Biomass Fuels

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Mechanical Engineering 496ALT
Alternative Energy

March 24, 2007

California State University Northridge

Classes and Midterm

- Thursday, Bob Litwin, Rocketdyne
- Tuesday, March 31 – Holiday
- Thursday, April 2 – Midterm
  - Open book and notes
  - Covers from nuclear to wind
  - Similar to previous midterm
    - Essay question and problems
    - Problems like those on homework assignments
    - More credit for general approach than for details of problem solution

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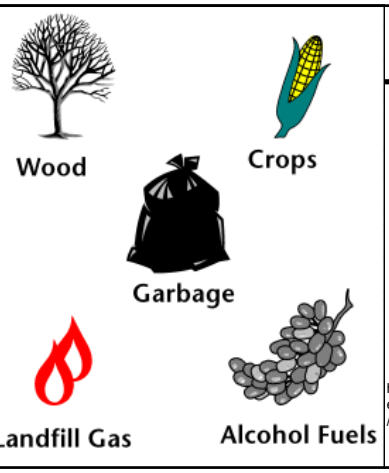

Outline

- Types
- Uses
- Data
- Benefits
- Costs
- Future

http://www.eia.doe.gov/kids/energyfacts/sources/renewable/biomass.html

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Review Synthetic Fuels

- Purpose: Convert fuels from natural form into a form more readily used
  - Gas from coal used prior to introduction of natural gas and possible future use
  - Liquid fuels from coal for transportation
  - Liquid fuels from "stranded" gas to allow economical transport alternative to LNG
  - Processing for new resources such as oil shale and tar sands (oil sands)

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Review Synthetic Fuels II

- Basic reaction for coal gasification, $C + H_2O \rightarrow CO + H_2$ is endothermic
- Shift reaction: $CO + H_2O = CO_2 + H_2$ can produce more hydrogen
- Fischer-Tropsch process for liquid fuels from coal gasification products
  - Also used for gas-to-liquids (GTL)
- Showed different gasification reactors

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Review IGCC

- Integrated gasification combined cycle
  - Coal is gasified to produce syngas
  - Syngas cleaned of pollutants and CO_2 capture is possible
  - Syngas routed to gas turbine to produce electric power
  - Turbine exhaust heats steam for more electric power from steam turbine
    - Steam and high pressure air from gas turbine compressor used in syngas production

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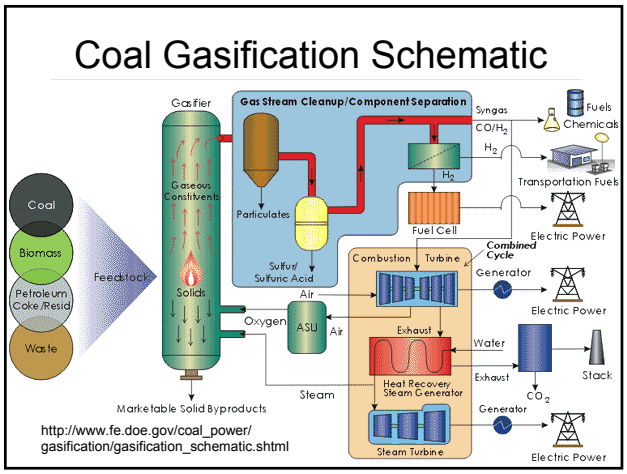

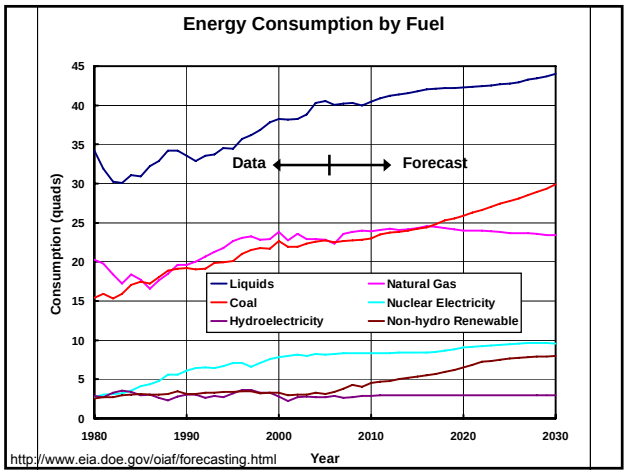

Biomass Categories

- Wood and wood waste
  - Largest source is “black liquor”, a waste stream from paper and pulp manufacture
- Municipal solid waste, industrial waste and landfill gas
- Alcohol fuels and biodiesel
- Agriculture byproducts/crops, sludge waste, tires, and other biomass solids, liquids and gases

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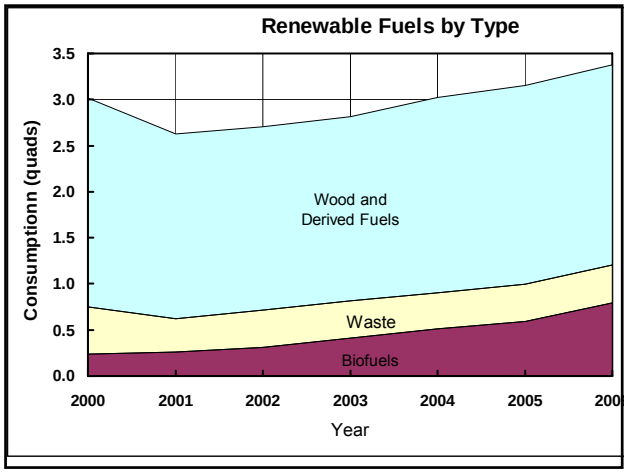

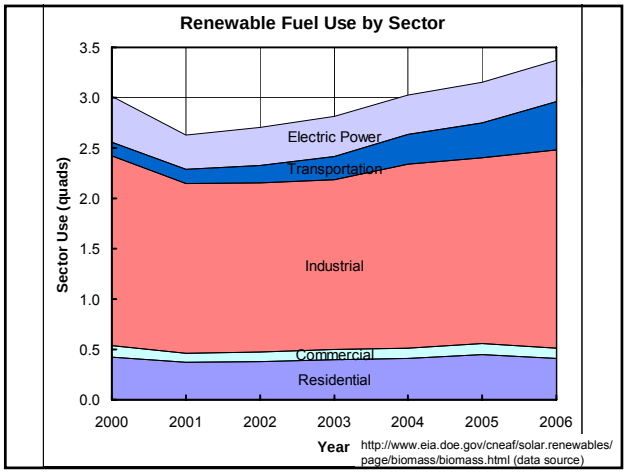

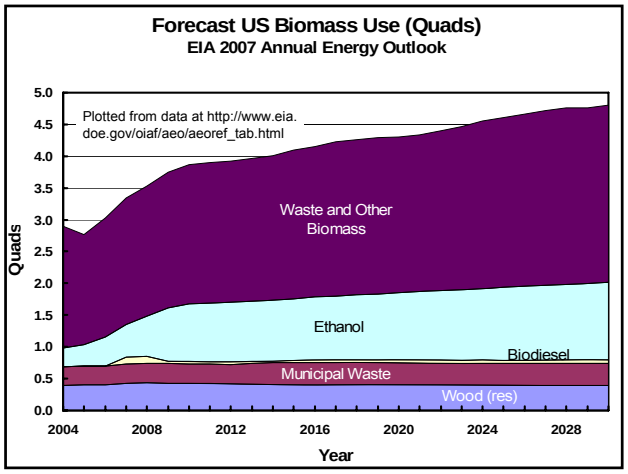

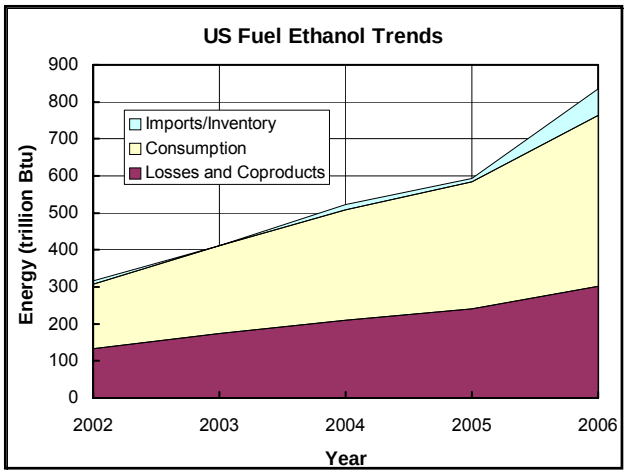

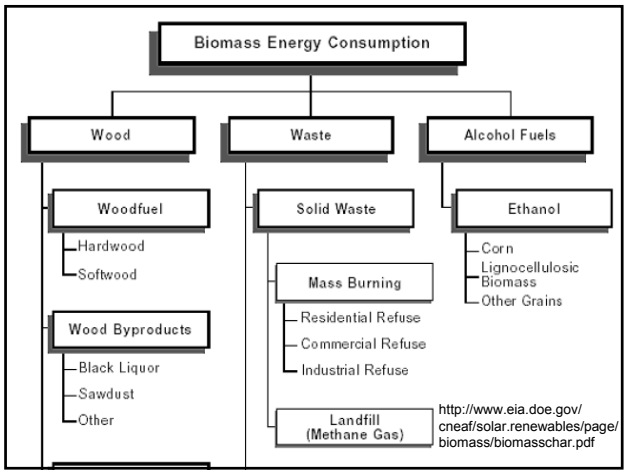

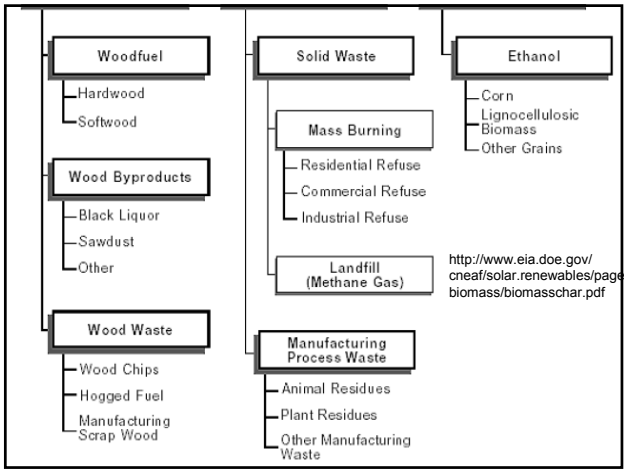

Energy Content MMBtu/Ton

- Petroleum fuels ~37
- Agricultural Byproducts 8.248
- Black Liquor 11.758
- Municipal Solid Waste 9.945
- Paper Pellets 13.029
- Peat 8.000
- Railroad Ties 12.618

http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/table10.html

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Energy Content MMBtu/Ton II

- Sludge Wood 10.071
- Solid Byproducts 25.830
- Spent Sulfite Liquor 2.720
- Tires 26.865
- Utility Poles 12.500
- Wood/Wood Waste 9.961

http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/table10.html

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Other Energy Content

- Million Btu per thousand cubic feet
- Digester Gas 0.619
- Landfill Gas 0.490
- Methane 0.841
- Million Btu/Barrel
- Waste Alcohol 3.800

http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/table10.html

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Biomass Uses

- Liquid fuels for transportation produced from biomass
- Direct use of biomass in combustion or converting biomass to a fuel that can be used in combustion
  - Produce thermal energy or electricity
  - Main use of biomass
- Convert biomass into products that are normally made from petrochemicals

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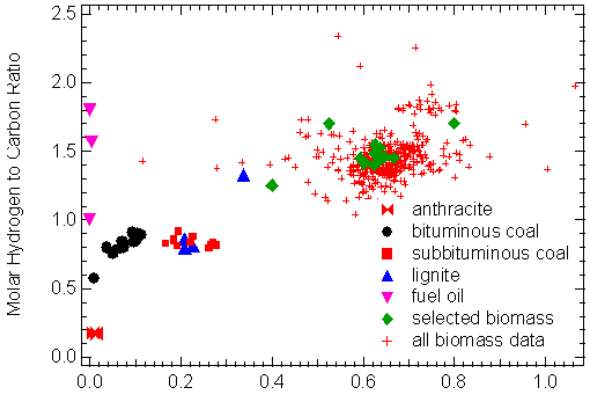

Northridge http://www.et.byu.edu/~larryb/fuel%20properties.htm

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Municipal Solid Waste

- Four categories of MSW
  - Recycling
  - Composting
  - Landfilling
  - Waste-to-energy via incineration
- MSW is defined as the total waste excluding industrial and agricultural wastes, and sewage sludge

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Municipal Solid Waste II

- Durable goods, non-durable goods, containers and packaging, food wastes, yard wastes, miscellaneous inorganic wastes
- Examples: appliances, newspapers, clothing, food scrapes, boxes, disposable tableware, office and classroom paper, wood pallets, rubber tires, and cafeteria wastes
- Waste-to-energy combustion and landfill gas byproducts of municipal solid waste

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Refuse Derived Fuels

- A solid fuel
- Acronym RDF
- Mentioned as possible fuel for integrated gasification-combined-cycle (IGCC) plants last week
- Convert municipal waste into fuel by extracting organic matter and treating it
- Not extensively used

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Landfill Gas

- Formed by biological fermentation of organic wastes in landfills
- Main component is methane
- Previously regarded as a safety hazard that has to be mitigated
- Now captured and used for electricity production in gas turbines
  - Medium Btu gas requiring special combustor design in turbines

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Industrial and Agricultural Use

- Generally well known practices using waste to energy
- Wood and paper process waste waste used to generate heat and power
- Bagasse (waste from sugar cane) combustion can provide enough energy to run sugar mills
  - Agricultural waste collection for power plants limited by transportation costs and pollution problems from waste combustion

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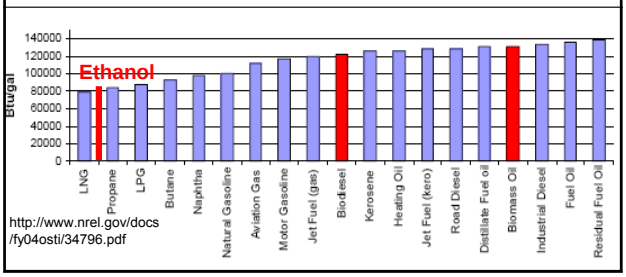
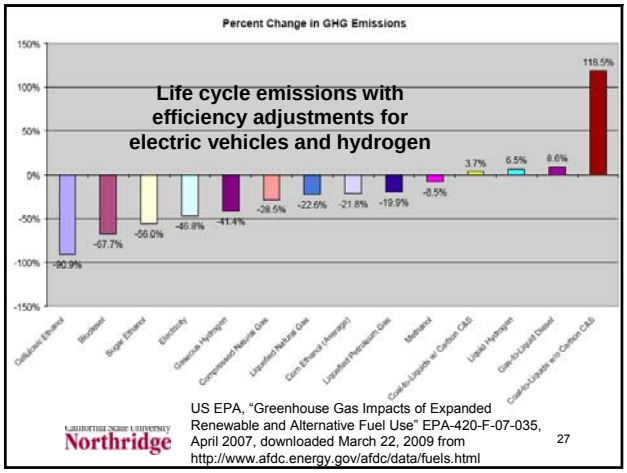
Transportation Fuels

- Ethanol from corn and sugar beets
- Biodiesel from fresh or used vegetable oils and waste grease



http://www.nrel.gov/docs/fy04osti/34796.pdf



US EPA, "Greenhouse Gas Impacts of Expanded Renewable and Alternative Fuel Use" EPA-420-F-07-035, April 2007, downloaded March 22, 2009 from http://www.afdc.energy.gov/afdc/data/fuels.html

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Transportation Fuel Notation

- Express the volume percent of a fuel in a mixture with conventional fuel
  - Letter designates the fuel
  - Number indicates the volume percent
    - E85 is a mixture of 85% ethanol and 15% gasoline
    - M100 is pure methanol
    - B20 is 20% biodiesel with 80% conventional diesel fuel
  - Ethanol used as additive (various amounts)

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Ethanol Production

- Long, but sporadic history of use as a transportation fuel
- Has high octane number but less energy per unit volume
- Made by fermenting sugars
  - Can convert other corps like corn, starches, and cellulose into sugar for processing
  - Long term economics not based on corn

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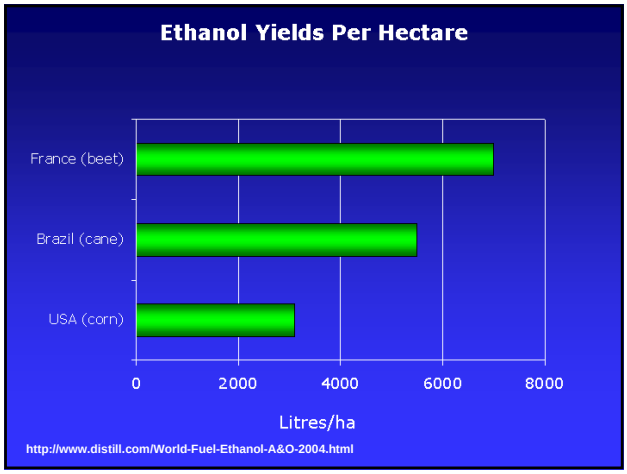

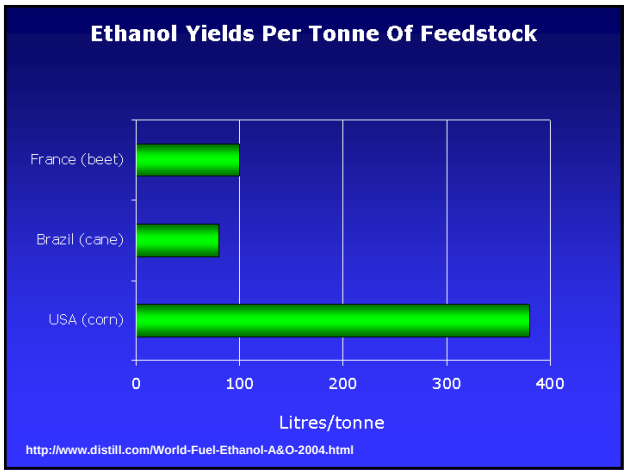

Gasoline Oxygen Requirement

- 1990 Clean Air Act Amendments required EPA to set rules for reformulated gasoline in certain regions
- Regulations included oxygen concentration requirement
  - Two additives used to get this: methyl-tert-butyl ether, MTBE, (preferred) and ethanol
  - Several states have banned MTBE because of deleterious effects on groundwater

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Octane Booster

- Antiknock performance of gasoline measured by octane number
- Ethanol has a high natural octane number and can be used as an additive
  - Nationwide ban on lead and state bans on MTBE make ethanol a leading candidate as an octane improving additive
    - Ethanol has higher vapor pressure than MTBE
  - Not required as oxygen booster after 2006 because of adaptive learning in modern automobile control systems

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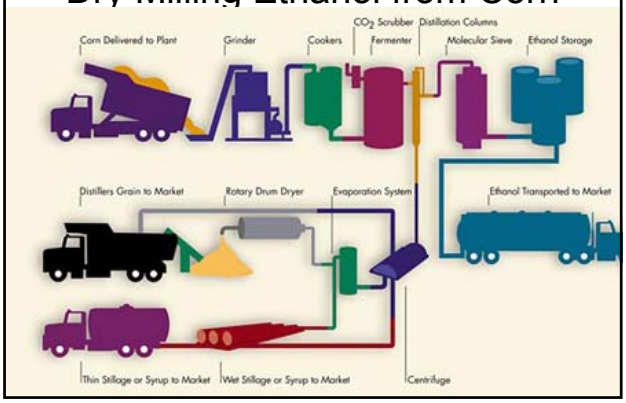
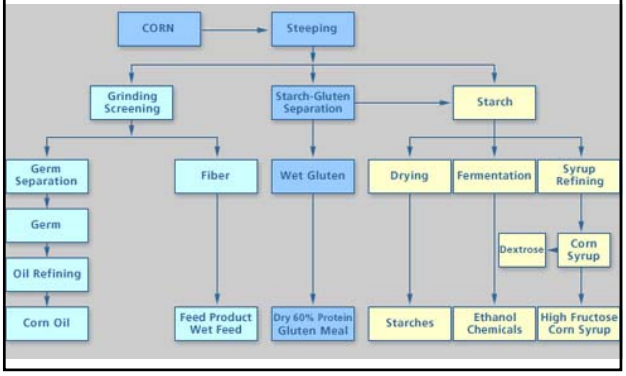
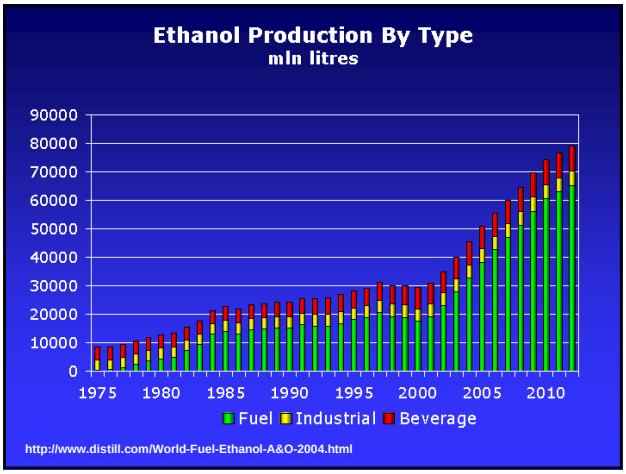
Dry Milling Ethanol from Corn



Wet Milling Ethanol from Corn





Ethanol Production (10^6 gal)

Country	2004	2005	2006	Total
Brazil	3,989	4,227	4,491	12,707
U.S.	3,535	4,264	4,855	12,654
China	964	1,004	1,017	2,985
India	462	449	502	1,413
France	219	240	251	710
Russia	198	198	171	567
Others	1,403	1,768	1,584	4,755
Total	10,770	12,150	12,871	35,791

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http://www.ethanolrfa.org/industry/statistics/#D

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Ethanol Cost

- Dominated by cost of crop
- Long term production increases predicated on use of low cost crops in place of corn
  - agricultural wastes, grasses and woods, and others such as municipal waste
  - Although resource costs are much less, processing costs are higher

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Ethanol Transport

- Cannot be transported in pipelines
  - Ethanol absorbs moisture from pipelines
  - Forms azeotropic mixture causing ethanol to separate from gasoline
- Ultimate shipment to fuel terminals where it is blended with gasoline prior to distribution
- Ethanol is shipped by truck or railcar
  - Rail to California: 2-3 weeks, 14-17 ¢/gal

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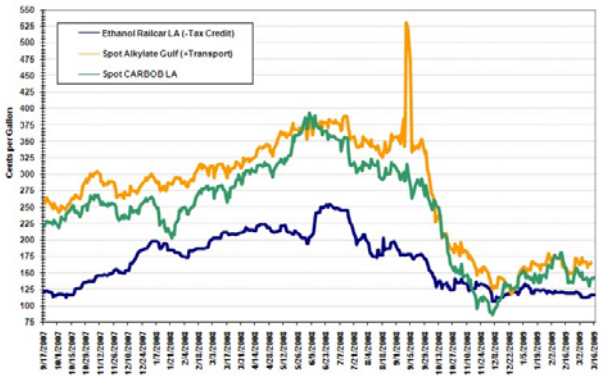

http://energyalmanac.ca.gov/gasoline/graphs/image_grabber.php?link=image6

Energy Cost of Corn Ethanol

- Controversy over costs and benefits
  - Two authors Patzek (Berkeley) and Pimentel (Cornell) say ethanol production consumes more energy than it produces
  - Other authors Wang (Argonne), Graboski (National Corn Growers Association), Shapouri (DS Department of Agriculture) and de Olivera see benefits
- Text covers this briefly

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Meta-analysis of Ethanol

- January 2006 *Science* paper
  - Farrell *et al.*, "Ethanol Can Contribute to Energy and Environmental Goals," *Science* **311**:506:508, 27 January 2006
  - Examine six different studies
  - Adjust results to have common boundaries for costs
  - Consider additional cases using ERG (Energy and Resources Group) Biofuel Analysis Meta Model – EBAMM

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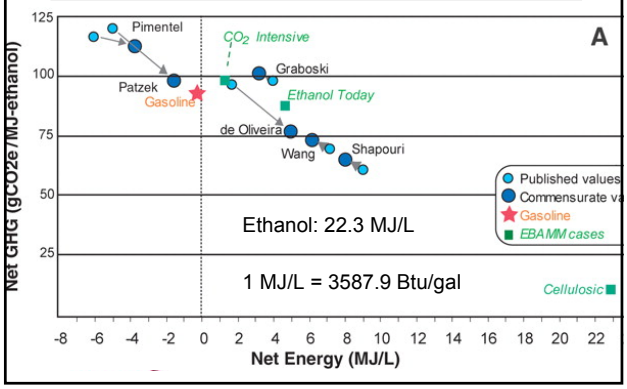
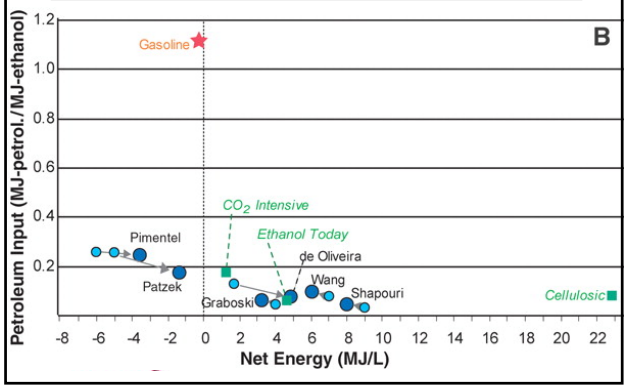
Meta-Analysis CO_2



Meta-Analysis Petroleum



Still No Agreement

- Patzek and Pimentel point to errors in meta-analysis
  - Dispute concerns over treatment of byproduct credits and data sources
  - Claim no biofuels are economic
- One clear issue: Patzek counts energy in corn as input; others do not
  - What if land were used for solar cells instead of growing corn?

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Other Biofuel Issues

- Effect on cost of food
  - Recent data show sharp prices increases in cost of corn and soybeans as food due to increased competition for biofuels
- Effect on rainforests
  - Increased demand for food crops has encourage development of rainforest for growing crops
    - Such diversion said to require hundreds of years to have positive energy balance

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Flexible Fuel Vehicles (FFV)

- Designed to be operated on a variety of fuels
  - !00% gasoline
  - 100% ethanol (or methanol)
  - Any intermediate alcohol percentage
- Alternative fuel vehicles (AFV) required by 1992 EPAct for government fleets
  - FFVs qualify as AFVs
  - Most operate on 100% gasoline

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Biodiesel

- Diesel fuel manufactured from new or used vegetable oils or cooking grease
  - monoalkyl esters of long chain fatty acids derived from plant or animal matter which meet EPA CAA section 211 and ASTM D6751 requirements
- Can be used as pure fuel, but more commonly used as 20% blend (B20) or as 2% additive (B2)

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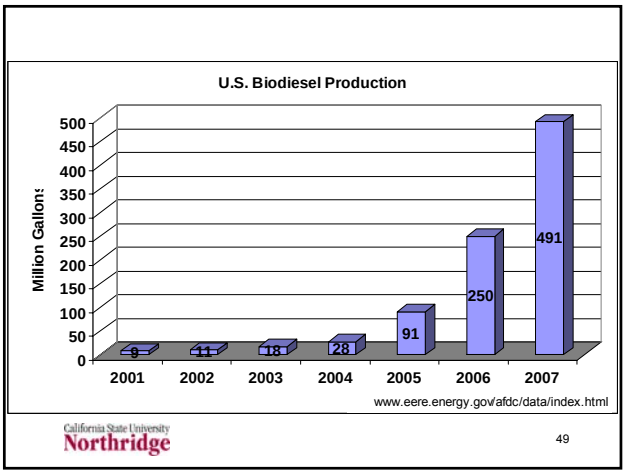
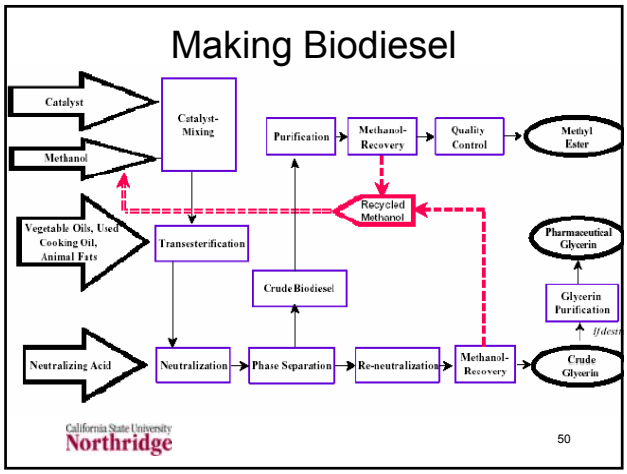
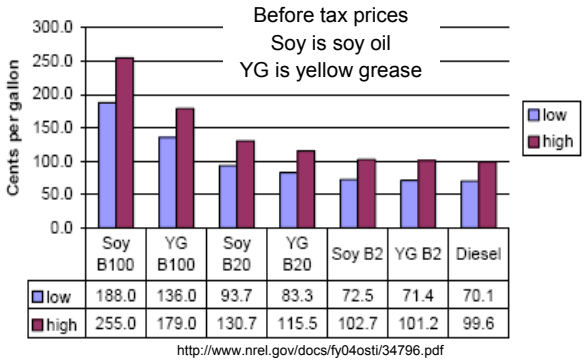




Biodiesel Prices 2002



	Soy B100	YG B100	Soy B20	YG B20	Soy B2	YG B2	Diesel
low	188.0	136.0	93.7	83.3	72.5	71.4	70.1
high	255.0	179.0	130.7	115.5	102.7	101.2	99.6

http://www.nrel.gov/docs/fy04osti/34796.pdf

Biodiesel Properties

- Cetane number (ignition property)
  - US petroleum diesel CN in low 40's
  - Biodiesel average 50.9
- Better lubricity (ability to self-lubricate engine fuel system)
- Poorer low temperature performance
  - Forms crystals that clog fuel system
- Has lower miles per gallon because of lower volumetric energy content

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Biodiesel Emissions

- Low sulfur consistent with ultra-low sulfur requirements for 2006 and later diesel fuels
- Eleven percent (11%) oxygen by mass that gives better combustion, but slightly higher oxides of nitrogen (NOx)
- Particulate emissions much lower
- No data available on MY 2007+ engines
  - EPA believes there will be differences

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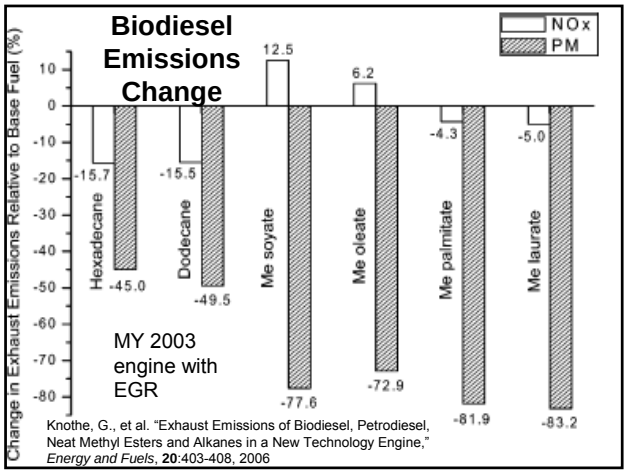
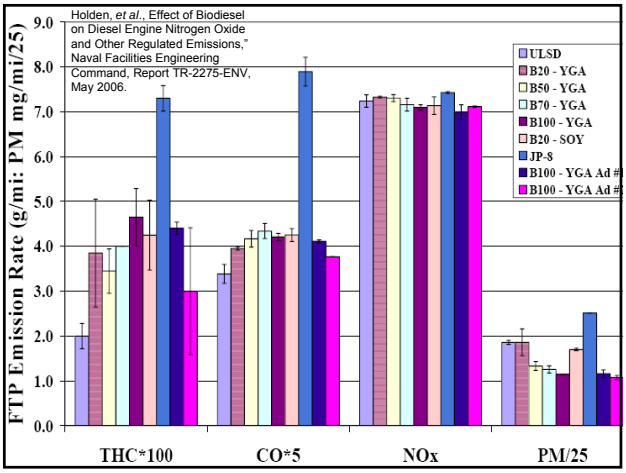


Knothe, G., et al. "Exhaust Emissions of Biodiesel, Petrodiesel, Neat Methyl Esters and Alkanes in a New Technology Engine," *Energy and Fuels*, **20**:403-408, 2006



Biodiesel CO_2 Emissions

- Life-cycle emissions studied by NREL
  - CO_2 emissions reduced by 78% for B100
  - Reduced by 16% for B20
  - Additional reductions in methane emissions
- B100 reduces petroleum use by 95% and B20 reduces use by 19%

J. Sheehan, V. Camobreco, J. Duffield, M. Graboski, and H. Shapouri, *Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus: Final Report*, NREL/SR-580-24089 (Golden, CO: National Renewable Energy Laboratory, May 1998), p. v, web site www. nrel.gov/docs/legosti/fy98/24089.pdf.

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Financial Incentives

- Federal tax credits
  - Alternative Fuel Infrastructure Tax Credit: 30% of the of cost alternative refueling property, up to $30,000 for businesses
  - Alternative Motor Vehicle Credit to buyers of new AFVs: 50% of incremental vehicle cost plus 30% of incremental cost for vehicles with near-zero emissions
  - Hybrid Motor Vehicle Credit for light-duty vehicles based on life-time fuel savings

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Financial Incentives II

- Fuel Cell Motor Vehicle Credit: tax credit of $8,000 until December 31, 2009 and $4,000 after that
- Electric Vehicle Tax Credit: 10% of the cost up to $4,000, reduced by 75% in 2006 and expired in 2007
- Biodiesel and Ethanol Tax Credit
  - biodiesel credit $.01 per percentage point of agri-biodiesel used or $.0050 per percentage point of waste-grease biodiesel from 1/1/2005 to 12/31/2010

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Financial Incentives III

- Biodiesel and Ethanol Tax Credit
  - ethanol credit $.0051 per percentage point of ethanol from 1/1/2005 to 12/31/2010
- Small ethanol producer tax credit of ten cents per gallon for up to 15 million gallons for producers making less than 60 million gallons of ethanol per year
- Small agri-biodiesel producer tax credit of $.10 per gallon for up to 15 million gallons for producers making less than 60 million gallons of biodiesel per year.

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Renewable Fuel Standard

- Required under the 2005 Energy Policy Act (EPAct 2005)
  - Directs EPA to develop regulations for minimum volume of renewable fuel
- Regulations approved by EPA on April 10, 2007
- For complete preamble, see http://www.epa.gov/otaq/renewable fuels/rfs-preamble.pdf

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Renewable Fuel Standard II

- 3.5 billion gallons used in 2005
- EPAct calls for increase to 7.5 million gallons in 2012 and proportionate levels thereafter
- Expected 2012 use: ~10 billion gallons
  - Economics expected to increase use more than required by regulations
  - Will reduce petroleum consumption by 0.8% to 1.6%

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Renewable Fuel Standard III

- Energy Independence and Security Act of 2007 – biofuels section
  - Total biofuels to increase to 36 billion gallons by 2022
  - 21 billion gallons of "advanced biofuels" to come from non-cornstarch sources (*i.e.* fuel must come from sources such as sugar or cellulose)
  - Many other biofuel provisions

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Fuel Ethanol Future

- 20 projects under "development and construction" at end of 2008
  - Compare to 2008 production of 10.6 billion gallons and 12.5 billion gallons capacity
  - Total capacity 0.4 billion gallons per year
    - Multiple feedstocks: corn stover, wheat straw, milo stubble, switchgranss, grass seed and straw, corn stalks, green waste, wood waste, cellulosic urban wastes, sugarcane, bagasse, corn fiber, corn cobs, wood residue, MSW, unrecyclable paper, construction debris, *etc*.

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Renewable Fuels Association, *2009 Ethanol Industry Outlook,* downloaded March 22, 2009 from http://www.ethanolrfa.org/industry/outlook/

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