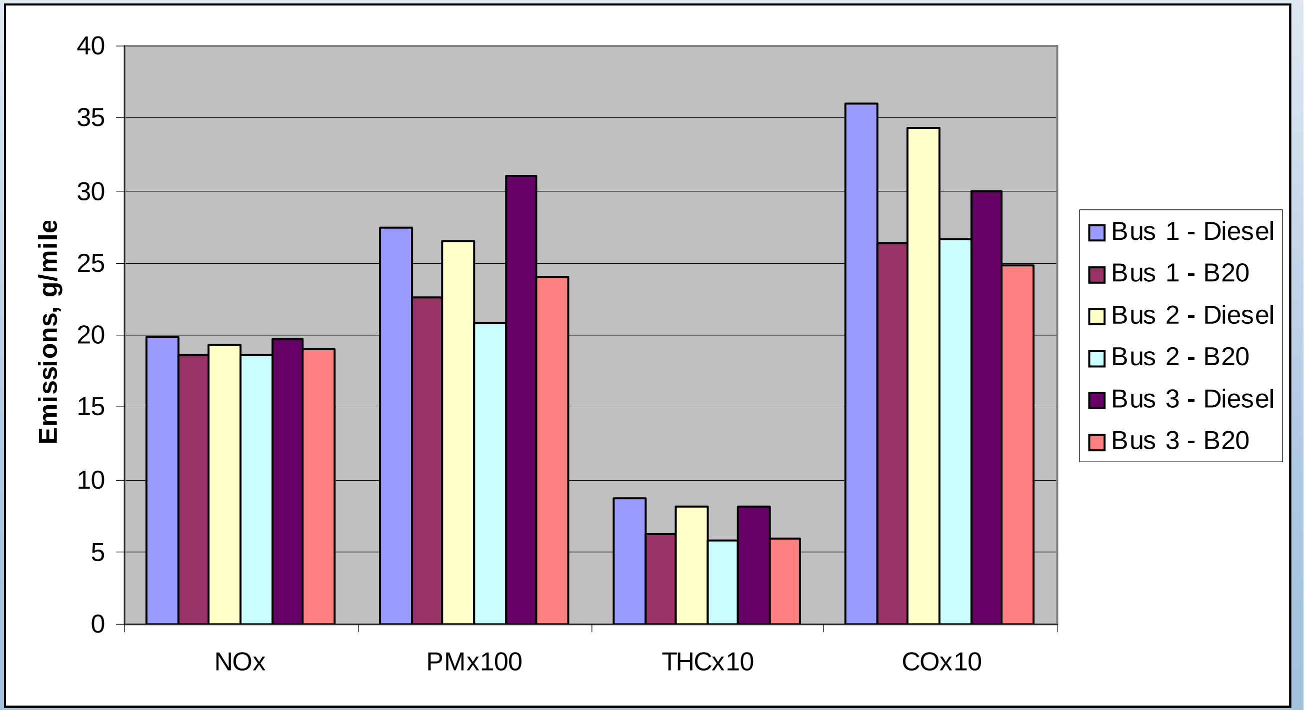
- 43 engines included
- 72% of engines pre-1994
- 95% pre-1997

Analysis for Pre-1998 Engines from EPA420-P-02-001, Draft Report, October 2002

Analysis for newer engines, McCormick, et al., SAE Paper No. 2005-01-2200

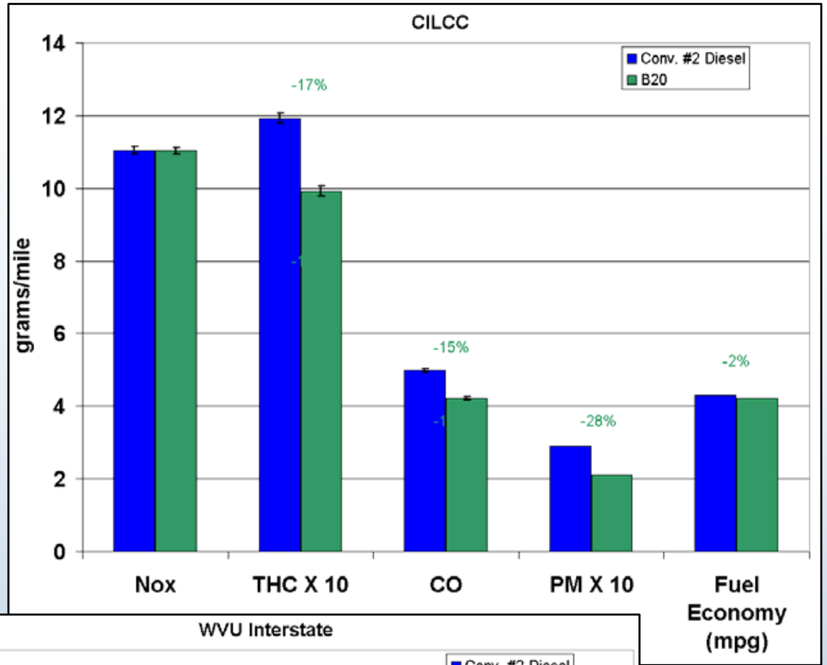
Bus Chassis Dynamometer Testing

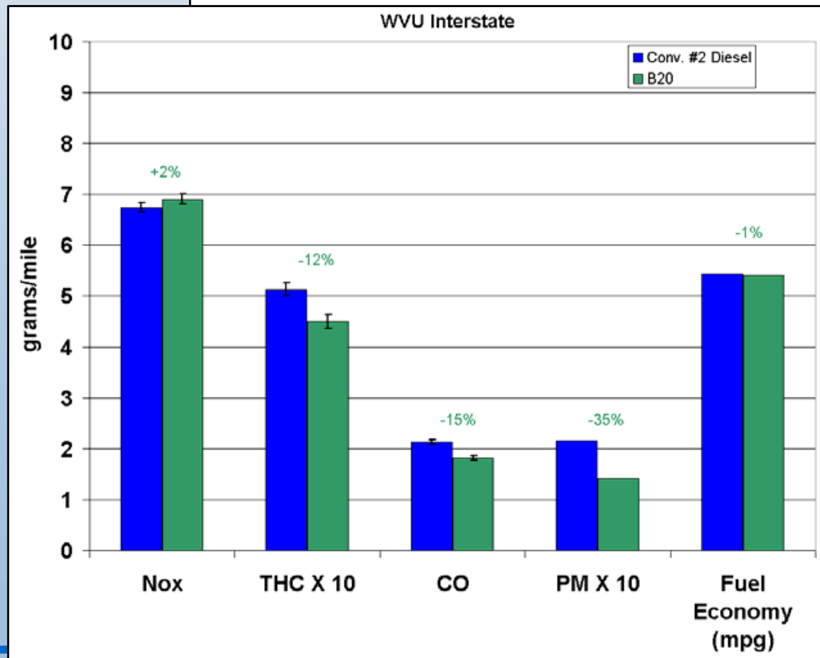
- B20 vs. conventional diesel fuel
- 3 buses tested (40,000 lb GVWR)
- City Suburban Heavy Vehicle Cycle (CSHVC) at 35,000 lb inertia
- Cummins ISM 2000 Engine – No EGR
- Average emission reductions (g/mile basis)
  - PM ≈ 18%
  - HC ≈ 29%
  - CO ≈ 24%
  - NO_x ≈ 4%
  - $p<0.01$



Class 8 Truck Chassis Dynamometer Testing

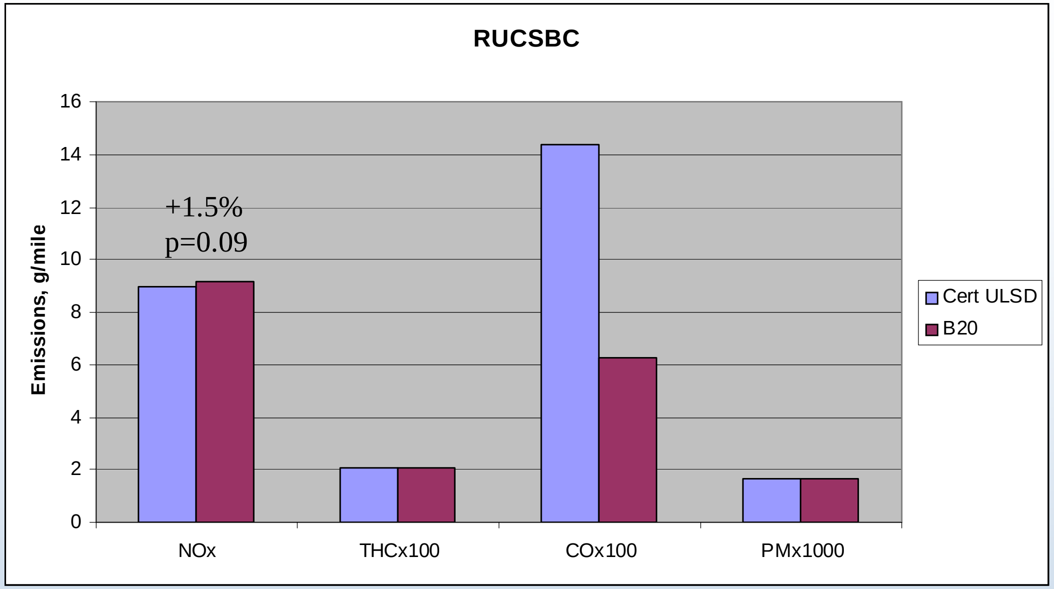
- MY2005 Cummins ISM Engine – cooled EGR
  - MY2005 International 8600
  - 64,000 lb test inertia weight
- B20 vs. Conventional Diesel Fuel
- Test Cycles: CILCC , WVU Interstate
- B20 reduces THC, CO, and PM on both cycles
- *NO_x depends on driving cycle*

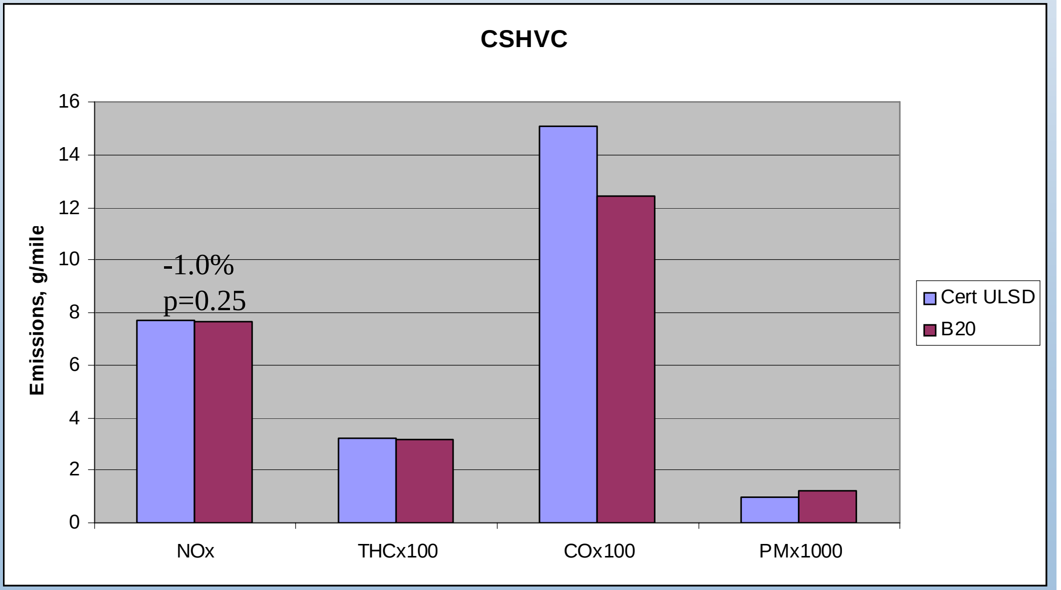




School Bus Chassis Dynamometer Testing

- 2005 MY International Green Diesel School Bus
- Equipped with DOC/DPF
- Compare ULSD and B20
- Rowan University Composite School Bus Cycle
- City-Suburban Heavy-Vehicle Cycle
- No difference for THC, PM
- B20 reduces CO
- *NO_x depends on driving cycle*





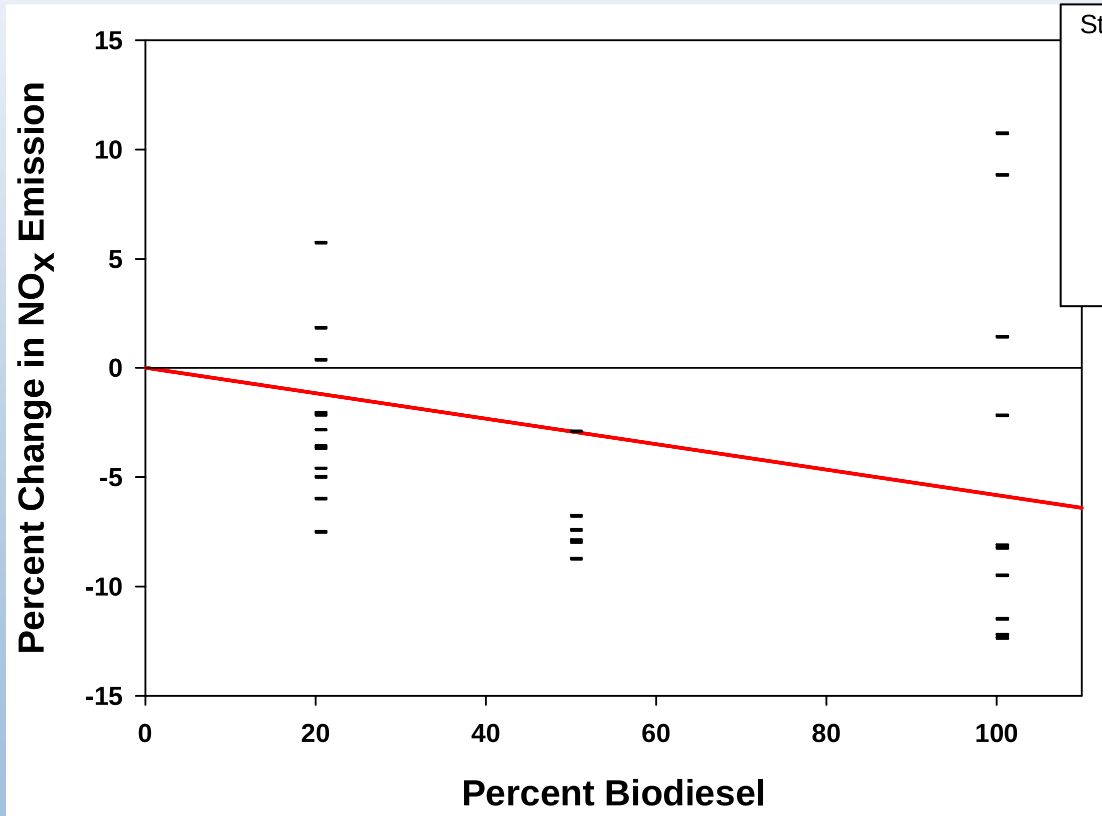
NREL Vehicle Testing Summary

- Average change in NO_x for B20 use is -0.6%
  - not statistically significant
- Magnitude and direction of NO_x impact is cycle dependent
  - Different test cycles give different NOx emissions
  - Chassis (vehicle) tests cycles appear to be a better estimate of what happens in the real world

Vehicle	Engine		MY	Cycle	NOx % Change
1	Cummins ISM	Transit Bus	2000	CSHVC	-3.8
2	Cummins ISM	Transit Bus	2000	CSHVC	-6.2
3	Cummins ISM	Transit Bus	2000	CSHVC	-4.1
4	Cummins ISM	Class 8	2005	CSHVC	0.0
4	Cummins ISM	Class 8	2005	WVU Interstate	2.0
5	International Green Diesel	School Bus	2005	RUCSBC	1.5
5	International Green Diesel	School Bus	2005	CSHVC	-1.0
6	Cummins ISB	Motorcoach	2003	CSHVC	2.8
6	Cummins ISB	Motorcoach	2003	UDDS	3.4

Biodiesel's Effect on NO_x Emissions -Vehicle (Chassis) Data

- *EPA study also reviewed published vehicle test data*
- *For these vehicles, on average, biodiesel has no impact on NO_x*
  - *Slope is not statistically significant (p=0.5)*



Standards Group	Model Years	#Vehicles
B	2002-2006	
C	1998-2001	
D	1994-1997	6
E	1991-1993	
F	1990	1
G	1988-1989	2
H	1984-1987	1
I	-1983	1

8 pickup trucks tested on UDDS
3 transit buses on various cycles

Data from EPA420-P-02-001, October 2002

Biodiesel Effect on NO_x Uncertainty

- Engine tests on average show NO_x increasing
  - NO_x can go up or down depending on engine and test cycle - this is not well understood fundamentally
  - Finding of a NO_x increase is not based on testing of a representative sample of in-use engines
  - Finding of NO_x increase is not based on a market share weighted average

- Vehicle tests on average show NO_x reductions
  - Very limited dataset
  - Again, not based on representative sample or market share weighted average

Bottom Line on Biodiesel and NO_x

There are insufficient data, and insufficiently representative data, to draw any conclusions regarding the average effect of biodiesel blends on NOx emissions, even directionally

100,000 Mile Fleet Performance Results on Biodiesel Blends(B20)

Nine (9) 40- foot Orion V transit buses included in two year study

- Five (5) buses used B20, four (4) used No.2 diesel

Fuel economy – No difference in average fuel economy (4.44 mpg)

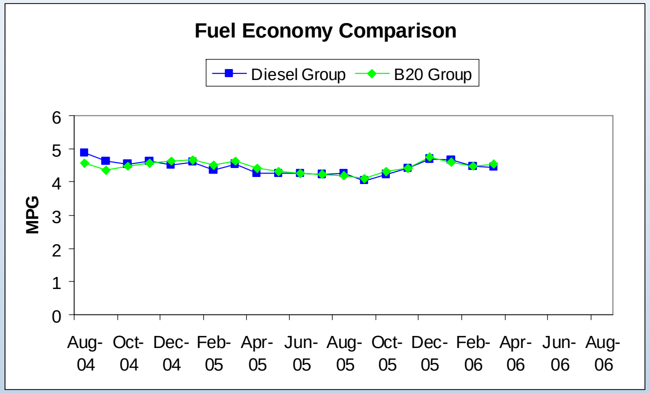
- B20 range: 4.40 - 4.49 mpg
- No.2 Diesel range: 4.24 - 4.52 mpg

Maintenance Costs – lower for B20 group

- B20 $0.49/mile (two fuel filter failures)
- No.2 Diesel $0.53/mile

Emissions – lower for B20 group on CSHVC cycle for all regulated emissions

- 3.9 to 5.8 % lower NOx emissions
- Average of 6-8 tests

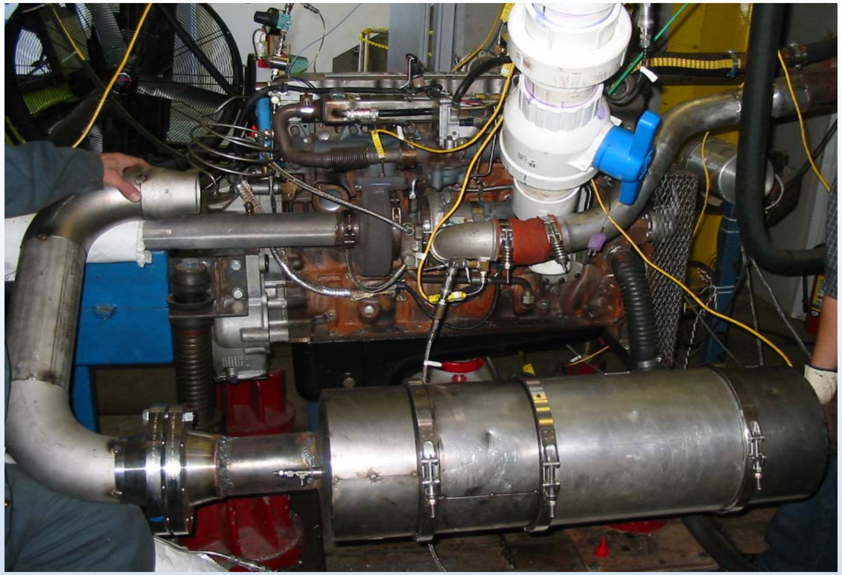


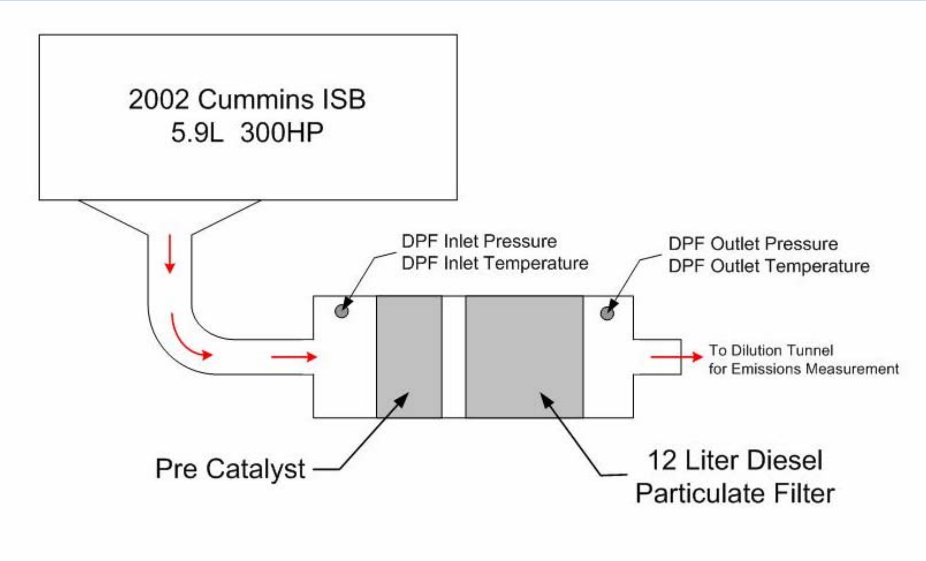
Fuel Filter Deposit

Skip Bus In Service

Biodiesel Testing with DPF – MD Engine

- Cummins ISB 300
  - 2002 Engine, 2004 Certification
  - Cooled EGR, VGT
- Johnson Matthey CCRT
  - 12 Liter DPF
  - Passively Regenerated System
  - Pre Catalyst (NO_2 Production)
- Fuels: ULSD, B100, B20, B5

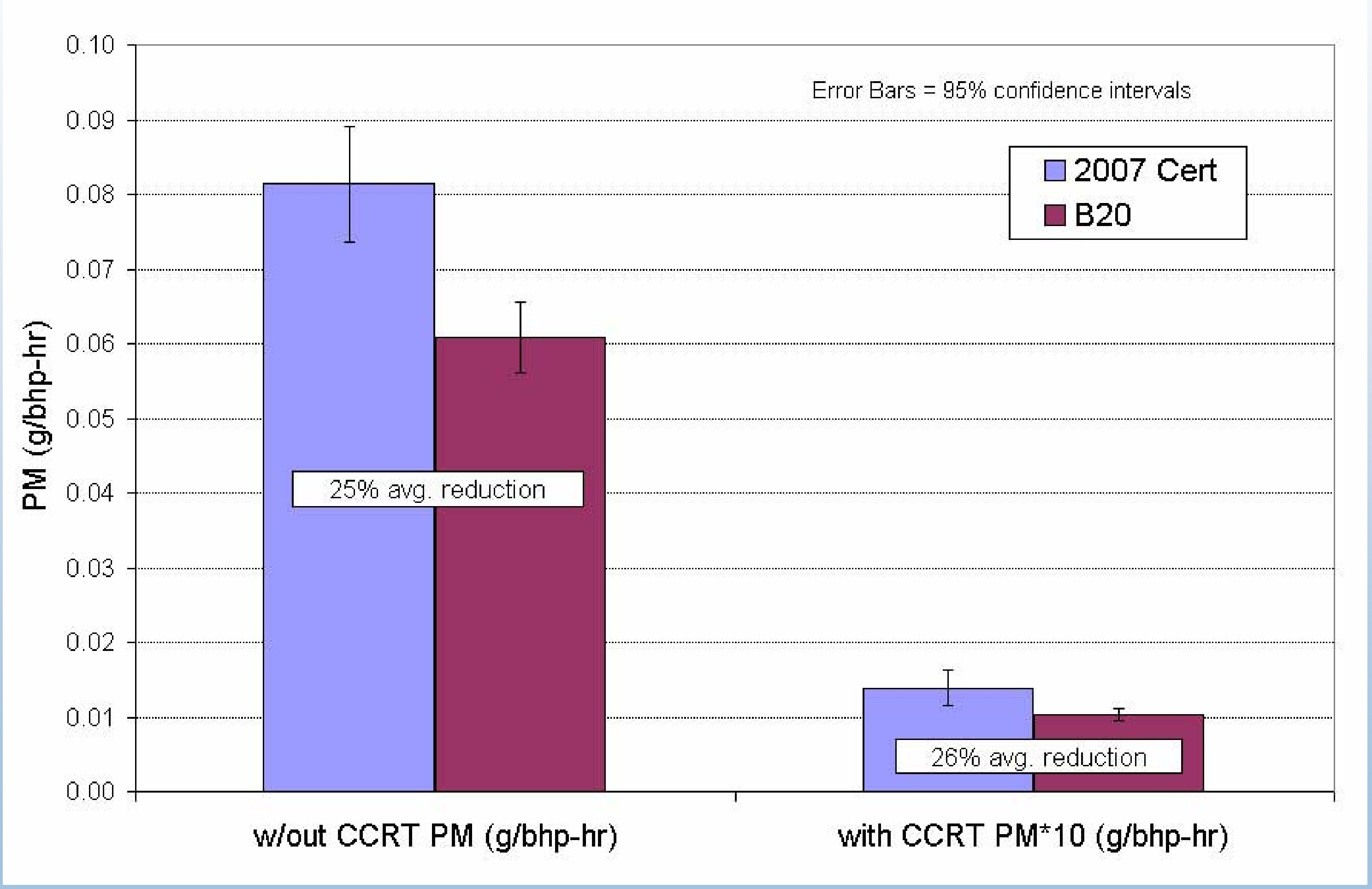




- ReFUEL Test Facility
  - 400 HP Dynamometer
  - Transient & Steady State Testing
- Cummins
  - Soot Characterization

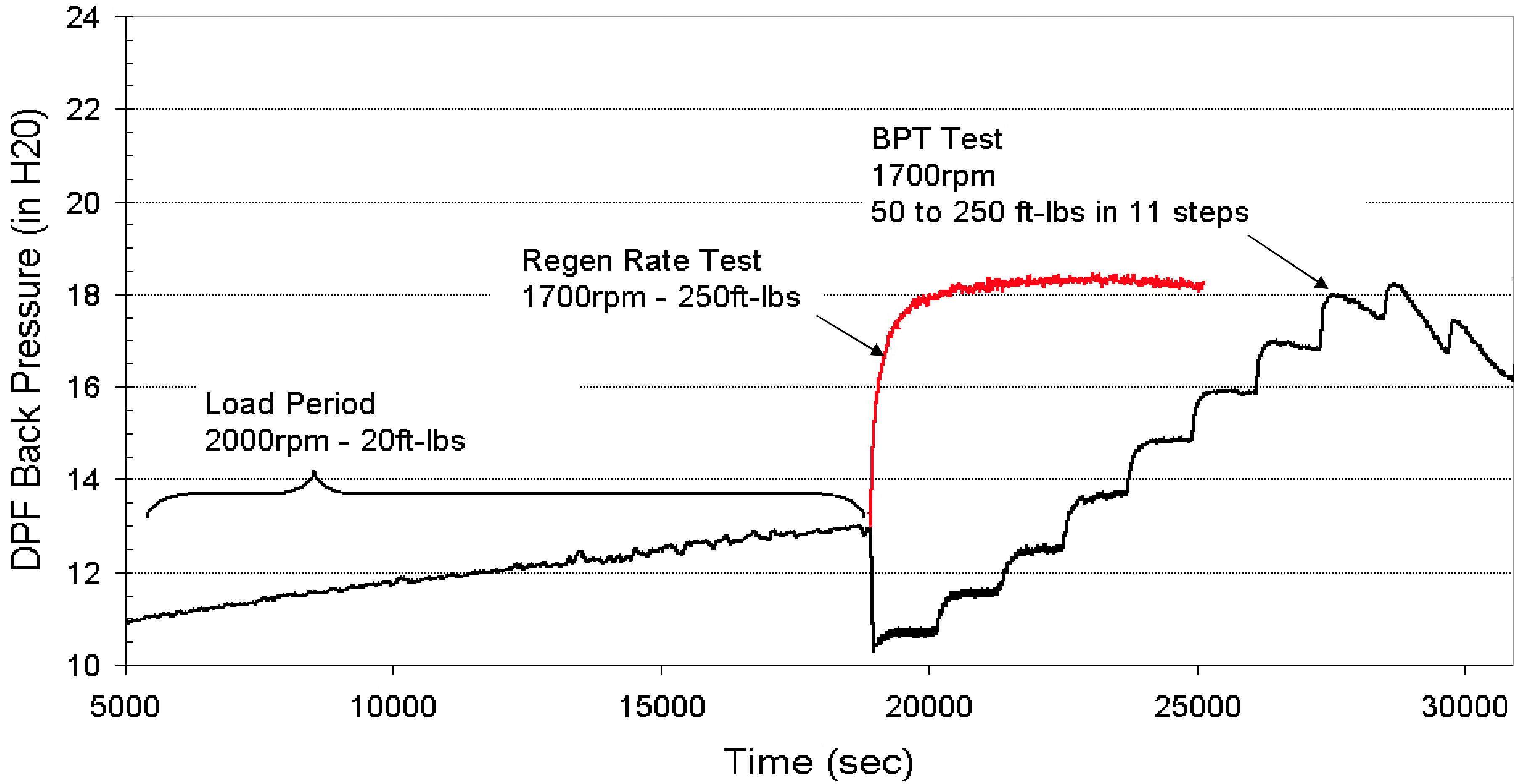
Heavy Duty Transient Test Results

- Installation of DPF (base fuel):
  –97% CO, –99% THC, –98% PM, +1% NOx, +1% BSFC
- B20 results in 25% PM reduction w/o DPF, 26% reduction w/ DPF



BPT and Regeneration Rate Test Procedures

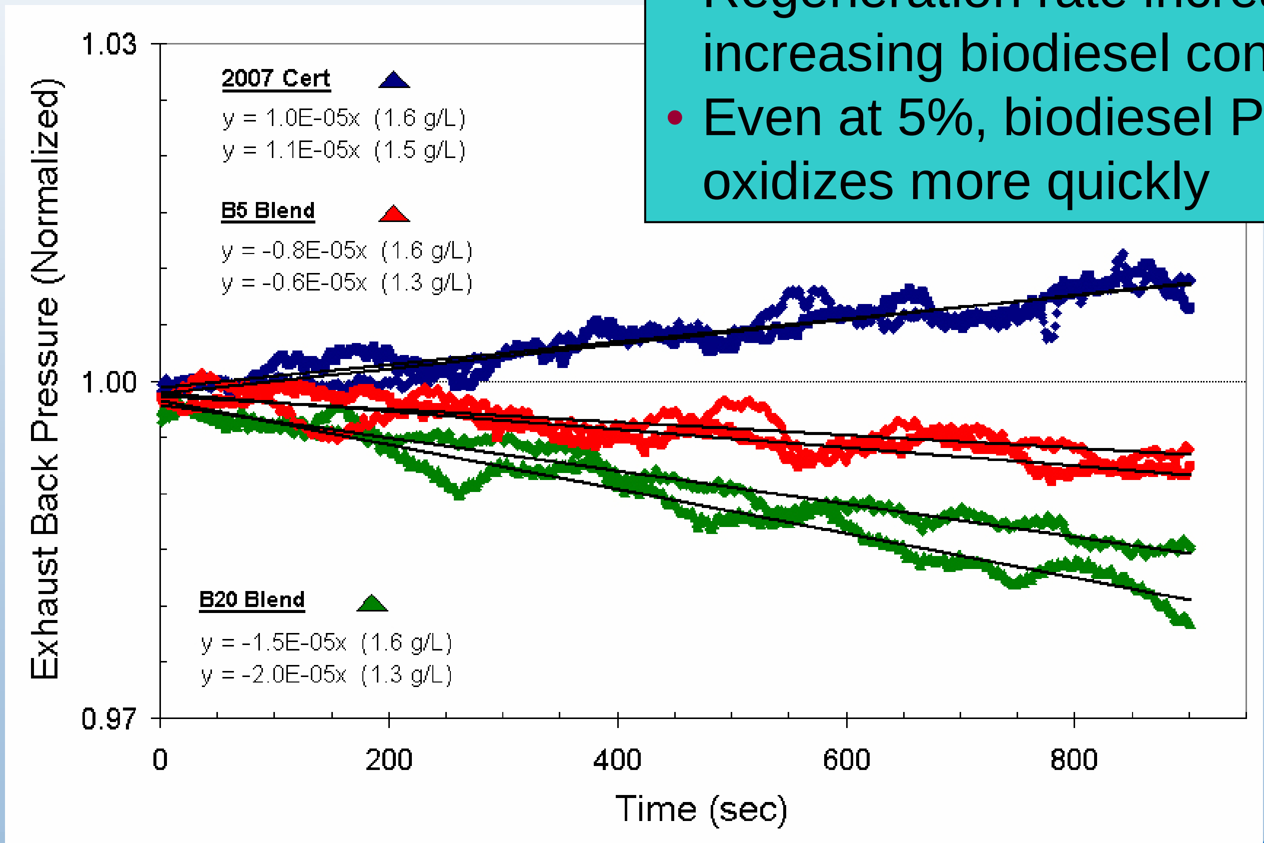
- Balance Point Temperature (BPT) – DPF temperature where rate of PM collection equals rate of PM oxidation
- BPT is determined by monitoring DPF back pressure
- Regeneration Rate Test – simulates active regeneration strategy



BPT/Regeneration Rate Results

BPT	
ULSD	360ºC
B20	320ºC
B100	250ºC

- BPT is 40ºC lower for B20
- Soot is more easily burned off of filter
- B20 can be used for lower temperature duty cycle



- Regeneration rate increases with increasing biodiesel content
- Even at 5%, biodiesel PM measurably oxidizes more quickly

Biodiesel DPF Results

- Even with a diesel particle filter installed B20 provides a measurable PM reduction
- Soot from biodiesel blends (even B5) will burn in the DPF at significantly lower temperature that diesel soot
- Laboratory studies of soot reactivity and structure confirm the lower temperature reactivity of soot from biodiesel blends
- Additional tests on other engines and actual 2007 engines required to confirm

Biodiesel Summary

- Significant Supply: 3.6 billion annual gallons by 2015
- Biodiesel (B20) provides:
  - *Energy security and greenhouse gas emissions benefits*
  - HC, toxic compound, and PM emissions reductions
  - No negative NO_x or ozone impact
- Considerable uncertainty about the effect of biodiesel on NO_x emissions
  - Effects of engine, vehicle size, test cycle
- In use testing shows little difference between B20 and No. 2 Diesel in terms of fuel economy, maintenance, and emissions
- Fuel Quality: impurity and oxidation issues

Biomass: Summary & Conclusions

- ✓ The only domestic & renewable option for liquid transportation fuels.
- ✓ Resource base is sufficient to supply a large fraction of U.S. needs
- ✓ A sustainable solution to meet the near-term “gap” expected to be caused by Peak Oil
- ✓ On-going R&D will create many opportunities that extend beyond today’s biopower, ethanol, and biodiesel facilities