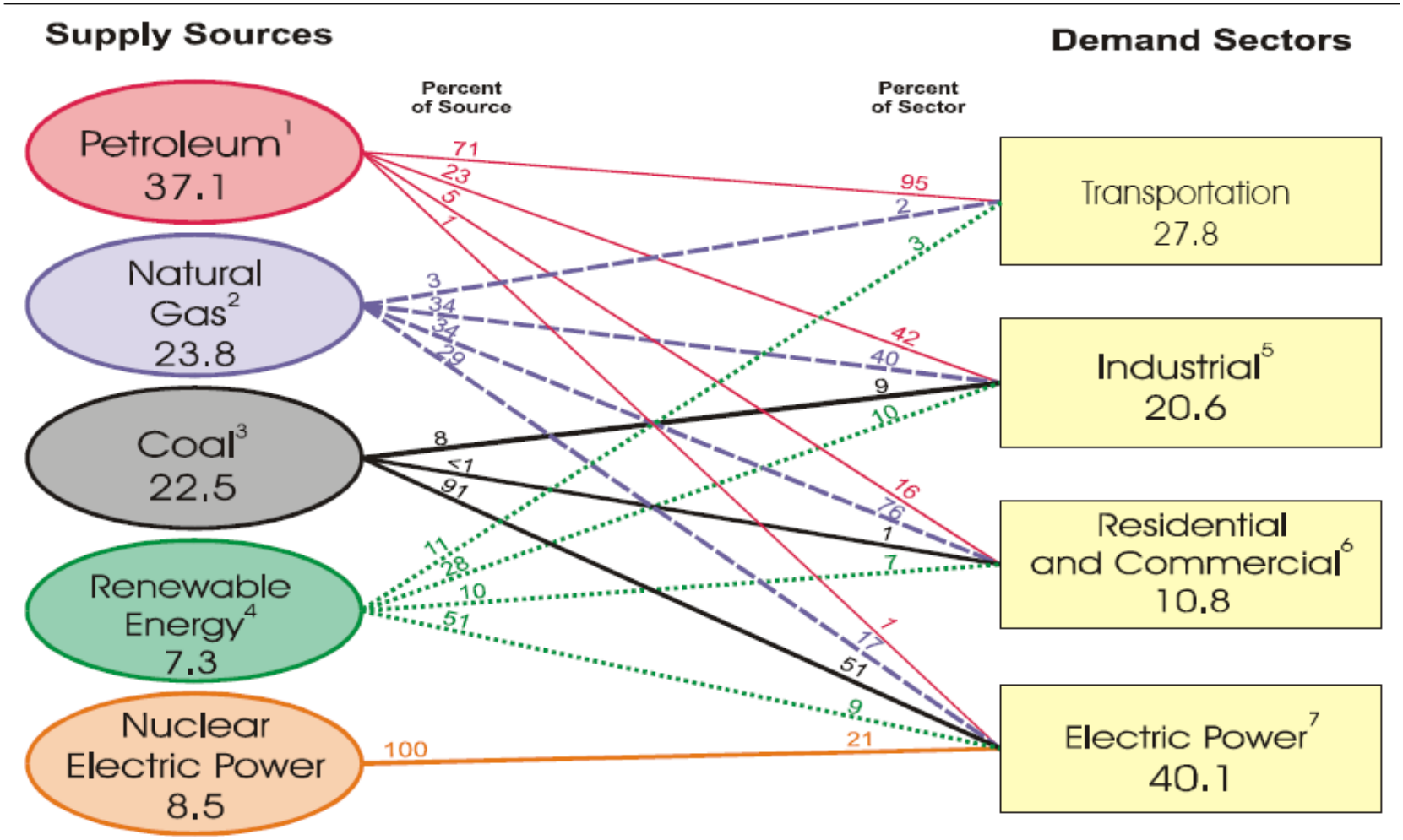
Biofuels

Educational Materials
December 2009

CITE AS: "Allen, D.T., R.E. Hebner and M.E. Webber, 'EPA Biofuels Educational Module I,' The University of Texas at Austin, December 2009."

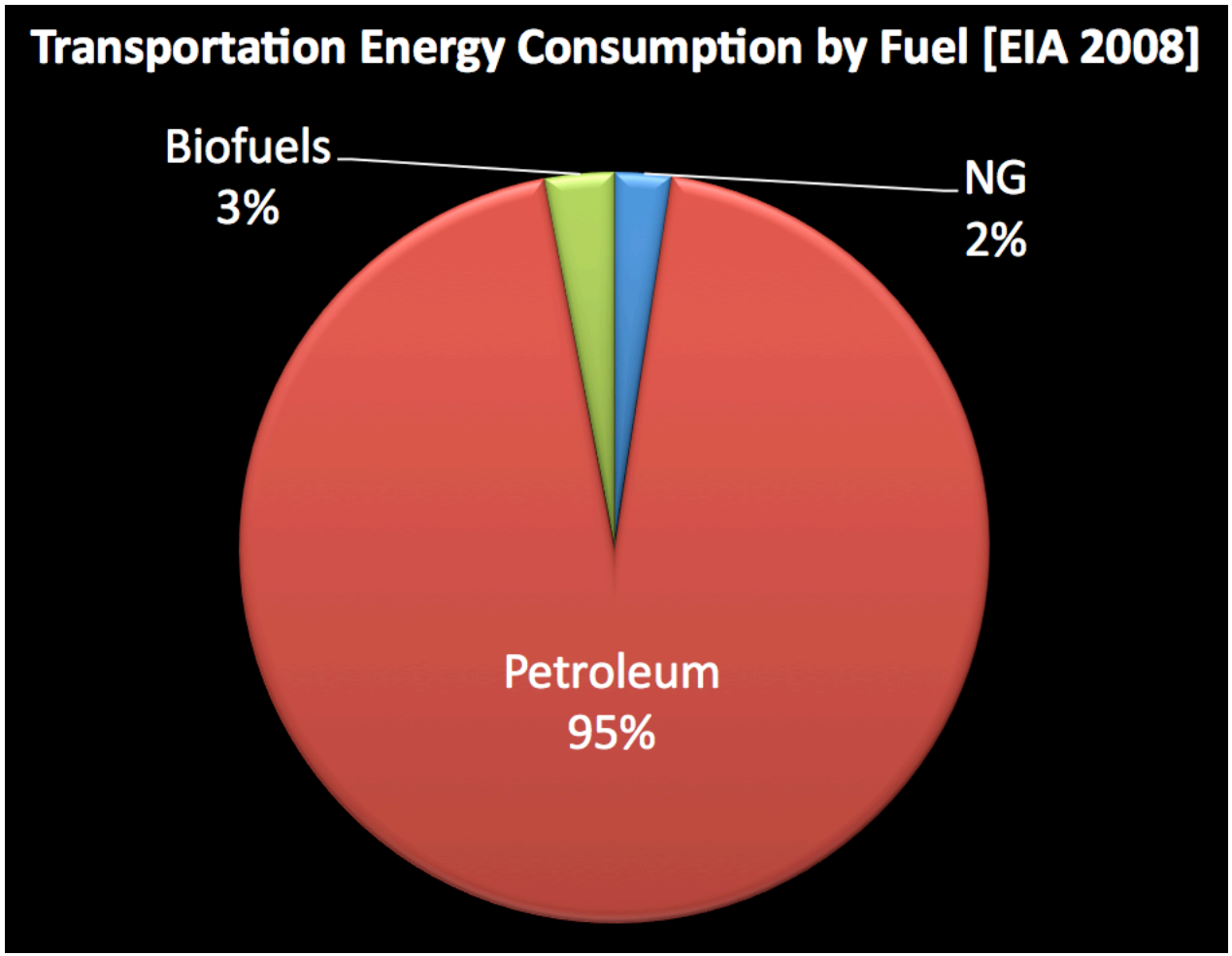
Transportation Is Responsible for 28% of National Consumption

Figure 2.0 Primary Energy Consumption by Source and Sector, 2008
(Quadrillion Btu)



EIA AER: U.S. Primary Energy Consumption (2008): 99.3 Quad

Petroleum Is the Dominant Fuel Source for Transportation

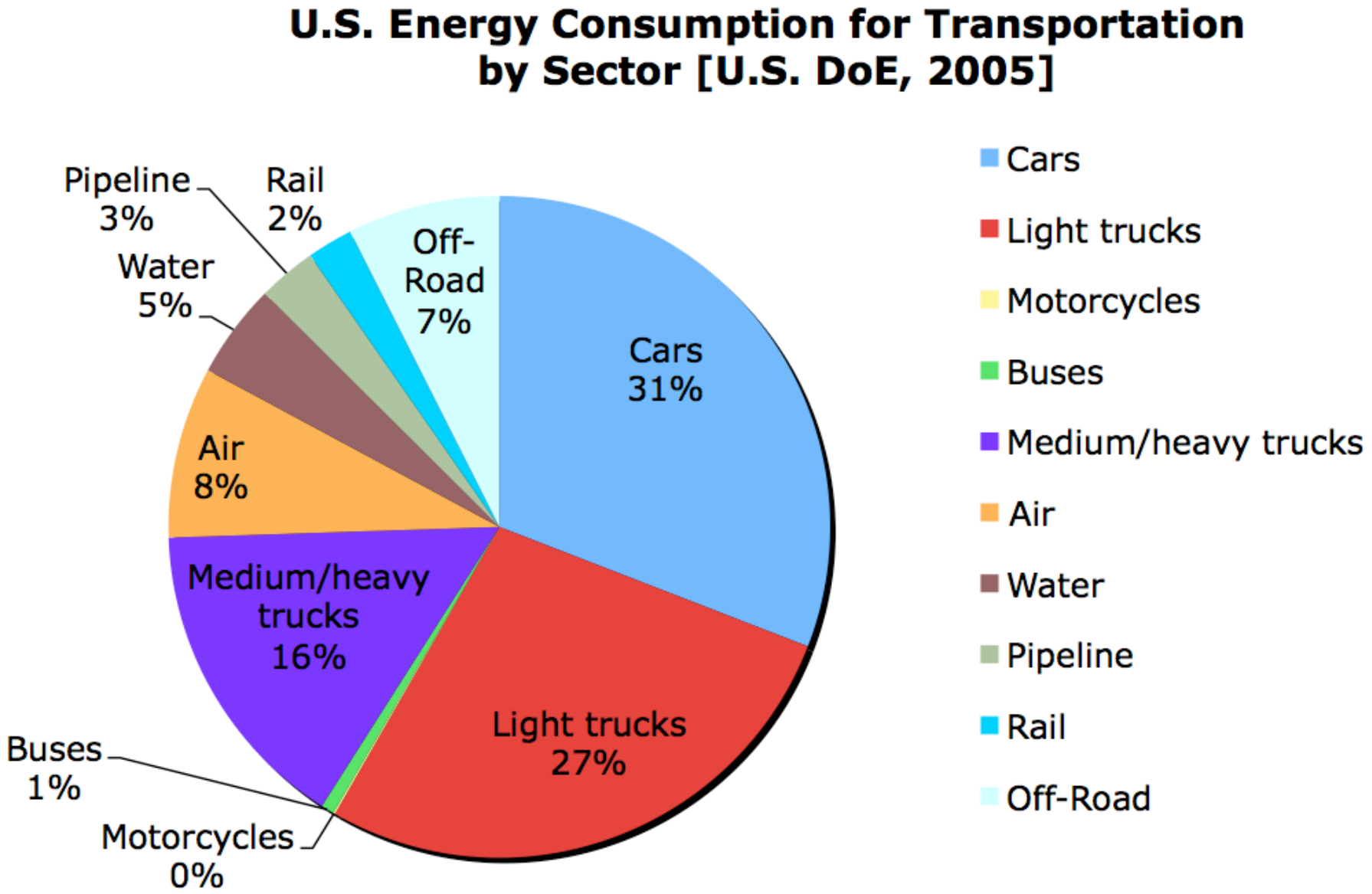


We Have Many Road Vehicles and We Drive Them Many Miles

- **US Population: 300 million**
- **Cars: 135 million**
  - **Median age: 9.2 years**
- **Trucks: 108 million**
- **Miles traveled: 3.1 trillion**

Source: DoE Transportation Energy Data Book 2008 (2006 data)

Three-Fourths of Transportation Energy Consumption Is From Road/Highway Travel



Biofuels have several advantages

- Crop-based biofuels consume CO_2 during photosynthesis
- Residue-based biofuels reduce demand for new fuels and bring value to waste products
- Domestic sources of biofuels are available
- Renewable
- Biodegradeable

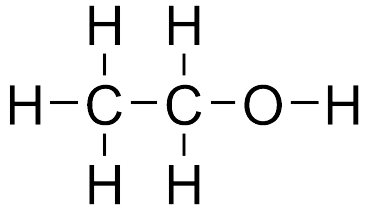
Biofuels terminology

- First letter indicates the fuel
  - B for Biodiesel (regardless of source)
  - E for Ethanol (regardless of source)
    - Not clear how to label biobutanol
- Second number indicates the percentage
- Some standard biofuel blends
  - B5 = Diesel blended with 5% biodiesel
  - B20 = Diesel blended with 20% biodiesel
  - E10 = Gasoline blended with 10% ethanol
  - E85 = Gasoline blended with 85% ethanol

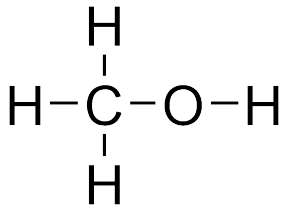
Ethanol

Alcohols Are Just Hydrocarbons with an "OH"

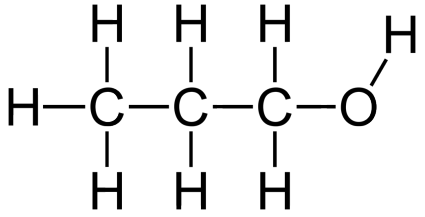
- **Ethanol = Ethane + OH**
  - **EtOH**
  - **C_2H_5OH**



- **Methanol = Methane + OH**
  - **very poisonous**
  - **"wood alcohol"**
  - **CH_3OH**



- **Propanol = Propane + OH**



There are several different sources of ethanol

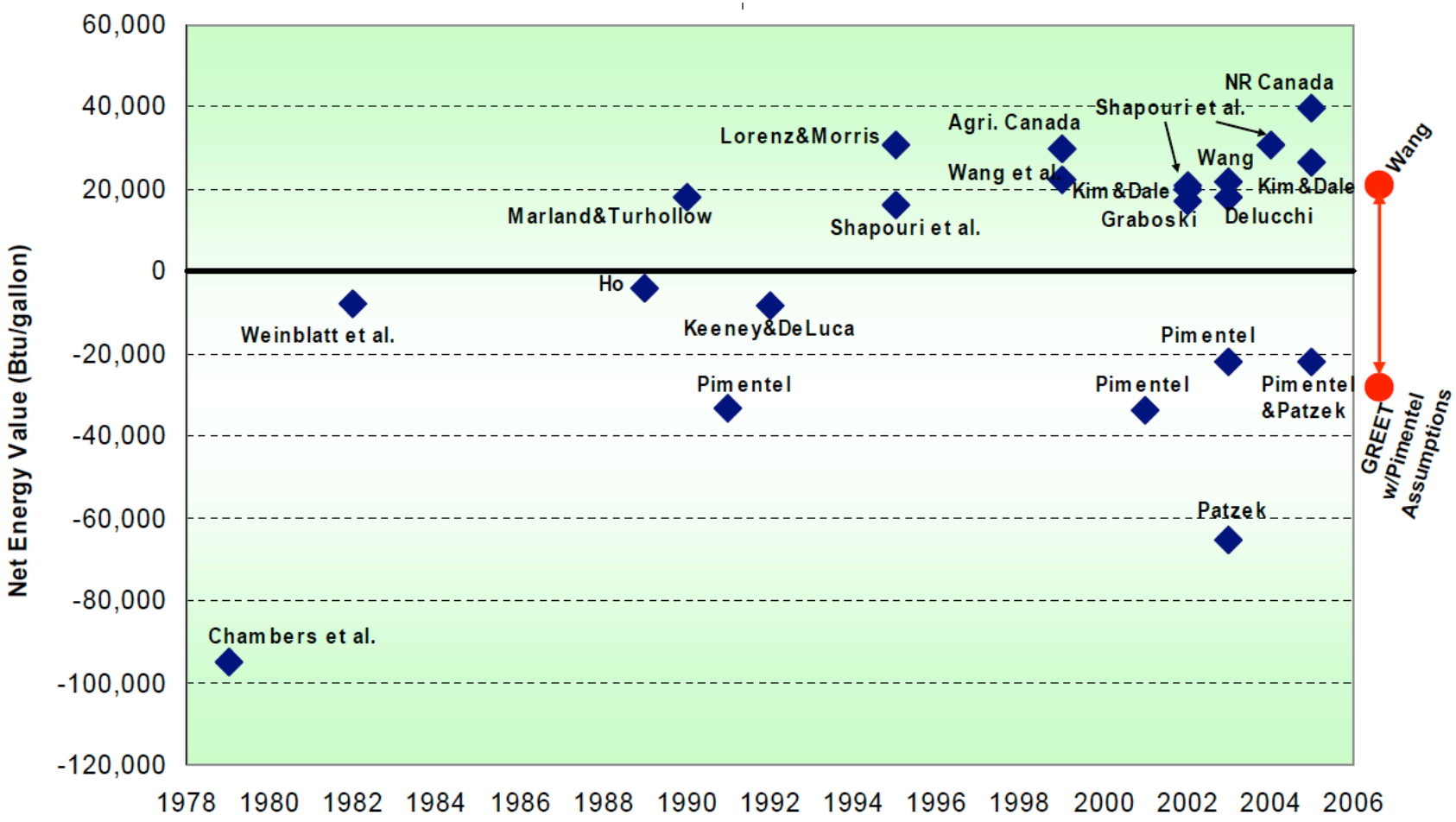
- **Starches: corn, etc.**
  - **least amount of energy return per unit mass**
  - **process into sugars, then ferment to alcohol**
- **Sugars: sugar cane, sugar beets, etc.**
  - **more energy output per unit mass than corn**
  - **ferment directly to alcohol**
- **Cellulosic materials: corn stover, wood chips, switchgrass,…**
  - **grows without irrigation, tillage, topsoil erosion**
    - **not everyone agrees with these claims**
  - **requires enzymes to break down lignin**

What makes a vehicle E85 capable?

- Your car already runs on E10
- To run E85:
  - Materials in fuel management system must be compatible with E85
    - Non-rubber hoses
    - Resistant engine seals
  - A new fuel sensor detects fuel mixture and adjusts injection and ignition characteristics

Corn-Based Ethanol

Not All Studies Show Positive Energy Balance for Corn-Based Ethanol

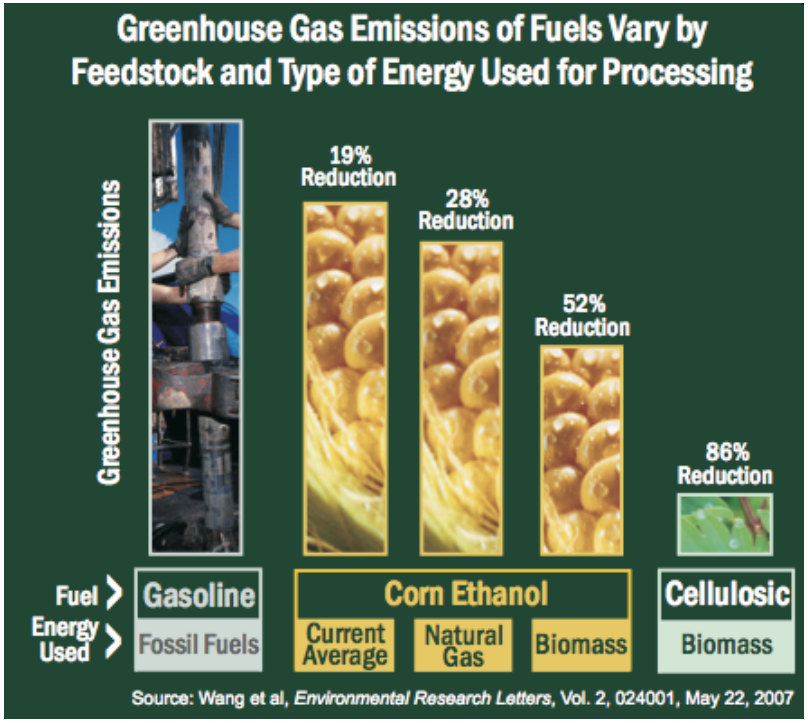


Energy balance here is defined as Btu content a gallon of ethanol minus fossil energy used to produce a gallon of ethanol

Energy required to produce ethanol includes energy required to make fertilizer, energy required to run farm equipment, energy required to perform irrigatio, and other energy demands; most recent studies show positive energy balance

Source: Wang, Argonne National Lab. *Updated Energy and Greenhouse Gas Emissions Results of Fuel Ethanol,* 2005.

Bioethanol Can Reduce GHG Emissions and Improve Performance



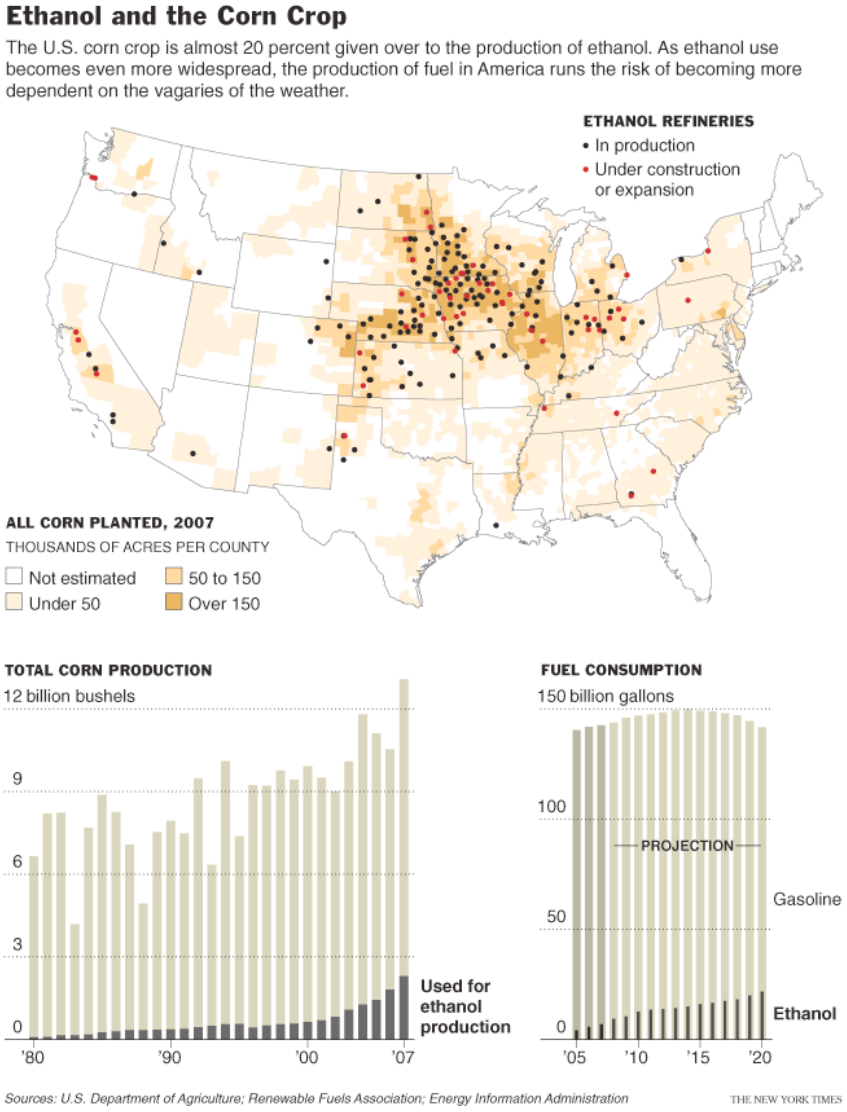
- WTW CO_2 reductions of 19-52%
  - WTW = well-to-wheel, or field-to-wheel
- Higher octane (108+) allows higher compression ratio, which is good for performance

Corn-Based Ethanol is not Problem-Free

- **Consumes fossil fuels: fertilizers, pesticides, heat for fermentation, diesel-powered trucks and farm equipment**
- **Consumes water:**
  - **6 gal H_2O/gal EtOh (processing), 600-1500 gal H_2O/gal (growing)**
- **Expedited topsoil erosion**
- **Negatively impacts the nitrogen cycle**
  - **growing dead zone in the Gulf of Mexico**
- **Ethanol has lower energy content than gasoline by ~30%**
- **Ethanol corrodes pipelines, so it must be trucked (w/Diesel)**
- **Corn cannot be piped, so it must be trucked (with Diesel)**

Ethanol is Subject to Weather Risks

- **"Weather Risks Cloud Promise of Biofuel," NYT, July 1, 2008, By JAD MOUAWAD**
  - **susceptible to drought & flood**
  - **"Eventually, the cost of filling Americans' gas tanks could be influenced as much by hail in Iowa as by the bombing of an oil pipeline in Nigeria."**
- **Traditional petroleum-based feedstocks are also subject to weather risks**
  - **Hurricanes often affect the oil and gas infrastructure along the gulf coast**



The Ethanol Fueling And Production Infrastructure Has Grown Quickly

- **E85 Station Count: 1,730 (as of 2/9/09)**
- **New E85 Stations Opened: 125 (9/1/08 to 2/9/09)**
- **Nameplate Ethanol Refineries 193 (as of 2/9/09)**
- **Nameplate Ethanol Production Capacity: 12,375 million gallons (as of 2/9/09)**
- **Source: Biofuels Market Data, DoE**
  - **http://www1.eere.energy.gov/biomass/biofuels_data.html**

As corn prices rise and ethanol prices decrease, profit margins shrink

Wall Street Journal Article Implies that Infrastructure Limitations Slow Ethanol Sales

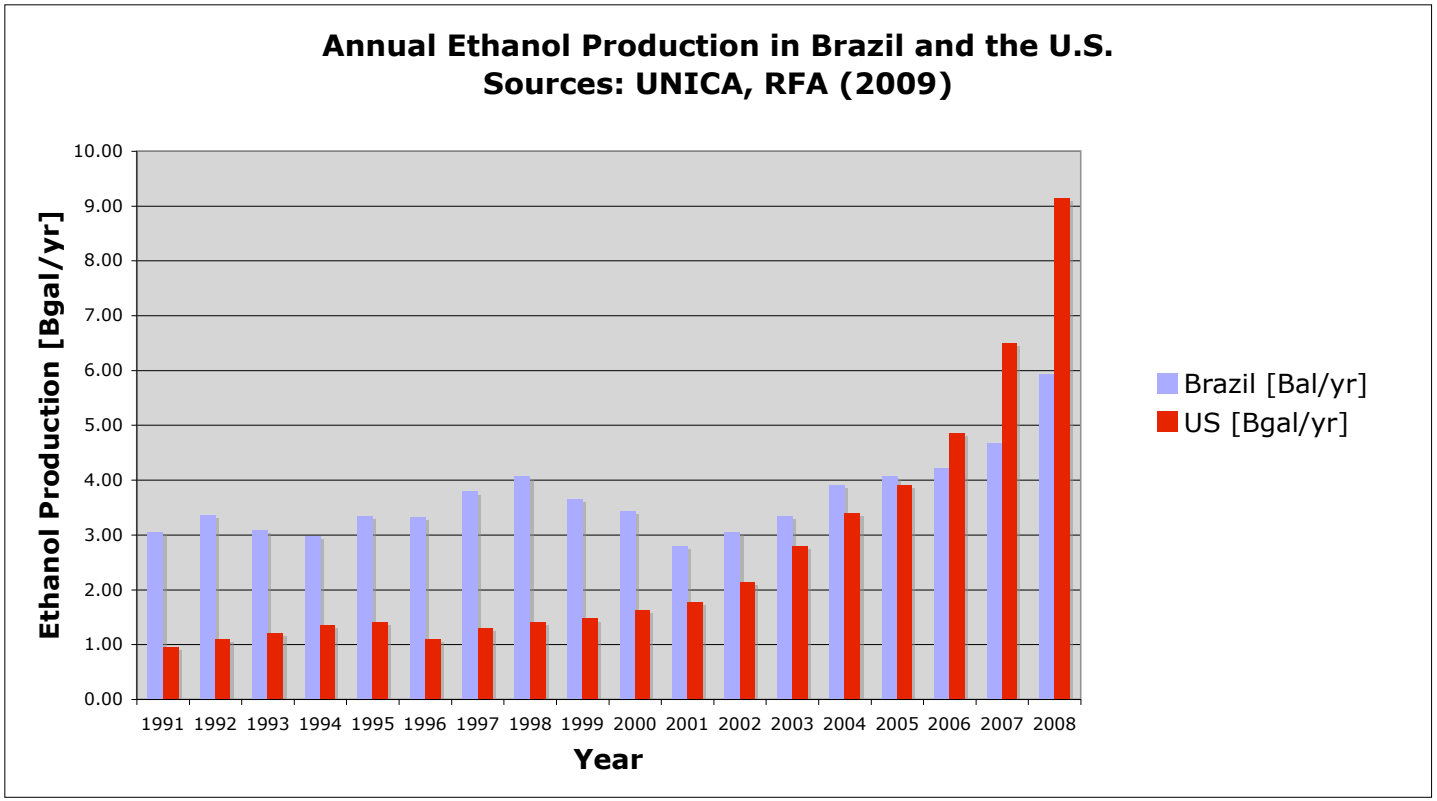
- ***Wall Street Journal*, April 2, 2007**
  - **"Fill up with Ethanol? One obstacle is big oil"**
    - **It's Big Oil's fault because they fail to install the appropriate retail infrastructure**

- ***Letters to the WSJ Editor* (in response), April 17, 2007**
  - **Sen. John Thune (Republican Senator, SD)**
    - **Congress' fault for failing to set clear mandates**
  - **S. Shariq Yosufzai, President, Chevron Global Marketing**
    - **It's the retailer's fault, for failing to install the appropriate retail infrastructure**

Brazil's ethanol production, which has been cited as a global example, uses sugar not corn

- Higher energy content per unit mass
- Does not require irrigation
- Does not require fertilizers, herbicides, pesticides
- Grown for ~500 years without depleting the topsoil
  - brought to Brazil in 1532 by Martim Afonso de Souza
- Sugar is semi-perennial, NOT annual
  - three crops/year, replanting every 5 years

Using Corn, the U.S. Has Already Exceeded Brazilian Production of Ethanol



Biodiesel

Biodiesel Looks Appealing

- **Uses waste and many non-food crops**
- **Similar energy content as petroleum based diesel**
- **Rudolf Diesel demonstrated his new engine at the Paris World Fair in 1901 using Peanut Oil**

Biodiesel Can Be Made From a Variety of Feedstocks

- **Soybean oil: most common source in the U.S.**
- **Canola (Rapeseed) oil: most common source in EU**
- **Palm oil: World production exceeds soybean oil and concentrated in Far East (Main producers: Malaysia and Indonesia)**
- **Coconut oil: High concentration of saturated fatty acids**
- **Beef lard: obtained from cows, restaurant grease, etc.**
- **Algae: highly productive, but experimental**

Biodiesel Productivity Varies for Different Feedstocks

Feedstock	Production [gallons/acre]
Algae	500-20,000
Palm Oil	625
Canola/Rapeseed	125
Castor	113
Sunflower	90
Jatropha	75
Soybeans	63
Cottonseed	38

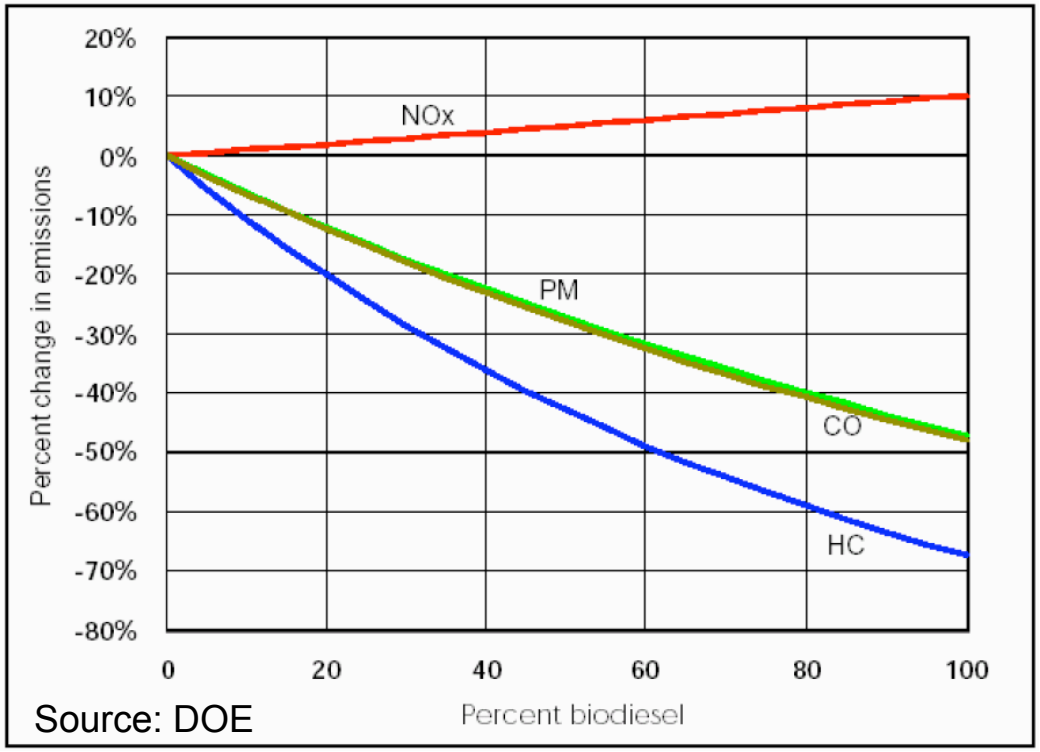
Sources: 1) *"Grow Your Own," Science Observer, American Scientist, Volume 94, September-October, 2006.* 2) National Renewable Energy Lab, U.S. Department of Energy, 1998. 3) NREL, Algal Biomass Summit 2007

Biodiesel Vehicles

- **B20 requires no vehicle modifications**
- **Greater than 20% biodiesel requires minor modifications to vehicle**
  - **Seals**
  - **Gaskets**
  - **Tank, fuel line, fuel filter heaters (for cold environments)**

Biodiesel Also Has Shortcomings

- **Tank-to-Wheel Emissions might be worse for NOx**
  - **The scientific community has not reached consensus on this point**
- **Does not perform well in low temperatures**
  - **need additives to help it improve its operating range of temps**



Source: DOE

Biodiesel from Jatropha Works at Low Temperatures

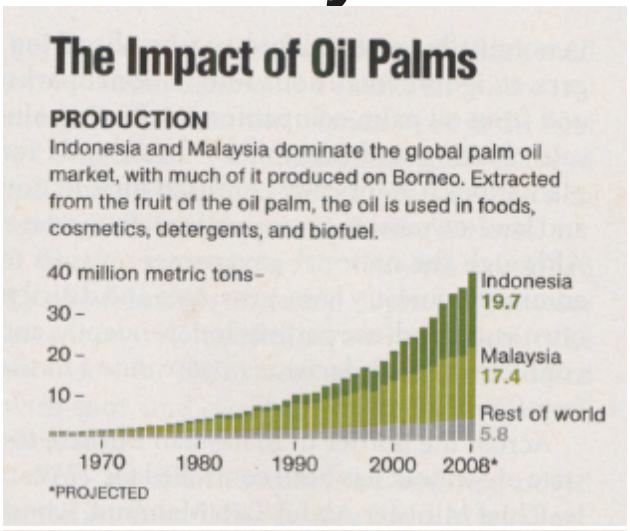
- "One engine of a Boeing 747-400 airplane was powered by a 50-50 blend of oil from jatropha plants and standard A1 jet fuel."

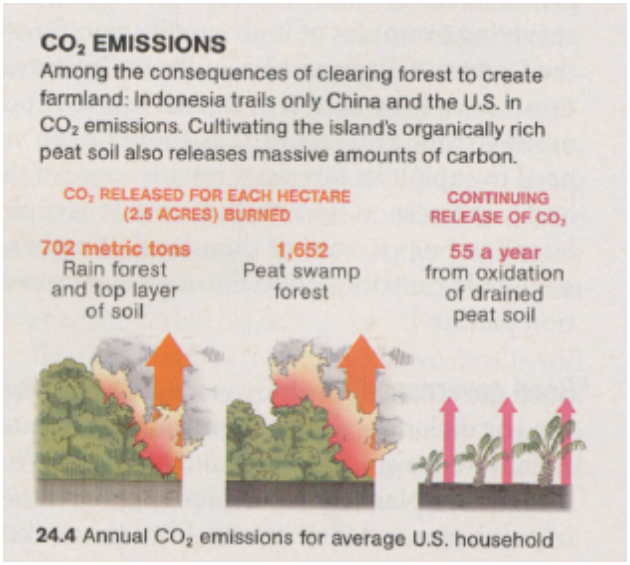
- "*Biofuels were once regarded as impractical for aviation because most freeze at the low temperatures encountered at cruising altitudes*. But tests show jatropha, whose seeds yield an oil already used to produce fuels like biodiesel, has an even lower freezing point than jet fuel."

Test Pilot , Captain Keith Pattie carries out pre-flight checks before their test of a Bio Fuel mixture in the left hand engine of Boeing 747 in Auckland, New Zealand, Tuesday, Dec. 30, 2008. Air New Zealand tested one engine of a Boeing 747-400 airplane powering it by a 50:50 blend of oil from jatropha plants and A1 jet fuel for the flight to test the fuel's viscosity.(AP Photo/NZ Herald, Paul Estcourt)

Source: National Geographic, Nov 2008

Biodiesel Is a Leading Cause of Deforestation in Malaysia





Biobutanol

Biobutanol Looks Promising, But Is Immature

- **Much higher energy content than ethanol**
  - **almost as good as gasoline**
- **Compatible with pipelines**
- **Object of industrial interest**

Recent Policies Have Emphasized Biofuels

Ethanol Production Has Been Actively Encouraged

- **Energy Policy Act of 2005 (EPACT 2005)**
  - **required 7.5 billion gallons of renewable fuels by 2012**

- **Energy Independence and Security Act of 2007 (EISA 2007)**
  - **Requires 36 billion gallons of biofuels by 2022**
  - **Up to 15 billion gallons per year from corn**
  - **21 billion gallons must be derived from non-cornstarch products**

Energy Independence and Security Act of 2007 (EISA 2007) Has Two Main Provisions

- **Signed into law December 19, 2007**
- **TITLE I: Energy Security Through Improved Vehicle Fuel Economy**
  - **Raises CAFE standards to 35 mpg by 2020**
    - **Accelerated by executive order of President Obama to 35.5 mpg by 2016**
- **TITLE II: Energy Security Through Increased Production Of Biofuels**
  - **Establishes renewable fuels standard (RFS) of 36 billion gallons of biofuels by 2022**
    - **15 Bgal/yr from corn starch (maximum)**
    - **21 Bgal/yr from "advanced biofuels"**
      - **16 Bgal/yr for cellulosic biofuels**
      - **5 Bgal/yr are undetermined??**

EISA 2007 Uses Many Definitions for Biofuels

- **RENEWABLE FUEL: all of the following**
- **CONVENTIONAL BIOFUEL: corn-based ethanol**
- **ADDITIONAL RENEWABLE FUEL: heating oil and jet fuel from renewable biomass**
- **ADVANCED BIOFUEL: renewable fuel with lifecycle greenhouse gas emissions 50% less than baseline (conv. gasoline and diesel in 2005)**
  - ***Corn-based ethanol explicitly NOT included***
  - **Cellulosic ethanol**
  - **Ethanol from sugar or non-corn starches**
  - **Waste-derived ethanol**
  - **Biomass-based diesel**
  - **Biogas**
  - **Butanol**
  - **Other fuel derived from cellulosic biomass**

§201 of EISA 2007 has definitions for fuels, etc.

EISA Calls for Aggressive Penetration of Renewable Fuels

- **We exceeded early targets with corn ethanol, but now are falling behind**

Source: §202 of EISA 2007

"Calendar year:	Applicable volume of renewable fuel (in billions of gallons):
2006	4.0
2007	4.7
2008	9.0
2009	11.1
2010	12.95
2011	13.95
2012	15.2
2013	16.55
2014	18.15
2015	20.5
2016	22.25
2017	24.0
2018	26.0
2019	28.0
2020	30.0
2021	33.0
2022	36.0

Year	US Ethanol Production [Billion Gals]
2005	3.9
2006	4.9
2007	6.8
2008	9.1

Source: EIA AER (2008), RFA Industry Statistics (Feb 2009)

EISA 2007 Calls for 600 Million Gallons of Advanced Biofuels Production This Year

Source: §202 of EISA 2007

"Calendar year:	Applicable volume of advanced biofuel (in billions of gallons):
2009	0.6
2010	0.95
2011	1.35
2012	2.0
2013	2.75
2014	3.75
2015	5.5
2016	7.25
2017	9.0
2018	11.0
2019	13.0
2020	15.0
2021	18.0
2022	21.0

- **21 Bgal by 2022**
- **16 Bgal from Cellulosic Ethanol**
- **5 Bgal from unspecified sources**

EISA 2007 Calls for 100 Million Gallons of Advanced Cellulosic Biofuels by 2010

Source: §202 of EISA 2007

"Calendar year:	Applicable volume of cellulosic biofuel (in billions of gallons):
2010	0.1
2011	0.25
2012	0.5
2013	1.0
2014	1.75
2015	3.0
2016	4.25
2017	5.5
2018	7.0
2019	8.5
2020	10.5
2021	13.5
2022	16.0

EISA 2007 Calls for 500 Million Gallons of Advanced Biodiesel by 2009

Source: §202 of EISA 2007

"Calendar year:	Applicable volume of biomass-based diesel (in billions of gallons):
2009	0.5
2010	0.65
2011	0.80
2012	1.0

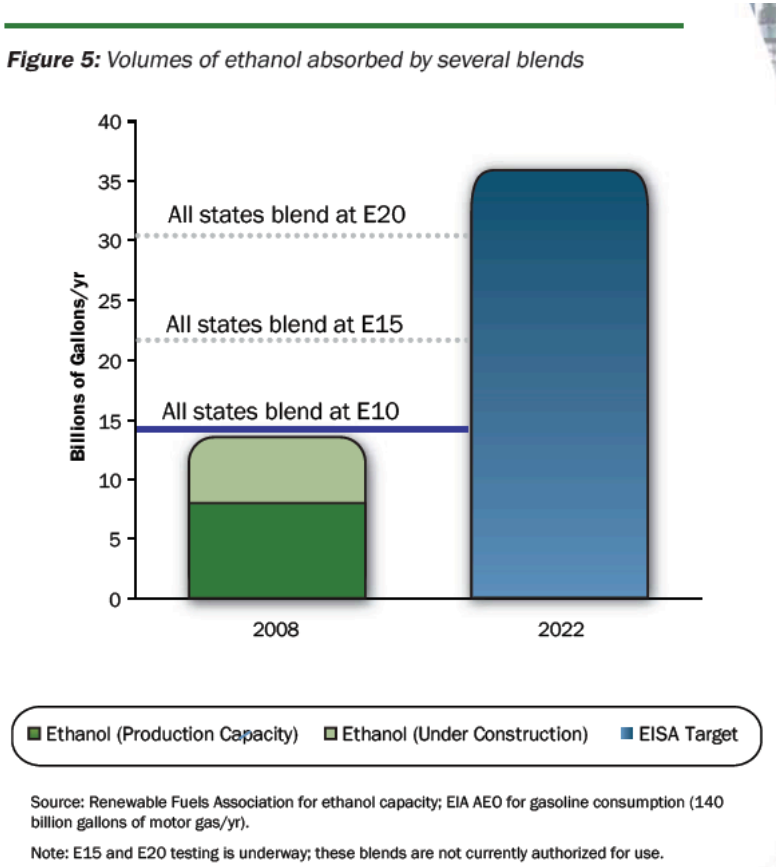
Year	US Biodiesel Production [Million Gals]
2005	75
2006	250
2007	450

Source: National Biodiesel Board, May 2008

- **Do we need another 4 Bgal of biodiesel by 2022?**
  - **To be determined later by Sec'y of Energy & Agriculture**
    - **environmental impact, production expectations, etc.**

- **It's not guaranteed existing biodiesel is "advanced"**
  - **existing routes: soy, palm oil, cottonseed, waste grease,…**
  - **50% GHG reduction requirement for advanced biodiesel**
  - **some scientists calculate that palm oil & soy increase lifecycle GHG emissions due to deforestation and land use**

We Have Essentially A Mandate for E10



"National Biofuels Action Plan," DoE, 10/08

- Today's consumption:
  - 140 Bgal/year Gasoline
  - 40 Bgal/year Diesel
- EISA Caps Corn-Ethanol at 15 Bgal/year by 2022
  - ~10% of annual consumption in 2022
- Blend limits become very important
  - E10 limit hits blend wall in 2014
  - E20 limit hits blend wall in 2022