Renewable Diesel Fuels: Status of Technology and R&D Needs

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Program Background

Renewable fuels utilization R&D at NREL is performed for:

U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy

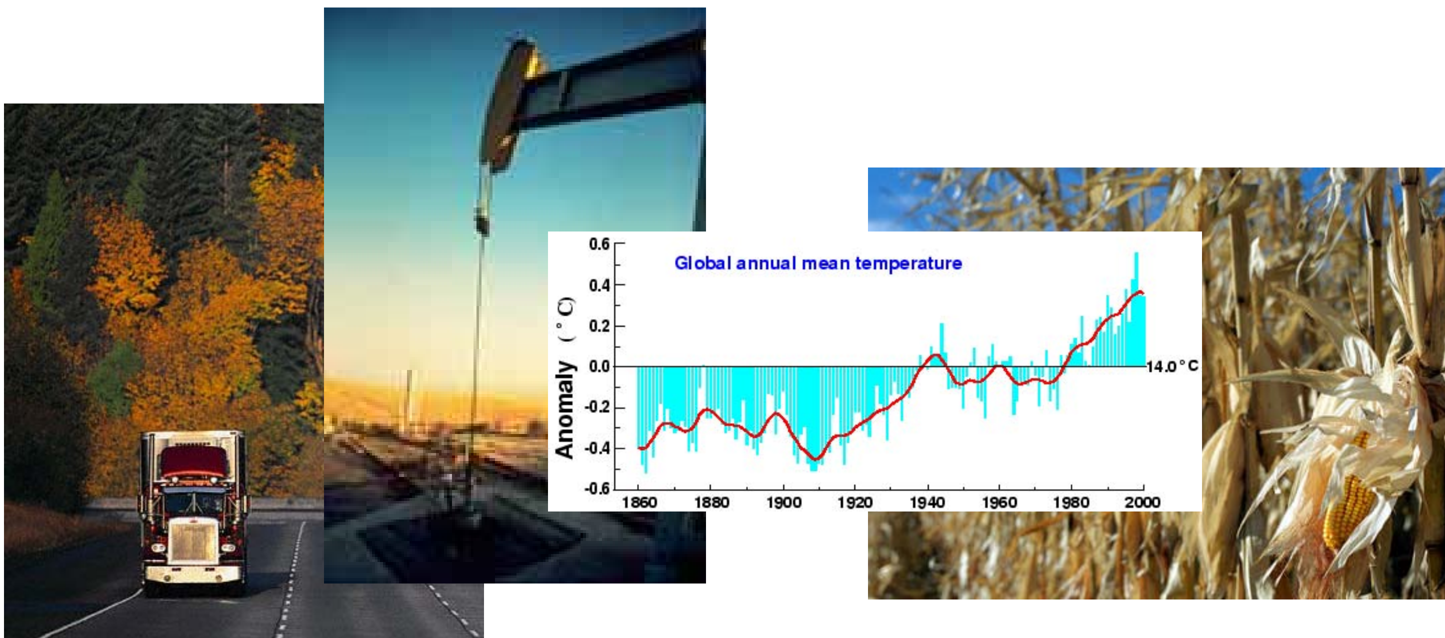
Advanced Petroleum-Based Fuels Activity
FreedomCAR and Vehicle Technologies Program
Steve Goguen and Kevin Stork, Program Managers

Renewable Diesel Activity
Biomass Program
Gerson Santos-Leon and Amy Miranda, Program Managers

NREL

Objectives for Renewable Fuels

- Energy supply-displacement of petroleum
- Emissions benefits-including global warming gases
- Rural economic development



Renewable Diesel Options

<u>Near-Term</u>

__***Biodiesel:*** **neat or up to 20% blend**

Ethanol: **up to 15% blend (E-diesel)**

<u>Medium-Term</u>

__***Biomass Derived FT-diesel:*** **neat or blend**

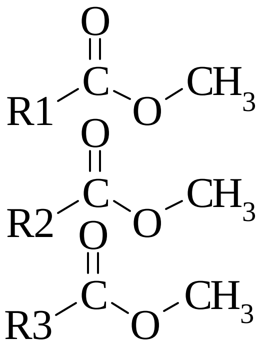
__***Oxygenates from Cellulose:*** **blending component**

<u>Long-Term Fuels</u>

New fuels for advanced combustion concepts

Biodiesel Overview

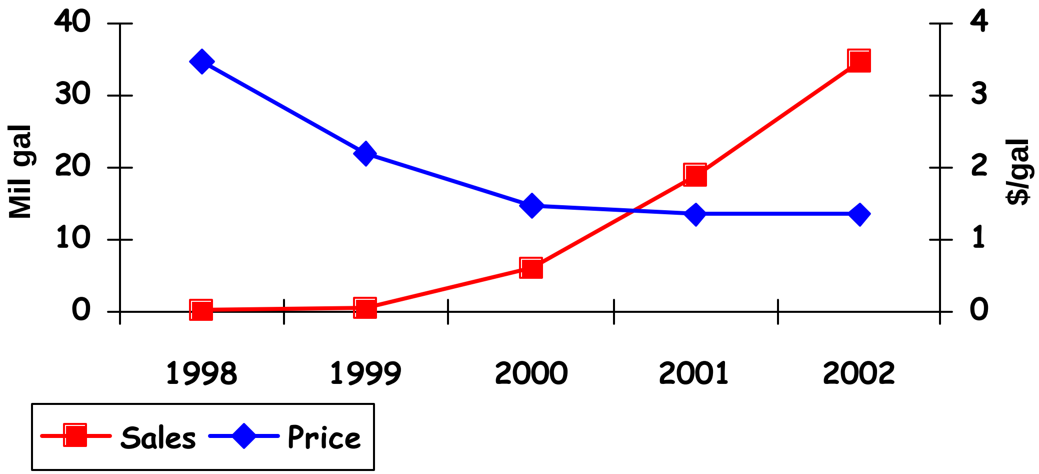
- Methyl esters of fatty acids, produced from a variety of waste and agricultural feedstocks
- Properties vary with double bonds in fatty acid chains
- Key properties:
  - CN=45-60
  - S<1ppm (soy) but can be as high as 30 ppm for YG
  - Very high lubricity
  - LHV is 117,000 btu/gal versus ~130,000 for No. 2 diesel
- Legal to sell for both on and off-road use, a commercial fuel:
  - ASTM standard finalized in January, 2002 (D6751)
  - EPA fuel registration requirements met (CCA 211b) by National Biodiesel Board

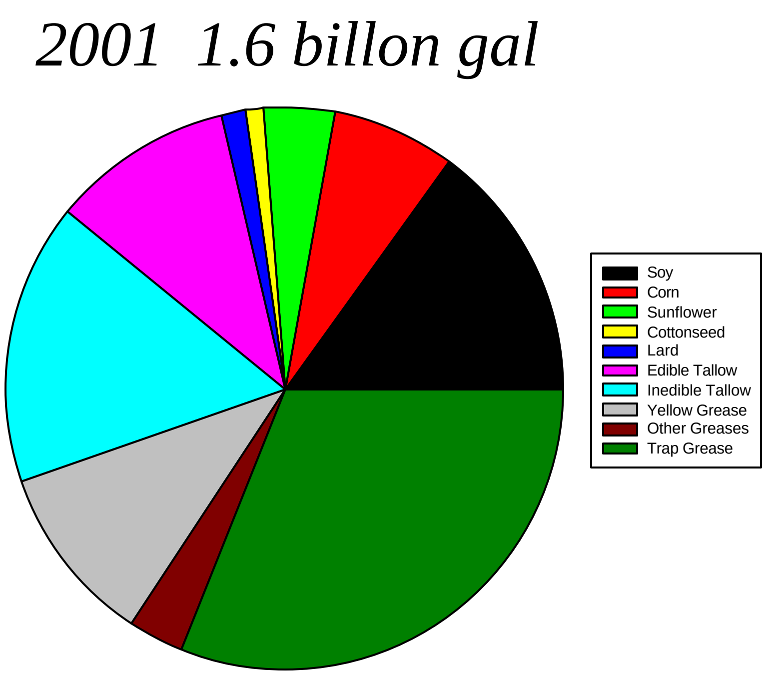


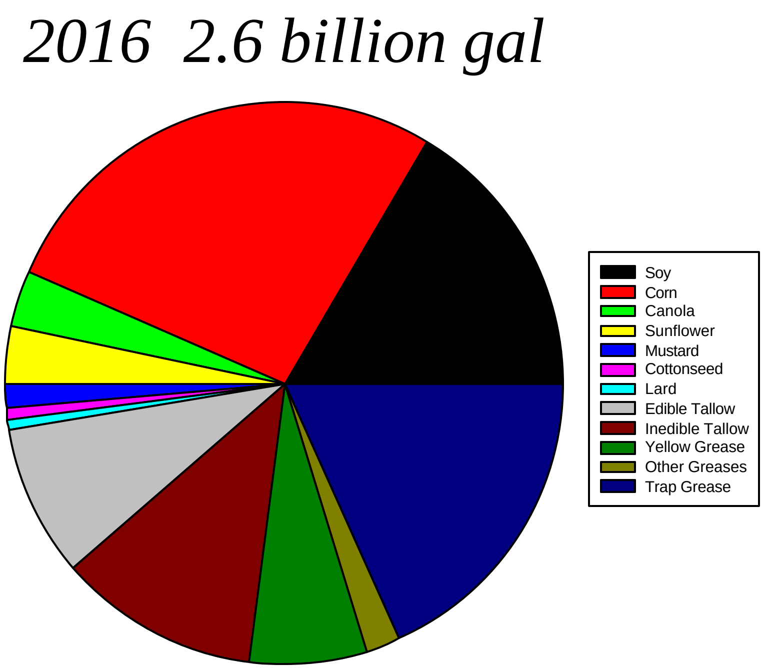
Methyl Esters

Biodiesel Supply and Production Potential

- Current production capacity ~150 million gal/yr
- 35 million gal in sales projected for CY 2002







Benefits of Biodiesel

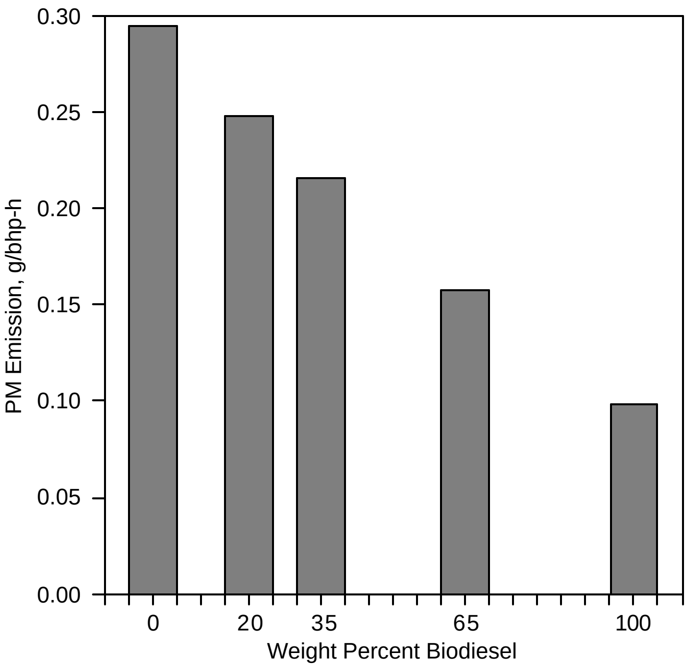
Energy security and global warming emission benefits
(Sheehan et al, 1998):

Life Cycle Energy Efficiency = *Fuel Energy/Total Primary Energy*
= 83% for petroleum diesel
= 81% for biodiesel
Fossil Energy Ratio = *Fuel Energy/Fossil Energy Inputs* = 3

Reduction in pollutant emissions:

PM reduced 15-20% for B20

Reduction in emissions of toxic compounds (Tier 1 study results)



Biodiesel Technical Barriers & Issues

- Broad acceptance of biodiesel from any feedstock blended at 5%

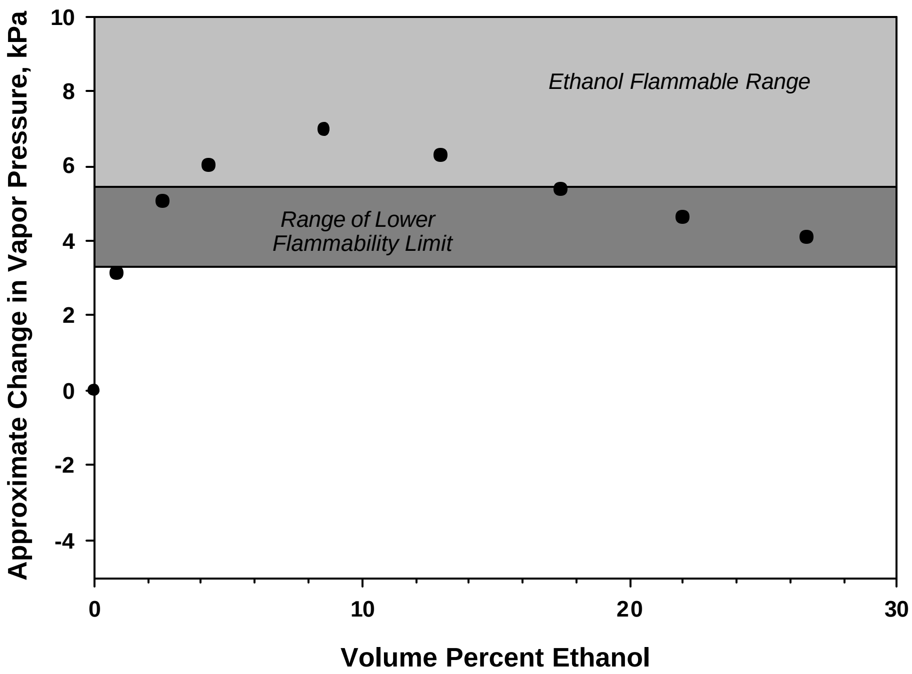
- For 20% biodiesel blends:
  - Oxidative stability
    - -ongoing R&D on test methods and stability requirements
  - Residual process chemicals can form deposits
  - Compatibility with fuel system elastomers
    - -ongoing R&D on O-ring compatibility
  - Low-temperature flow properties for animal fat-based fuels
  - NO_x increases 2-4% for B20
    - -CN treating additives bring NOx down
    - -air quality modeling suggests no impact on ozone for 100% market penetration of B20
    - -ongoing R&D on fundamental and engineering aspects
- Relatively small resource (~2 billion gallons)
  - -ongoing R&D to identify new sources of triglycerides

Blending Ethanol in Diesel: E-Diesel

	Ethanol	Diesel
Cetane Number	8	42-50
Boiling Point, °C	78	170-340
Flash Point, °C	13	75 (>52)
Reid Vapor Pressure, psi	2.3	<0.1
Lubricity	none	*

- *Ethanol has limited solubility in diesel*
- *<u>Fuel additive technology</u> is used to overcome solubility, cetane number, lubricity issues*
- *Benefits:*
  - *Reduced PM emissions*
  - *Displacement of petroleum*

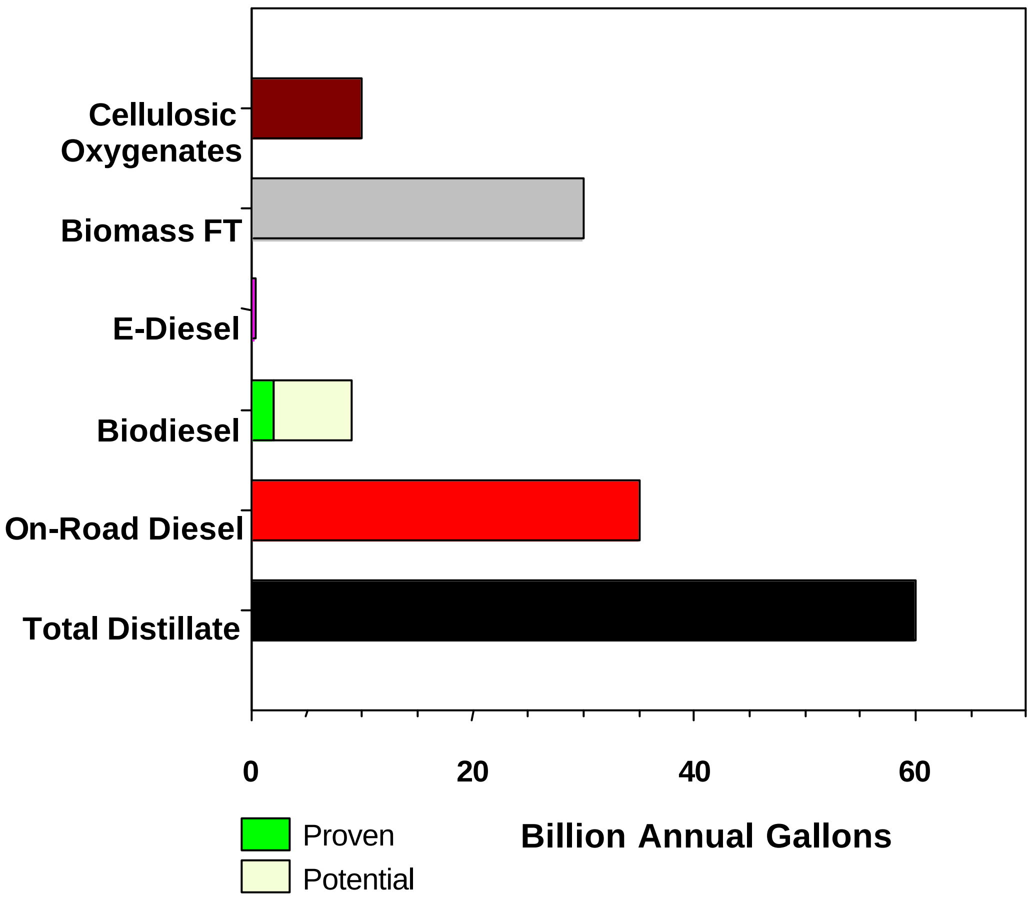
E-Diesel Flashpoint/Flammability



- Flashpoint defines e-diesel as a Class I liquid (like gasoline) for fire safety purposes
- Additionally, tank vapor space is flammable under some conditions
- Likely to limit the market to centrally refueled fleets (~300 to 500 million gallons of ethanol)

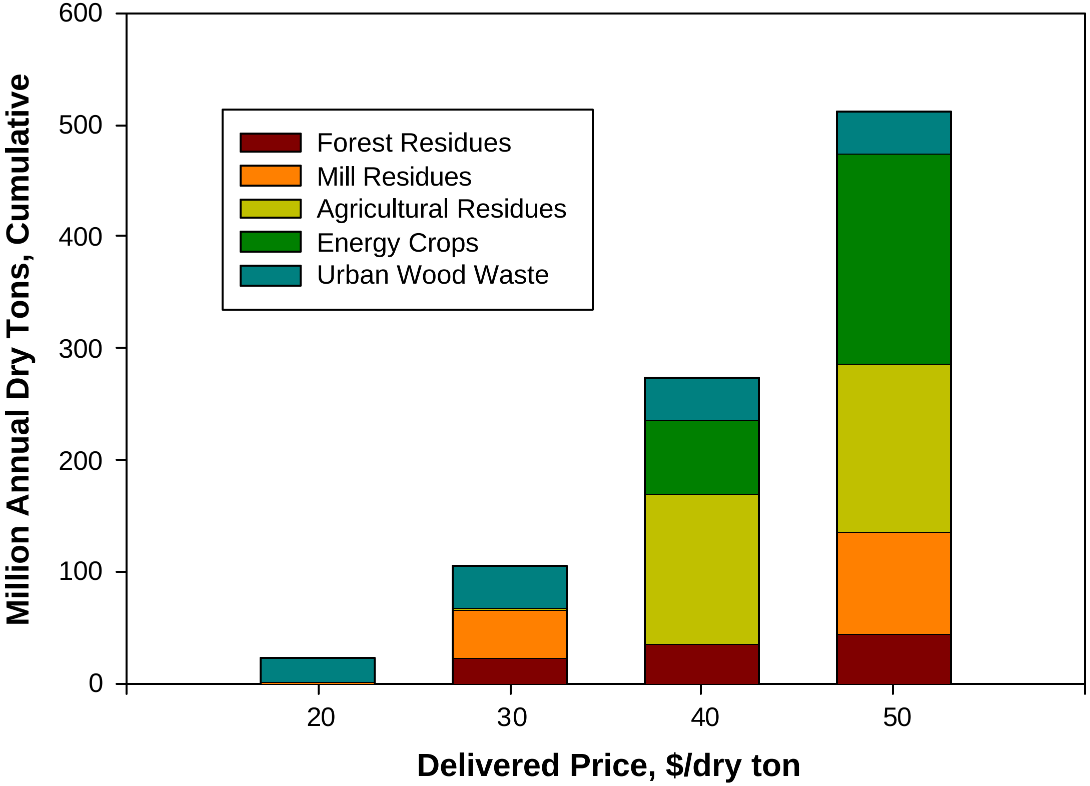
R&D directed at reducing vapor pressure using fuel additives or other approaches is needed

Energy Security Implications of Renewable Diesel Options



- Biodiesel and E-Diesel have minimal impact today
- Options are:
  - Develop new sources of biodiesel
  - Solve technical barriers to e-diesel
  - Biomass-derived FT
  - Oxygenates from cellulosic biomass

Biomass Resources



ORNL, 2002

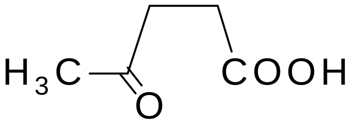
- **Typically ~50% carbon**
- **50% carbon conversion to products**
- **Potential for 125 million tons of fuel product or 30 billion gallons**

Biomass-Derived FT Diesel

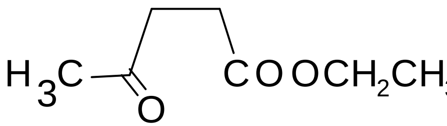
- Biomass-FT and natural gas-derived FT diesel (GTL) are essentially identical
- Biomass gasification with steam/oxygen to produce CO/H_2 (syngas) then FT-synthesis to produce n-paraffins
- $32/bbl based on <$20/ton biomass (Mitre study) for single pass FT with co-production of power
- Very high cetane number
- Low emissions of PM, NOx, toxic compounds
- Very low (<1 ppm) sulfur content
- Poor lubricity
- Poor cold flow properties

Cellulose Hydrolysis to Levulinic Acid

- Levulinic acid produced by acid hydrolysis of cellulose
- 50% yield-but production technology is not commercial
- A selling price of <10¢/lb is claimed for LA (80¢/gal)
- Easily converted to ethyl or methyl ester
- Properties of Ethyl Levulinate have been examined:
  - Good lubricity, flashpoint
  - Blends up to 10% stable based on preliminary tests
  - Cetane number of 10% blends unchanged



levulinic acid



ethyl levulinate

	No. 2 Diesel	Ethyl Levulinate
Boiling Point, °C	185-350	206
Flash Point, °C	>52	91
Reid Vapor Pressure, psi	<0.2	<0.01
HHV, btu/lb	19,200-20,000	11241
LHV, btu/lb	18,000-19,000 (126,000-130,000 btu/gal)	10,459 (88,692 btu/gal)
Density, g/ml	0.81-0.89 (6.7-7.4 lb/gal)	1.016 (8.48 lb/gal)

Long-Term Renewable Fuels

- Long-term energy security requires development of new fuels for future engines
- Future engines will access new combustion regimes with the potential for higher efficiency and dramatically lower emissions
- Optimal fuel properties are very different from those of today's fuels
- Future engine development will require development of the new fuel and engine as a system
    - Maximum possible fuel economy, minimum possible emissions
    - Reduce cost and complexity, improve reliability of system

Conclusions

- Renewable diesel fuels can have an impact on U.S. energy security
- Issues for production include:
    - Development of new feedstocks for increased biodiesel production
    - Demonstration of biomass gasification/FT processes on larger scale
    - Proof of concept for conversion of cellulose to fuel oxygenate
- Fuel/engine compatibility, emissions, and other regulatory issues remain to be resolved for all of these fuels
- For future advanced combustion concepts the fuel and engine must be developed as a system