Bio-fuels

1

The backdrop

2

Transportation and Mobility

- Transportation/mobility is vital to modern economy
  - Transport of People
  - Transport of goods and produce
- People get accustomed to the ability to travel

3

Transportation needs special kind of energy source

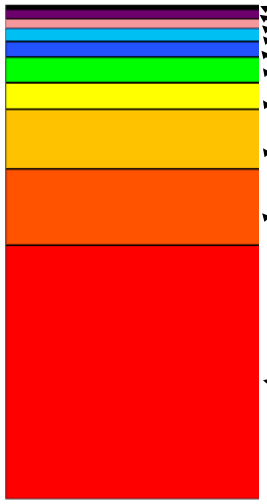
- Vehicles need to carry source of energy on board
- Hydrocarbons are unparalleled in terms of energy density
  - For example, look at refueling of gasoline
    - ~40 Liters in 2 minutes (~0.25 Kg/sec)
  - Corresponding energy flow
    = 0.25 Kg/sec x 44 MJ/Kg
    = 11 Mega Watts

Liquid hydrocarbons !

4

What is in a barrel of oil ?

(42 gallon oil → ~46 gallon products)



Typical US output

Lubricants	0.90%
Other Refined Products	1.50%
Asphalt and Road Oil	1.90%
Liquefied Refinery Gas	2.80%
Residual Fuel Oil	3.30%
Marketable Coke	5.00%
Still Gas	5.40%
Jet Fuel	12.60%
Distillate Fuel Oil	15.30%
Finished Motor Gasoline	51.40%

Source: California Energy Commission, Fuels Office

5

Refinery

6

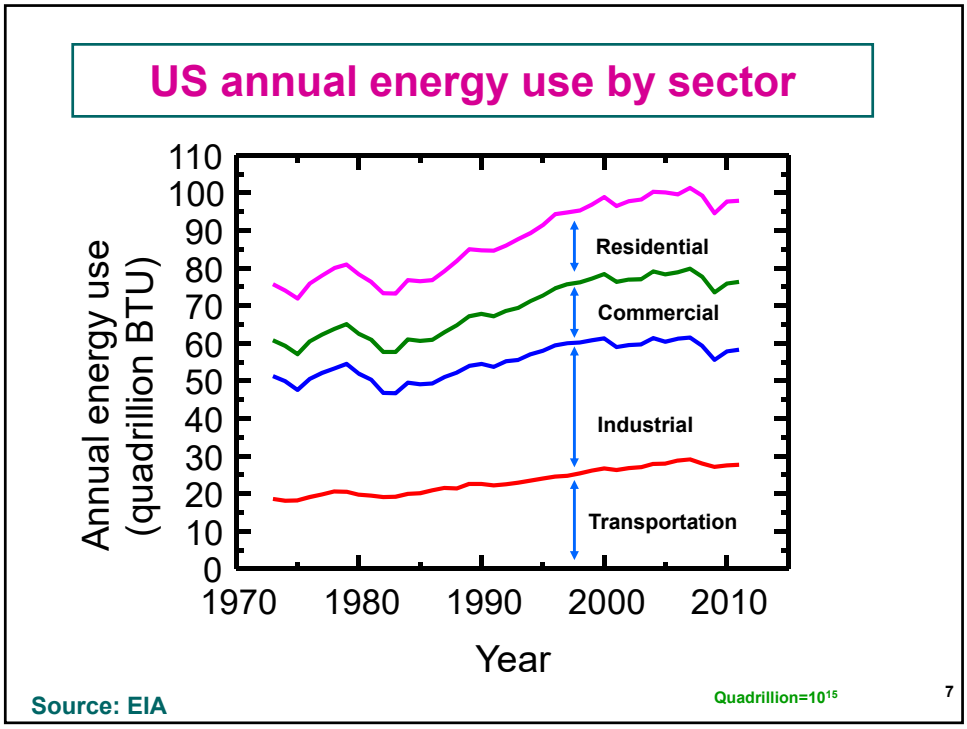


Image courtesy of the U.S. Energy Information Administration.

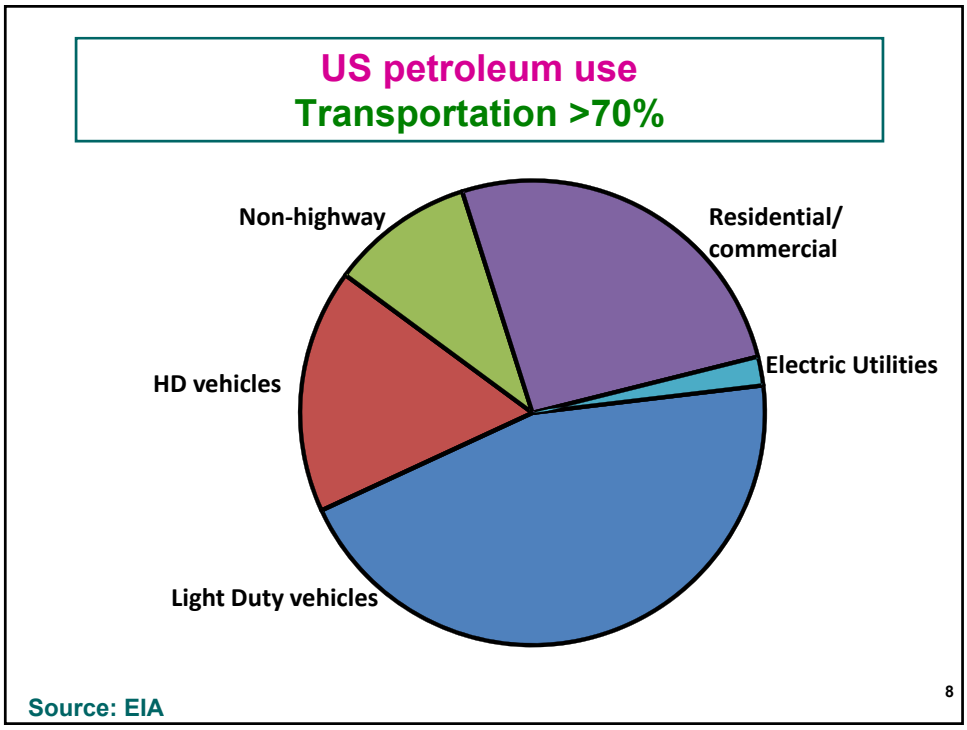


Image courtesy of the U.S. Energy Information Administration.

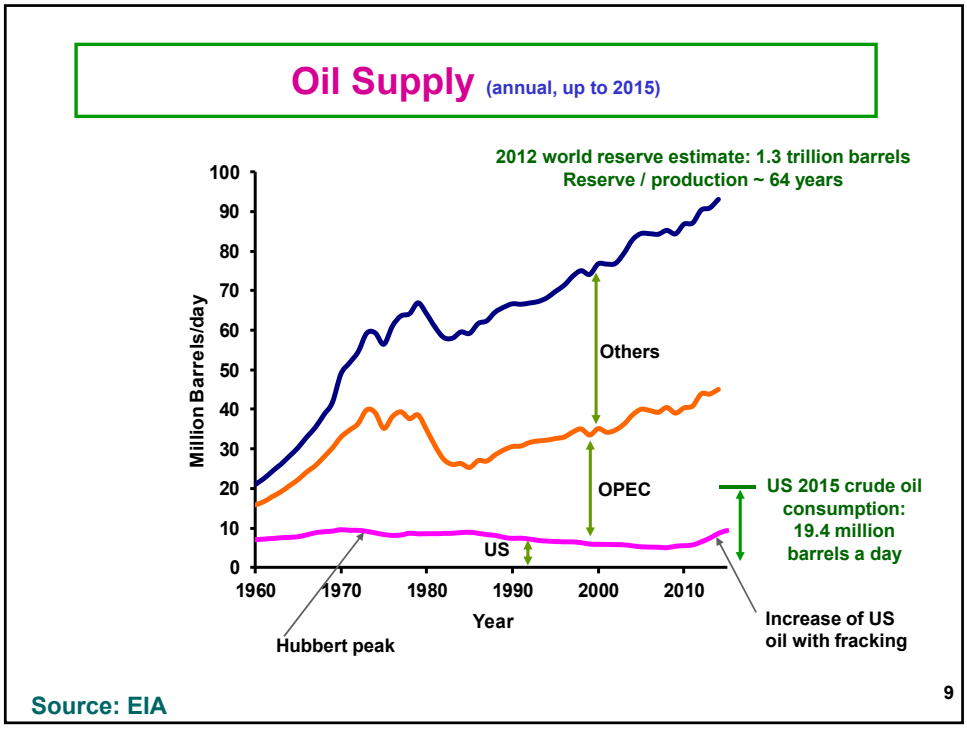


Image courtesy of the U.S. Energy Information Administration.

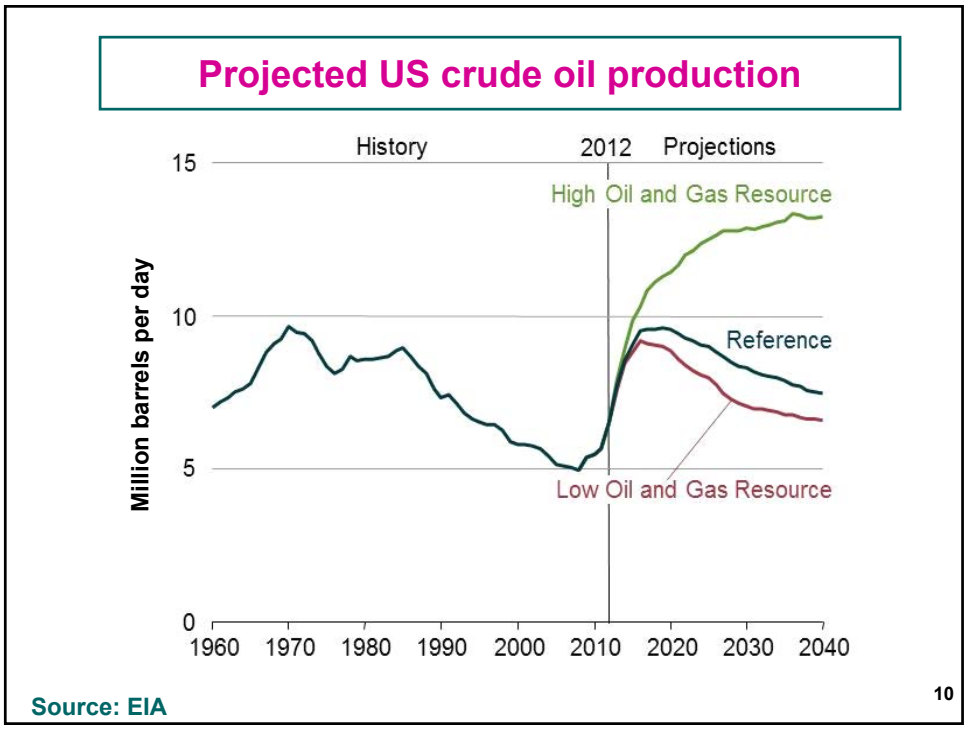


Image courtesy of the U.S. Energy Information Administration.

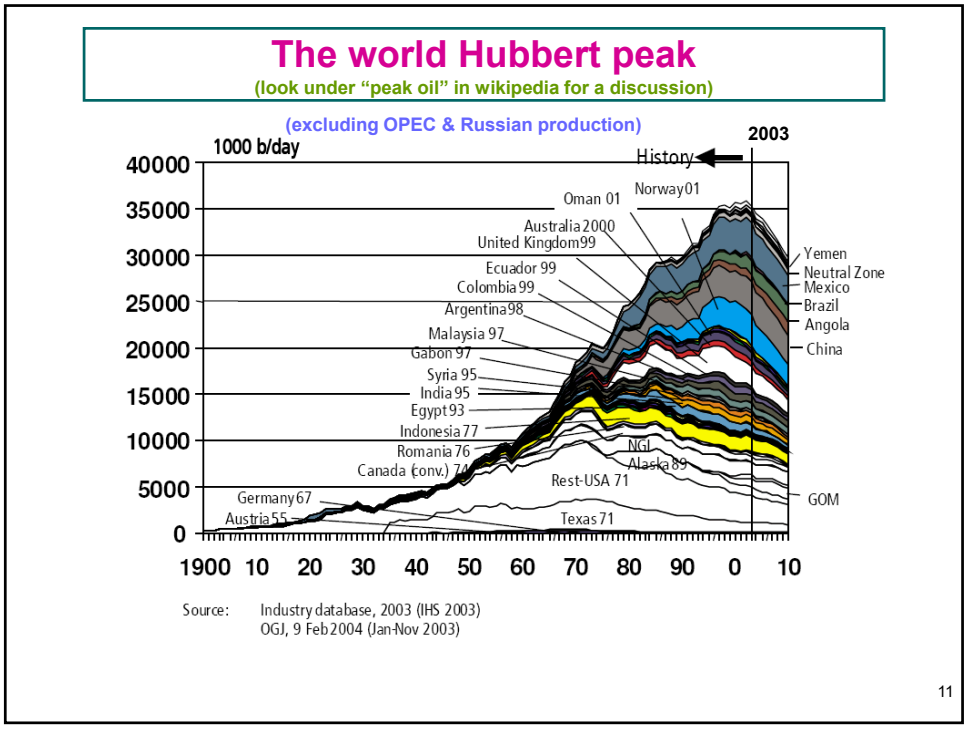


Image courtesy of the U.S. Department of Energy.

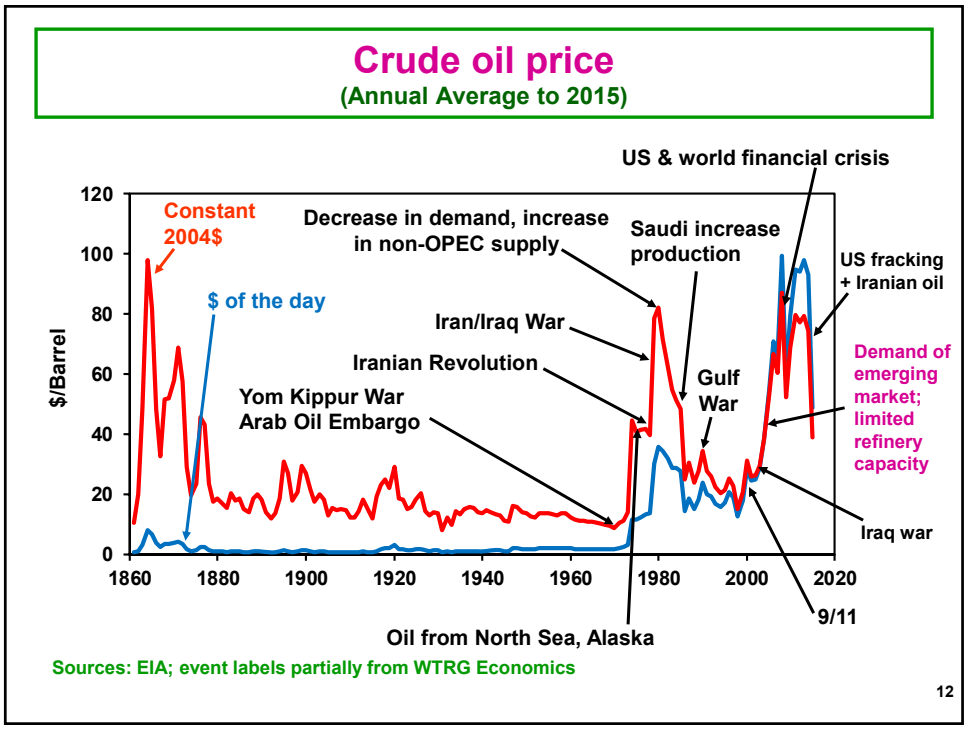
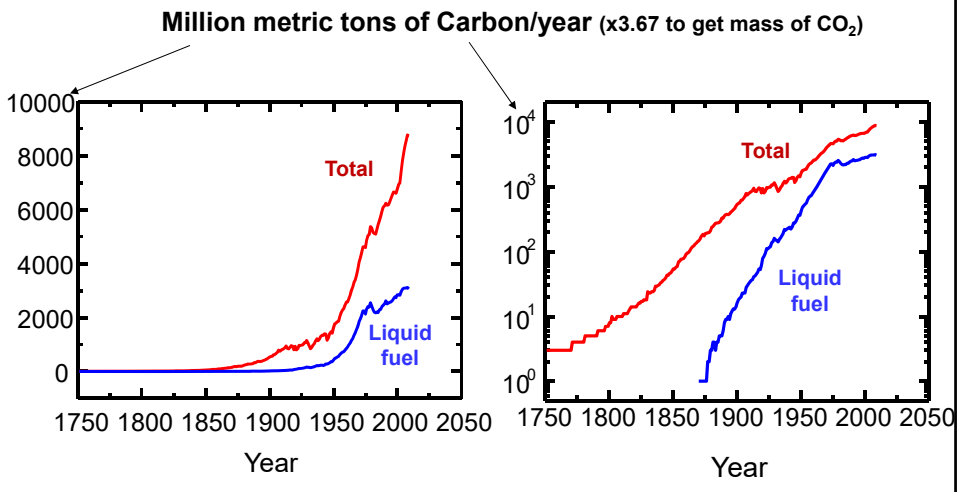


Image courtesy of the U.S. Energy Information Administration.

CO2 emissions from fossil fuel



13

The drive to bio-fuel

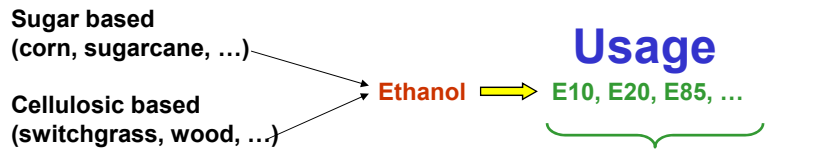
- Increasing demand of liquid fuel for transportation
  - Population
  - Society affluence
- Drive for lower CO2 production
- Perceived decline of petroleum reserve
- Fuel price
- Government Policy
  - Tax credit
  - Required bio-fuel content

14

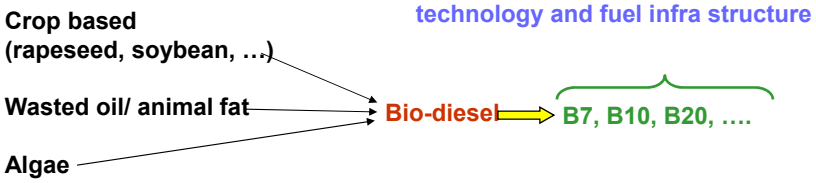
What is bio-fuel?

15

Dominant biofuels



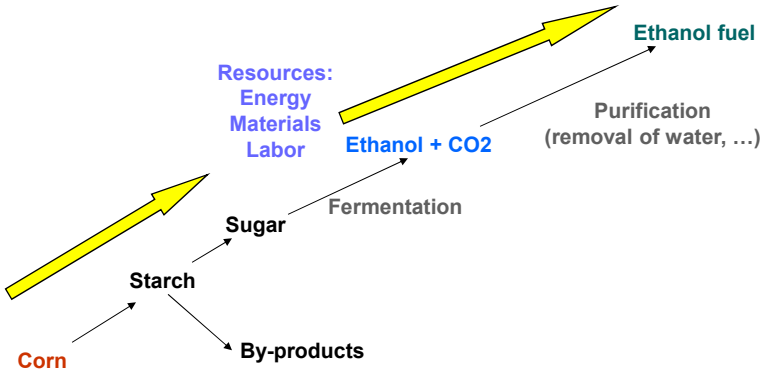
Compatible with current engine technology and fuel infra structure



(BTL fuel not included in this discussion)

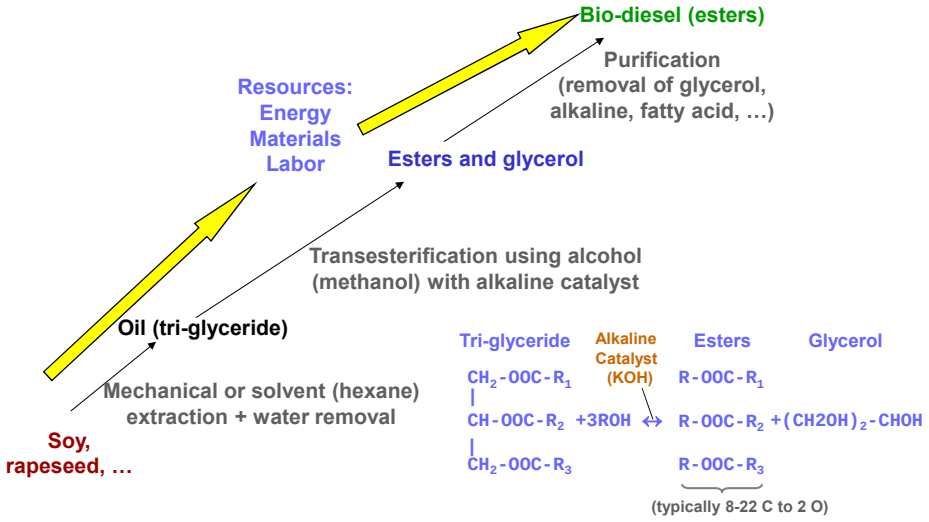
16

Example: Ethanol production from corn



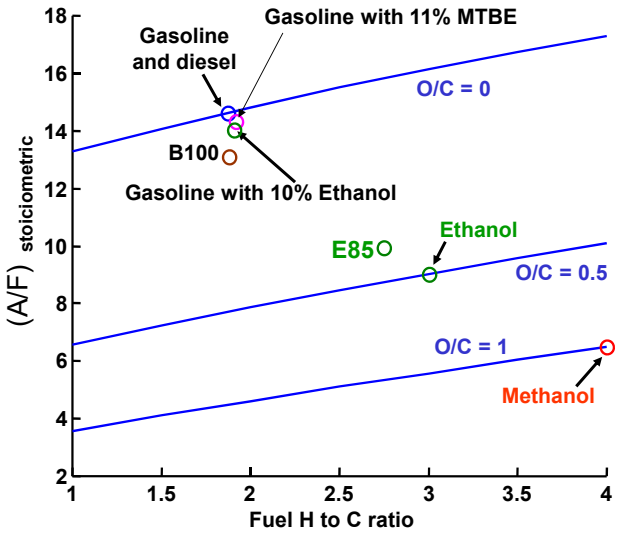
17

Example: bio-diesel production



18

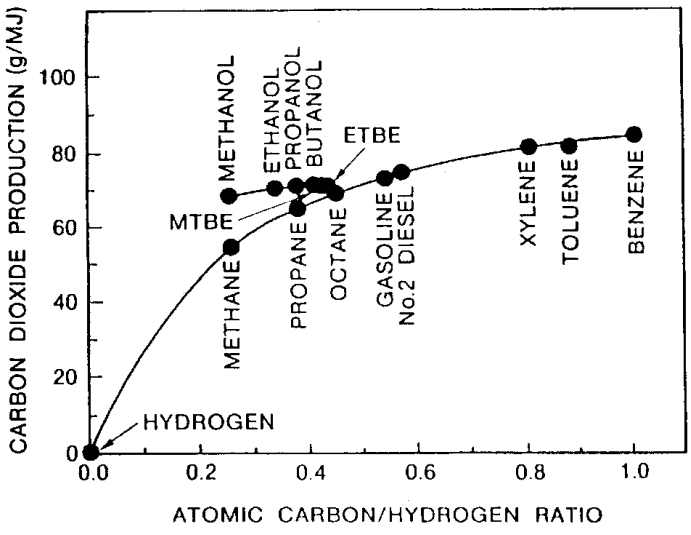
Stoichiometric requirement for different fuels



O/C ratios of bio-diesel esters ~ 0.12

19

Relative CO2 production from burning different fuel molecules



C. Amann, SAE Paper 9092099 20

Bio-fuel combustion properties

- Bio-diesels and ethanol are fundamentally clean and attractive fuels to be used in engines
- The use of these fuels as supplements to petroleum base fuel are compatible with current engine configuration and fuel infra-structure
- Practical issues can be adequately handled by engineering
  - Fuel quality
  - Engine calibration
  - Materials compatibility, viscosity, …

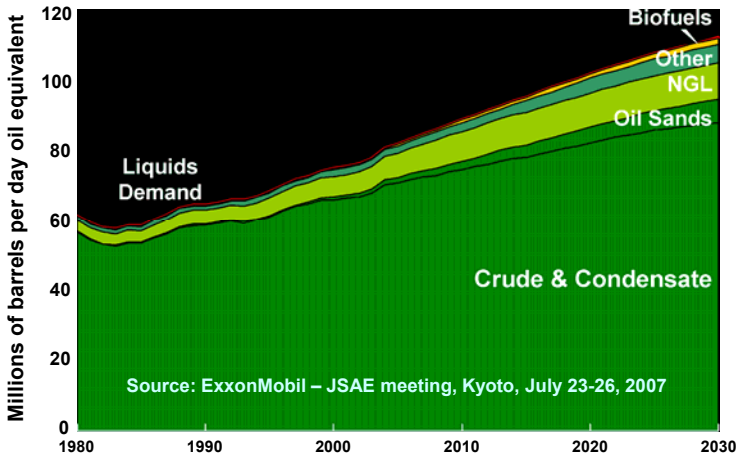
Burning the fuel is the least of the problem !!!

21

Status of bio-fuel production

22

Liquid fuel supply projection



23

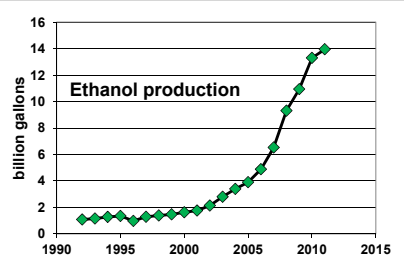
Effect of government policy on bio-fuel

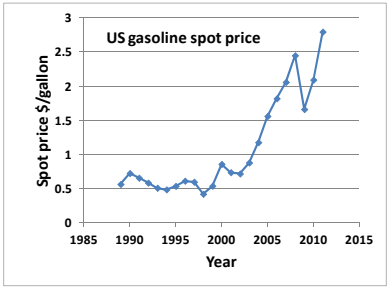
- US demand for ethanol has been driven by government regulations and incentives
  - Ethanol flex-fuel vehicles produced because of the 74% credit towards CAFE requirement
    - **(E85 vehicle equivalent mph = mpg x 1.74)**
  - Gasoline oxygenate mandate, and phase out of MTBE
  - Energy bill (Aug. 05) mandated a threshold of 7.5 billion gallons (180 million barrels) production by 2012
  - 2007 Energy and Security Act calls for 36 billion gallons production by 2022
  - Tax subsidy
    - blender's tax credit $0.51/gallon alcohol
    - $0.051/gallon fuel tax exemption for gasohol
      - minimum 10 vol % alcohol

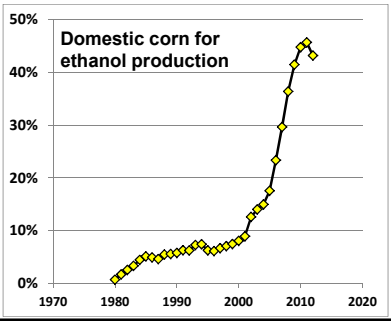
24

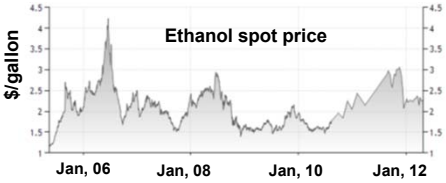
Crop-based bio-fuel

Example: Corn ethanol in US









2012 figure: 134 billion gallons of gasoline; of which 14 billion gallon is ethanol (~10% by vol.); uses 43% of the corn; Energy of ethanol is 7% of the total fuel energy

25

US crop-based bio-fuel capacity

US biofuels

US harvested crop land (US agriculture census 2002), hectare	**1.23E+08**
US all distillate use (diesel+jet+power gen etc.) EIA2007; L/yr	3.34E+11
US gasoline use, EIA 2007; L/yr	5.40E+11

*** To get energy ratio, multiplied by 0.93 for biodiesel and by 0.59 for ethanol**

	gal/acre	L/hectare	Limit of production (gal)	Limit of production (L)	Liq. vol ratio of limit to Demand*
bio-diesel					
palm oil	5.08E+02	4,756	1.54E+11	5.85E+11	**1.63**
coconut	2.30E+02	2,153	6.99E+10	2.65E+11	**0.74**
rapeseed	1.02E+02	955	3.10E+10	1.17E+11	**0.33**
soy	6.00E+01	562	1.82E+10	6.91E+10	**0.19**
peanut	9.00E+01	843	2.73E+10	1.04E+11	**0.29**
sunflower	8.20E+01	768	2.49E+10	9.44E+10	**0.27**
jatropia (SE Asia)	2.00E+02	1,872	6.08E+10	2.30E+11	**0.64**
ethanol					
corn	3.44E+02	3,217	1.04E+11	3.96E+11	**0.71**
sugar cane (Brazil)	8.00E+02	7,489	2.43E+11	9.21E+11	**1.71**

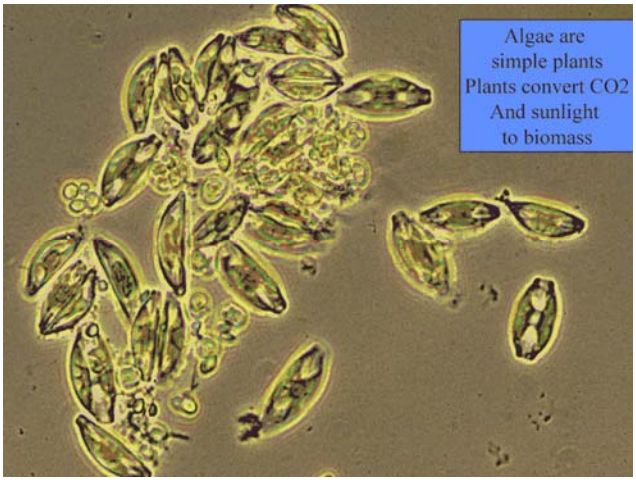
Crop-based bio-fuels do not have enough capacity to meet the liquid fuel demand !!!

Yield dependent on location and weather

1 hectare=$10^4 m^2$~2.5 acre

26

Algae: micro-seaweeds



Issues

- Production
  - Need high lipid content species
  - Need fast growth species
  - Growth in dense environment
- Harvest techniques
- Oil extraction

27

Image courtesy of the U.S. Department of Energy.

Current largest algae plant (production of algae for salmon feeding)

Hawaii

28

Image courtesy of the U.S. Department of Energy.

Second generation bio-fuel

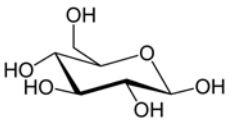
- Feedstock
  - Non-food part of food crops (stems, leaves, husks, …
  - Non-food crops (switchgrass, jatropha,…)
    - Cultivated in marginal land

29

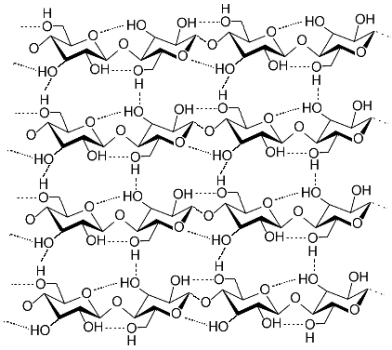
Image courtesy of the U.S. Department of Agriculture.

Technical difficulties of producing liquid fuel from plants

- Cellulose much more difficult to break down than sugar



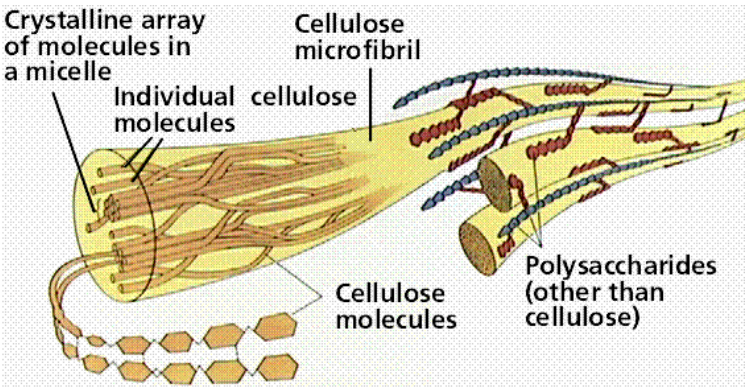
Glucose

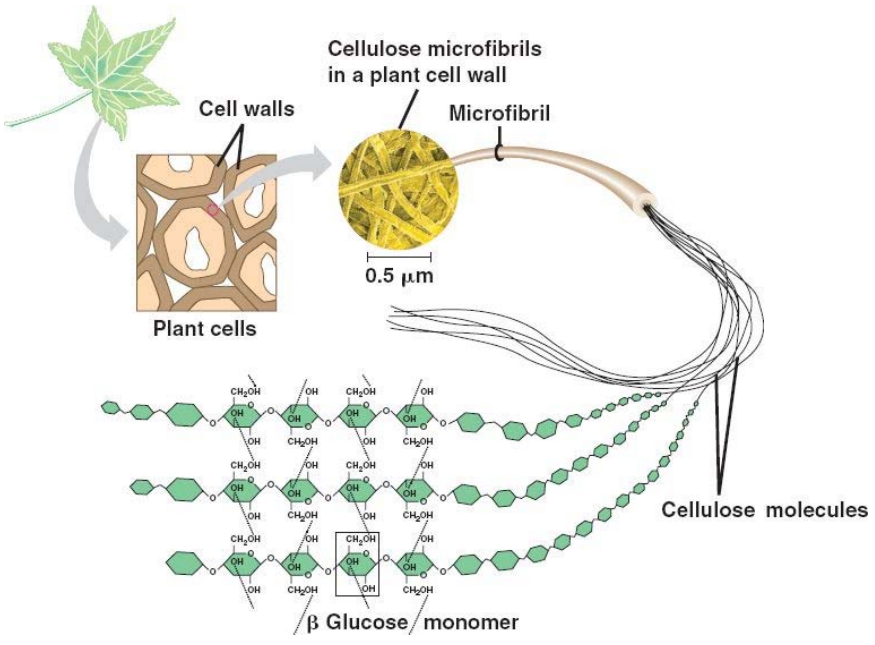


Cellulose

Source: Wikipedia

30





Second generation bio-fuel: challenges

- Sustainability issues
  - Energy budget
  - Water use
  - CO_2 intensity especially with land use replacement
  - Bio-diversity
  - Other issues
    - Feedstock collection
    - ➢Bio-fuel plant waste treatment
    - ➢Resources requirement

Technology not yet ready

33

Sustainability

34

Energy balance
Example: Corn ethanol in US

Ethanol from corn

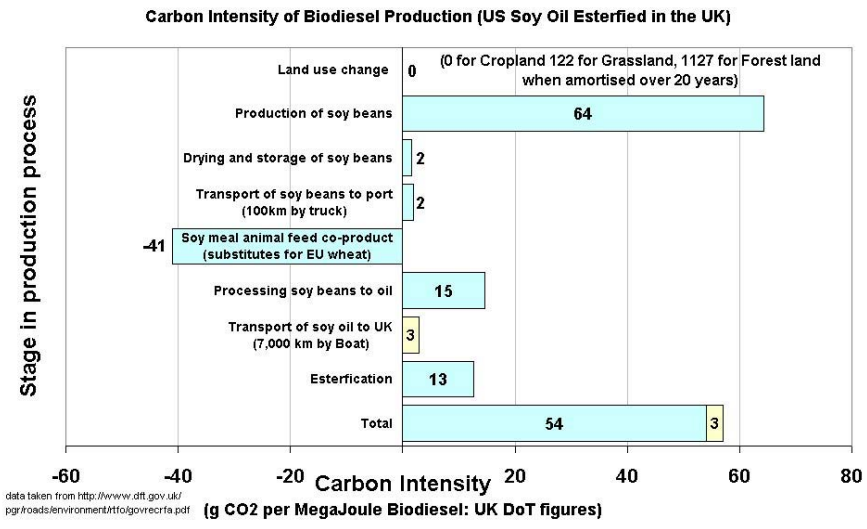
- Several studies of the overall energy budget
  - P = energy used in production
    - feedstock production/ transport + processing
  - E = Energy of the ethanol output
  - Return (%) = (E – P) / P
- **Studies**
  - Pimentel and Patzek (2003, 2005): **negative return**
    - Return* = **- 22.5%**
  - USDA (Shapouri et al 2002, 2004): **positive return**
    - Return = **+5.9%**
    - Return = **+67%** if by products (Corn gluten meal, etc.) are accounted for

Verdict: Substantial environmental and economic cost; return not clear

*** For comparison purpose, the figure has been converted from the value of (E-P)/E of -29% in the original publication**

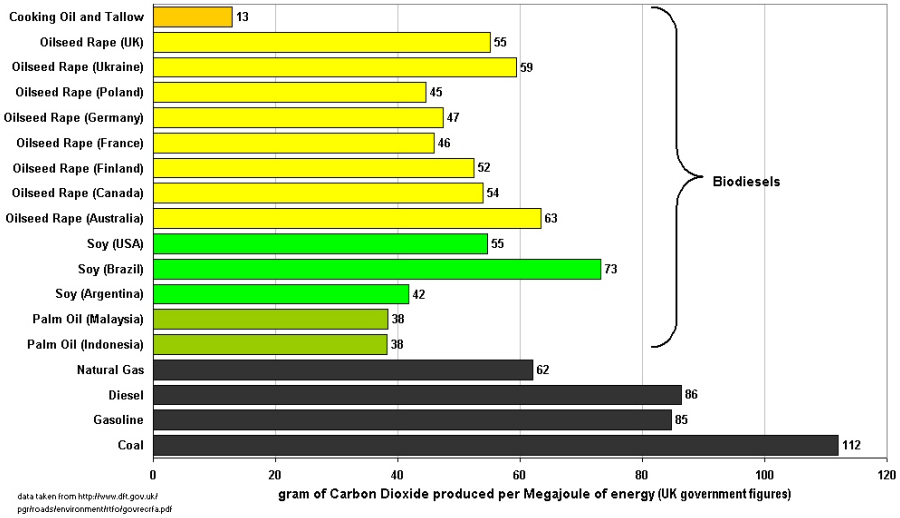
35

Carbon intensity
(net mass of CO2 produced per unit fuel energy)



36

Carbon intensity



37

Other environmental impact

- Water resources
- Fertilizer
- Soil
- Bio-diversity
- Plant waste treatment

38

Closure

- Bio-diesel and alcohols are excellent fuels for transportation use
  - Good combustion characteristics
  - Compatible with current engine technology
- Sustainability
  - Bio-fuels from crops are not likely to make any significant impact on the global liquid fuel supply picture in the near future
    - Land capacity
    - Effect on food price
  - Further development on other feed stocks needed
    - Algae for bio-diesel production
    - Cellulosic alcohol

39

TRANSPORTATION EFFICIENCY

$$\text{Transportation Efficiency} = \frac{\text{"Useful people mile"}}{\text{Fuel energy}}$$

$$= \frac{\text{"Useful people mile"}}{\text{People mile}} \times \frac{\text{People mile}}{\text{Vehicle mile}} \times \frac{\text{Vehicle mile}}{\text{Road work}} \times \frac{\text{Road work}}{\text{Fuel energy}}$$

Personal efficiency

Vehicle utilization efficiency

Route, traffic pattern
Vehicle weight/speed

Engineering

40

Options?

- **Alternative Fuels and Power Plants ?**
- **Alternative Life Styles ?**

41

2.61 Internal Combustion Engines
Spring 2017