

Bio-fuels and hybrids

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The backdrop

Transportation and Mobility

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

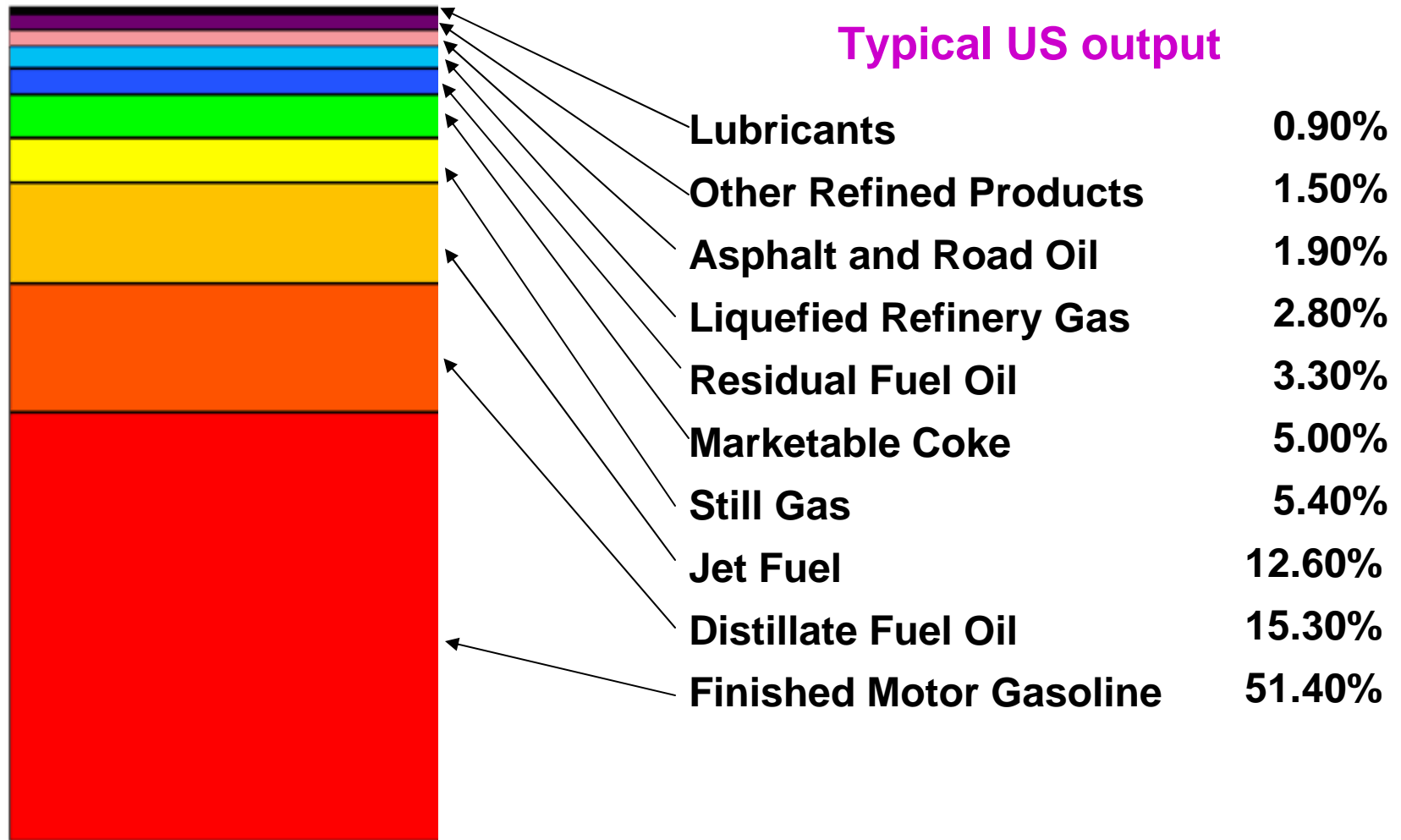
Transportation needs special kind of energy source

- 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 !

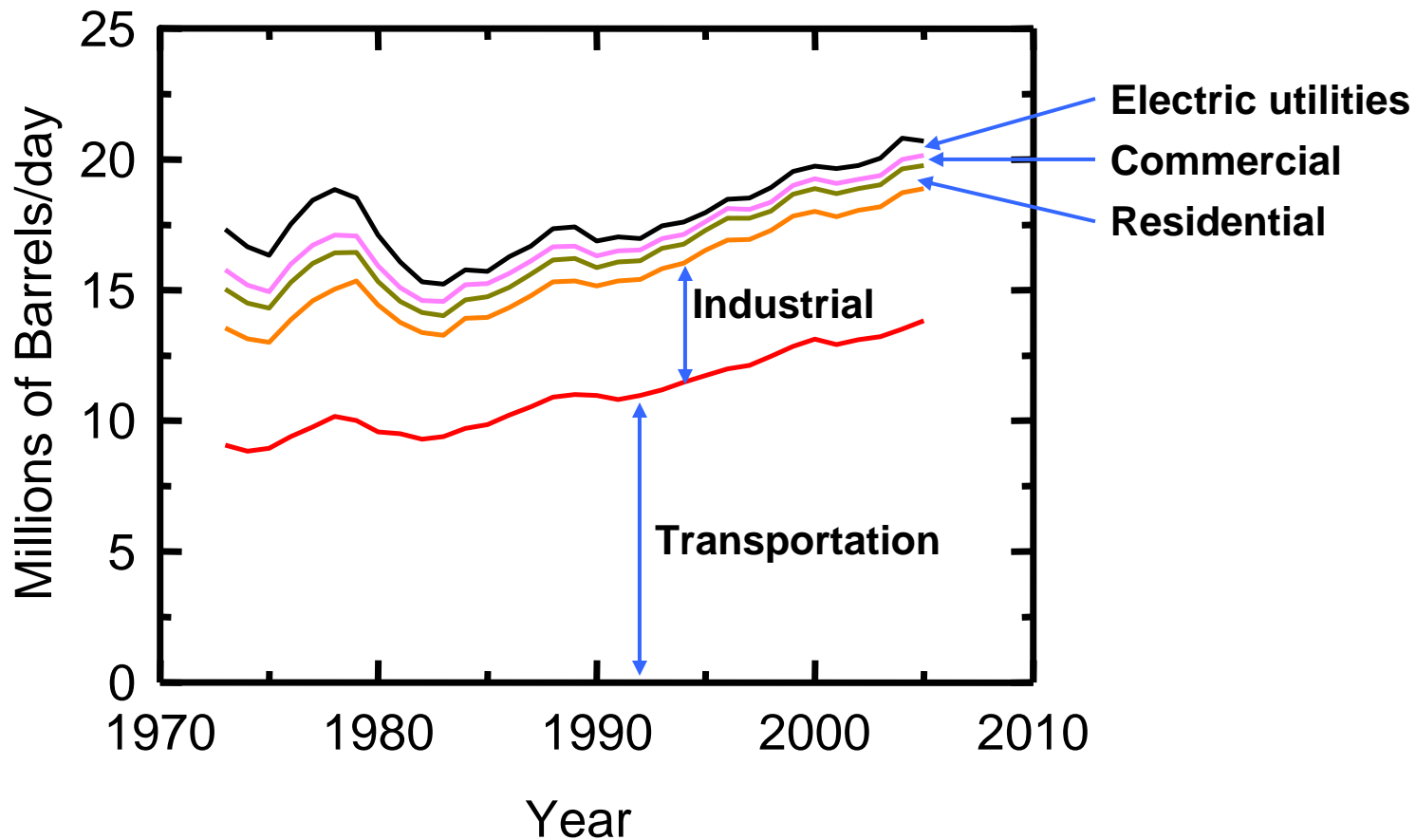
What is in a barrel of oil ?

(42 gallon oil → ~46 gallon products)



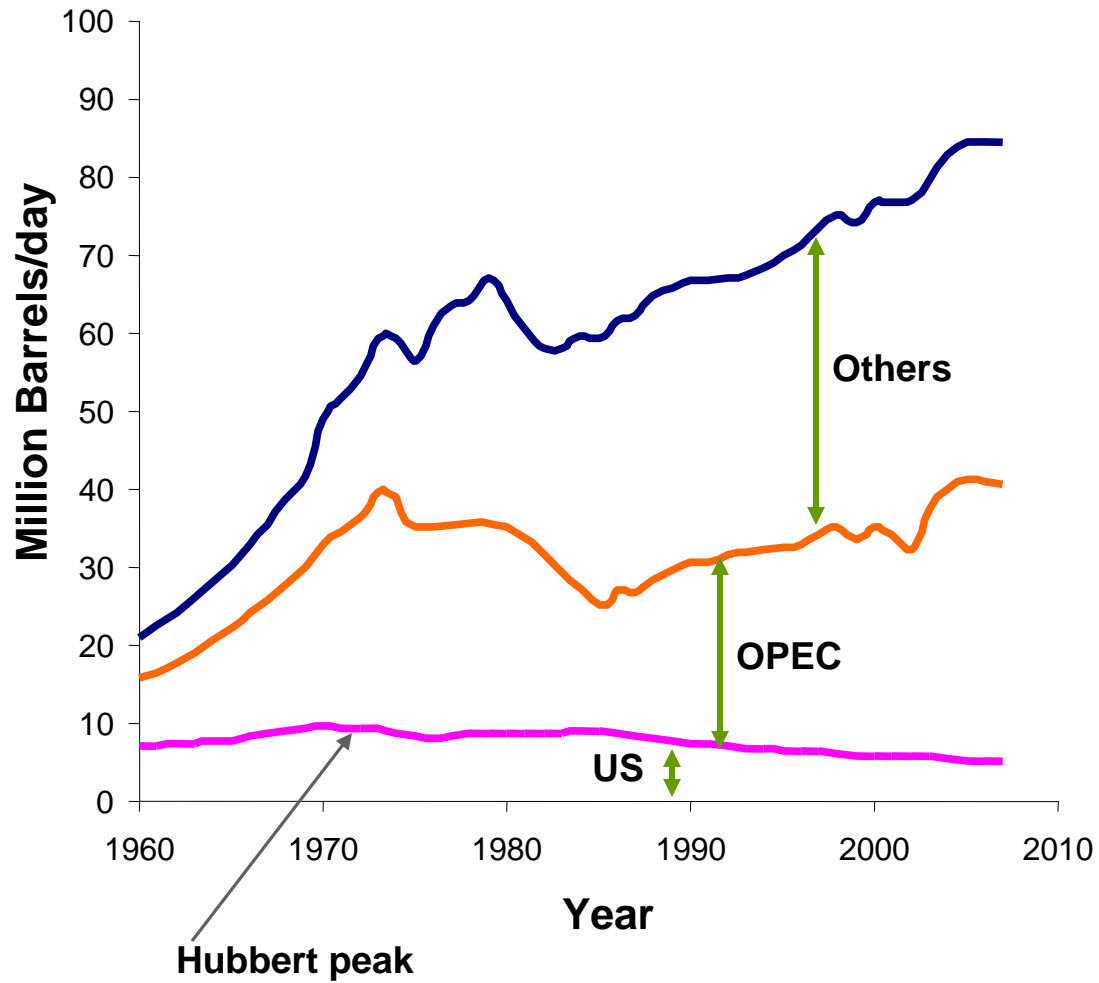
Source: California Energy Commission, Fuels Office

US Use of Petroleum by sector



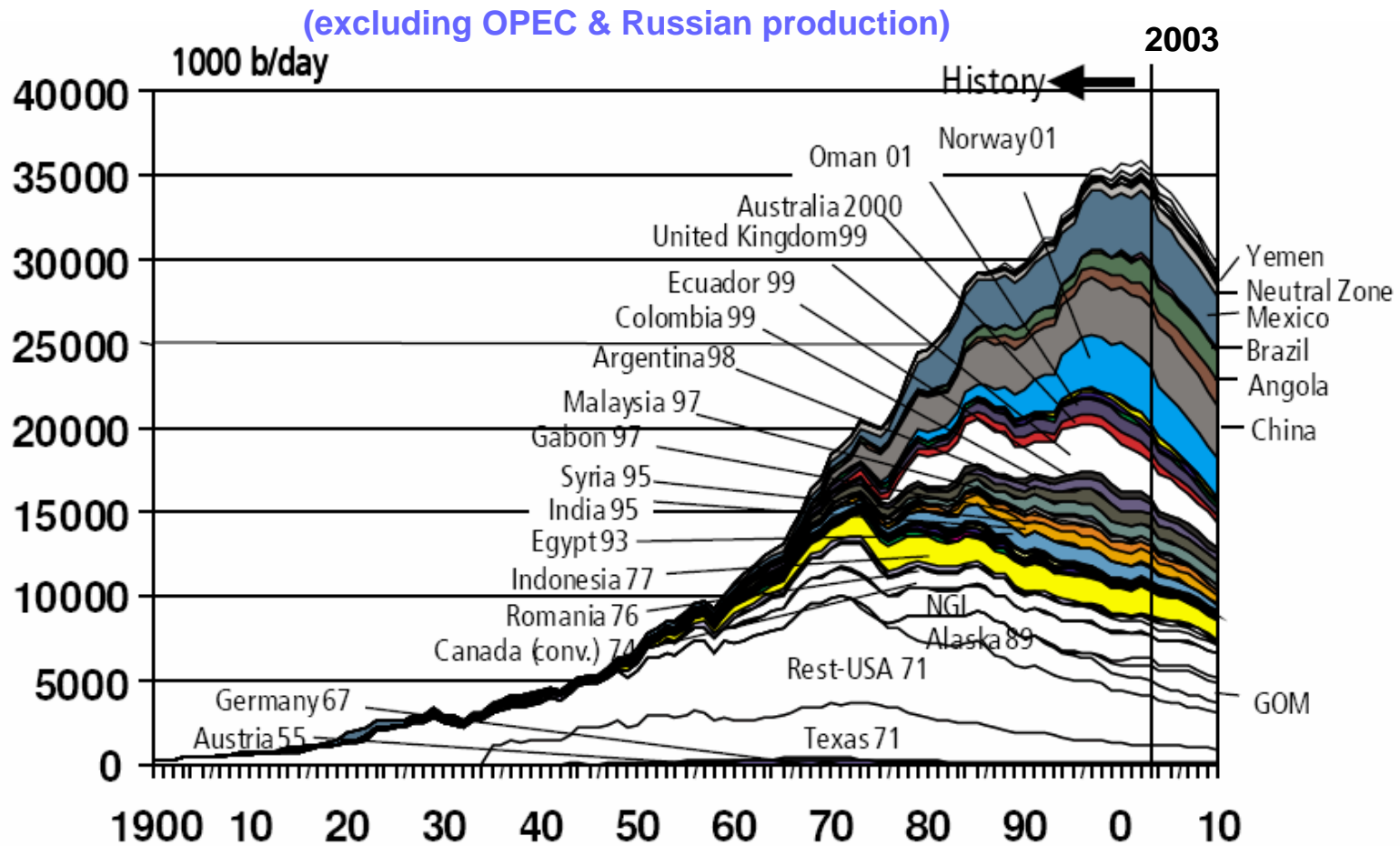
Source: US Dept. of Energy

Oil Supply (annual average up to 2007)



Source: EIA

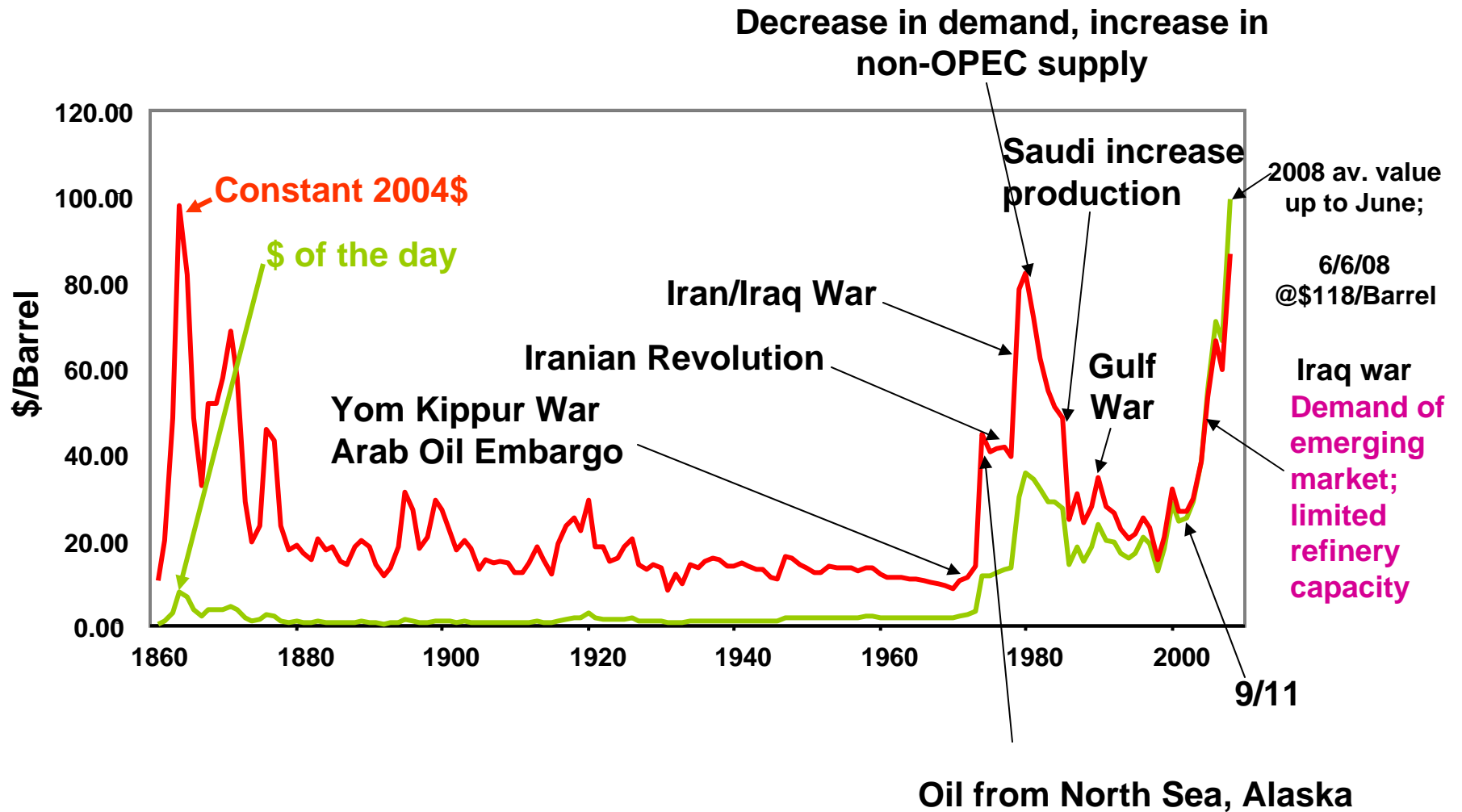
The world Hubbert peak



Source: Industry database, 2003 (IHS 2003)
OGJ, 9 Feb 2004 (Jan-Nov 2003)

Source: http://www.fossil.energy.gov/programs/reserves/npr/publications/npr_strategic_significancev1.pdf

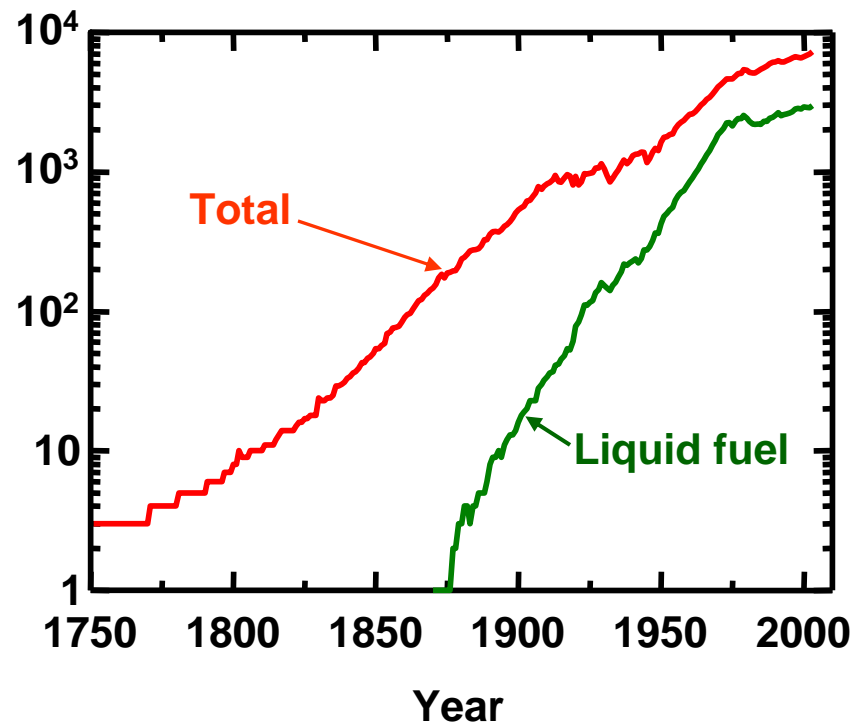
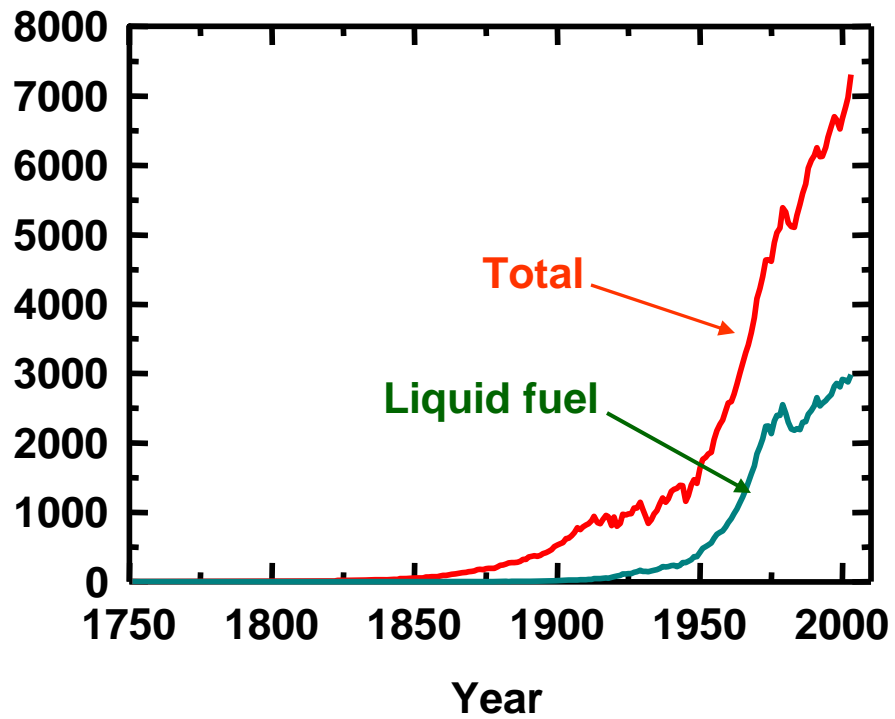
Petroleum price



Sources:
Data from EIA; event labels from WTRG Economics

CO₂ emissions from fossil fuel

Million metric tons of Carbon/year



Source: EIA

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

What is bio-fuel?

Dominant biofuels

Sugar based
(corn, sugarcane, ...)

Cellulosic based
(switchgrass, wood, ...)

Ethanol



Usage

E10, E20, E85, ...



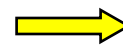
Compatible with current engine
technology and fuel infra structure

Crop based
(rapeseed, soybean, ...)

Wasted oil/ animal fat

Algae

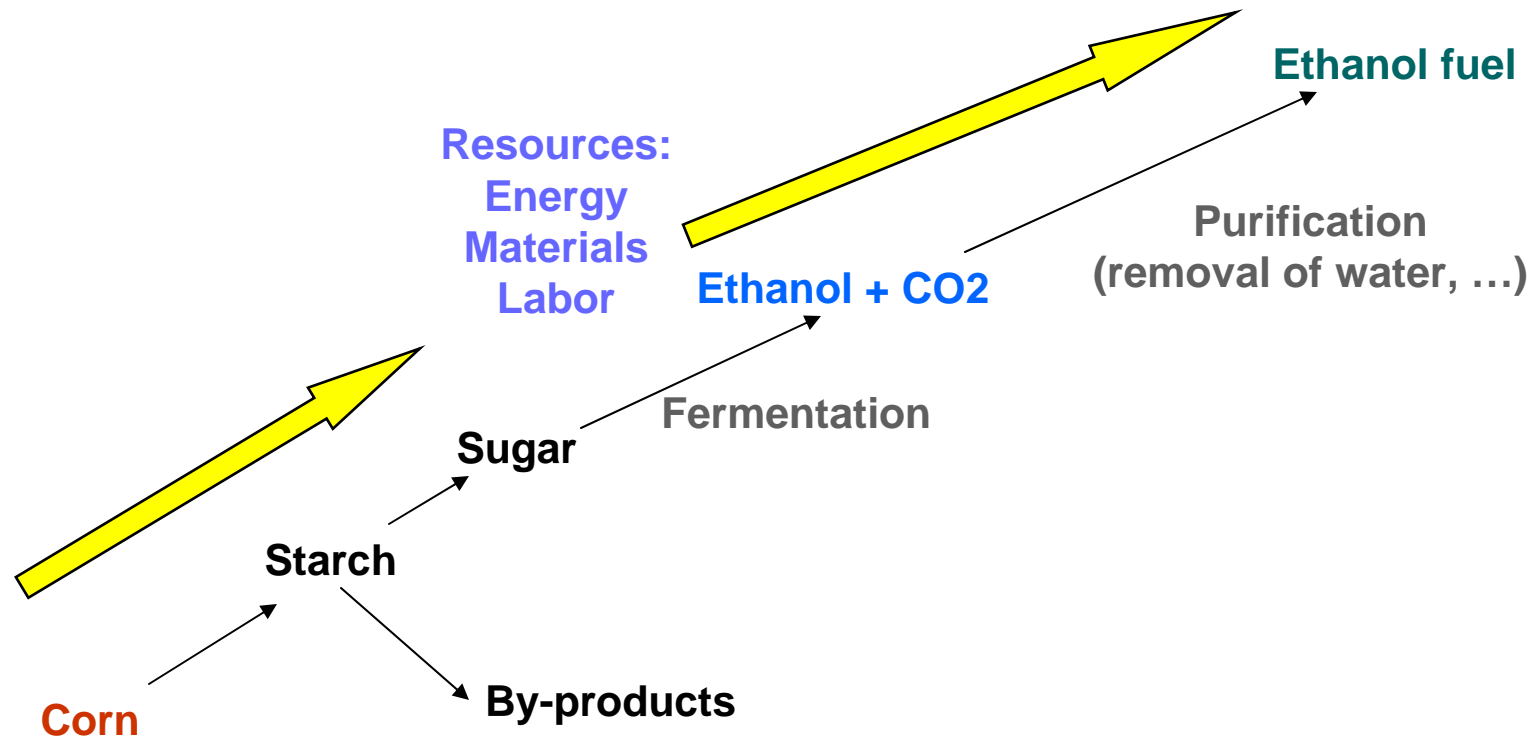
Bio-diesel



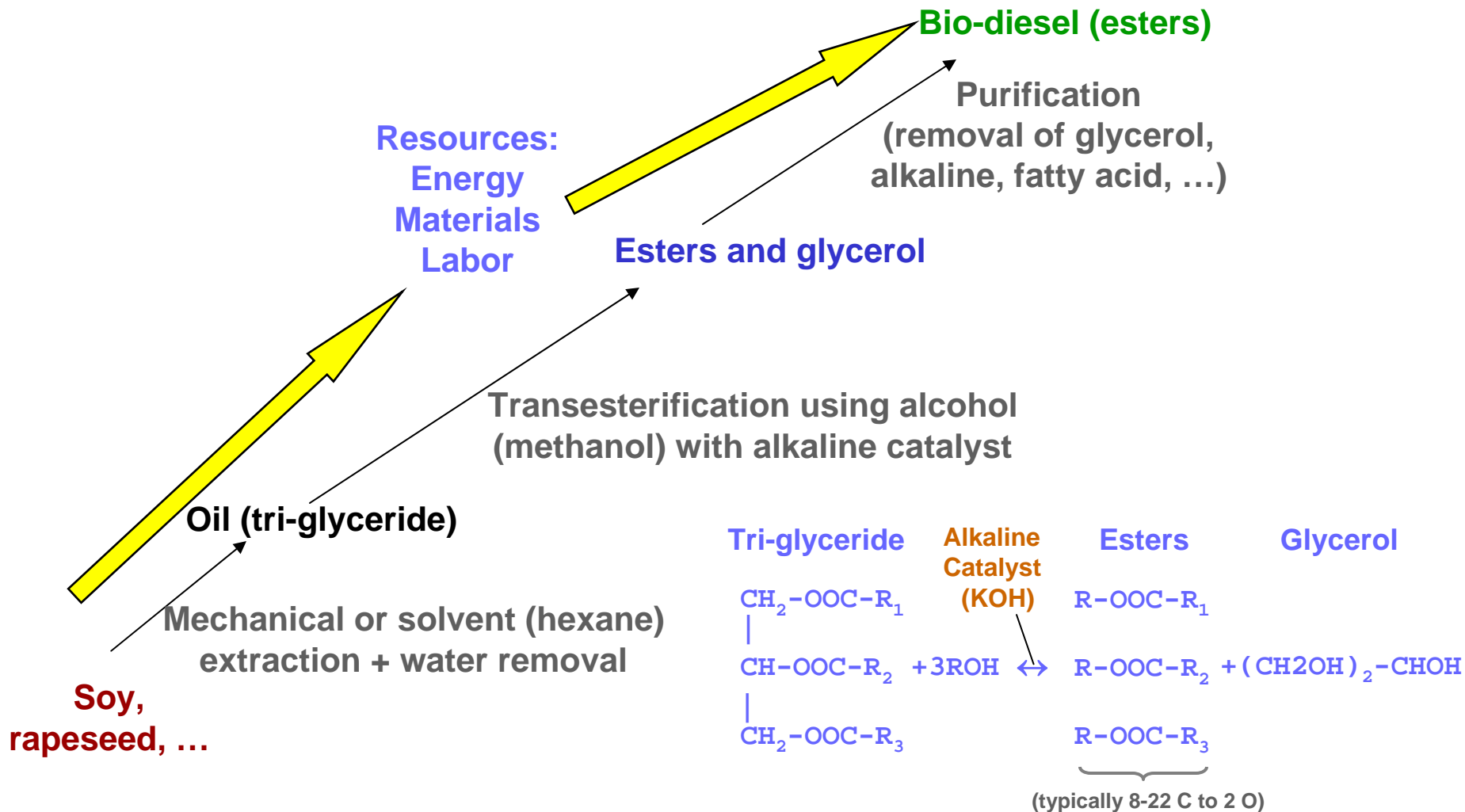
B10, B20,



Example: Ethanol production from corn



Example: bio-diesel production

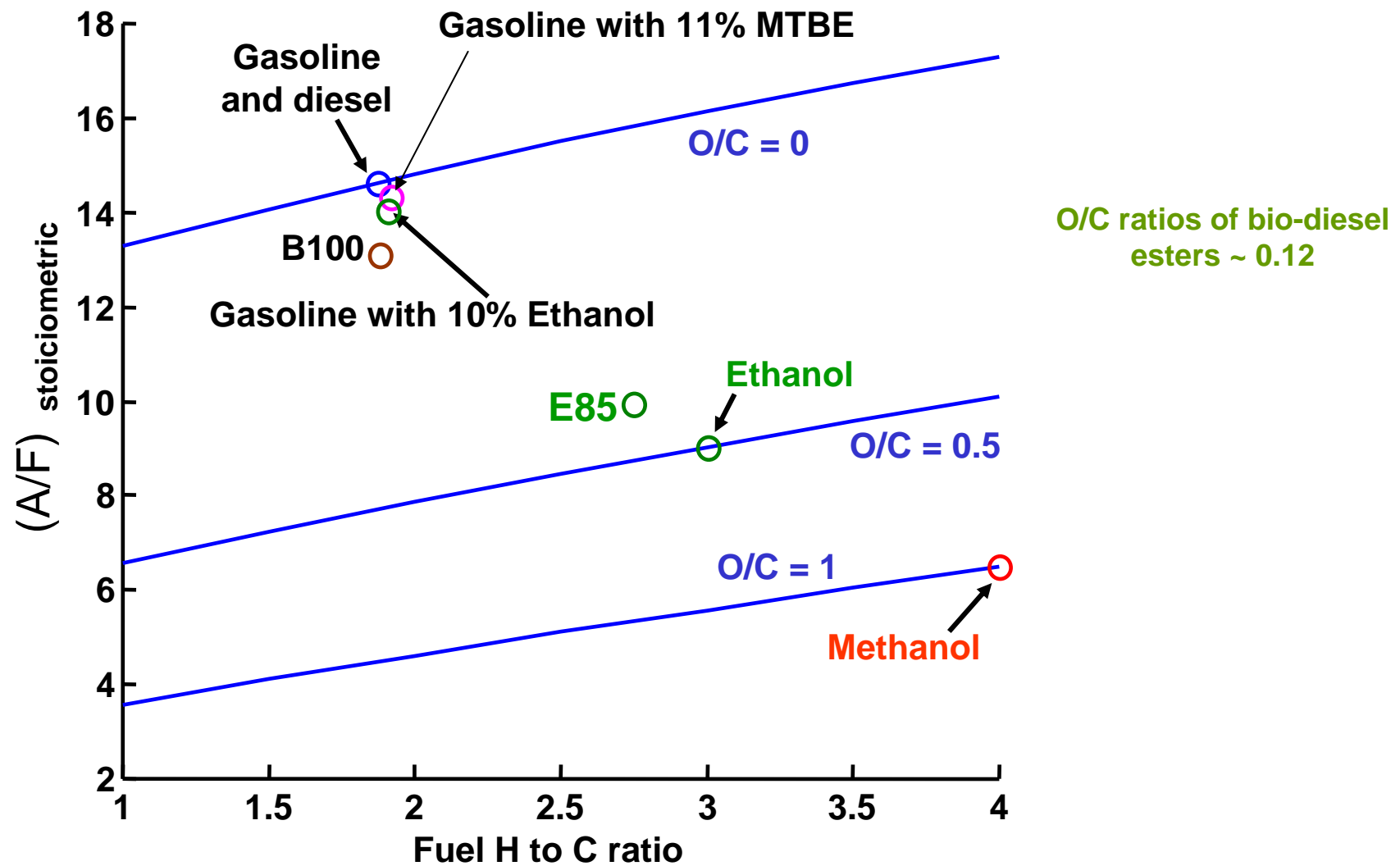


Combustion characteristics of bio-fuel

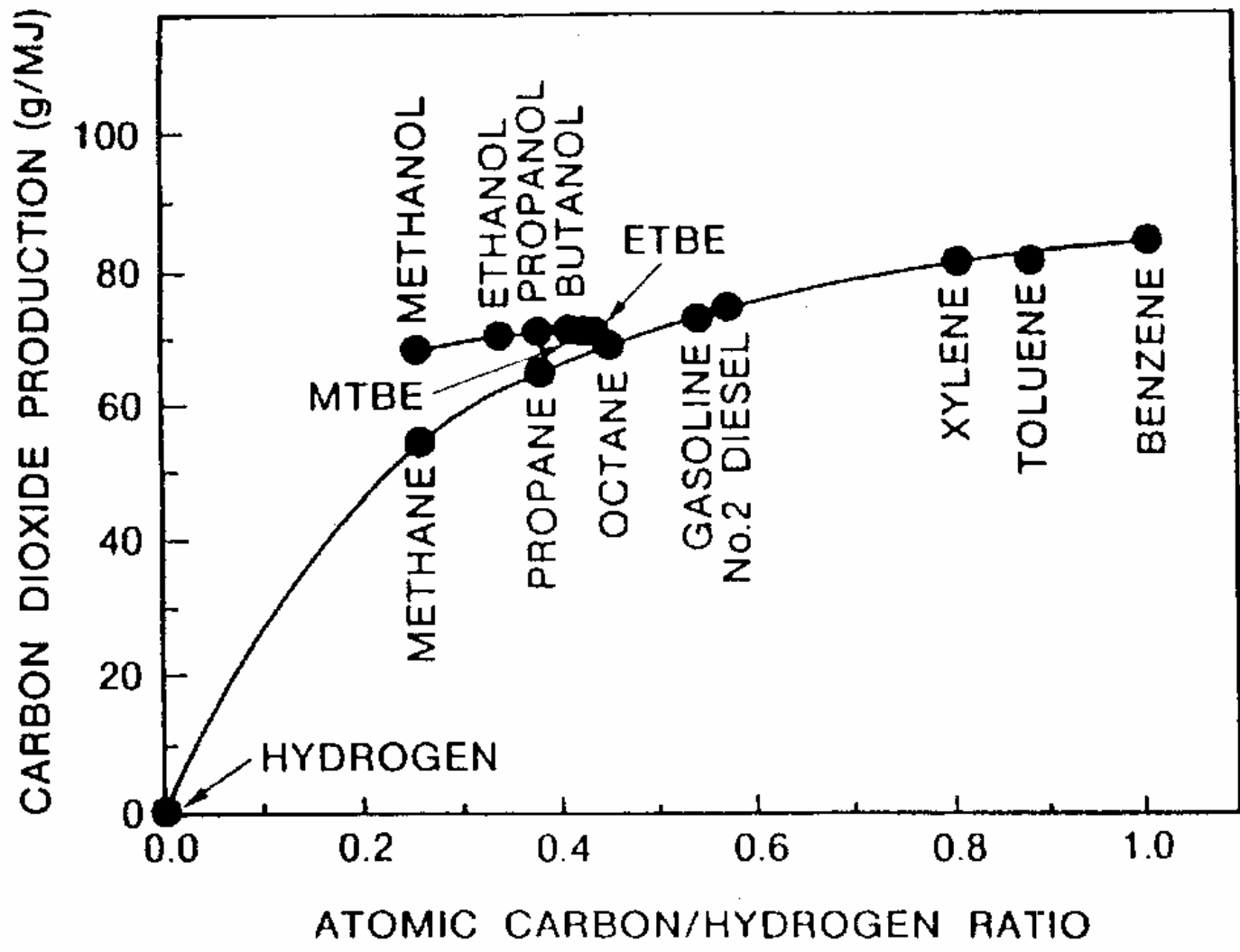
	Cetane number	s.g.	LHV (MJ/kg)	LHV (MJ/L)	B10 LHV (MJ/L)	B20 LHV (MJ/L)	LHV B10/ Diesel (by vol.)	LHV B20/ Diesel (by vol.)
Diesel	45-55	0.820	43.22	35.44				
Soybean oil methylester	50.9	0.885	37.01	32.76	35.17	34.91	0.992	0.985
Rapeseed oil methylester	52.9	0.882	37.30	32.90	35.19	34.93	0.993	0.986
Sunflower oil methylester	49	0.880	38.53	33.91	35.29	35.14	0.996	0.991
Frying oil ethylester	61	0.872	37.19	32.41	35.14	34.84	0.991	0.983
	Octane number	s.g.	LHV (MJ/kg)	LHV (MJ/L)	E10 LHV (MJ/L)	E85 LHV (MJ/L)	LHV E10/ Gasoline (by vol.)	LHV E85/ Gasoline (by vol.)
Gasoline	95	0.780	44.00	34.32				
Ethanol	107	0.785	26.90	21.12	33.00	23.10	0.962	0.673

Bio-ester data from Graboski and McCormick, Prog. Energy Comb. Sc., Vol. 24, 1998

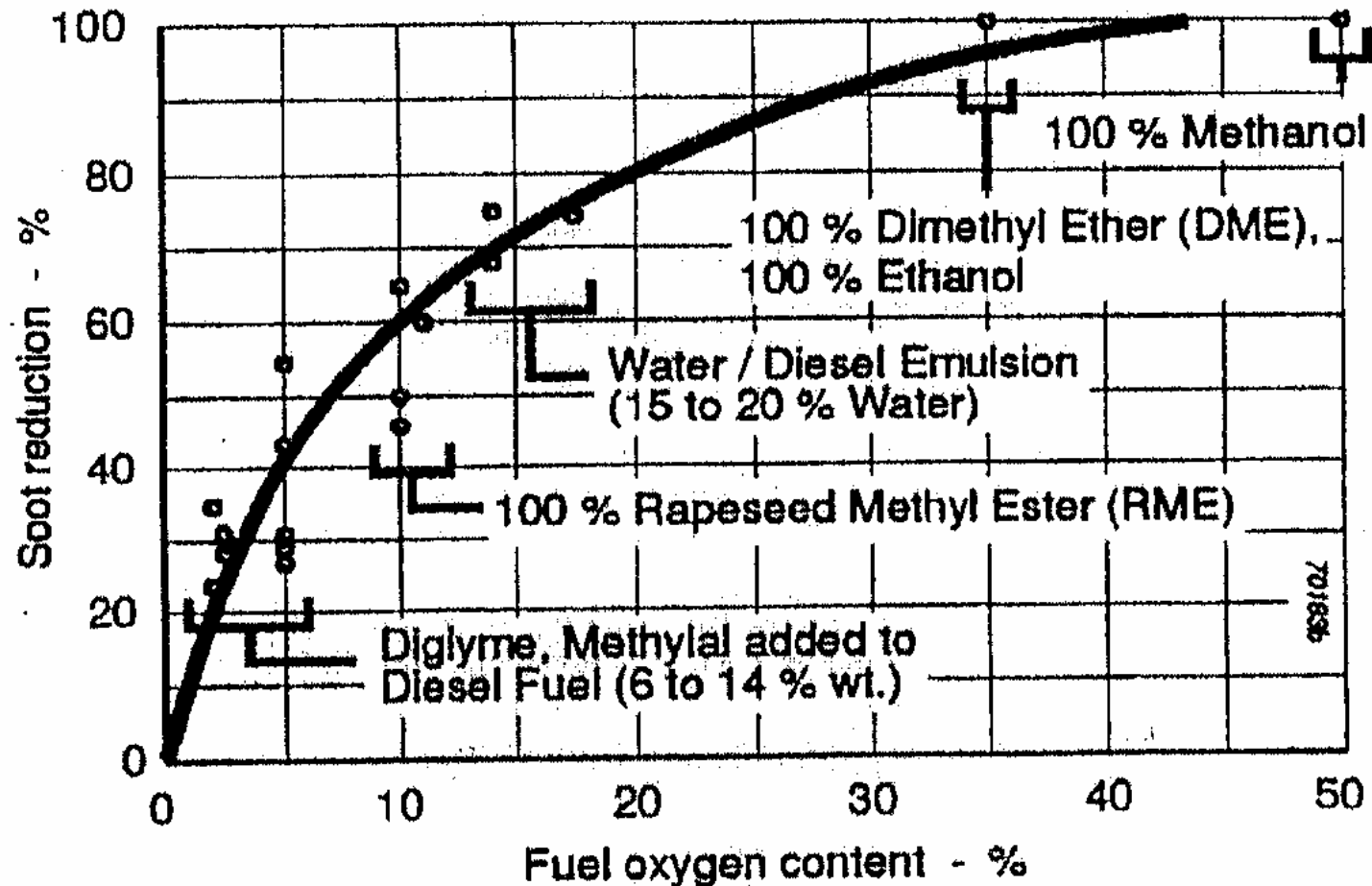
Stoichiometric requirement for different fuels



Relative CO₂ production from **burning** different fuel molecules



Effects of Oxygenates on PM emission



AVL Publication (by Wolfgang Cartellieri in JSME 1998 Conference in Toykyo)

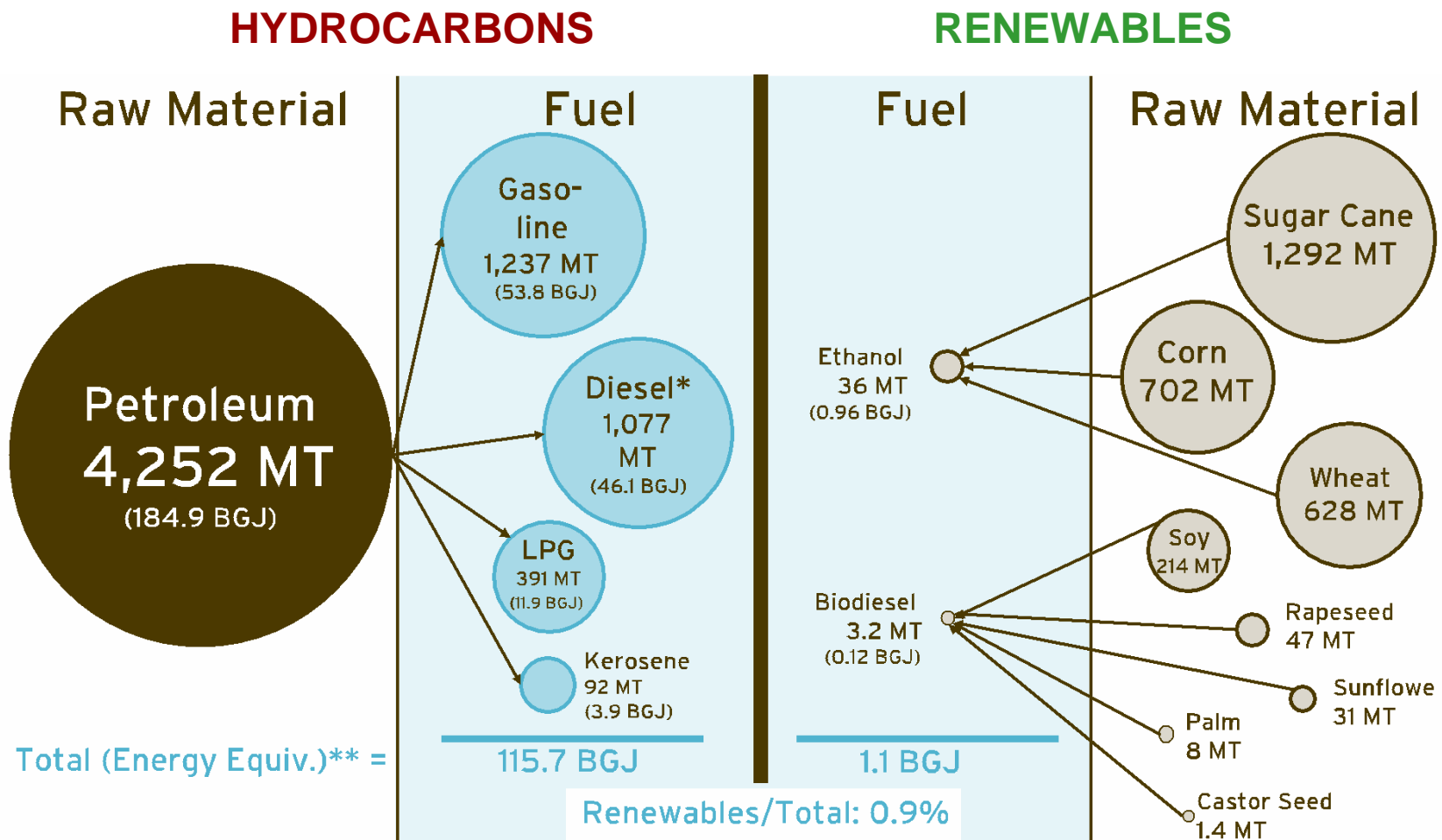
Bio-fuel combustion properties

- 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 !!!

Status of bio-fuel production

World liquid fuel production (2005)

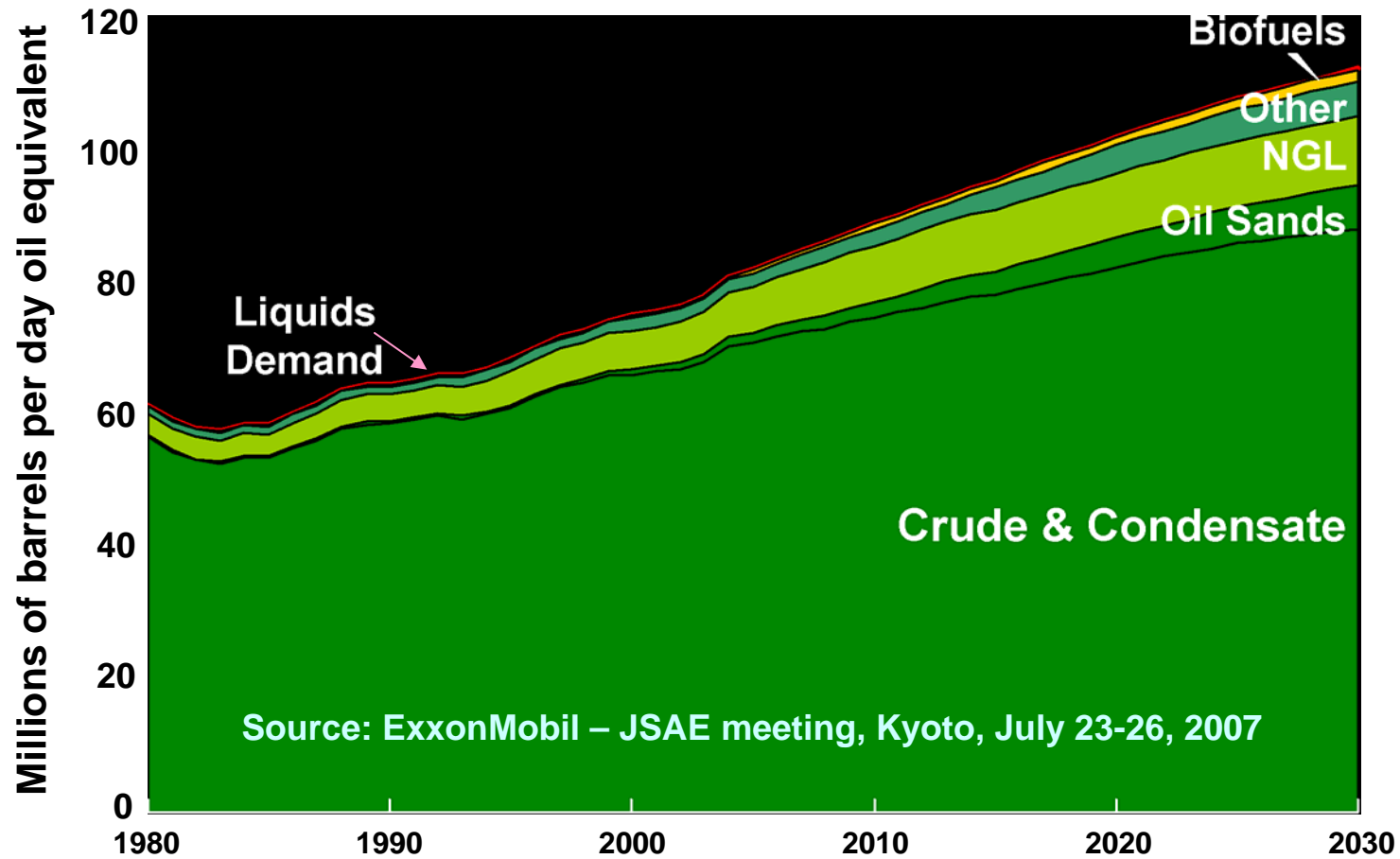


MT = Million tons

BGJ = Billions of giga (10^{18})Joules

Source: http://www.wilsoncenter.org/topics/pubs/Brazil_SR_e3.pdf

Liquid fuel supply projection



US bio-fuel capacity

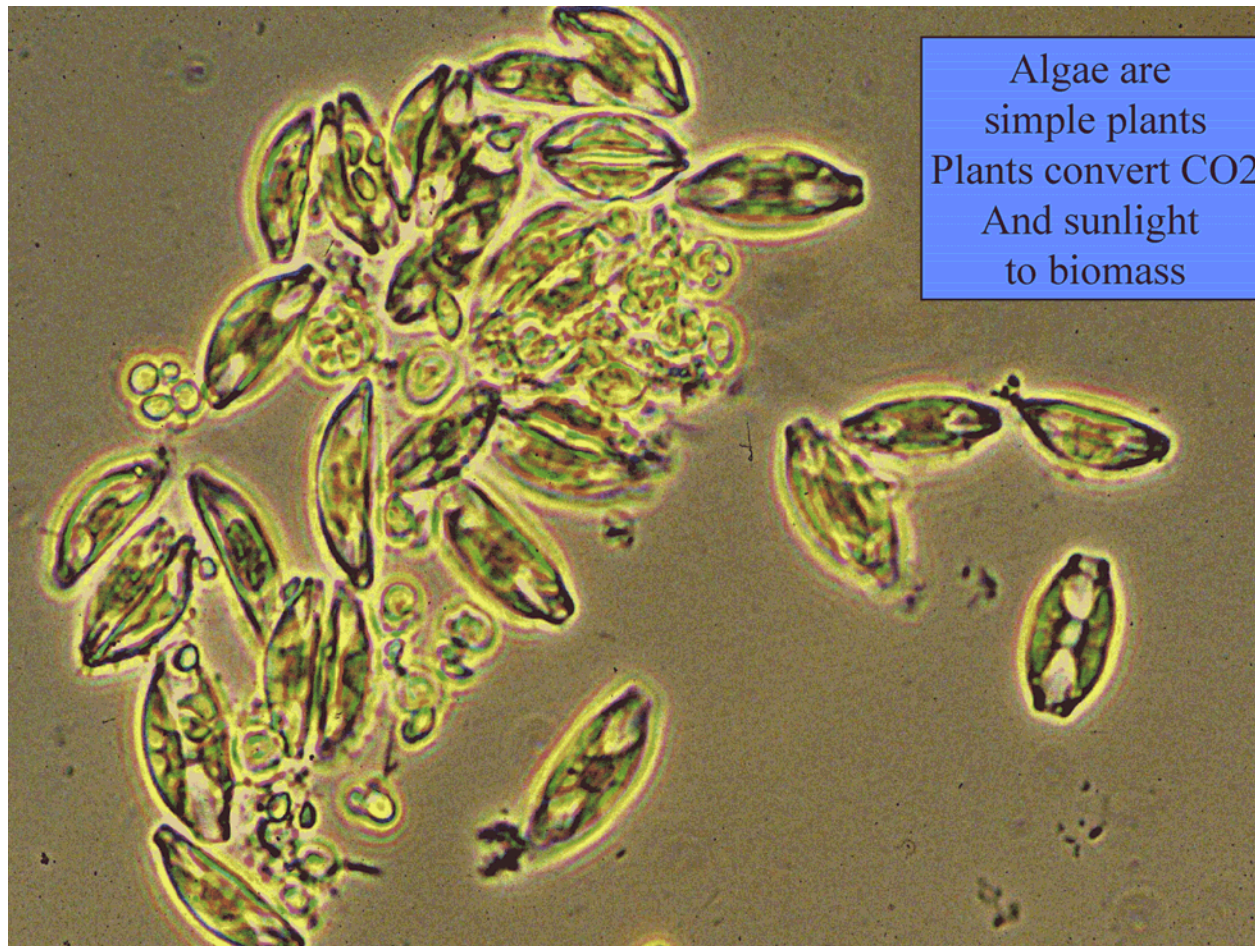
US biofuels

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

	gal/acre	L/hectare	Limit of production (gal)	Limit of production (L)	Energy 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
jatrophia (SE Asia)	2.00E+02	1,872	6.08E+10	2.30E+11	0.64
algae (?)	1.80E+03	16,850	5.47E+11	2.07E+12	5.78
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 !!!

Algae: micro-seaweeds



Issues

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

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



Hawaii

Sustainability

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 (%) = $(E - P) / E$
- **Studies**
 - Pimentel and Patzek (2003, 2005): **negative return**
 - Return = **- 29%**
 - USDA (Shapouri et al 2002, 2004): **positive return**
 - Return* = **+5.6%**
 - Return* = **+40%** if by products (Corn gluten meal, etc.) are accounted for

Verdict:
Substantial
environmental
and economic
cost; return not
clear

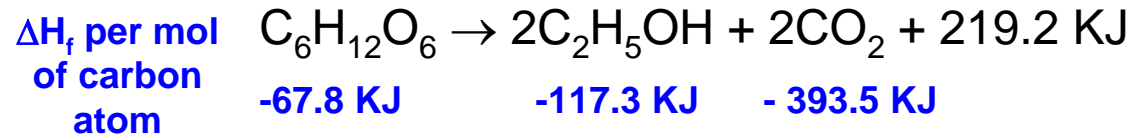
* For comparison purpose, these figures were converted from the values of $(E-P)/P$ of +5.9% and +67% in the original publication

Other bio-fuels

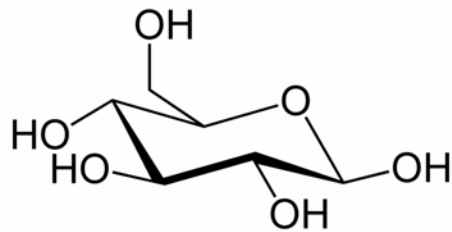
- Pimentel and Patzek also estimated energy budget for other bio-fuels. Returns:
 - Ethanol from switchgrass = -50%
 - Ethanol from wood biomass = -57%
 - Bio-diesel from soybean = -27%
 - Bio-diesel from sunflower = -118%
- Other more positive estimates:
 - Bio-diesel from rapeseed = +32% (EU)
 - Bio-diesel production = +324% (US National Bio-diesel Board)
- Outlook: NOT CLEAR
 - New technology needed to change the picture

Technical difficulties of producing liquid fuel from plants

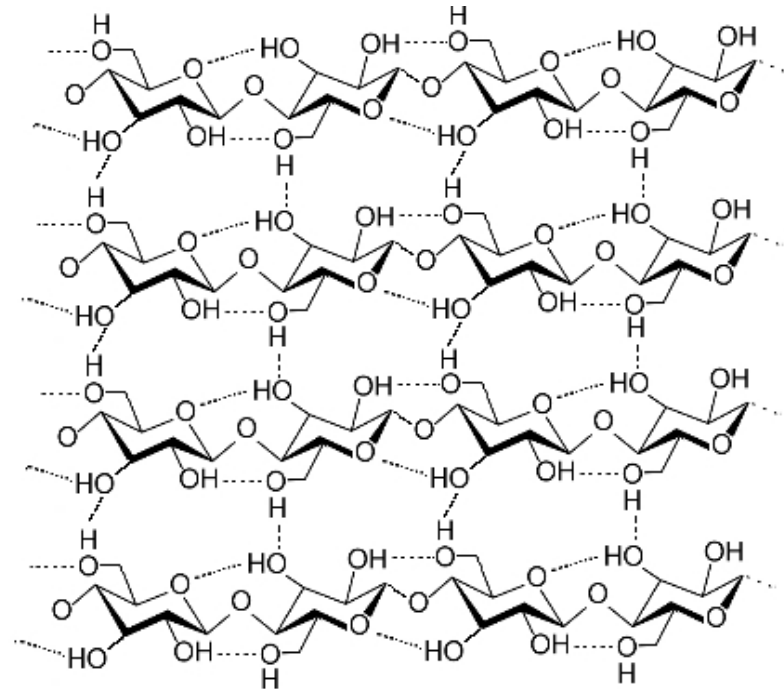
- Glucose fermentation produces significant CO₂ out and energy loss



- Cellulose much more difficult to break down than sugar



Glucose



Cellulose

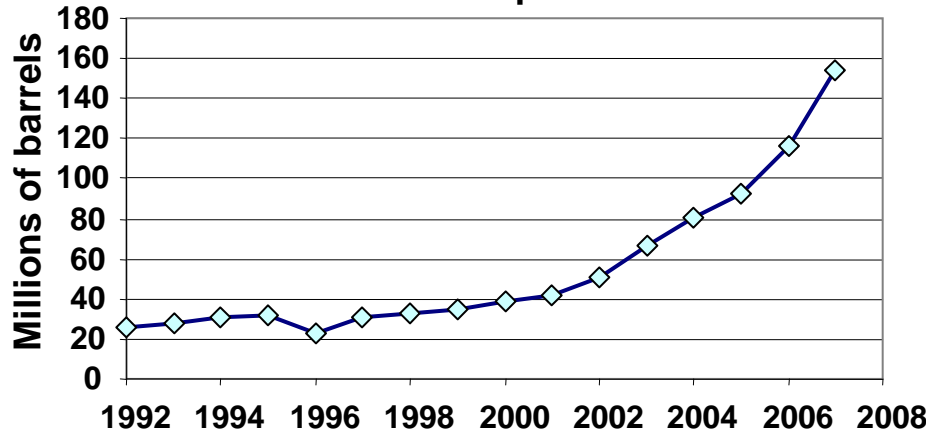
Effect of government policy on bio-fuel

- Current US demand for ethanol is 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
 - Tax subsidy
 - blender's tax credit \$0.51/gallon alcohol
 - \$0.051/gallon fuel tax exemption for gasohol
 - minimum 10 vol % alcohol

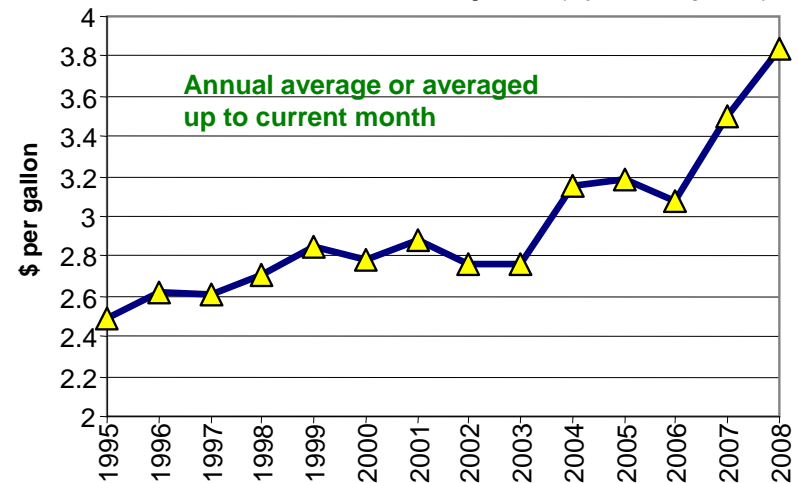
Economic impact of crop-based bio-fuel

Example: Corn ethanol in US (~20% of total corn production in 2007)

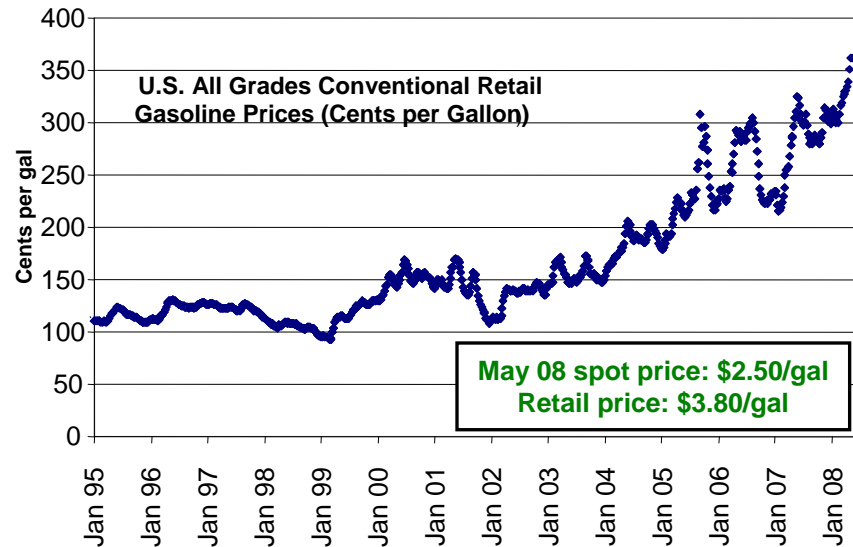
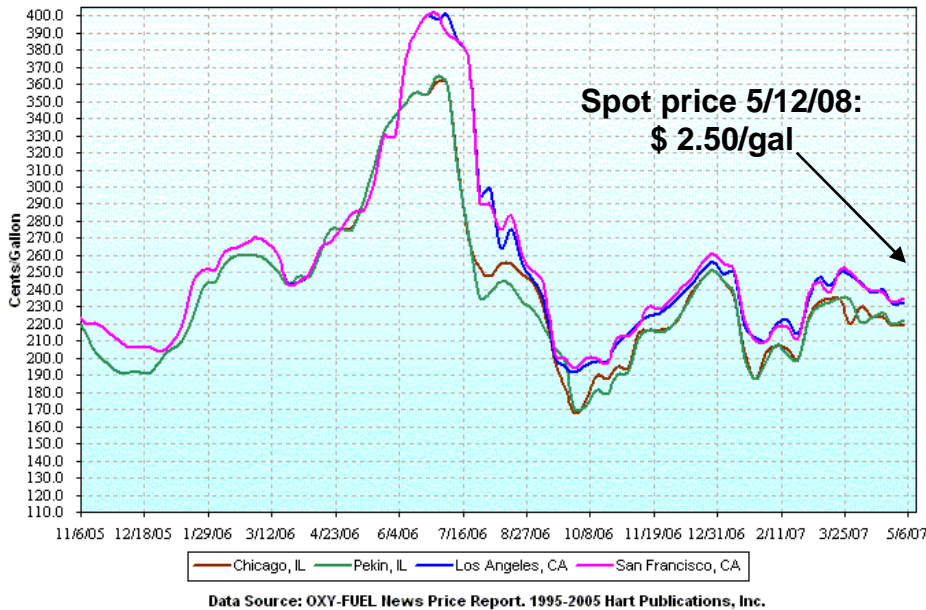
Annual fuel ethanol production



Fresh whole milk retail price (up to May, 08)



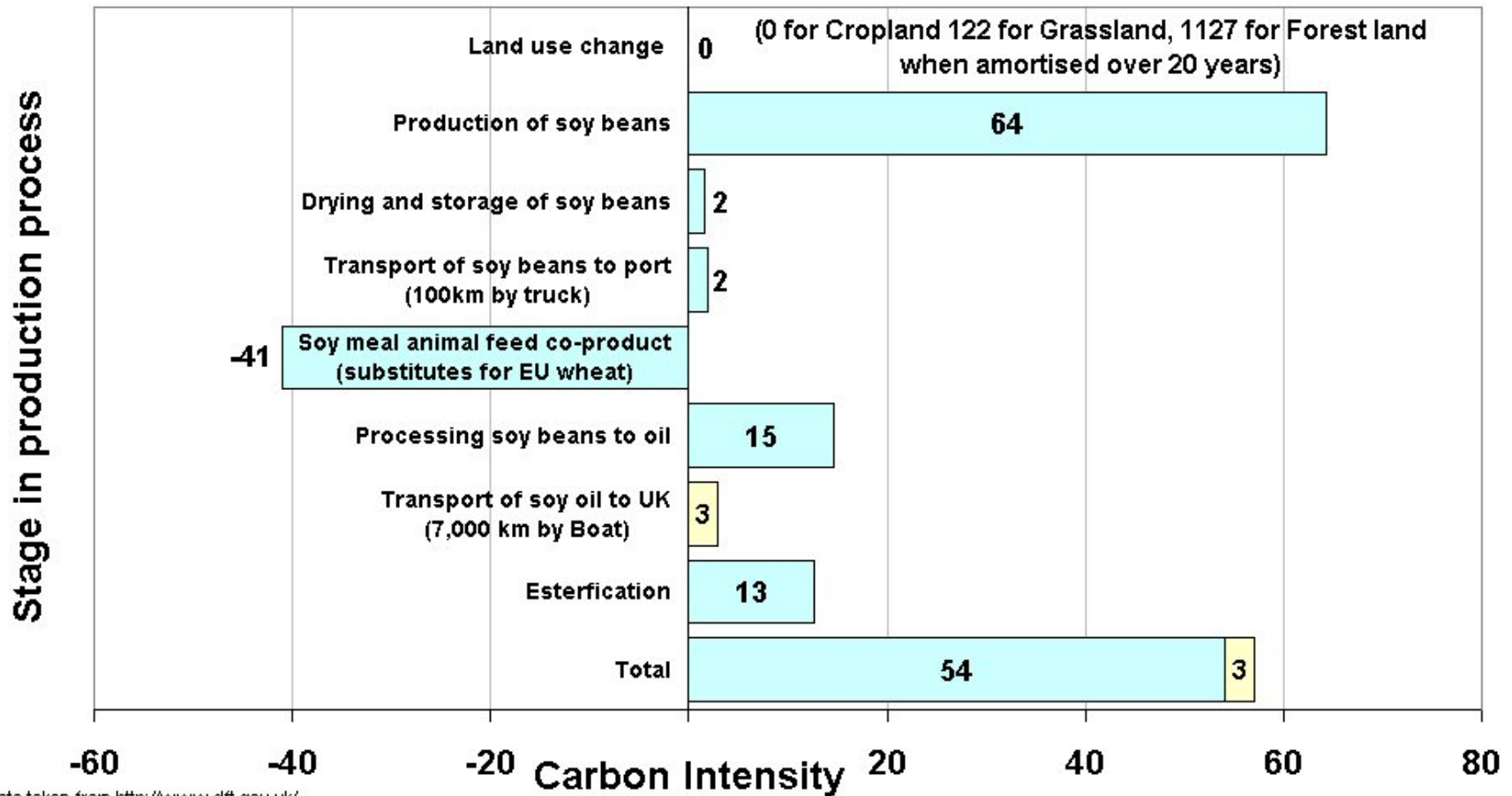
Fuel Ethanol Terminal Market Price - 18-Month History



Carbon intensity

(net mass of CO₂ produced per unit fuel energy)

Carbon Intensity of Biodiesel Production (US Soy Oil Esterified in the UK)

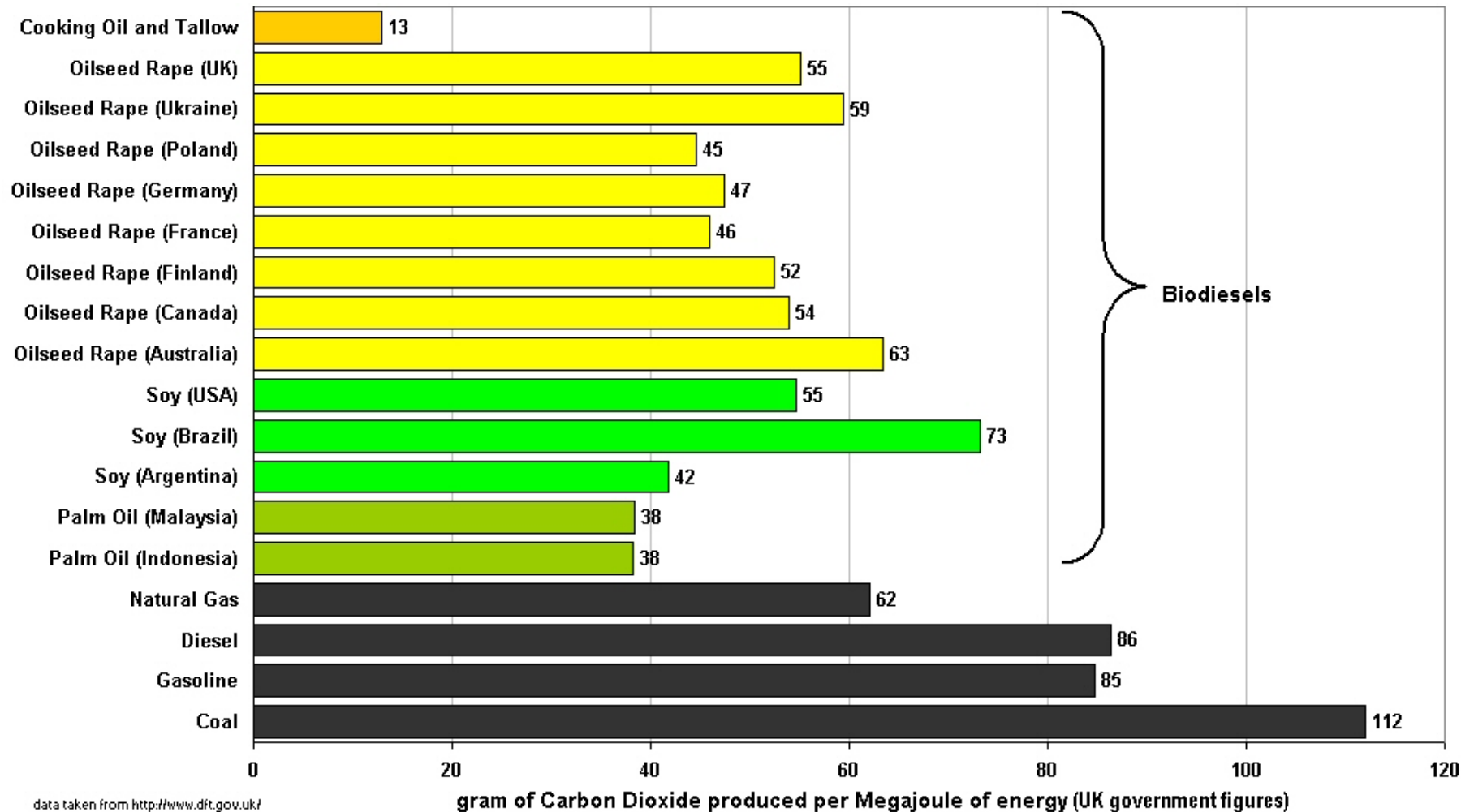


data taken from <http://www.dft.gov.uk/pgr/roads/environment/tfo/govrecrfa.pdf>

(g CO₂ per MegaJoule Biodiesel: UK DoT figures)

Source: <http://en.wikipedia.org/wiki/Biodiesel>

Carbon intensity



data taken from <http://www.dft.gov.uk/pgr/roads/environment/itf/foi/govrecrfa.pdf>

Source: <http://en.wikipedia.org/wiki/Biodiesel>

Other environmental impact

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

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
 - Land capacity
 - Effect on food price
 - Further development on other feed stocks needed
 - Algae for bio-diesel production
 - Cellulosic alcohol

Closure (continue)

- Sustainability issues
 - Energy budget
 - Water use
 - CO₂ intensity especially with land use replacement
 - Bio-diversity
 - Other issues
 - Bio-fuel plant waste treatment
 - Resources requirement

Hybrid vehicles

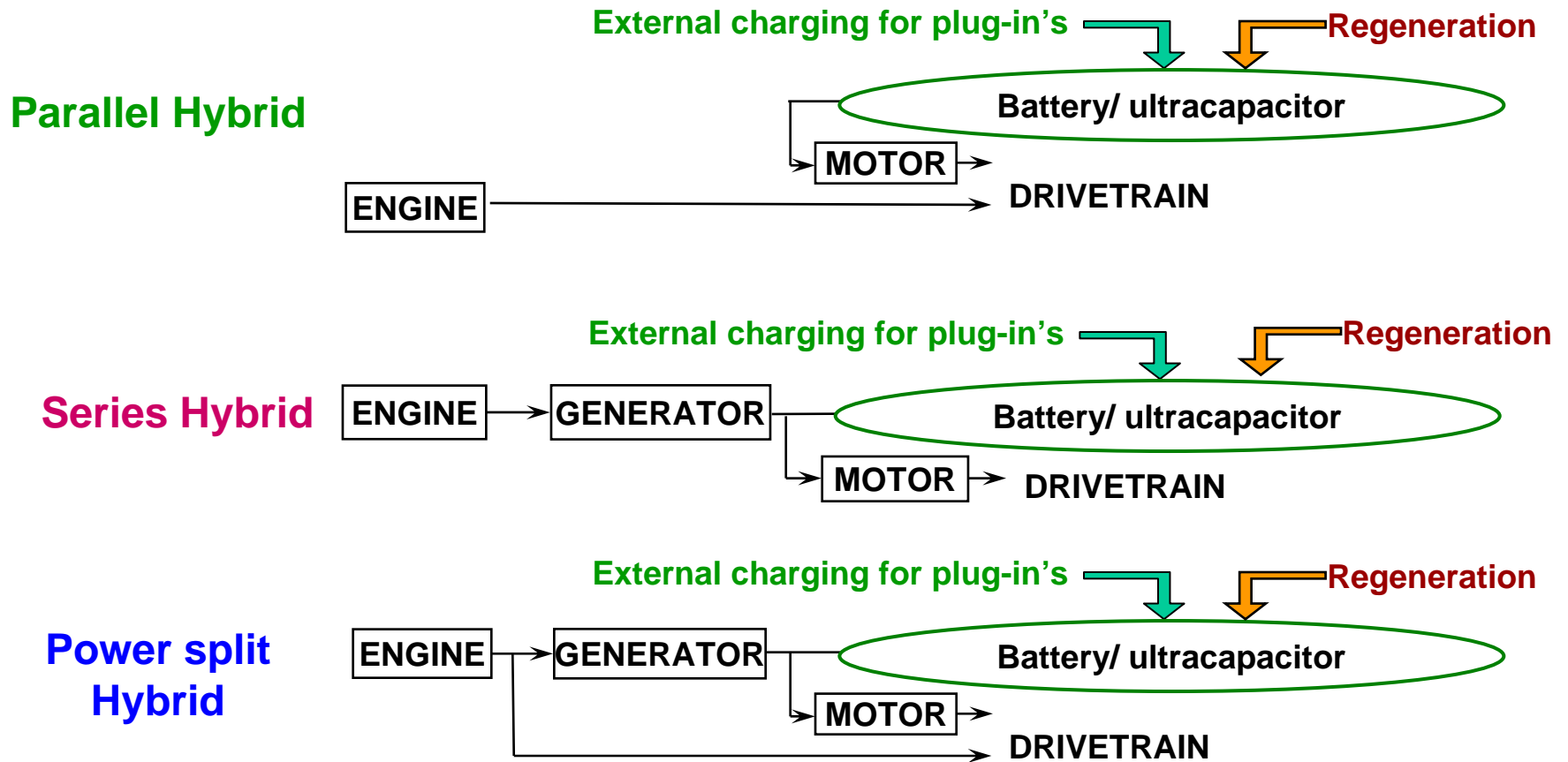
Configuration:

IC Engine + Generator + Battery + Electric Motor

Concept

- Eliminates external charging
- As “load leveler”
 - Improved overall efficiency
- Regeneration ability
- Plug-in hybrids: use external electricity supply

Hybrid Vehicles



Examples: Parallel hybrid: Honda Insight
Series hybrid: GM E-Flex System
Power split hybrid: Toyota Prius

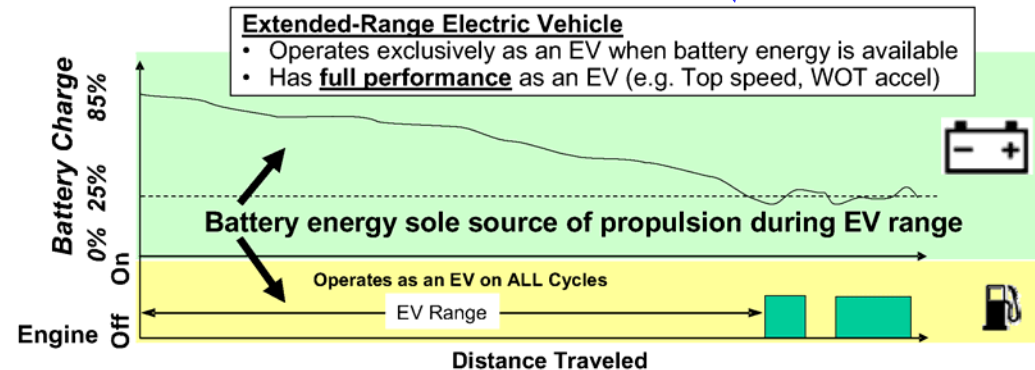
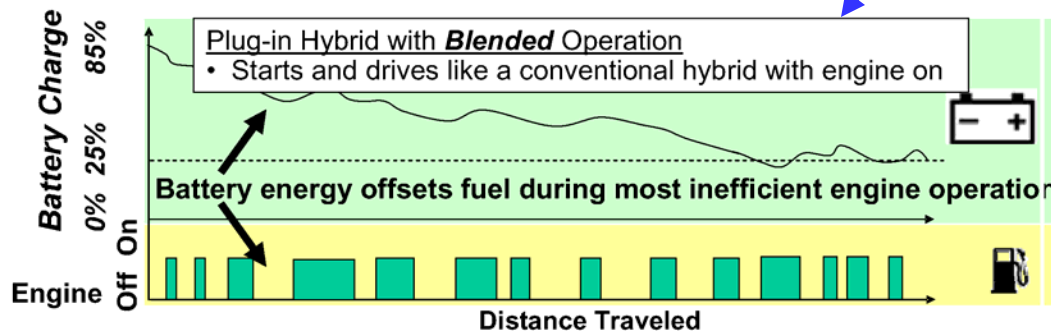
Hybrids and Plug-in hybrids

Hybrids (HEV)

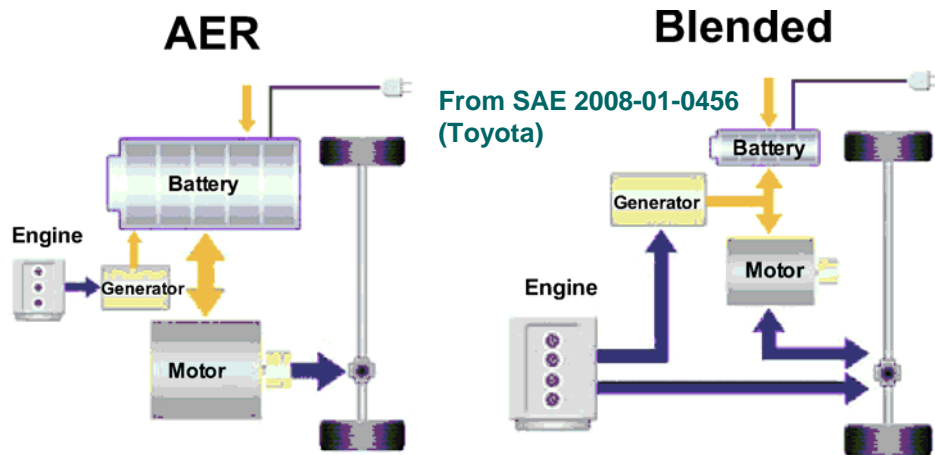
- “Stored fuel centered”
 - Full hybrid
 - Mild hybrid /power assist

Plug-in hybrids (PHEV)

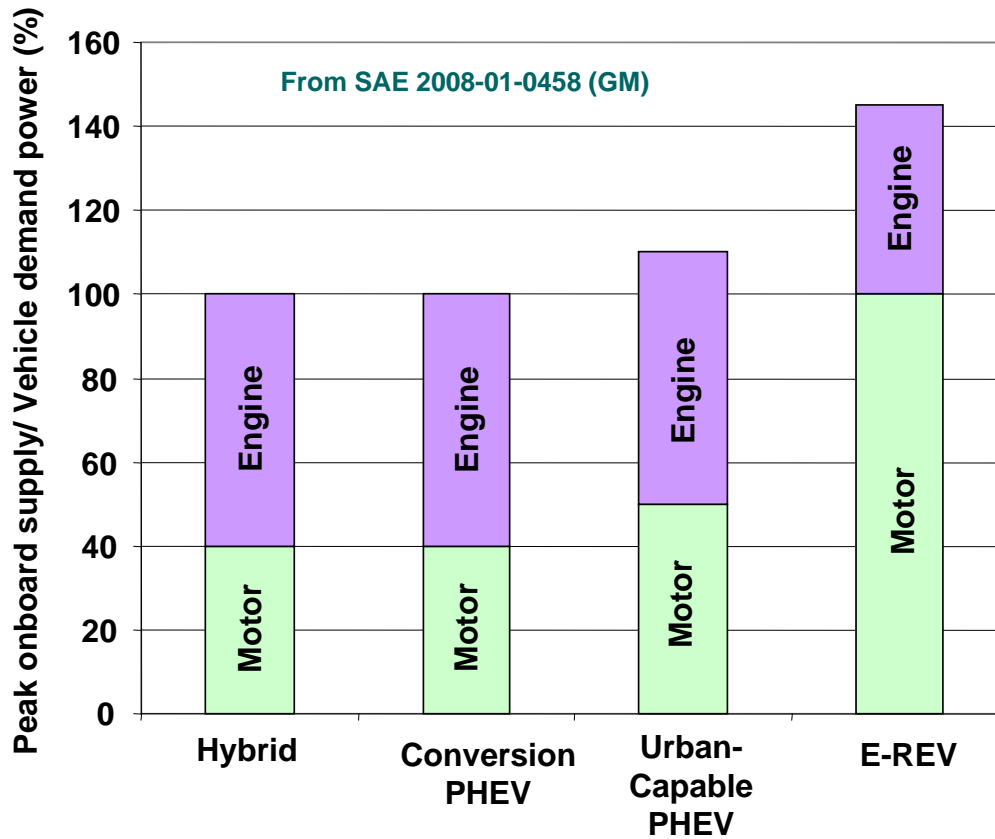
- “Stored electricity centered”
 - Blended PHEV
 - Urban capable PHEV
 - AER/ E-REV



From SAE 2008-01-0458 (GM)

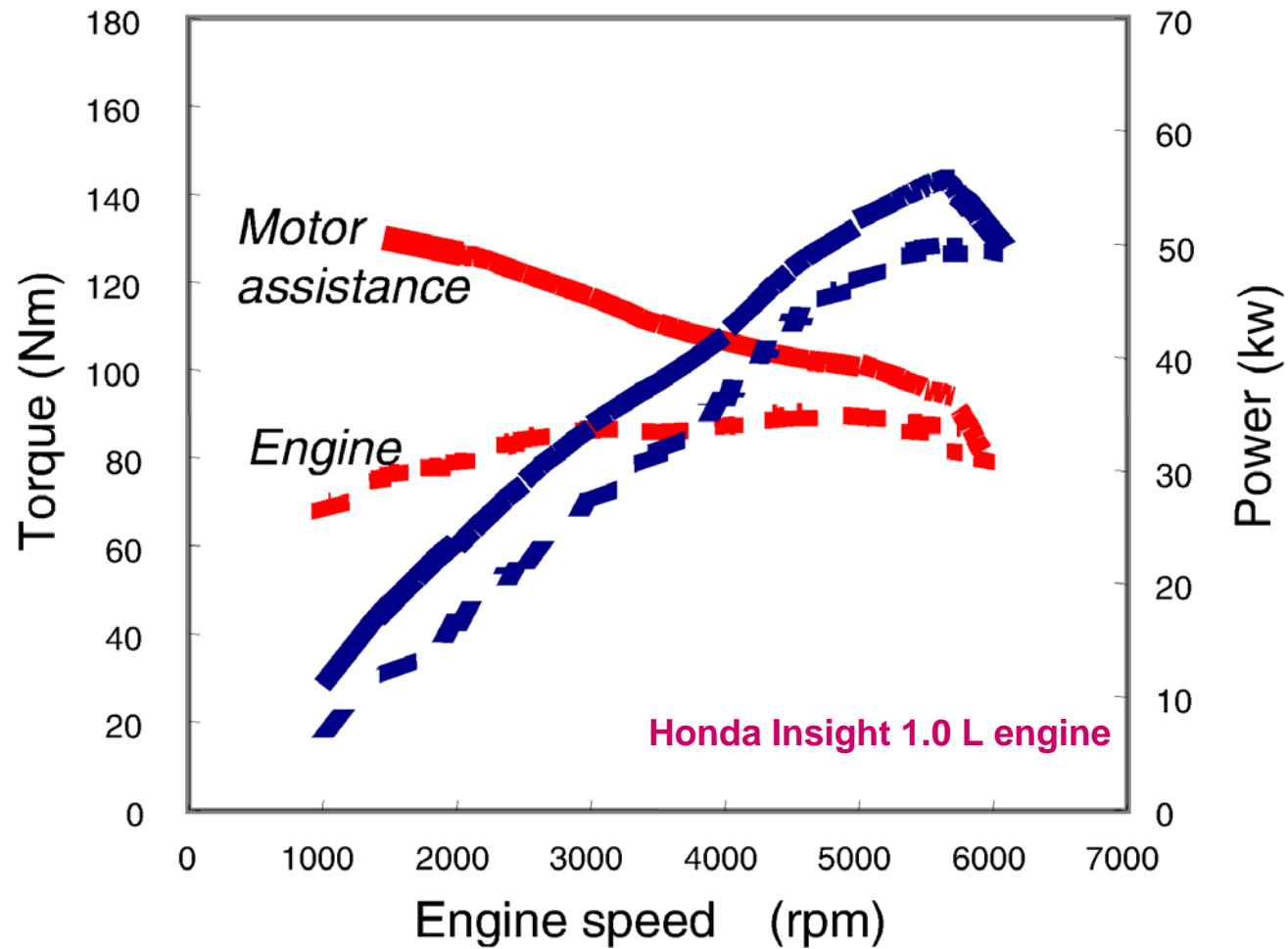


Engine/ motor sizing



The optimal component sizing and power distribution strategy depend on the required performance, range, and drive cycle

The reduced load/ speed dynamic range required from the engine offers design opportunities



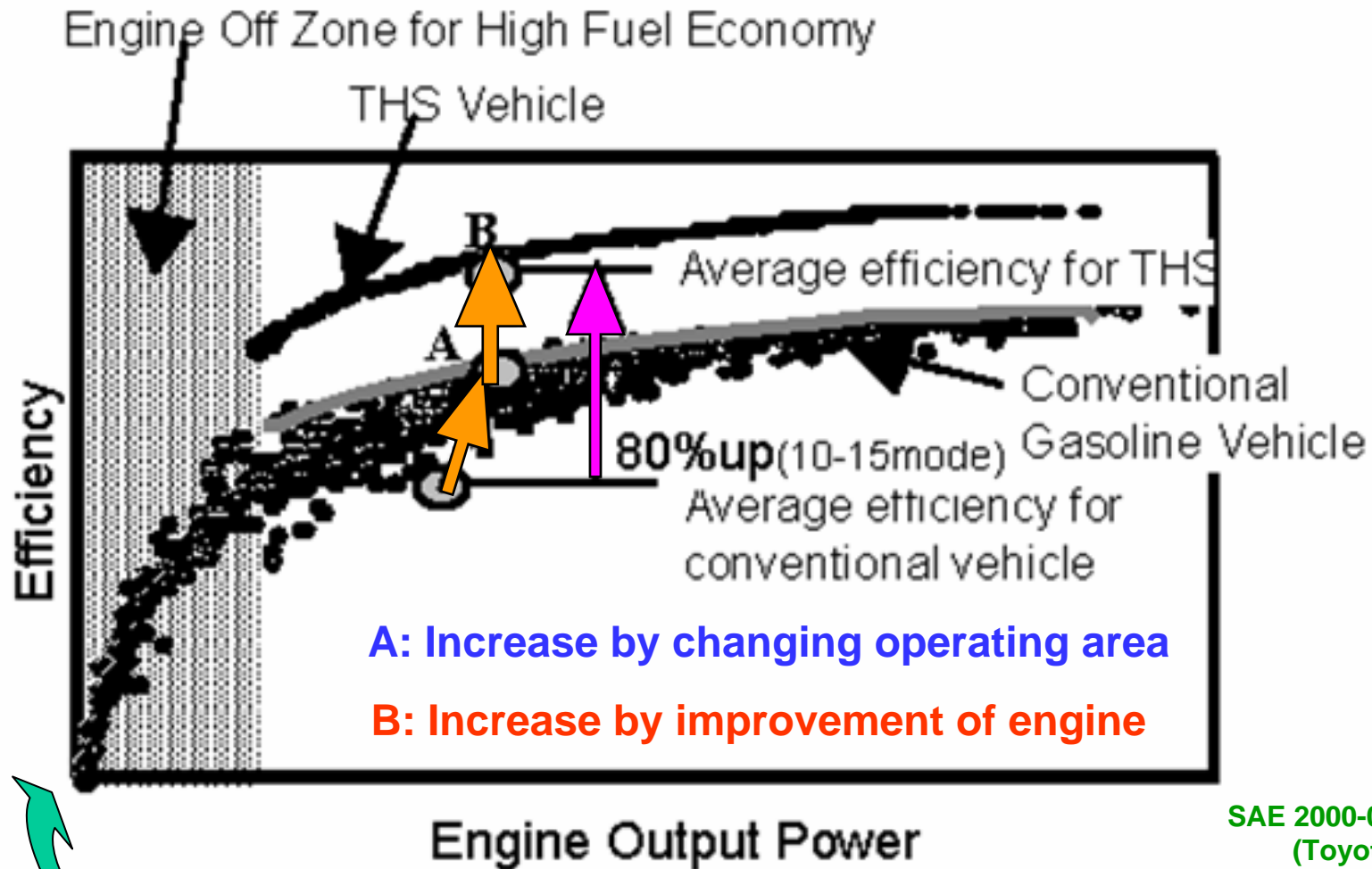
From SAE 2000-01-2216 (Honda)

HEV TECHNOLOGY

Toyota Prius

- Engine: 1.5 L, Variable Valve Timing, Atkinson/Miller Cycle (13.5 expansion ratio), Continuously Variable Transmission
 - 57 KW at 5000 rpm
- Motor - 50 KW
- Max system output – 82 KW
- Battery - Nickel-Metal Hydride, 288V; 21 KW
- Fuel efficiency:
 - 66 mpg (Japanese cycle)
 - 43 mpg (EPA city driving cycle)
 - 41 mpg (EPA highway driving cycle)
- Efficiency improvement (in Japanese cycle) attributed to:
 - 50% load distribution; 25% regeneration; 25% stop and go
- Cost: ~\$20K

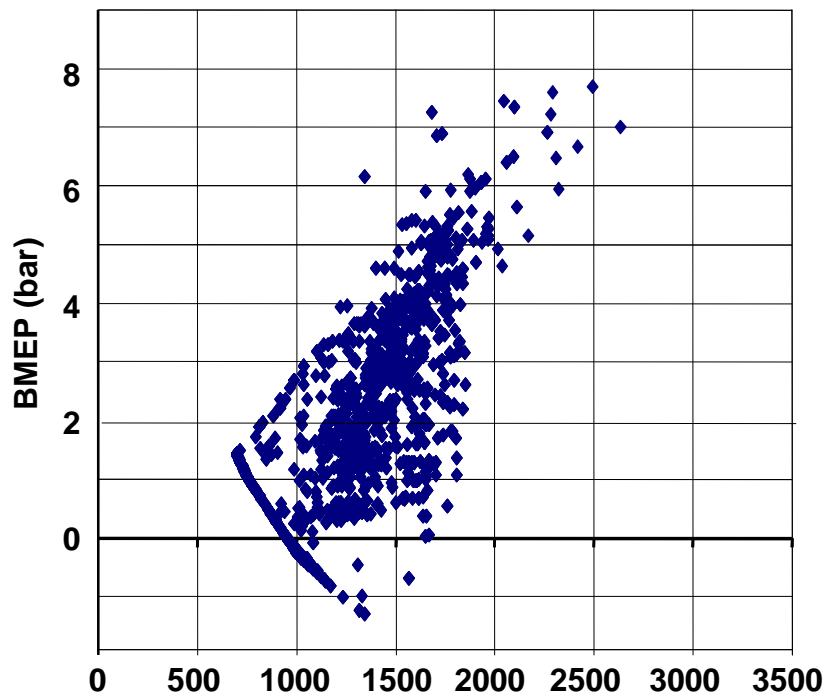
Efficiency improvement: Toyota Hybrid System (THS)



Efficiency improvement (in Japanese 10-15 mode cycle) attributed to:
50% load distribution; 25% regeneration; 25% stop and go

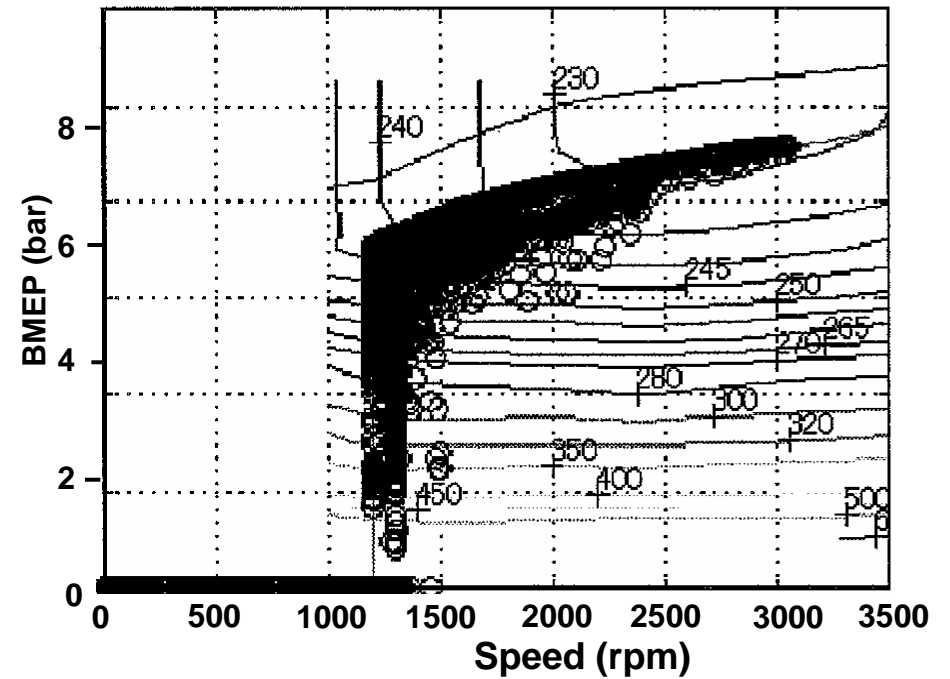
Operating map in LA4 driving cycle

Typical passenger car engine



Toyota THS II

Data from SAE 2004-01-0164



Cost factor

If $\Delta\$$ is price premium for hybrid vehicle
 P is price of gasoline (per gallon)
 δ is fractional improvement in mpg

Then mileage (M) to be driven to break even is

$$M = \frac{\Delta\$ \times \text{mpg}}{P \times \delta}$$

(assume that interest rate is zero)

Cost Factor

Example:

Honda Civic and Civic-Hybrid

Price premium (Δ \$, MY08 listed)	= \$7155 (\$22600-15445)
mpg (city and highway av.)	= 29 mpg (42 for hybrid)
hybrid improvement in mpg(%)	= 45%

At gasoline price of \$4.00 per gallon, mileage (M) driven to break even is

$$M = \frac{\$7155 \times 29}{\$4 \times 45\%} = 115,000 \text{ miles}$$

(excluding interest cost)

Barrier to Hybrid Vehicles

- Cost factor
 - difficult to justify especially for the small, already fuel efficient vehicles
- Battery replacement (not included in the previous breakeven analysis)
 - California ZEV mandate, battery packs must be warranted for 15 years or 150,000 miles : a technical challenge

Hybrid Vehicle Outlook

- Hybrid configuration will capture a fraction of the passenger market, especially when there is significant fuel price increase
- Competition
 - Customers downsize their cars
 - Small diesel vehicles
- Plug-in hybrids?
 - Weight penalty (battery + motor + engine)
 - No substantial advantage for overall CO₂ emissions
 - Limited battery life

Sales figure for hybrid vehicles

