

GEOS 3310 Lecture Notes: Energy Resources

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Introduction

Fundamental trends:

- worldwide energy demand increasing rapidly (30% increase by 2030, Fig. 1)
- this will provide upward pressure on oil prices (Fig. 2)
- but expanding supplies of U.S. natural gas prices keep prices down (Fig. 3)
- increasing domestic oil production reducing imports (Fig. 4)
- alas coal remains king for electricity production (Fig. 5)

- transition from coal to natural gas, increasing energy efficiency keep CO₂ emissions below 2005 peak (Fig. 6)

World Energy Consumption

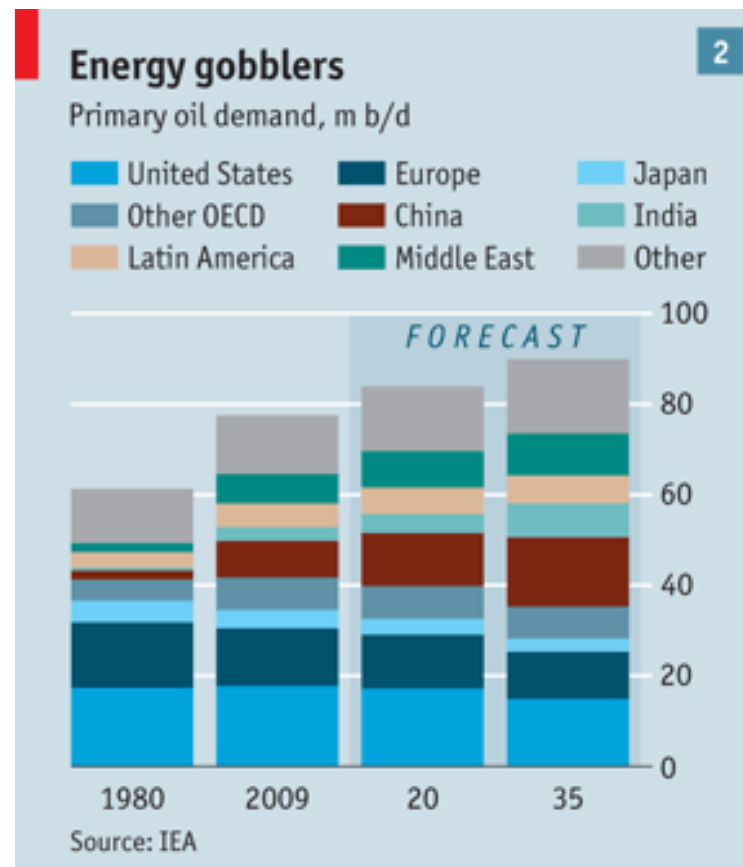
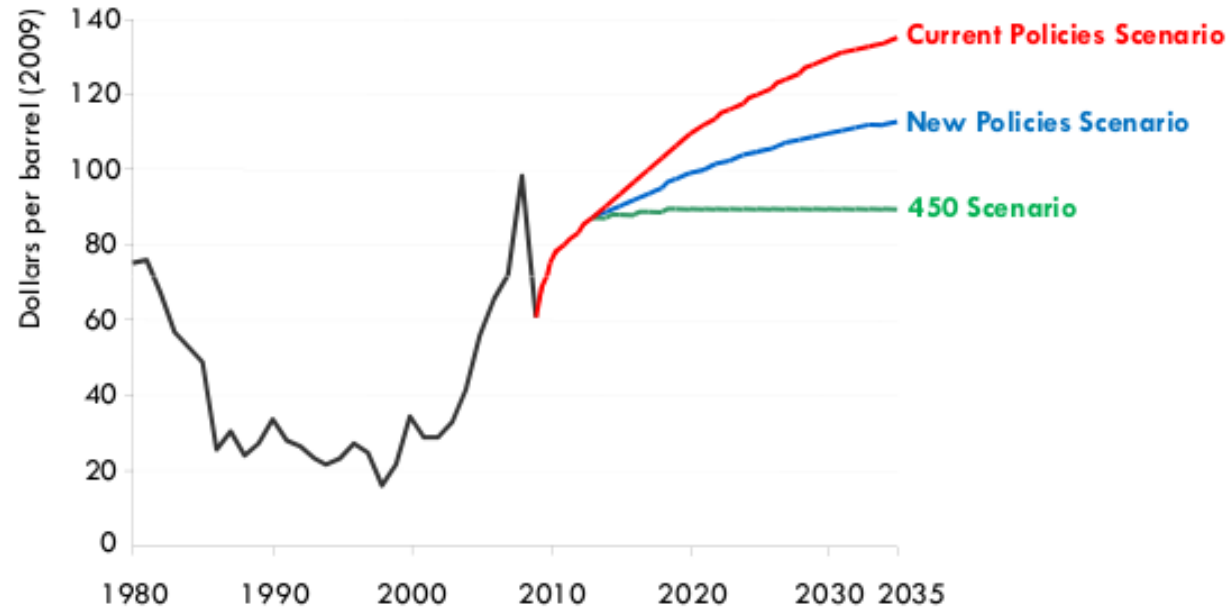


Figure 1: World consumption expected to increase by 36%, most of that growth from China. After IEA World Energy Outlook .

World Oil Prices



The age of cheap oil is over, though policy action could bring lower international prices than would otherwise be the case

Figure 2: Continued demand growth should drive oil prices higher, from IEA World Energy Outlook . “450 Scenario” refers to strategy to keep atmospheric CO₂ ≤ 450 ppm (currently about 390 ppm).

US NatGas Supplies

Figure 2. U.S. natural gas production, 1990-2035 (trillion cubic feet)

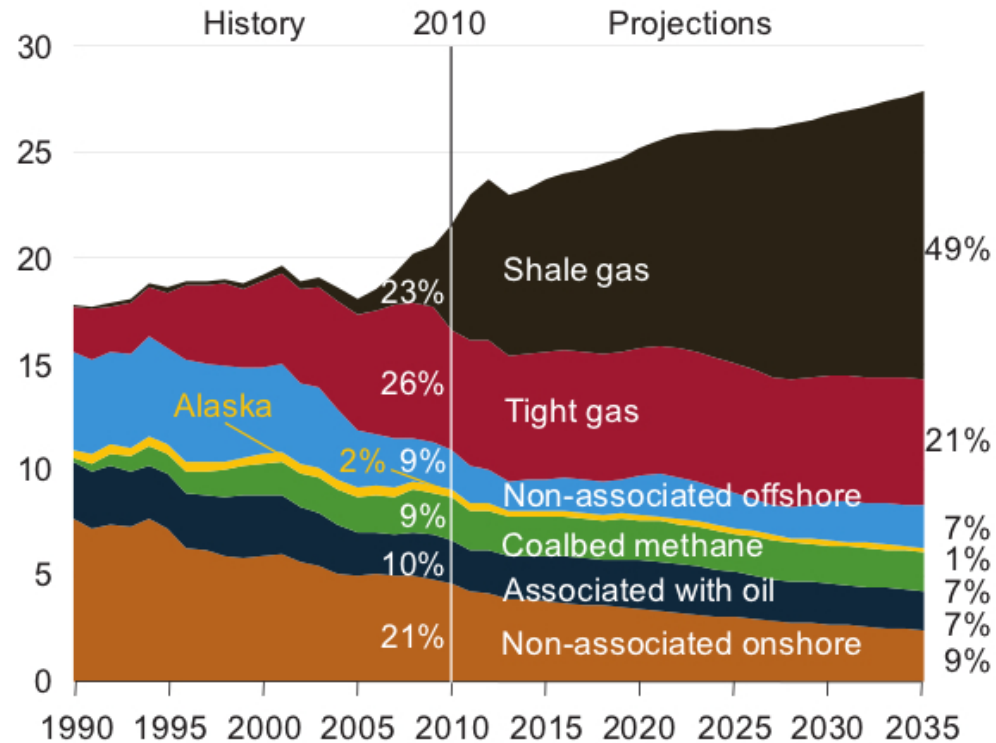


Figure 3: EIA projections of US natural gas supplies, after EIA Energy Outlook .

US Petroleum Supplies

Figure 1. U.S. liquid fuels supply, 1970-2035
(million barrels per day)

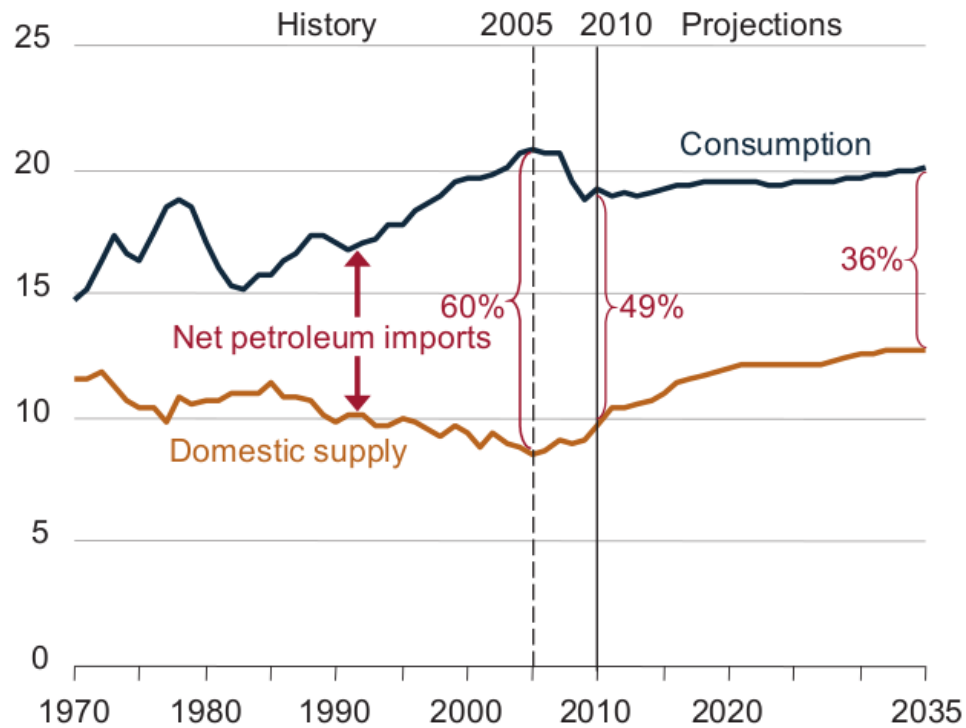


Figure 4: EIA projections of US liquid fuel (petroleum) supplies, from EIA Energy Outlook . Good news: increased production (primarily using hydrofracking) is reducing dependence on imports.

US Electricity Production by Fuel

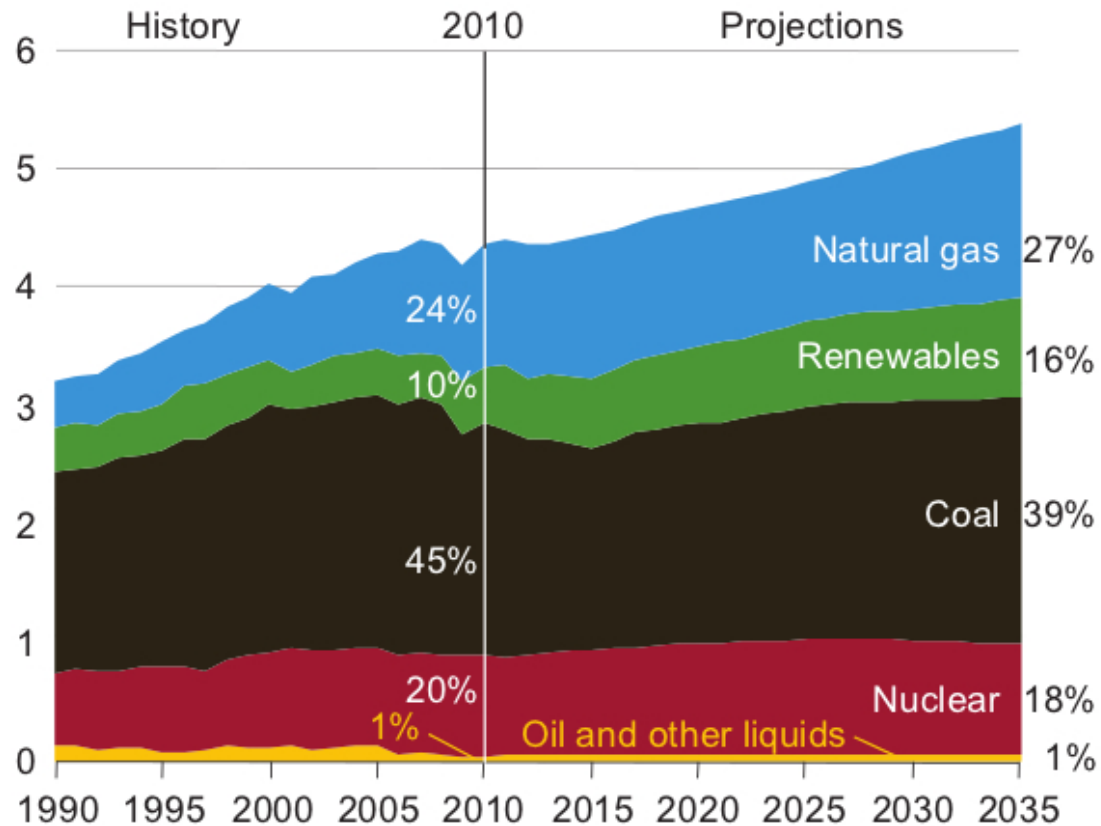


Figure 5: EIA projections of US electricity production by fuel EIA Energy Outlook .

Projected CO₂ Emissions

Figure 4. U.S. energy-related carbon dioxide emissions, 1990-2035 (billion metric tons)

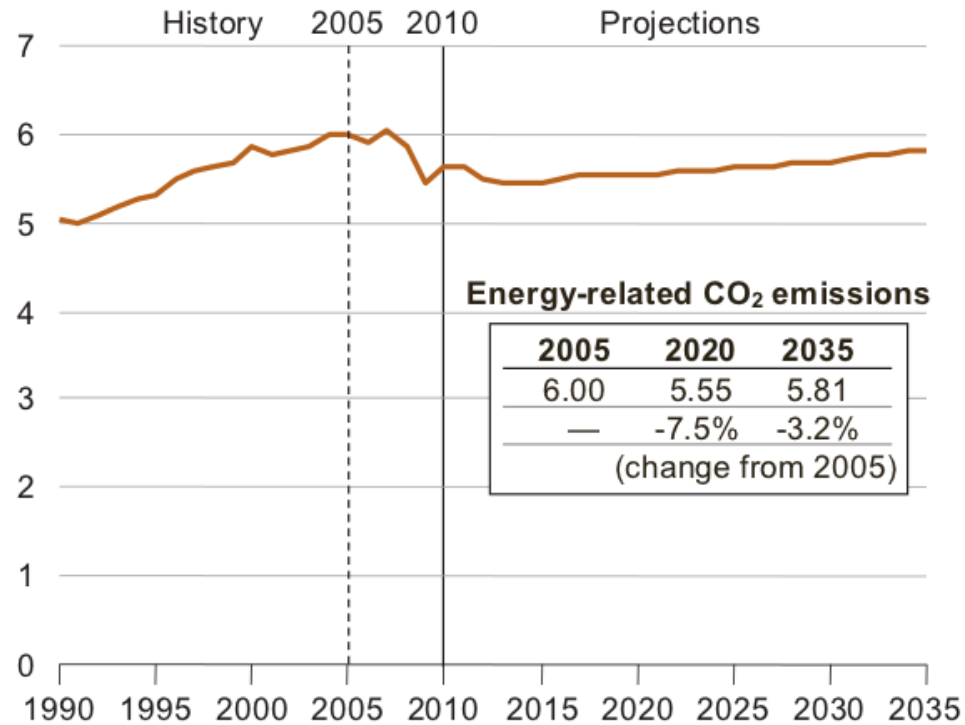


Figure 6: EIA projections of US CO₂ emissions EIA Energy Outlook .

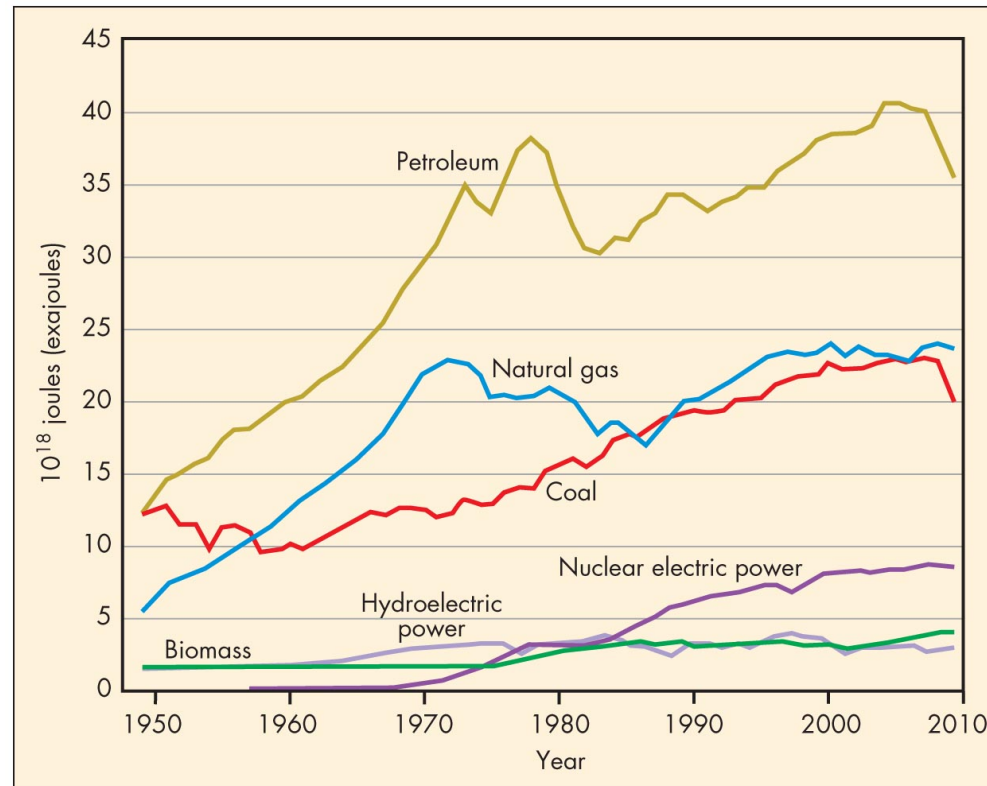
Introduction

Many of the things and almost all of the energy we use are extracted from the Earth. This section discusses the formation, extraction, existing supply, and consequences of energy resources.

- U.S. Energy usage
 - usage has steadily increased, except during oil crises/major recessions (Fig. 7)
 - the U.S. consumes about 30% of all energy produced in the world (Fig. 1)
 - U.S. consumption has exceeded discovery since 1980 [Fig. 15.1, Keller, 2008]
 - we have about 3% of the world's petroleum reserves, and consume about 25% of the world's petroleum production

- World distribution of energy resources
 - *petroleum* (oil) is highly concentrated in the Middle East (Fig. 8)
 - *natural gas* is concentrated in the former Soviet Union and Middle East (Fig. 9)
 - * also heavy dependence on Russian gas in Europe , which affects geopolitics
 - *coal* is relatively uniform world-wide (Fig. 10)

U.S. Energy Consumption By Source



(a)

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Figure 7: U.S. energy consumption by source, [Fig. 16., Keller, 2011].

Worldwide Oil Distribution

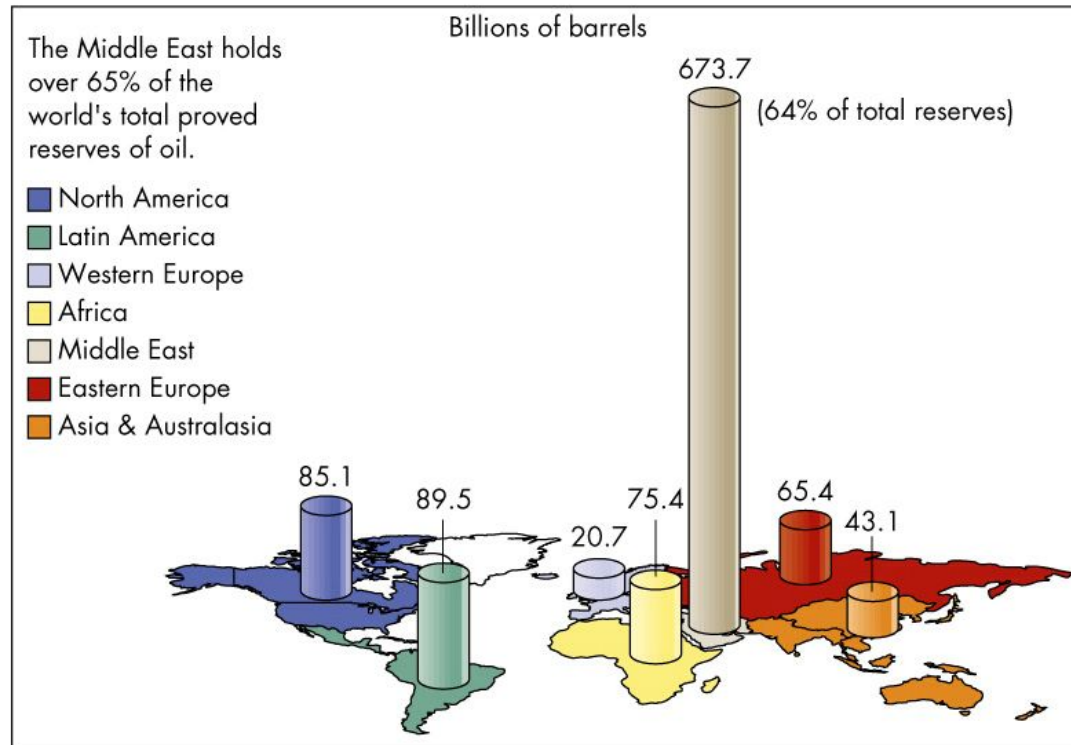


Figure 8: Distribution of petroleum reserves worldwide [Fig. 16.16, Keller, 2011]. Concentration of resources in the Middle East has a dramatic impact on world politics and finance.

Worldwide Natural Gas Distribution

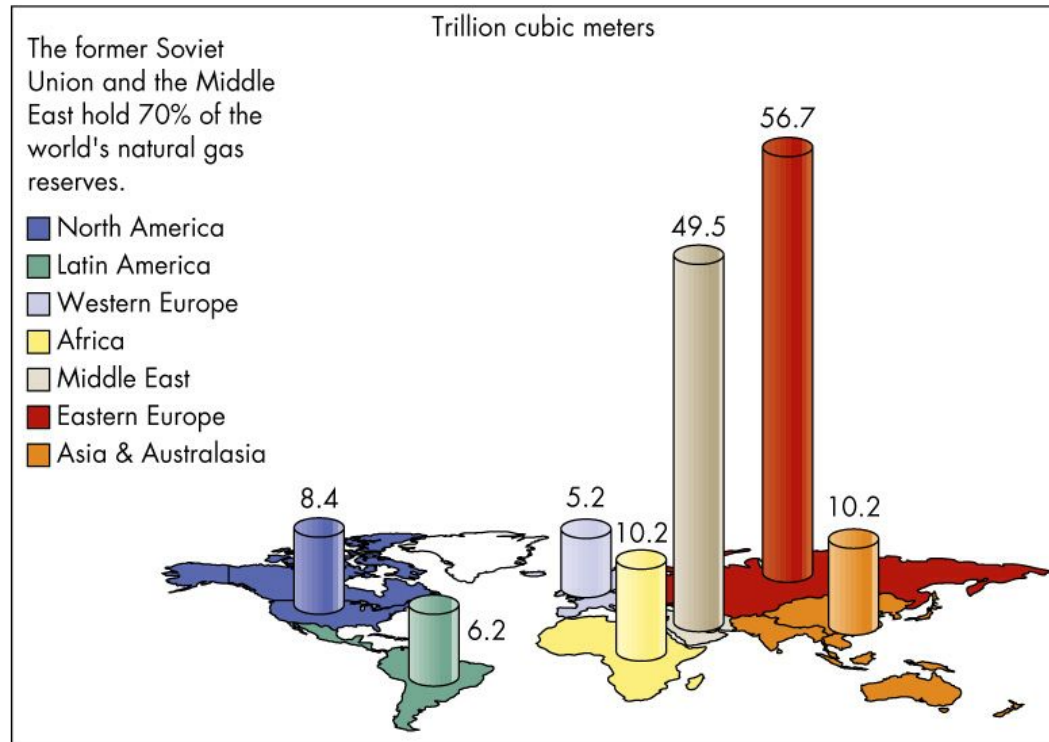


Figure 9: Distribution of natural gas reserves worldwide [Fig. 13.11b, Keller, 2005]. Concentration of resources in the former Soviet Union is important, but overseas export will be difficult. Figure doesn't account for recent shale gas development (U.S. share much higher than shown).

Worldwide Coal Distribution

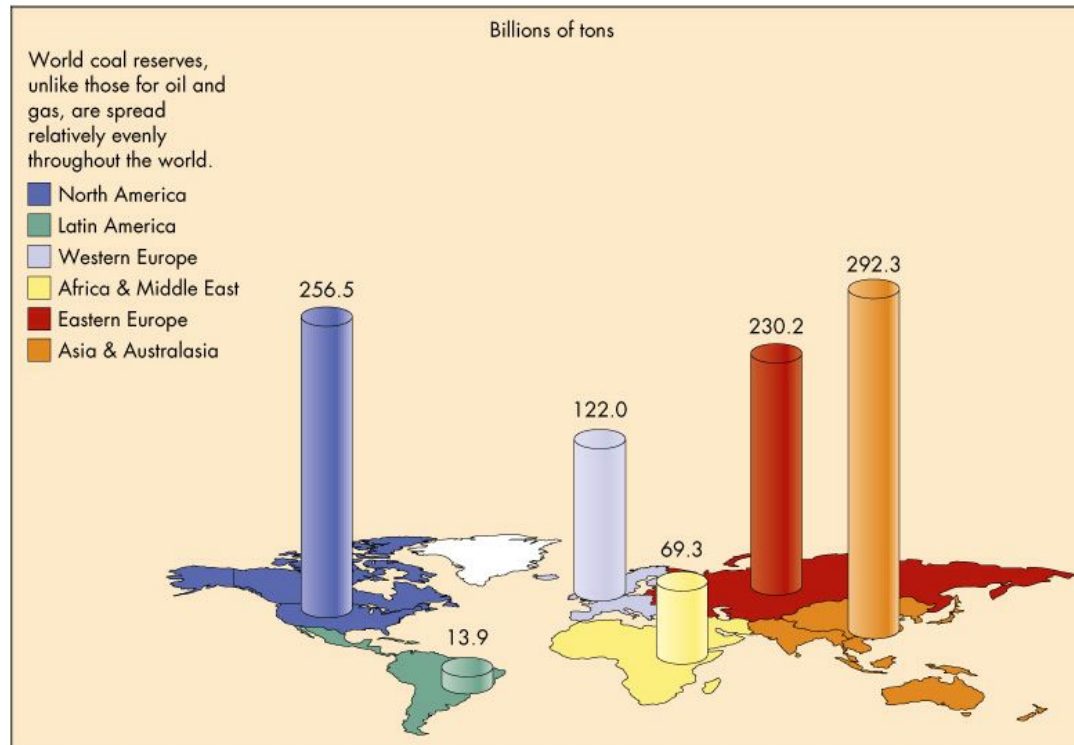


Figure 10: Distribution of coal reserves worldwide [Fig. 16.8b, Keller, 2011]. These are relatively uniform, making coal the universal “fallback” energy source.

Coal

Coal Details

- coal forms from a 3-step process, usually beginning with coastal swamps [Fig. 16.6, Keller, 2011]
- maturation of coal removes volatiles and moisture, increasing the carbon content and *heat value* (energy content) [Fig. 16.7, Keller, 2011]
- most U.S. coal has low sulfur content (i.e. produces less pollution), but is bituminous (moderate heat value) [Fig. 16.8a, Keller, 2011] [Tbl. 16.2, Keller, 2011]
- a list of the largest U.S. coal mines is available from the U.S. EIA (most in WY; TX Jewett Canyon is 38th largest)

- impacts of coal mining
 - primarily environmental disruption from *strip mining* [Fig. 15.6, Keller, 2000], *contour mining* [Fig. 15.7, Keller, 2000], and *mountaintop removal* (which primarily disrupts drainage)
 - and *acid mine drainage* (indirectly *acid rain* from coal combustion)

Clean Coal

Somewhat of an oxymoron, this refers to pollution-limiting technologies applied to coal-fired power plants.

- refers to removal of major pollutants, e.g. SO_2 , and more recently CO_2
- CO_2 removal and storage is new technology,
 - likely to be expensive
 - will take 10-15 years to implement (e.g. ThisIsReality commercial)
- removing other pollutants is relatively well-established technology (e.g. scrubbing, see Air Pollution chapter)

Petroleum

Petroleum Occurrence

- hydrocarbons (oil and natural gas) are derived from buried organic material that didn't completely decompose after burial
- the bulk of the source material for hydrocarbons was deposited in a few geologic time periods (e.g. the Cretaceous, 60-120 MY ago)
- the buried hydrocarbons must be metamorphosed by mild heat (by burial 1-3 km deep [Fig. 16.13, Keller, 2011])
- then these matured hydrocarbons migrate in permeable *reservoir rocks* to locations where they can accumulate (*traps*) [Fig. 16.14, Keller, 2011]

- world petroleum resources are strongly concentrated near tectonic belts that have been active in the last 60 million years [Fig. 15.11, Keller, 2000]
- petroleum production requires a complex system (Fig. 11) of wells, pipelines, refineries and disposal systems (e.g. for *oilfield brines*)
- alternative sources of petroleum are *tar sands*, where oil can be mined directly (e.g. Alberta, Canada , 24% of our imports), and *oil shales* (e.g. Colorado-Utah) [Fig. 15.13, Keller, 2000]. See USGS Report

Petroleum Production System

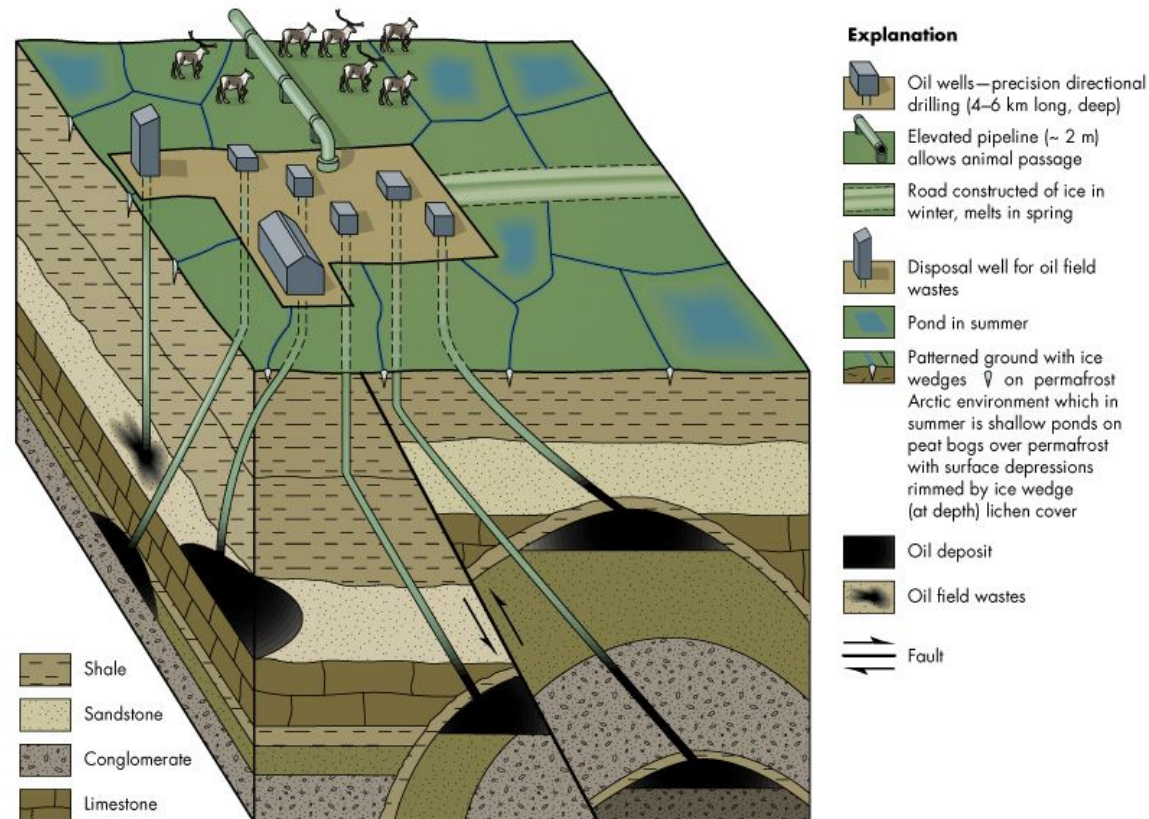


Figure 11: Extraction and distribution for petroleum reserves in Arctic conditions [Fig. 16.19a, Keller, 2011].

Oil Supply Limitations

- “Peak Oil”
 - world oil production can be viewed as having peaked (Fig. 12)
 - see also Wikipedia images
 - good U.S. summary of production peaks for non-OPEC nations (Fig. 6-7)
- perhaps more important is peak price
 - demand tends to decline as oil price rises, often around the \$100/bbl mark
 - petroleum prices are extremely volatile , as should be expected for a commodity

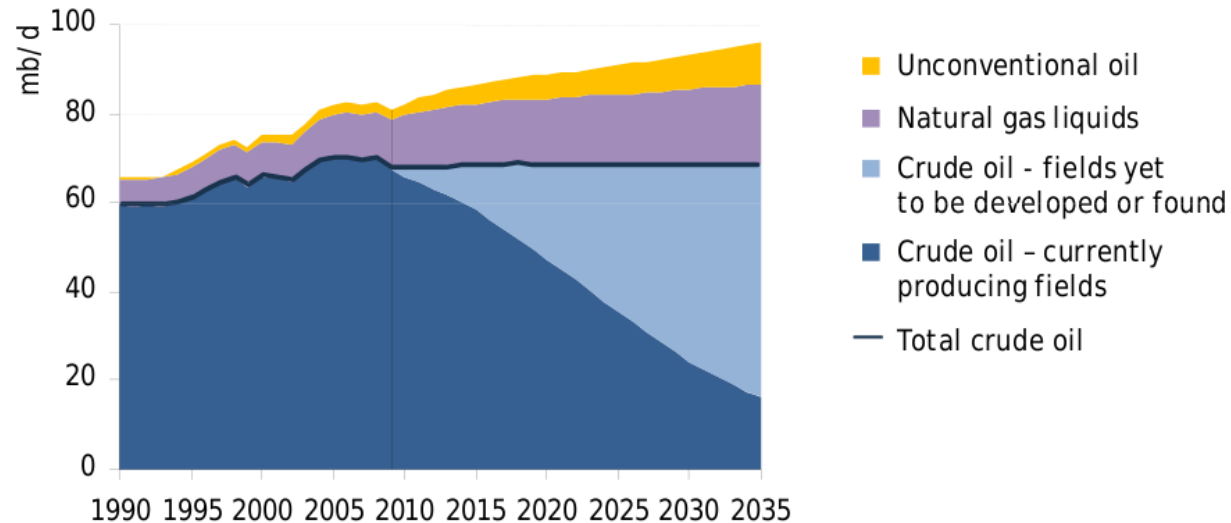
- inflated worldwide reserves?
 - see Wikileaks cable
 - or (potentially biased) detailed summary)

” [World] reserves are confused and in fact inflated. Many of the so-called reserves are in fact resources. They’re not delineated, they’re not accessible, they’re not available for production.”

Sadad I. Al-Husseini, former VP of Aramco, presentation to the Oil and Money conference, October 2007.

Peak Oil

World oil production by type in the New Policies Scenario



Global oil production reaches 96 mb/d in 2035 on the back of rising output of natural gas liquids & unconventional oil, as crude oil production plateaus

Figure 12: Oil production plateau in known resources indicated by IEA . *Undiscovered resources* may be significant, at least we hope. . .

Arctic National Wildlife Refuge

- drilling in this nature preserve north of the Arctic Circle in Alaska (Fig. 13) is very controversial
- development would threaten caribou herds and general environmental health
- resulting oil supply is estimated to be no more than 6-month's total supply for the U.S. (7.7 billion barrels)
- world oil price impact would be minimal. From the EIA in March 2004:
 - ”It is expected that the price of ANWR coastal plain production might reduce world oil prices by as much as

30 to 50 cents per barrel... Assuming that world oil markets continue to work as they do today, the OPEC could countermand any potential price impact of ANWR coastal plain production by reducing its exports by an equal amount.”

- so we must be careful not to let the ANWR debate distract us from the much larger energy import problem faced by the U.S.

ANWR Location Map



Figure 13: Location of the Arctic National Wildlife Refuge [Fig. 16.18a, Keller, 2011].

Offshore U.S. Drilling

Offshore Oil Predictions		
Estimated results from expanded drilling in Outer Continental Shelf		
	EIA	NPC/ARI
Added barrels per day, 2025	220,000	990,000
% of total U.S. crude-oil consumption	1.4%	6.1%
Years to start first production	4-6	3

Figure 14: Estimated output from offshore drilling, after FactCheck.org . EIA is U.S. Energy Info. Agency estimate, NPC is National Petroleum Council (industry group). U.S. resources probably insufficient to allow us to “ Drill Here, Drill Now, Pay Less ” , but dependence on imports is decreasing significantly.

Fossil Fuels and Acid Rain

Acid Rain Details

- fossil fuels rich in sulfur dioxide yield sulfur compounds in smokestack and tailpipe effluent [Fig. 16.21, Keller, 2011]
- these accumulate in precipitation and surface water bodies.
- concentrated in Eastern U.S. , steadily decreasing with time
- Particularly along the East Coast the net effect has been marked [Fig. 16.20, Keller, 2011]
- vegetation is most harmed by acid rain, followed by man-made structures. Mountainous areas are most sensitive to acid rain [Fig. 16.22, Keller, 2011]

- switching to low-sulfur fuels and/or addition of smokestack controls can greatly reduce acid rain

Nuclear Energy

Nuclear Fission

- *fission* produces energy when atomic nuclei are split apart by neutron bombardment. The process can produce a self-sustaining *chain reaction* [Fig. 16.24, Keller, 2011]
- nuclear power plants produce energy by heating water or other liquids which expand to drive a turbine [Fig. 16.25, Keller, 2011] functioning the same way as a conventional power plant [Fig. 15.21a, Keller, 2008]
- since nuclear fuel utilizes a self-sustaining reaction, dampers (neutron absorbers) or control rods are used to control the reaction [Fig. 15.22a, Keller, 2008] inside of a *containment structure* designed to withstand at least minor runaway reactions

- the U.S. produces about 20% of its electricity from nuclear, other nations such as France much more
- Risks:
 - runaway reaction, e.g. Chernobyl (Fig. 15) and [Fig. 15.E, Keller, 2000]
 - * accident caused by severe operator error
 - Fukushima Plant, Japan
 - * designed for 6 m tsunami, hit by 15 m (48 ft) high tsunami
 - * older risky design stored spent fuel on top floor, requiring well-maintained supply of cooling water (this failed after tsunami, allowing melting and explosion of spent fuel)
 - * see comparison to Chernobyl

- long-lived toxic waste (high-level nuclear waste) that must be stored for thousands of years
- nuclear appears to be safest way to generate power in terms of environmental health risks (Fig. 16)

Chernobyl Contamination

Figure 31. Radiation Hotspots Resulting From the Chornobyl' Nuclear Power Plant Accident



Figure 15: Radiation map from Chernobyl reactor accident. After CIA study .

Electricity Generation and Health

Table 2
Health effects of electricity generation in Europe by primary energy source (deaths/cases per TWh)

	Deaths from accidents		Air pollution-related effects		
	Among the public	Occupational	Deaths*	Serious illness†	Minor illness‡
Lignite ¹⁰	0.02 (0.005-0.08)	0.10 (0.025-0.4)	32.6 (8.2-130)	298 (74.6-1193)	17 676 (4419-70 704)
Coal ¹¹	0.02 (0.005-0.08)	0.10 (0.025-0.4)	24.5 (6.1-98.0)	225 (56.2-899)	13 288 (3322-53 150)
Gas ¹¹	0.02 (0.005-0.08)	0.001 (0.0003-0.004)	2.8 (0.70-11.2)	30 (7.48-120)	703 (176-2813)
Oil ¹¹	0.03 (0.008-0.12)	--	18.4 (4.6-73.6)	161 (40.4-645.6)	9551 (2388-38 204)
Biomass ¹¹	--	--	4.63 (1.16-18.5)	43 (10.8-172.6)	2276 (569-9104)
Nuclear ^{11,12}	0.003	0.019	0.052	0.22	--

Data are mean estimate (95% CI).

* Includes acute and chronic effects. Chronic effect deaths are between 88% and 99% of total. For nuclear power, they include all cancer-related deaths.

† Includes respiratory and cerebrovascular hospital admissions, congestive heart failure, and chronic bronchitis. For nuclear power, they include all non-fatal cancers and hereditary effects.

‡ Includes restricted activity days, bronchodilator use cases, cough, and lower-respiratory symptom days in patients with asthma, and cases, cough, chronic cough episodes. TWh=10¹² Watt hours.

Figure 16: Health effects from electricity generation in Europe, from [Markandya and Wilkinson, 2007]. Nuclear is the safest, but nuclear accidents remain quite prominent in the public mind.

Nuclear Fusion

- *nuclear fusion* is the assembly or combination of light elements to make heavier elements [Fig. 15.24, Keller, 2000]
- this process is the source of the Sun's energy
- essentially non-polluting
- very safe, since the reaction halts if there is any breakdown in containment
- slow progress on development, although recent European test was the first output more energy than was consumed for containment

Radioactive Waste

Waste Disposal Methods

- two main categories, low and high-level waste
- *Low-Level Waste*: [Fig. 12.15, Keller, 2000] .
 - typically medical wastes, etc.
 - must be kept away from accessible environment for *500 years*
 - usually 2-3 states will form a compact and bury each other's wastes.
 - Texas has a compact with Vermont , which may be opened to 36 other states
- High-Level Waste

- very nasty, must be kept away from accessible environment for *10,000 years* [Fig. 12.14, Keller, 2000] .
- a few centralized facilities are available
 - * WIPP site for defense-related waste in NM [Fig.16.26, Keller, 2011]
 - * Yucca Mountain Repository [Fig. 15.24, Keller, 2008], currently abandoned, now being revisited
- very problematic to try to understand and predict system for that time period:
 - * WIPP site is in salt, and is experiencing great problems with liquid migrating as isolated pores in the malleable salt [Bredehoeft, 1988]
 - * Yucca Mountain was found to have 10-100 times more water moving through the proposed repository than predicted [Flint et al., 2001]

Renewable Energy

Geothermal Energy

- *geothermal energy* utilizes the Earth's heat to produce electricity, or for direct cooling or heating
- sometimes a magmatic heat source is nearby [Fig. 16.29, Keller, 2011]
- geothermal energy is most cost-effective where the *geothermal gradient* is highest [Fig. 16.27a, Keller, 2011], and that is in the Western U.S. where igneous activity and crustal thinning are relatively common [Fig. 16.27b, Keller, 2011], contributing to high surface heat-flow
- elsewhere in the U.S., *geothermal (or ground source) heat pumps* can be valuable, exchanging heat with the subsurface

(which remains at around 55 F) to reduce energy used for heating/cooling. See also Wikipedia .

- Very important in areas like Iceland, where abundant renewable energy has sparked a major industrial boom (aluminum production , banana growing)
- even possible in deep abandoned oil wells in Texas

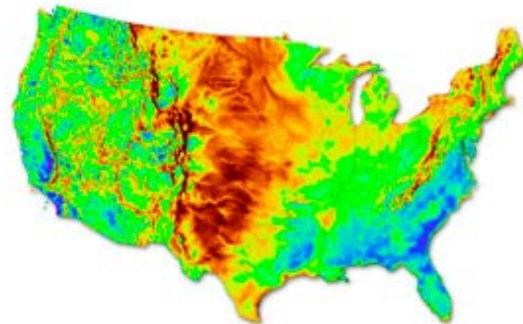
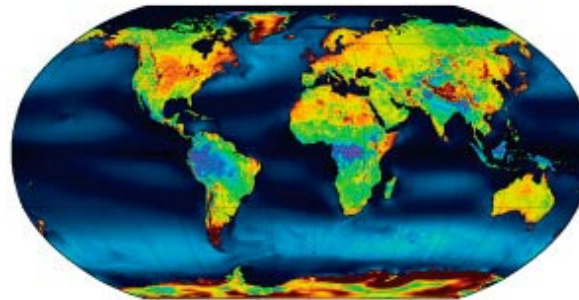
Wind Energy

- becoming important in many areas of the U.S. , e.g. Texas had 4,600 MW of installed wind-power capacity in 2007
- especially the mid-west has excellent wind resources (Fig. 17)
- Locations take advantage of geographic features such as mountain passes that focus wind [Fig. 16.34a, Keller, 2011] or regionally windy areas
- unreliable (can't be scheduled, e.g. Feb. 2008 TX wind "failure")

- needed: ways to transport produced energy to cities, and to store the energy

Surface Winds, U.S. and World

Wind speed over land



3TIER
U.S. National Wind Map
© Copyright 1998-2000, 3TIER, Inc.

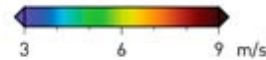


Figure 17: Average wind speed over land, U.S. and World. Large turbines need speeds $\geq 7 \frac{\text{m}}{\text{sec}}$. From NASA .

Other Renewables

- generally renewable energy sources are directly or indirectly derived from the Sun [Fig. 16.31, Keller, 2011],
- solar energy can be used to heat water for turbine-electricity generation, [Fig. 15.36, Keller, 2000], but most often photovoltaic cells [Fig. 15.33, Keller, 2000] are used for direct electricity generation, or *passive solar* energy is used to heat water for direct use or space heating
- almost all of the U.S. has sufficient solar usability to allow solar energy development) insolation $\geq 150 \frac{\text{W}}{\text{m}^2}$)
- solar prices declining rapidly , but natural gas giving it stiff competition for cheapness

- *hydroelectric* uses dams to pool water to drive turbines, and is an important source of electricity in the U.S. Future hydroelectric development will be very limited because most suitable rivers have already been developed

Biofuels

- another potential energy source is alcohol or methane generated from agricultural or other products (see DOE Biomass webpage)
- often politically popular since this approach allows existing farm subsidies to be applied to energy problems (e.g. see BioWillie)
- generally energy inefficient:
 - agricultural biofuels require 1 unit of fossil fuels to produce 2-3 units of biofuel (see EEC report)
 - corn is worse, requiring 7 units of fossil fuel to produce 8 of corn-based ethanol (based on 2002 farming efficiency data)

- * see also 2006 “Corn Can’t Solve Our Problem”
- *cellulosic sources* like switchgrass or algae can reduce petroleum usage by 90% per vehicle mile (Fig. 18)
- automotive fuel efficiency declines significantly (around 20%) when ethanol fuels are used
- biofuels tend to release high amounts of NO₂, a strong greenhouse gas. So while biofuels may reduce mass of greenhouse gases released per gallon, the greenhouse effect per gallon may be increased.
- EPA draft analysis of lifetime reductions in greenhouse gases highlights these trends (corn bad, cellulosic good. . . section *Environmental effects*)

Ethanol Energy Benefits

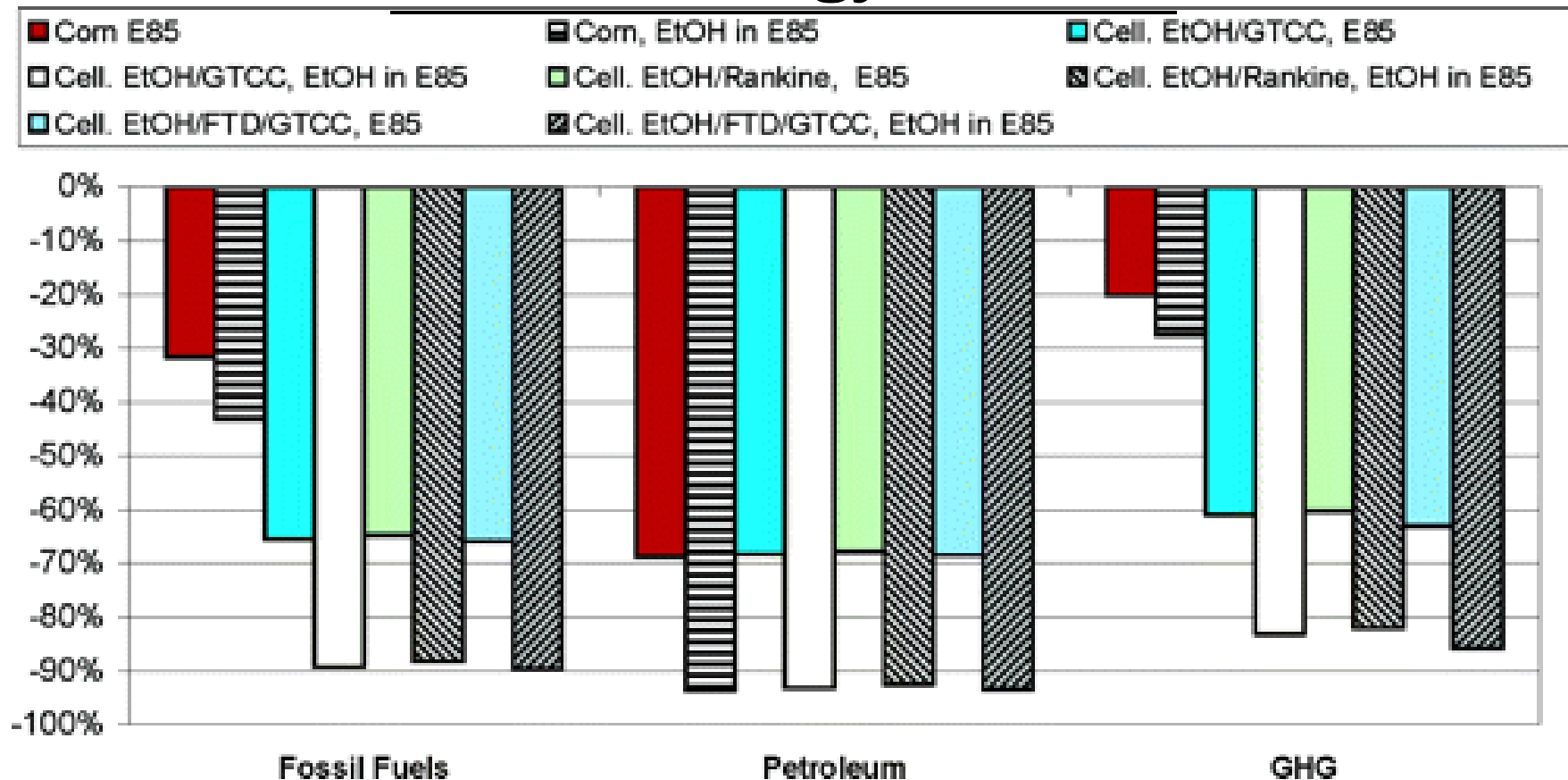


Figure 18: Theoretical optimum energy savings and greenhouse gas (GHG) emissions reduction for biofuels. Corn ethanol is starch-based, requiring much fossil energy usage, cellulosic fuels produced using waste biomass as energy source. Use of high-efficiency production and consumption (i.e. biofuel-hybrid vehicles) is assumed, after Wu et al. [2006].

U.S. Energy Supply

- de-politicising conservation issues often quite effective (e.g. better than Al Gore).
See DOE Case Studies

Texas Deregulation

- Texas deregulated the former electric utility monopoly in 2002
- since then consumers can choose their electric provider
- a central website provided by the TX Public Utilities Commission gives comparative quotes
- each utility provides an *energy facts label* giving fuels mix, waste/CO2 generation, etc.
- independent consumer organizations also publish useful reviews. E.g. Consumers Union clarifies the fine print and

notes that single-digit savings ($<10\%$) were most likely in 2002.

Other Resources

Useful Links

This is intended to be an ever-evolving list of useful links on the general topic of this note set.

- National Petroleum Council report . A reasonably unbiased look at energy future, released July 2007.
- good summary of world production/demand/consumption by BP . For 2007 global oil production fell for the first time in five years, down 0.2%, while consumption increased by 1.1%
- MSNBC Answer Desk quick summary of drilling vs. conservation
- USGS study of likely Arctic oil resources

- FactCheck.org relatively unbiased assessment of “tire inflation vs. offshore drilling” controversy
- American Wind Energy Assn.
- Barnett Shale information
 - summary of history and status as of 2007
 - hydrofracking per se presents little hazard (too deep), poorly constructed wells & surface activities pose the main hazard
- U.S. Military warning of Peak Oil by 2015
- good animation of hydrofracing and wastewater issues

- UT Hydrofracking study shows its mostly poor waste disposal. Similar indications from USGS study that addresses 25% increase in $>M3$ quakes in central US this century
- Guy, AK earthquake swarm shows very strong probability of being linked to wastewater injection [Horton, March/April 2012]

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