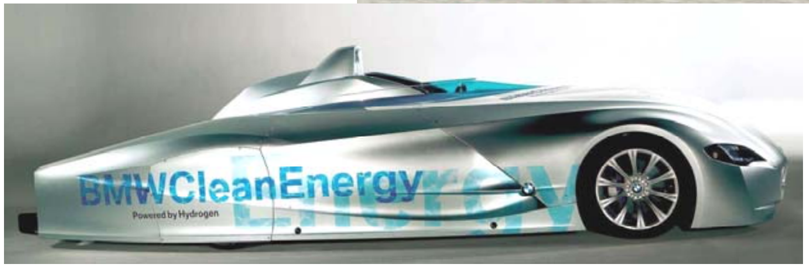
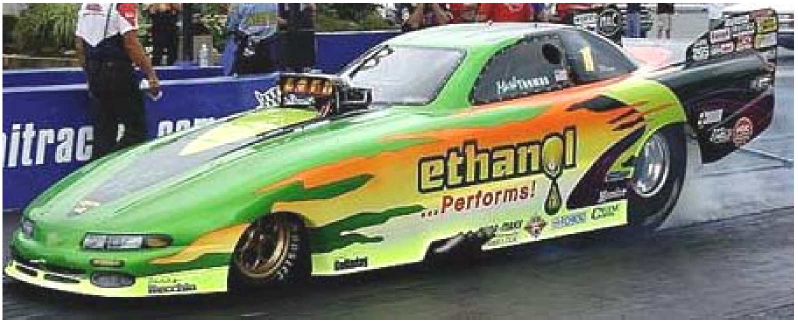
The race for 21st century fuels



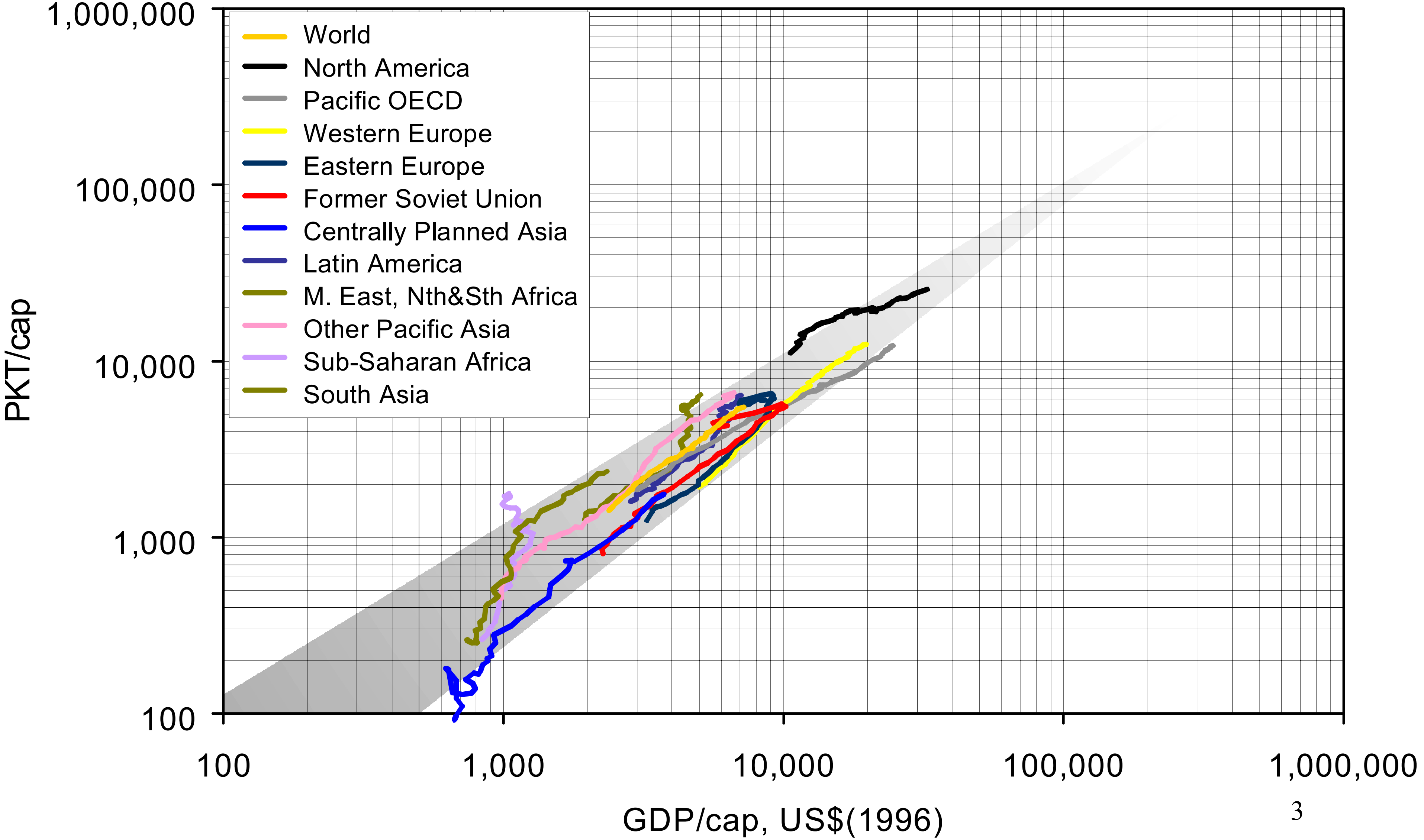


Prof. Alex Farrell
Energy & Resources Group
UC Berkeley

APS Short Course
Physics of Sustainable Energy
March 2, 2008
Berkeley, CA

The race

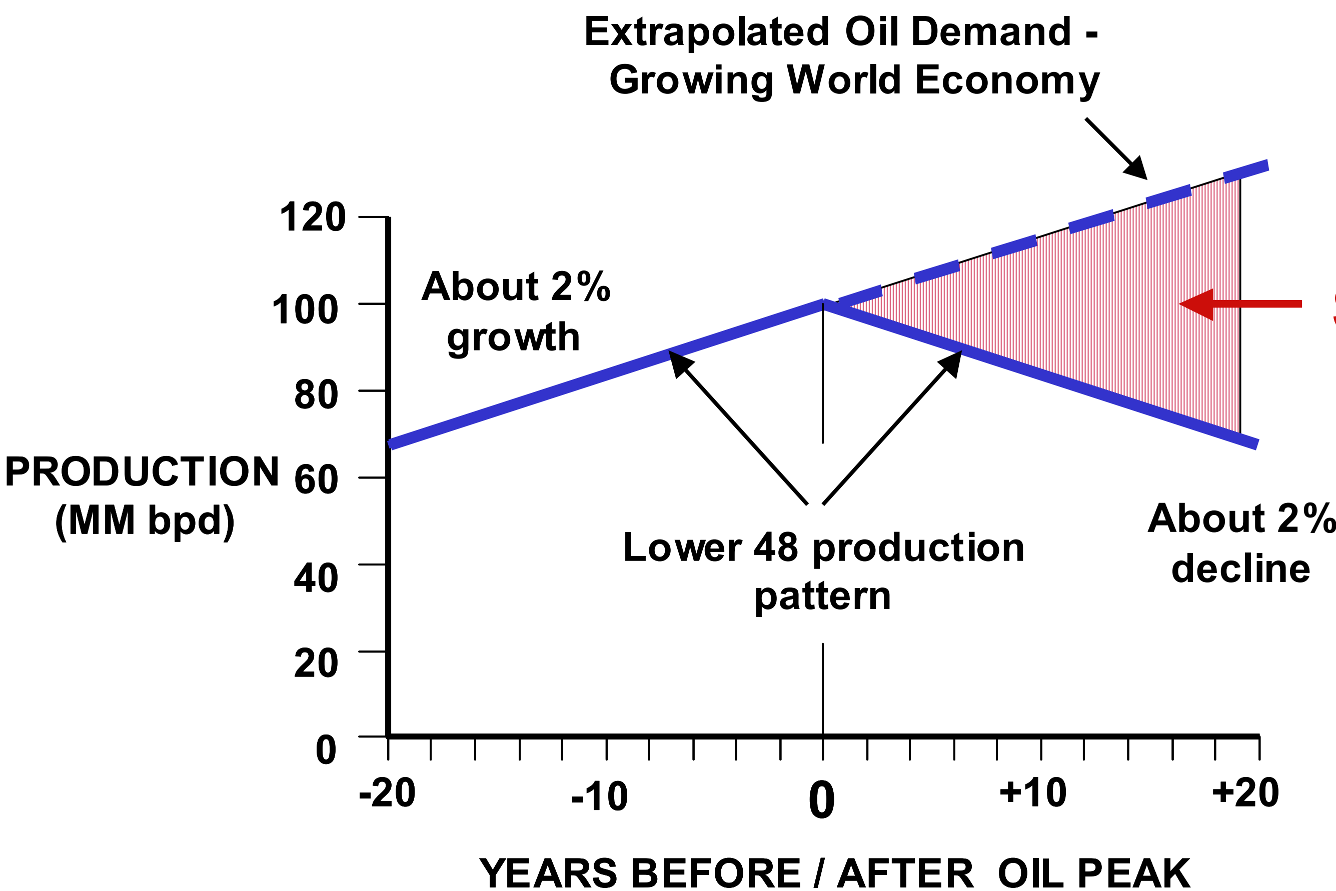
Economic growth brings more and faster travel, which requires more fuel



Source: Schäfer (2005)

Conventional oil production will peak some day

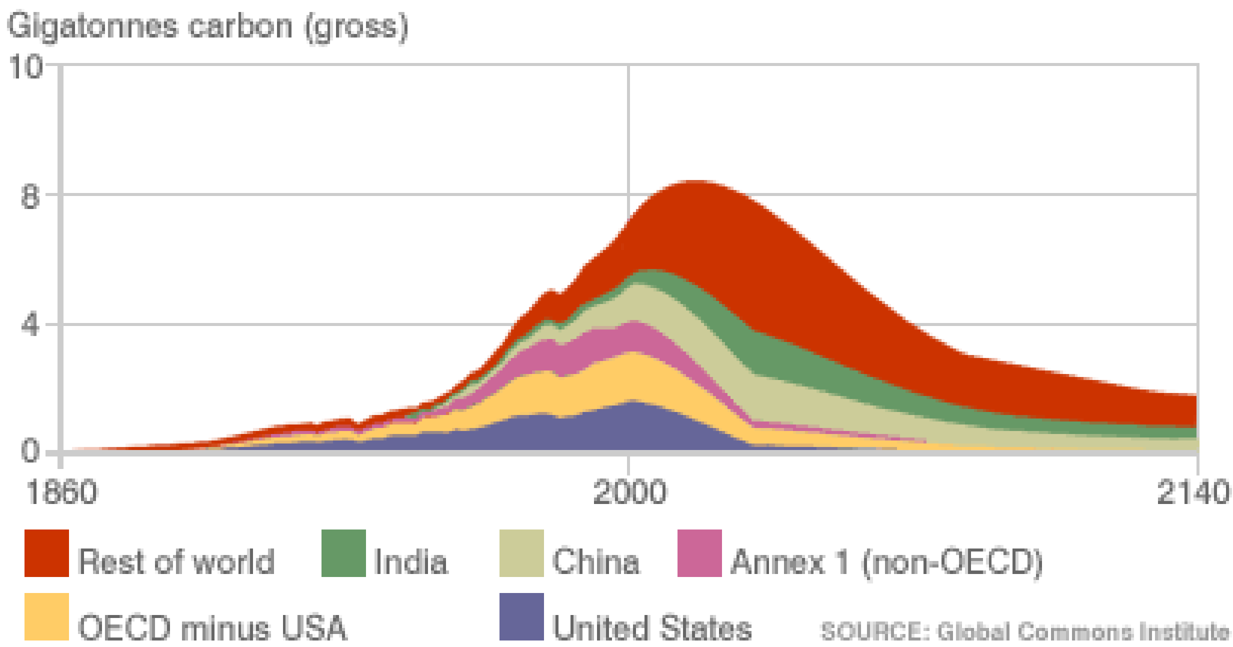
- At what rate will innovation and investments in new technologies be made to replace conventional petroleum?



Source: Hirsch et *al.* (2005)

Greenhouse gas emissions must be essentially eliminated (*pace* geo-engineering)

- **What technological innovations, investments, and lifestyle changes will allow us stabilize the climate?**



"Contraction and convergence" to an atmospheric GHG concentration of 450 ppm.

Source: Global Commons Initiative

- **Other environmental issues are also important**

Security risks may be growing but have not motivated large scale substitution yet.

- Oil supply disruptions
  - Concentration of reserves in Middle East creates physical and economic security risks
  - Infrastructure costs make energy supply path dependent

- Poor governance
  - Many people in oil-rich countries have poor life prospects

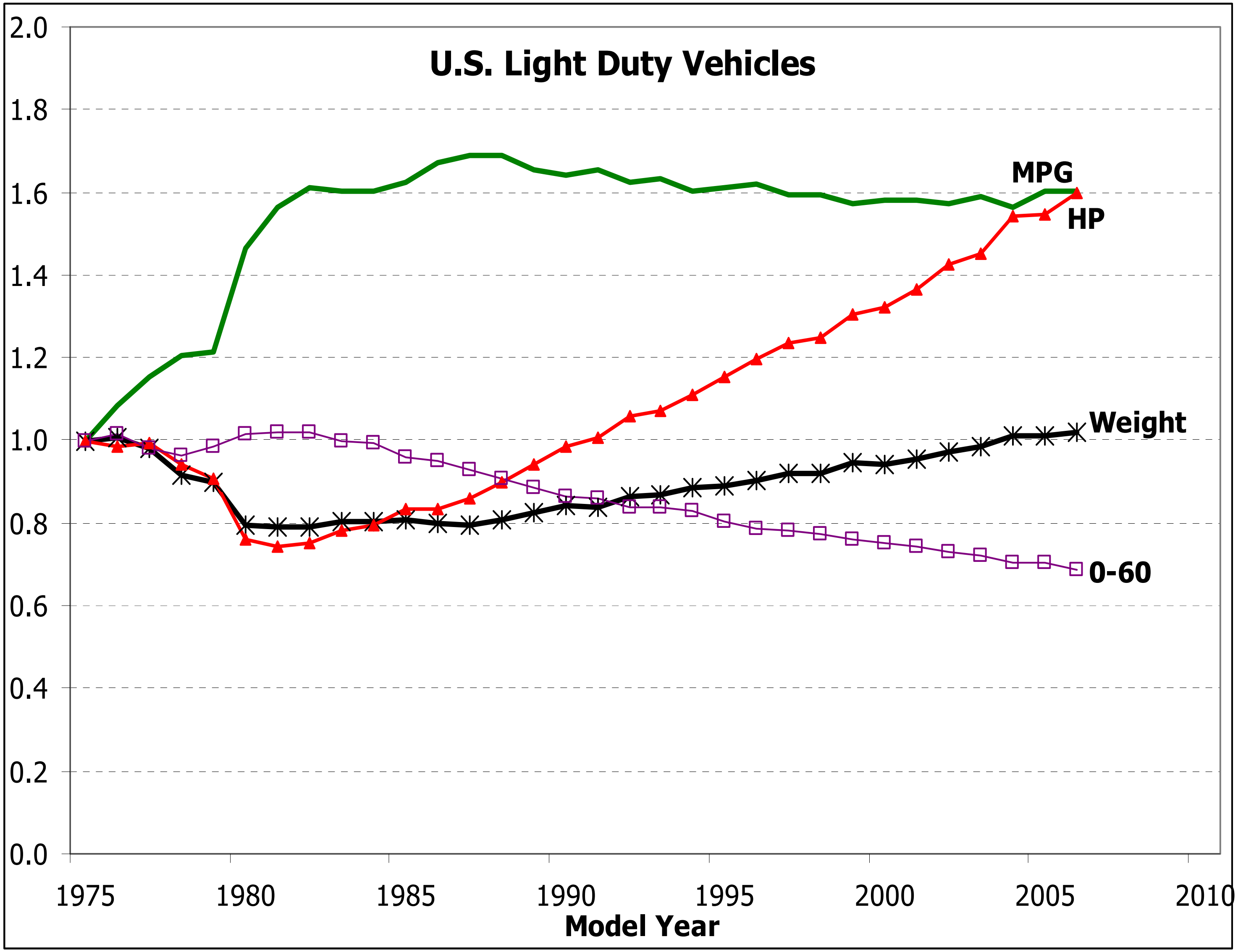
The race for 21st century fuels: Providing fuels that customers will buy

	Efficiency	Fossil	Biofuels	Electricity	Hydrogen
Infrastructure					
Vehicles					
Resources					
Environment					

Note: These are rough, subjective judgments that depend on how various fuels are produced, and they will change with innovation.

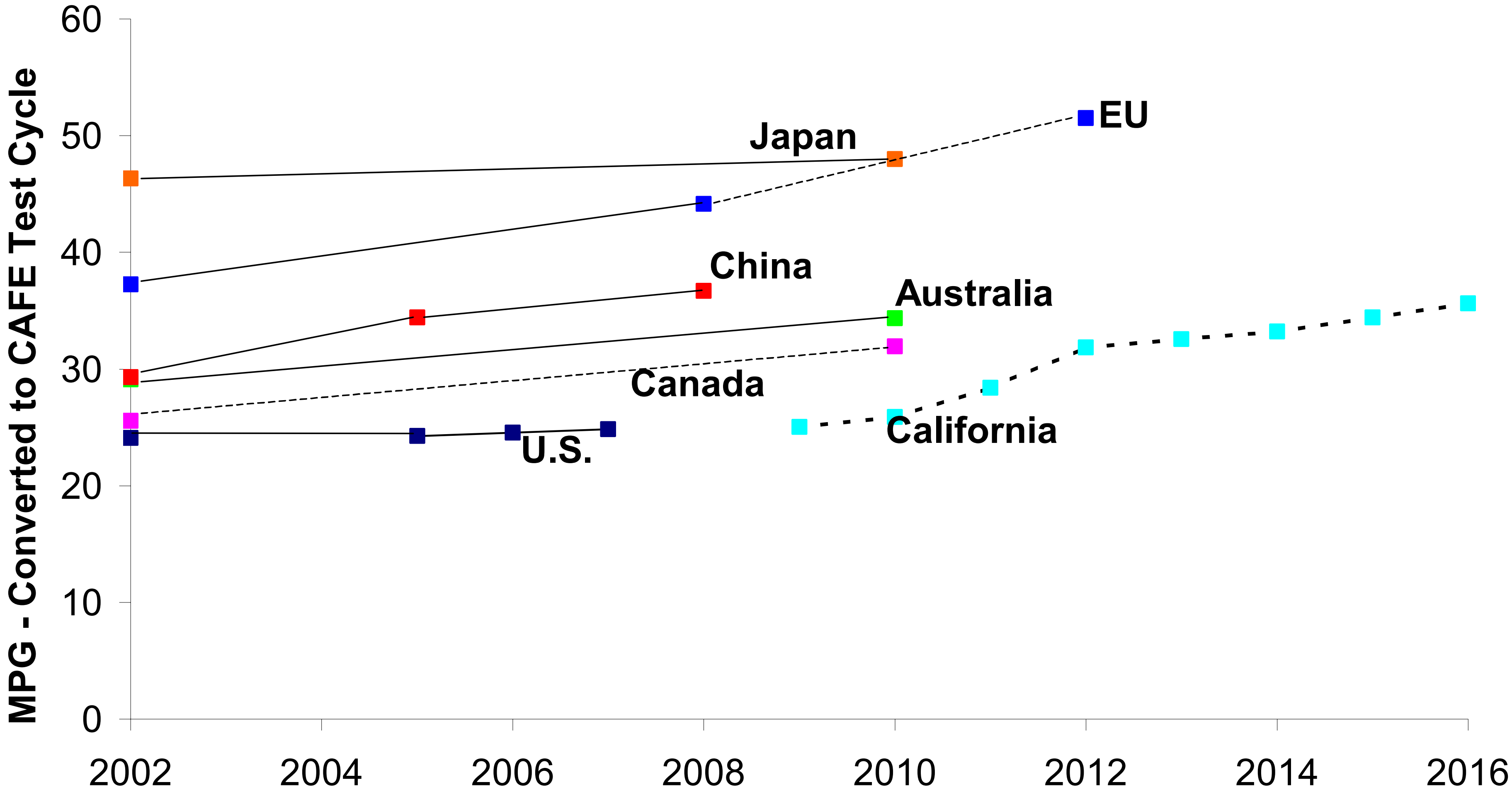
Efficiency is Job 1

U.S. vehicle efficiency has *declined* as innovation was used to improved performance



Source: EPA (2006)

U.S. (and California) vehicle efficiency lags behind world standards



Source: Energy and Transportation Technologies LLC

Higher vehicle efficiency should be our first priority, it will even save us money!

	Average fuel economy improvement	Net savings (3 years, no discount)
Subcompact car	12%	$200
Midsize car	20%	$350
Large car	27%	$1,500
Small SUV	25%	$1,500
Large SUV	42%	$1,300
Large Pickup	38%	$1,100

Notes: Gasoline $1.50/gal.

Diesel engines are ignored

Hybrid drivetrains are ignored

Source: NRC 2002

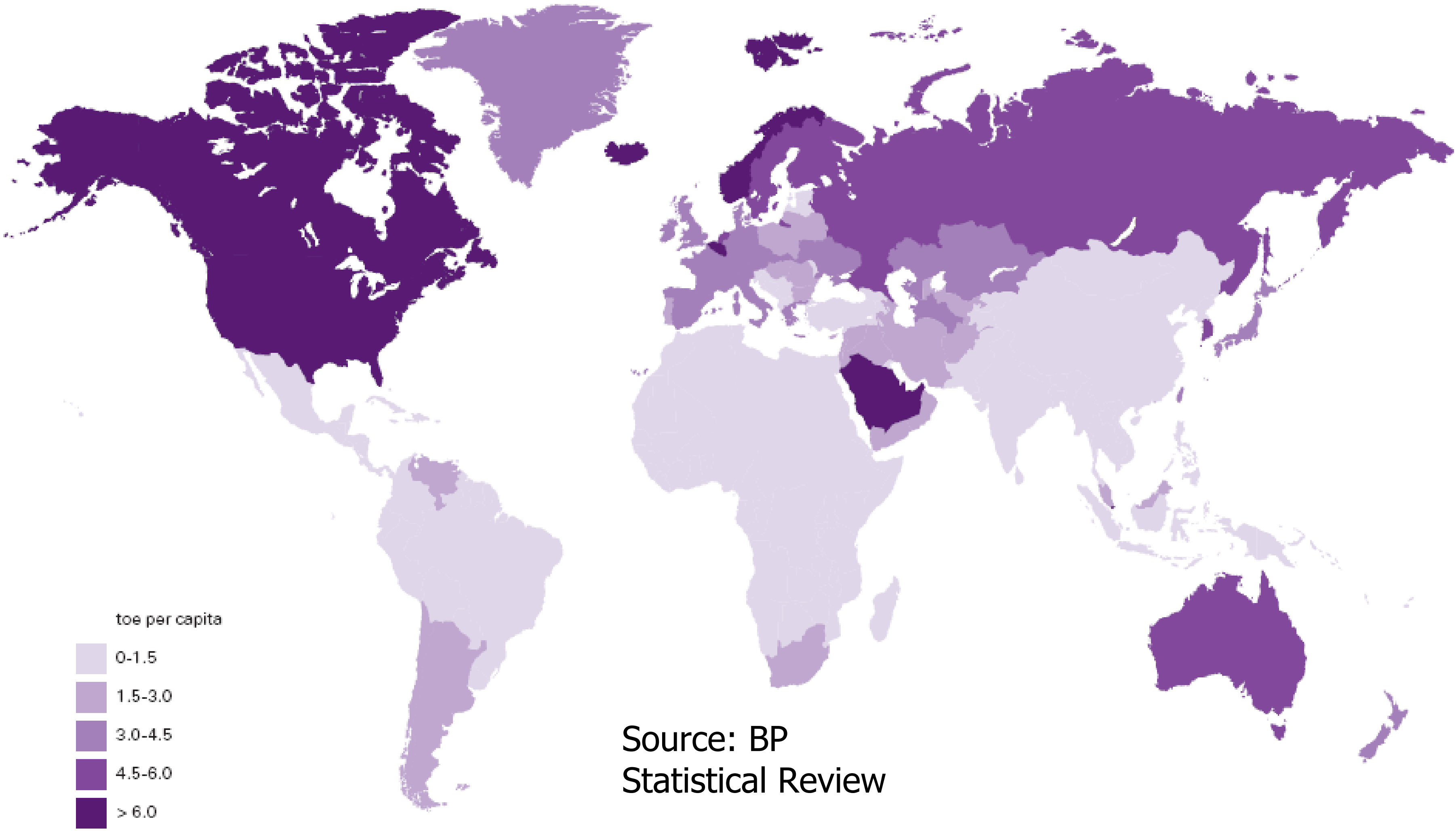
But, efficiency is not the entire answer

- U.S. automakers and unions are poorly positioned to compete
- Inherent tradeoffs in vehicle performance and cost will eventually emerge

- Efficiency is not a source of energy, fuels will still be needed.
- And, …

Billions of people deserve access to *more* energy in the future

Energy Consumption per capita
(tonnes oil equivalent/yr.)



Source: BP
Statistical Review

The competitors

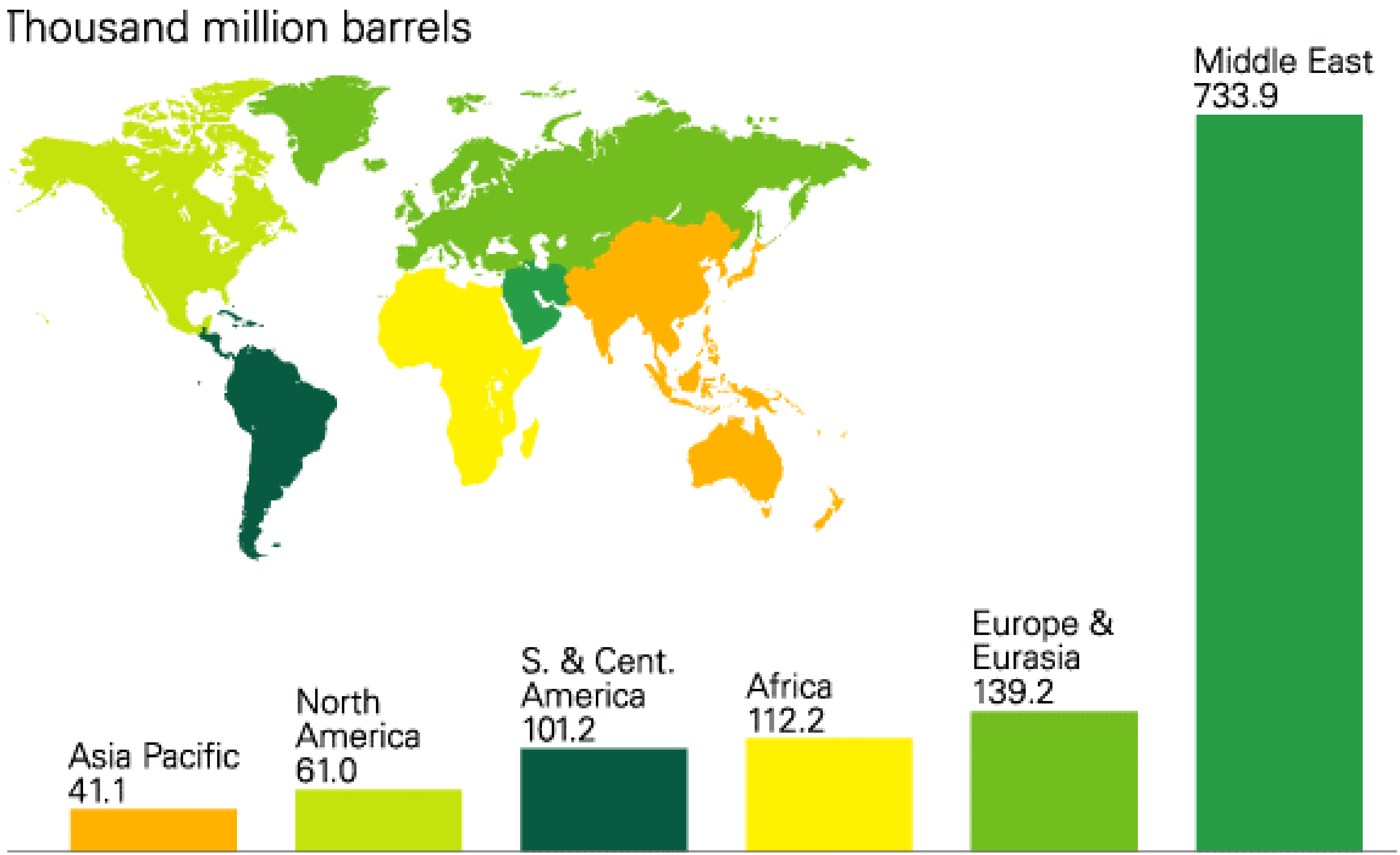
Criteria

- Supply infrastructure
- Vehicles
- Resource base
- Environment

Fossil fuels

- Existing infrastructure needs expansion and protection
- Excellent energy storage and obviously compatible with existing vehicles
- Resource base is very large
- Worsening environmental effects

Access: >90% of conventional oil are nationalized, challenging private oil companies



Source: BP (2005)

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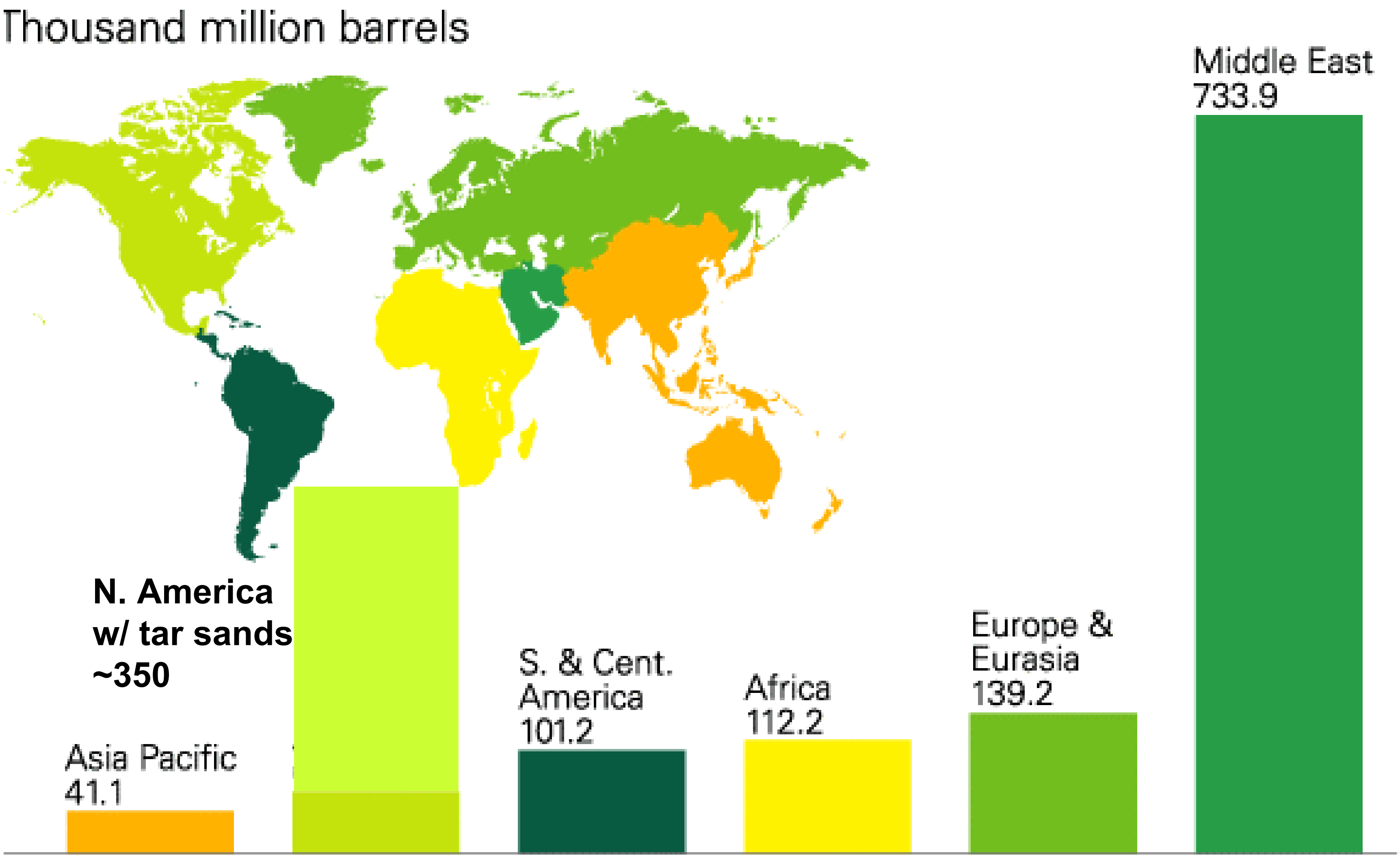
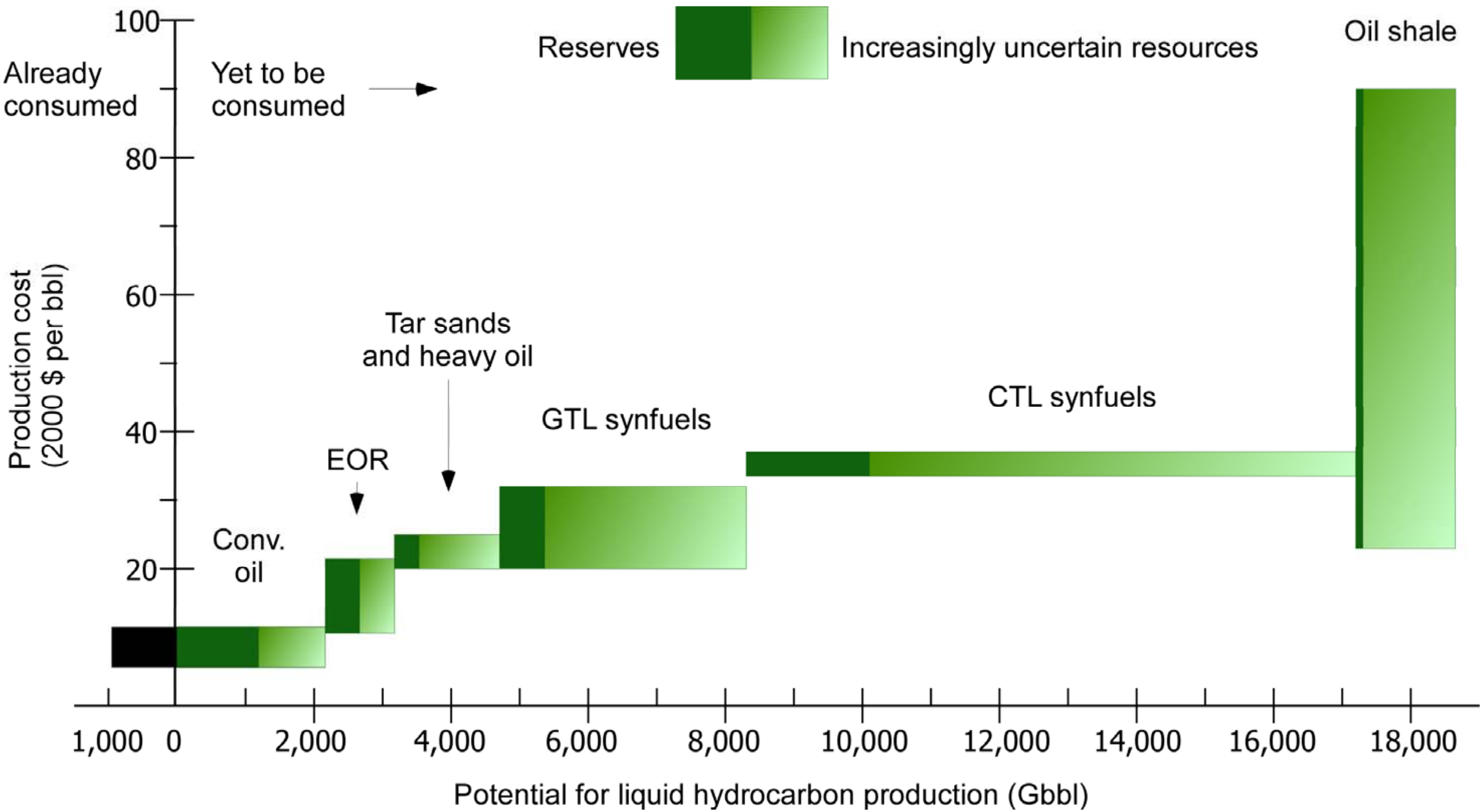


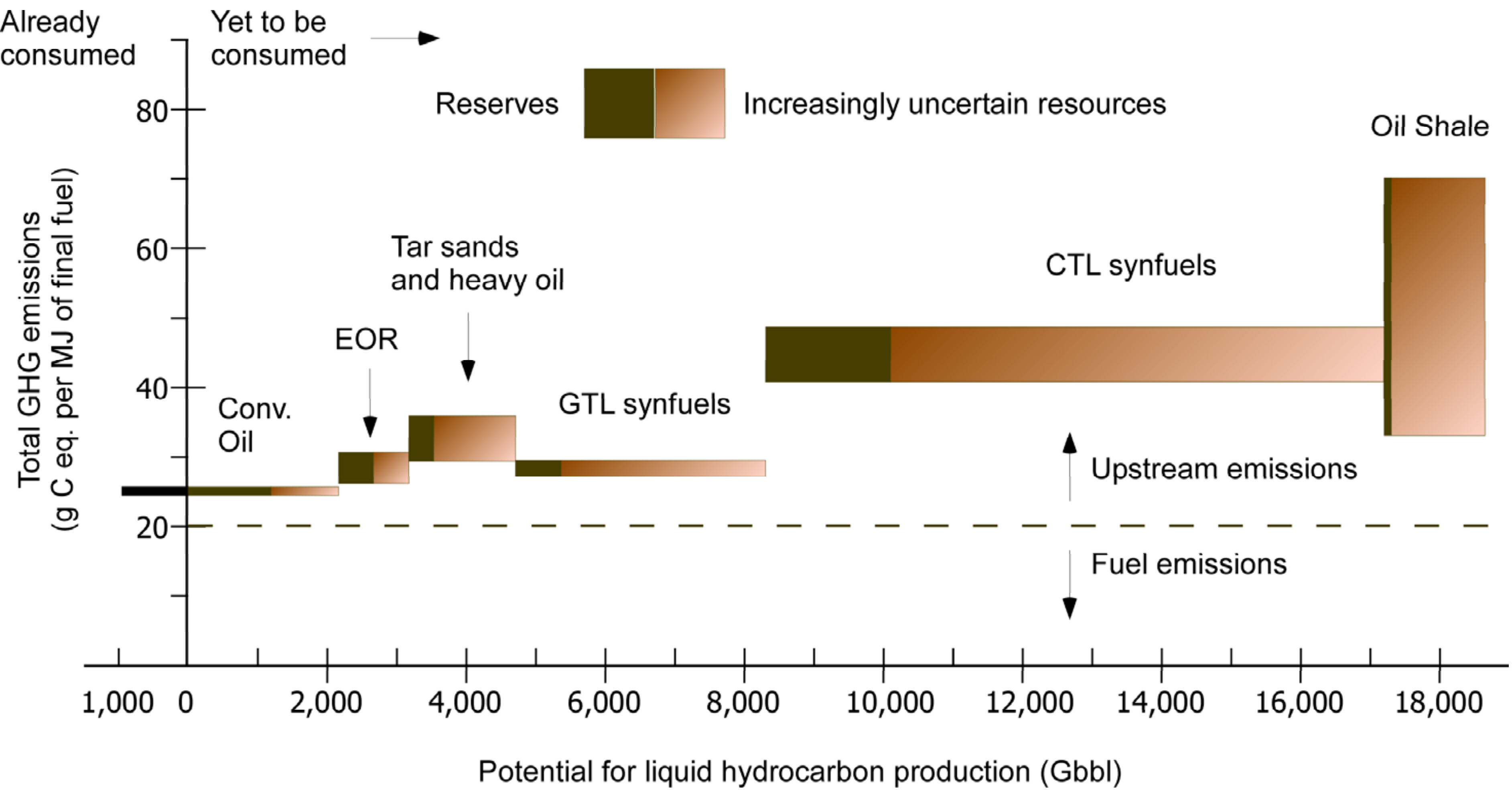
Source: BP (2005)

Economics and access are driving oil production towards abundant, low-quality resources



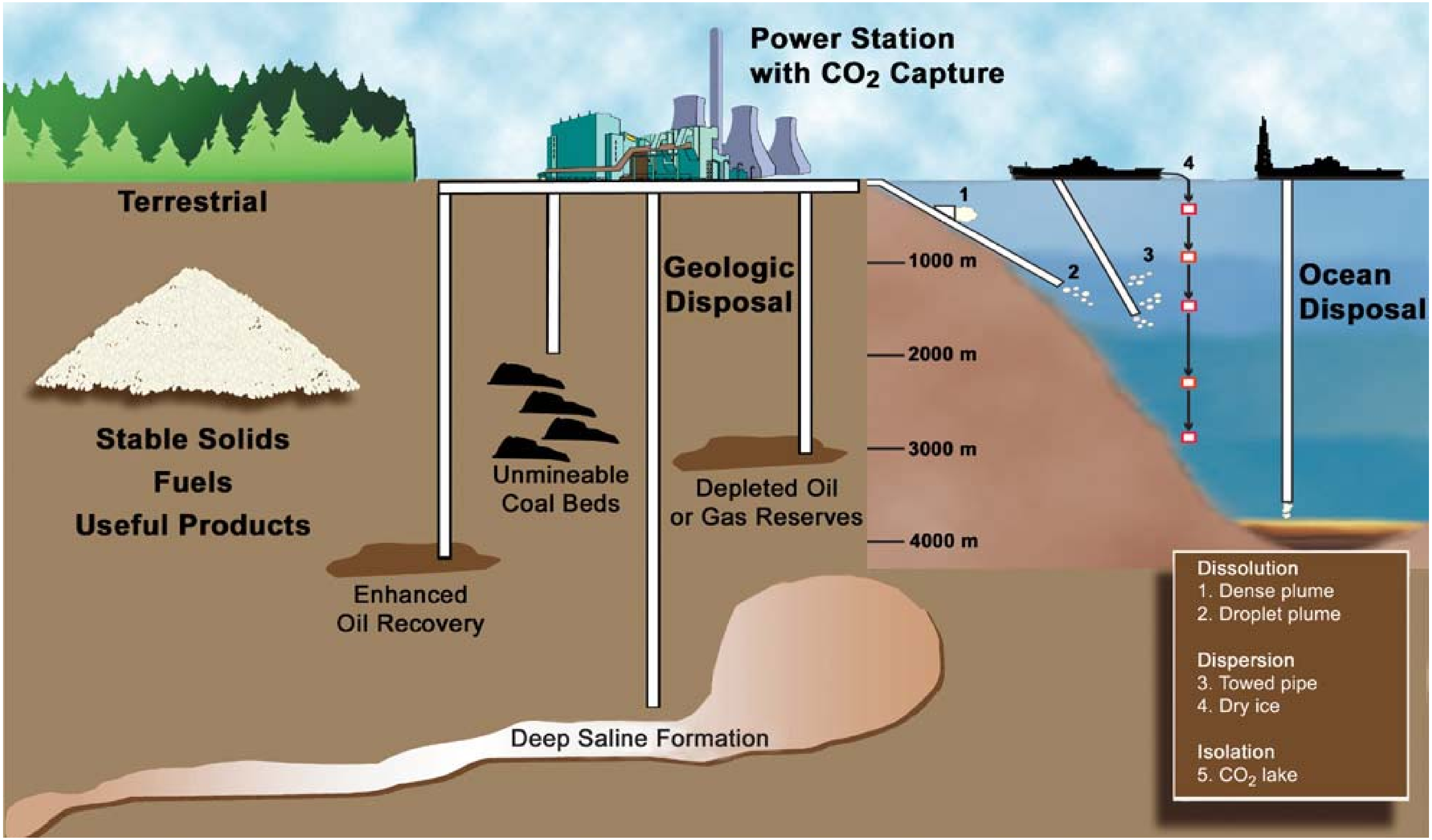
Source: Brandt and Farrell (2007) http://www.iop.org/EJ/toc/1748-9326/1/1

Low-quality fossil fuels have large environmental consequences



Source: Brandt and Farrell (2007) http://www.iop.org/EJ/toc/1748-9326/1/1

Carbon capture and storage (CCS) may let us use fossil fuels *and* stabilize the climate



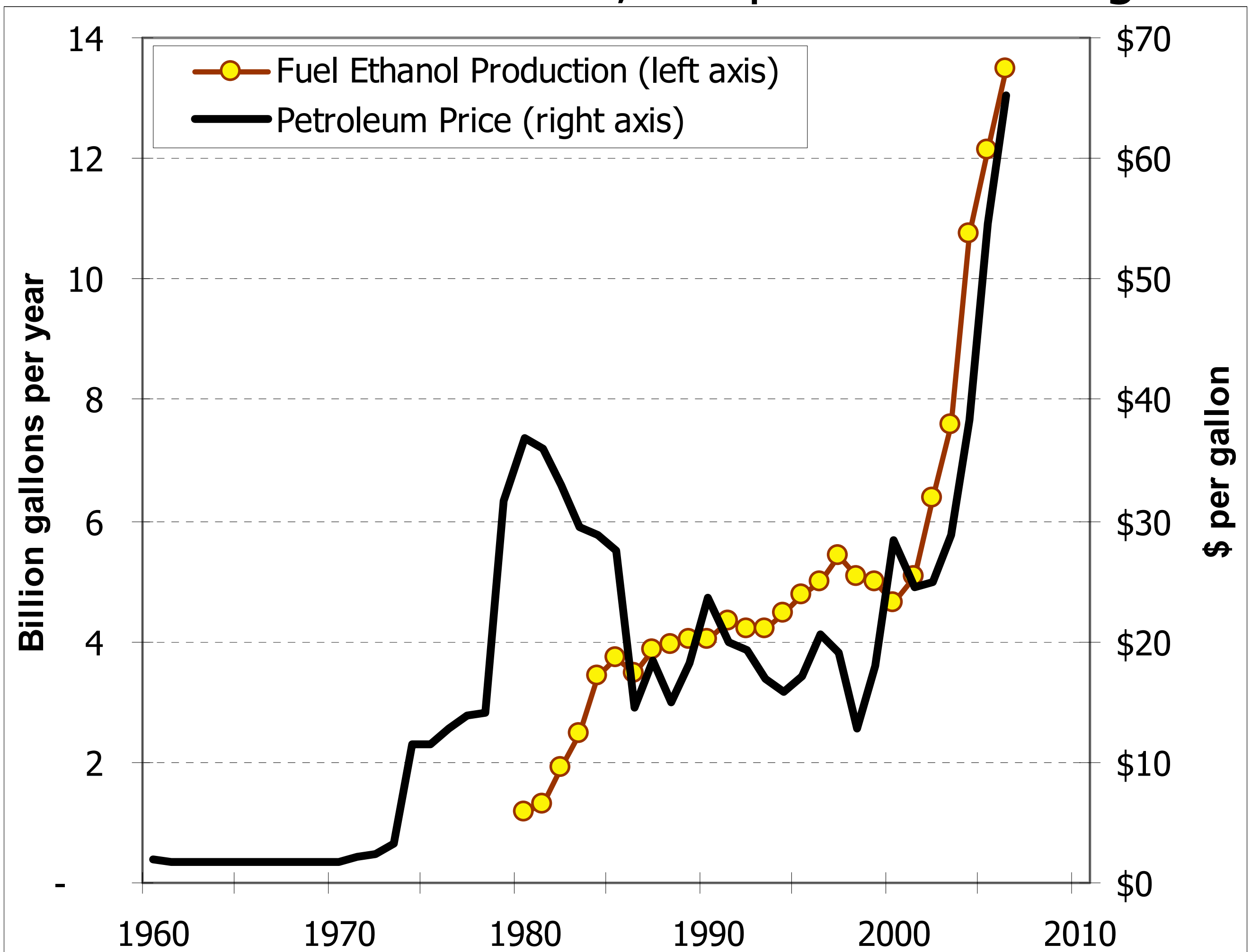
Note: CCS does not address other environmental issues like water use, land disturbance, etc.

Biofuels

- Some new distribution infrastructure may be needed
- Good to excellent energy storage, current vehicles need little to no change
- Limited resource base
- Uncertain environmental effects

Today's biofuel industry

- Feedstocks are agricultural commodities
- Fuels are traditional substances
- Success depends on subsidies and mandates
- Small, but profitable and growing rapidly



Sources: US EIA, BP, RFA

Land use is central to most environmental and social effects of biofuels

- **Direct land use**
  - Soil erosion
  - Biodiversity loss
  - Most biofuel income goes to landowners
- **Indirect land use (displacement)**
  - Global markets for energy and food create global competition for land use

Market forces cause indirect GHG emissions

(Land use change is only one indirect effect)

U.S. corn farmer switches from corn/soy to corn/corn to supply a new ethanol plant

U.S. soy exports go down and world soy prices rise

Additional land in Brazil (for instance) is put into soy production

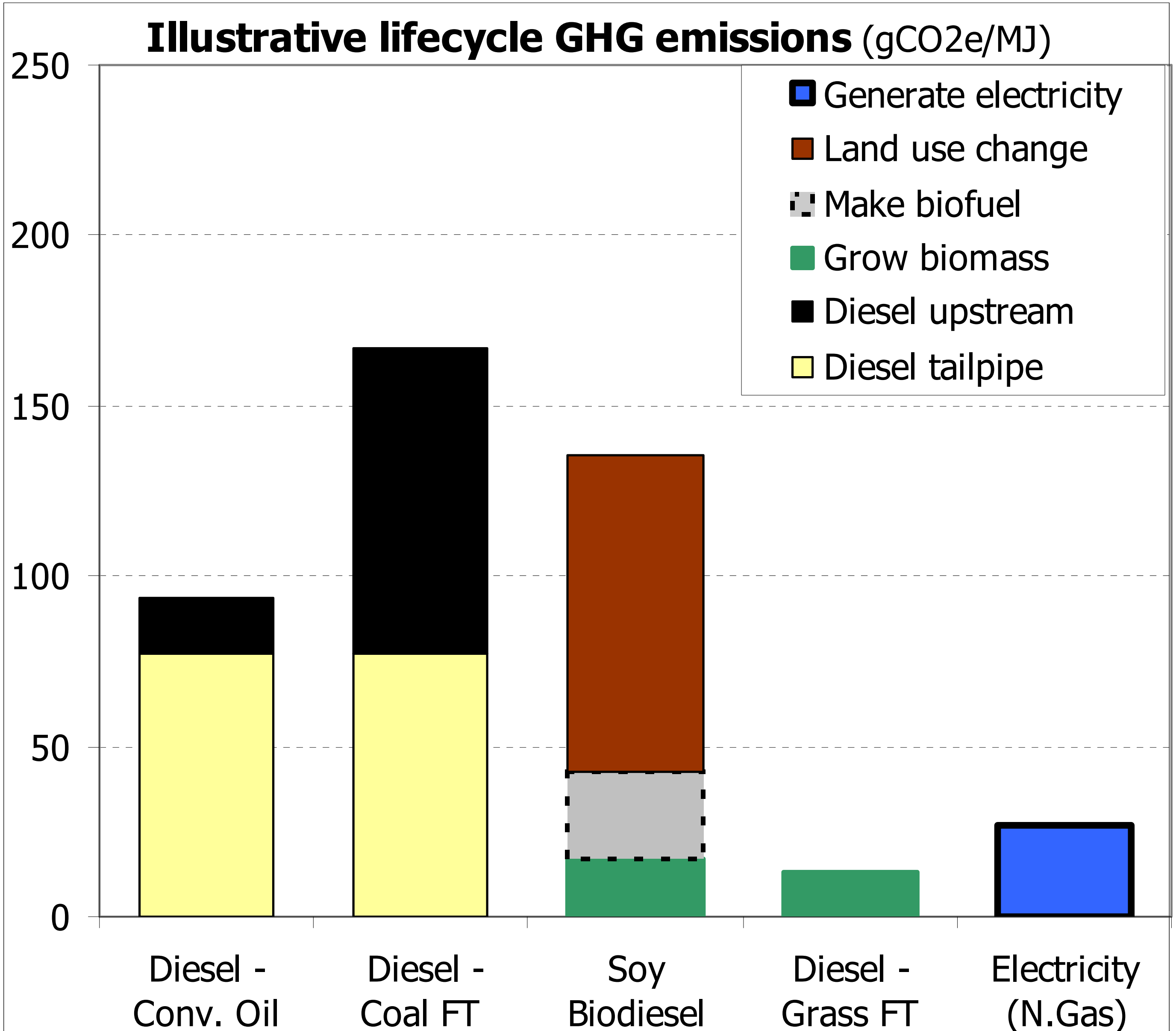
Soy farmers everywhere use more inputs to increase yields

Indirect emissions

Production emissions

NOTE: These changes are all *relative* to no additional biofuels

Indirect land use *may* be very significant



Notes:

Illustrative values only

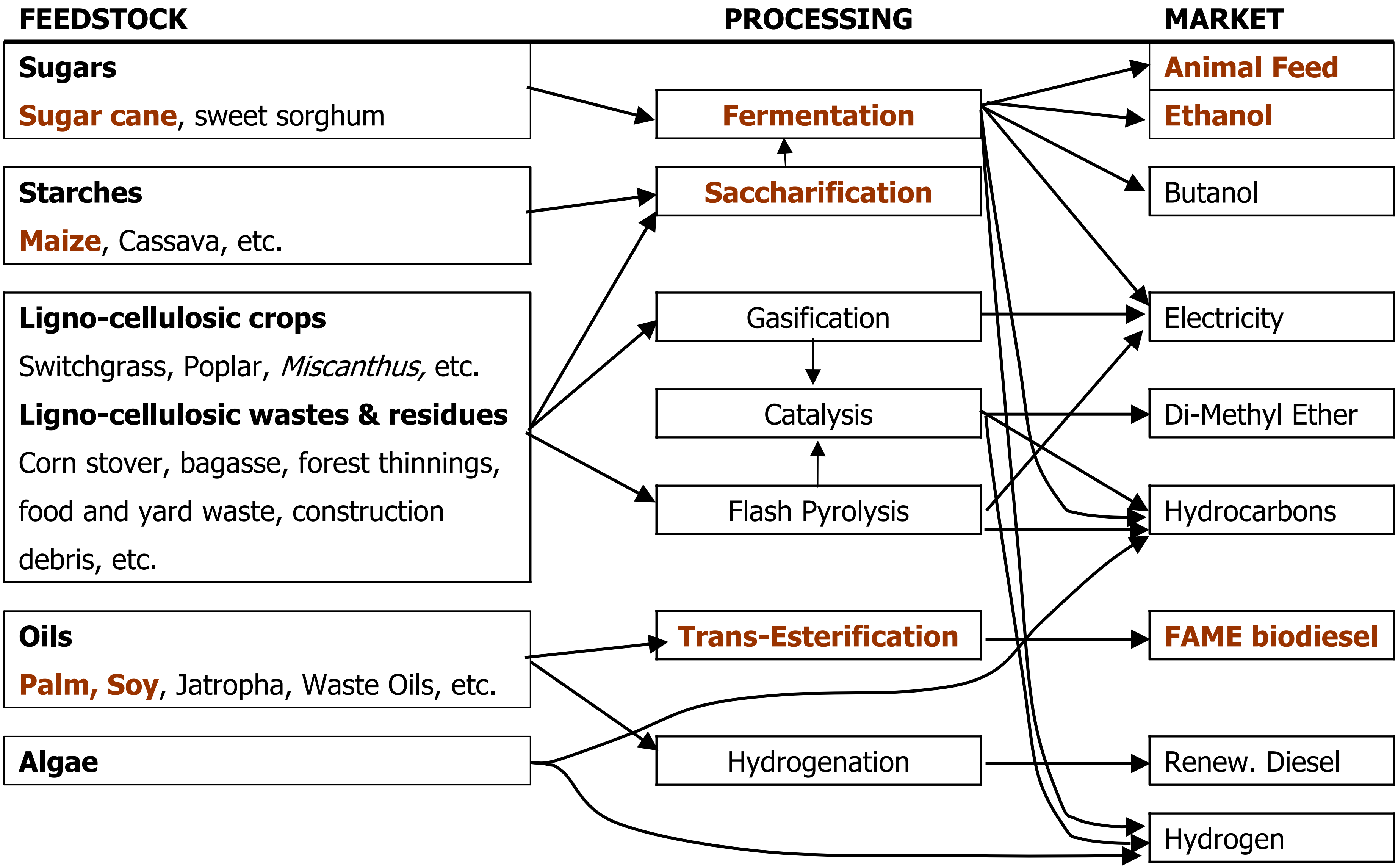
FT = Fischer Tropsch

LUC values from Searchinger et al (2008)

Grass FT from Hill et al (2006) and assumes degraded land

Electricity: combined cycle generation and 5x drivetrain efficiency

Many possible biofuel production pathways exist



Source: Farrell and Gopal (2008)

Partial representation – not all possibilities shown

Research may liberate us from the need to use arable land for biofuels

- **Ligno-cellulosic fermentation**
- **Gasification & synthesis**
- **Fast Pyrolysis**
- **Algae**




Electricity

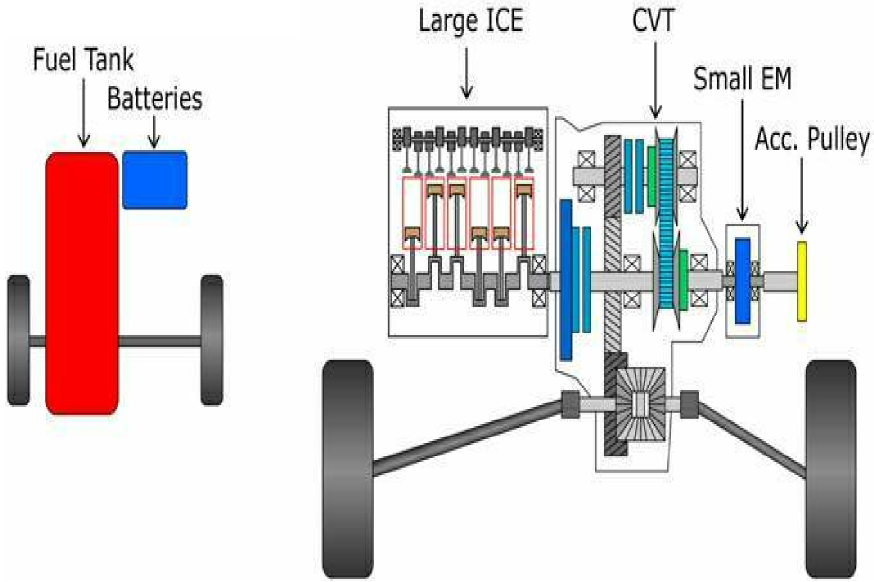
- Little new distribution infrastructure is needed, at least at first
- Energy storage batteries are poor, so vehicles may be expensive
- Resource base is very large
- Uncertain environmental effects

The Plug-in Hybrid Electric Vehicle (PHEV)

(Values given for all Electric Range, AER)

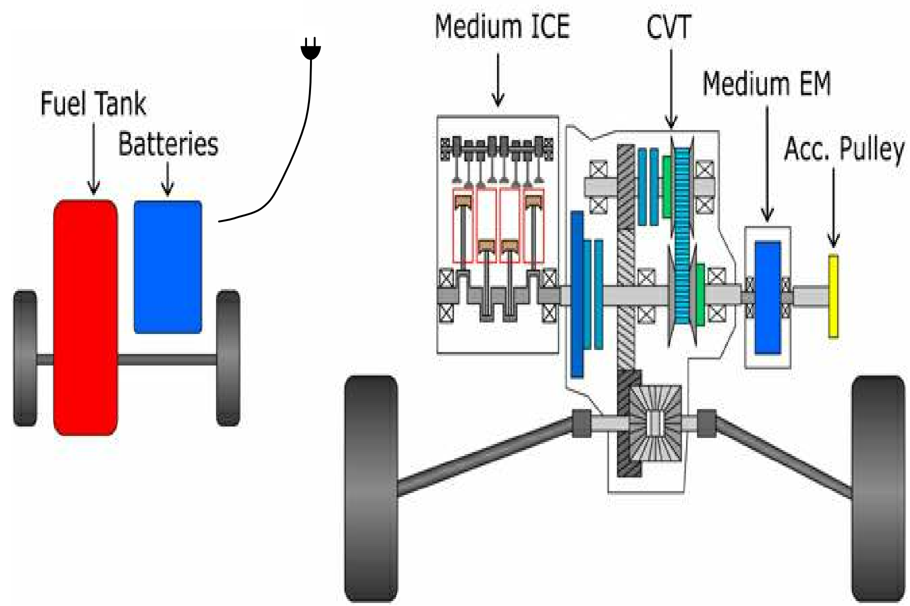
Hybrid Electric Vehicle HEV 0

- Engine downsized ~15%
- Idle-off and regenerative braking
- Efficiency increased ~50%
- Battery state of charge kept in narrow range



Hybrid Electric Vehicle HEV 20

- Engine downsized ~33%
- Larger battery and grid charging
- Energy for short trips is from grid
- Deeper discharge of batteries



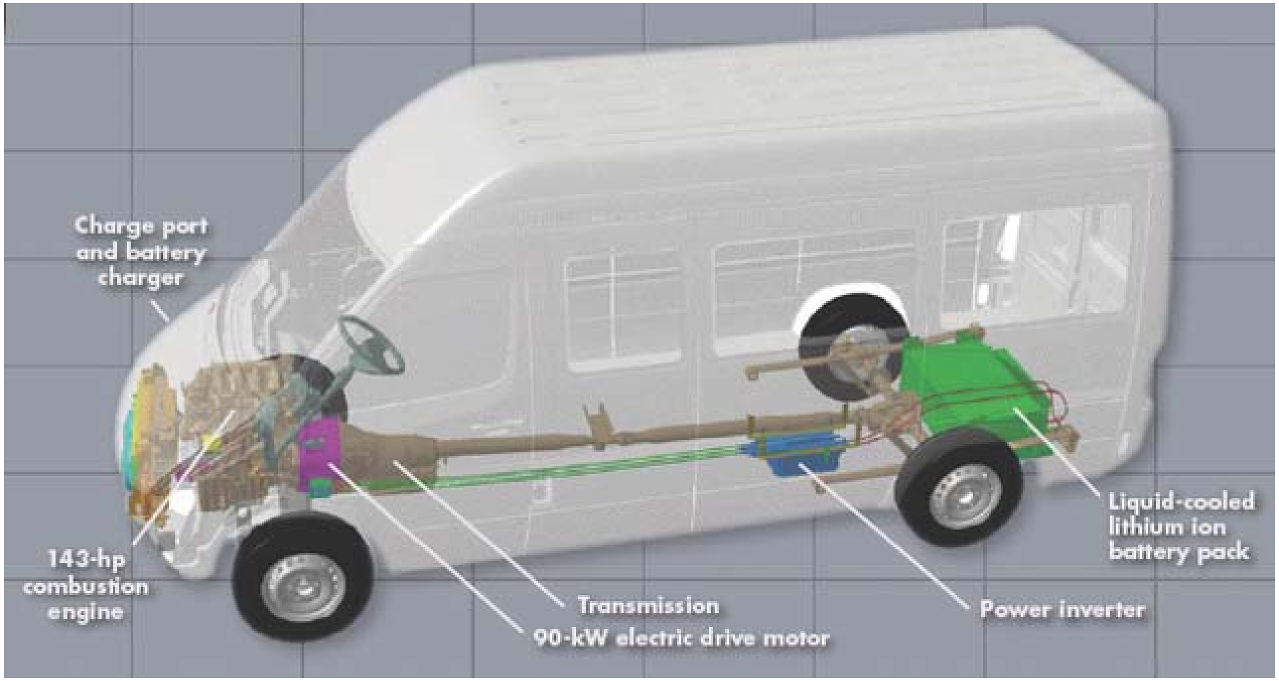
Source: Prof. Andy Frank, UC Davis

Example: Hymotion PHEV

- Plug-In Hybrid Electric Vehicle
- 20 mile Li-Ion battery pack
- Initial cost ~$10,000 (maybe $5,000 in volume)
- Voids warranty, battery life unknown

Example: Tesla – high performance niche

Many manufacturers are developing (PH)EVs



Fuel savings are less than today's battery prices

Gasoline price	$2/gal		$3/gal		$4/gal	
Annual PHEV fuel savings						
Elec. Price ($/kWh)	CV	HEV	CV	HEV	CV	HEV
$0.05	$294	$155	$471	$264	$649	$373
$0.10	$231	$93	$409	$202	$587	$311
NPV of PHEV fuel savings (n=12, r=16%)						
Elec. Price ($/kWh)	CV	HEV	CV	HEV	CV	HEV
$0.05	$1,525	$807	$2,450	$1,372	$3,375	$1,938
$0.10	$1,201	$483	$2,216	$1,048	$3,051	$1,614
Breakeven battery costs ($/kWh, n=12, r=16%)						
Elec. Price ($/kWh)	CV	HEV	CV	HEV	CV	HEV
$0.05	$298	$277	$479	$472	$600	$666
$0.10	$235	$166	$416	$360	$597	$555

Source: Lemoine et al (2008)

PHEVs can reduce GHG emissions substantially

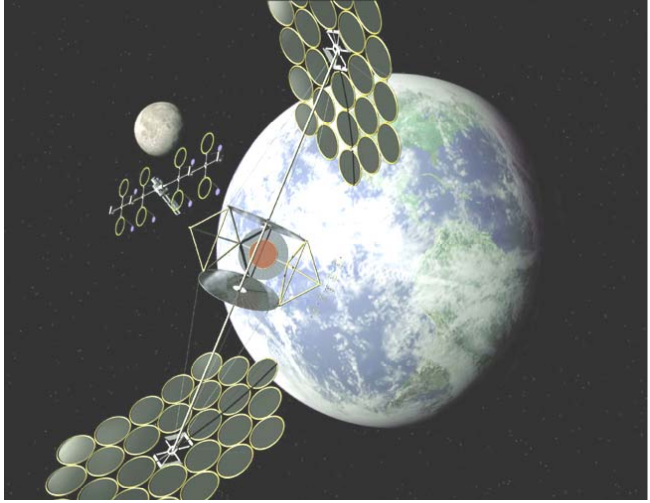
Energy sources				
	Gasoline	US avg.	CA avg.	Wind
Compact Car				
CV	294			
HEV	225			
PHEV20	211	199	116	1
PHEV60	203	198	115	1
Sport Utility Vehicle				
CV	605			
HEV	401			
PHEV20	375	346	202	2
PHEV60	367	329	192	2

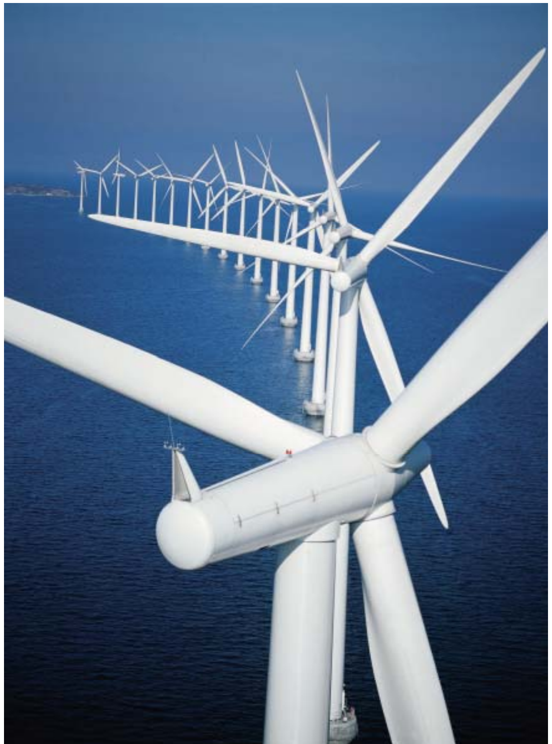
Units: gCO2e/mi.

Source: Arons et al (2008)

Hydrogen

- Major new distribution infrastructure is needed
- Energy storage is poor and fuel cell vehicles will likely be expensive
- Resource base is very large
- Uncertain environmental effects





The race for 21st century fuels

	Efficiency	Fossil	Biofuels	Electricity	Hydrogen
Infrastructure	+	+	+	+	–
Vehicles	+	+	+	–	–
Resources	–	+	–	+	+
Environment	+	–	?	?	?

Note: These are rough, subjective judgments that depend on how various fuels are produced, and they will change with innovation.