World Energy Needs, Fossil Fuel Reserves (cont'd), and CO_2 Sequestration

AOSC 434/658R & CHEM 434/678A

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Class Web Site: http://www.atmos.umd.edu/~rjs/class/spr2011

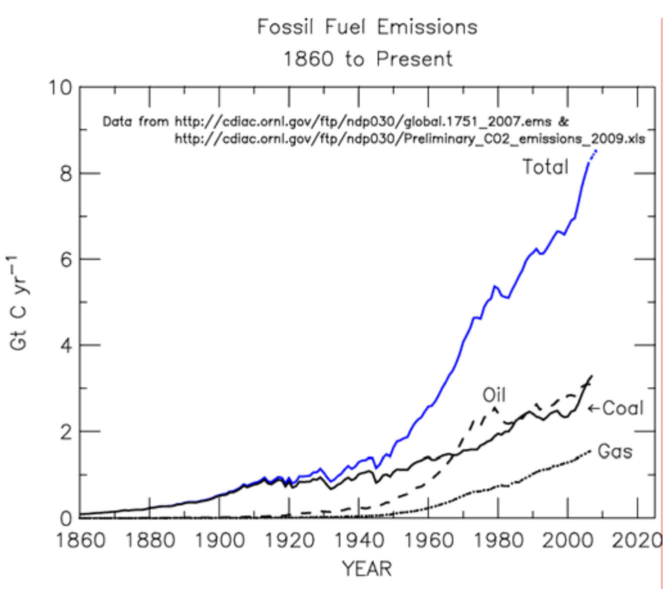
Topics for today:

- **Review of Fossil fuel Reserves (focus on natural gas)**
- **Overview of attempts to regulate future atmospheric CO_2 via:**
  - **Public policy**
  - **Engineering**
- **World Energy Needs: Population and Standard of Living**

Lecture 19

19 April 2011

Fossil Fuel Emissions and Reserves



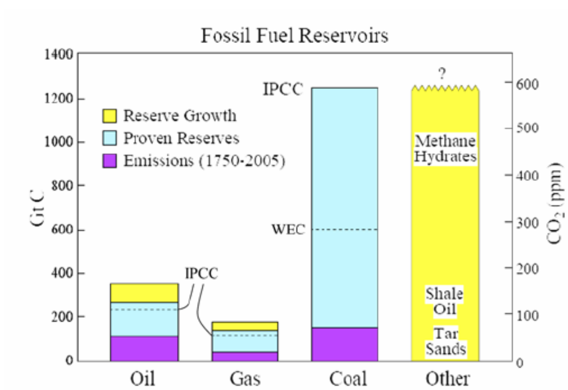
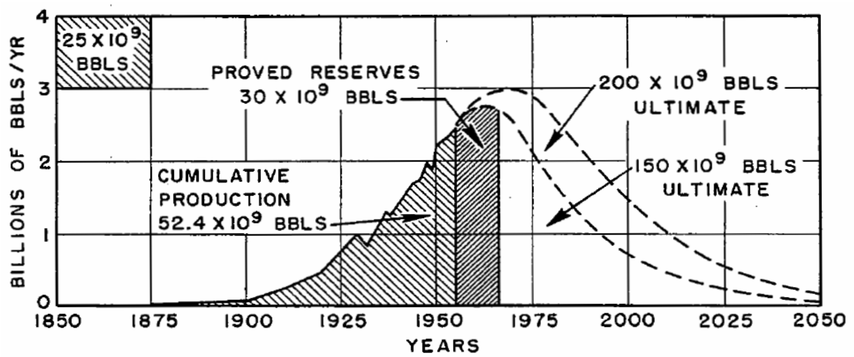


Figure 1. Fossil fuel-related estimates used in this study. Historical fossil fuel CO_2 emissions from the Carbon Dioxide Information Analysis Center [CDIAC; *Marland et al.*, 2006] and British Petroleum [*BP*, 2006]. Lower limits for current proven conventional reserve estimates for oil and gas from *IPCC* [2001a] (dashed lines), upper limits and reserve growth values from US Energy Information Administration [*EIA*, 2006]. Lower limit for conventional coal reserves from World Energy Council [*WEC*, 2007; dashed line], upper limit from *IPCC* [2001a]. Possible amounts of unconventional fossil resources from *IPCC* [2001a].

Kharecha and Hansen, *GBC*, 2008.

How Much Fossil Fuel Reserve Does The World Really Have?

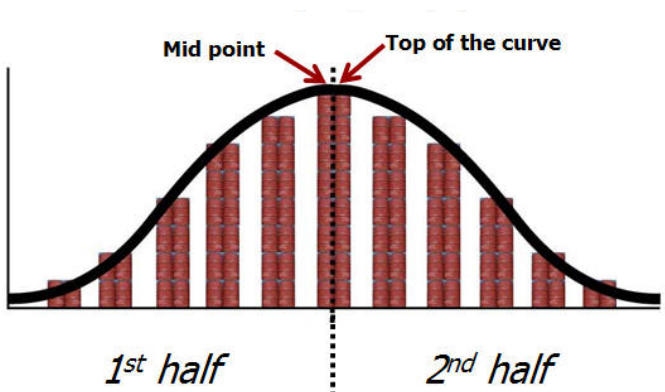
Hubbert's Peak



- **M. King Hubbert: Shell geophysicist**
- **1956 : presented a paper "Nuclear Energy and Fossil Fuels" that predicted US oil production would peak in 1970**
- **Paper was met with skepticism & ridicule**
- **But: *<u>this prediction was remarkably accurate</u>* !**

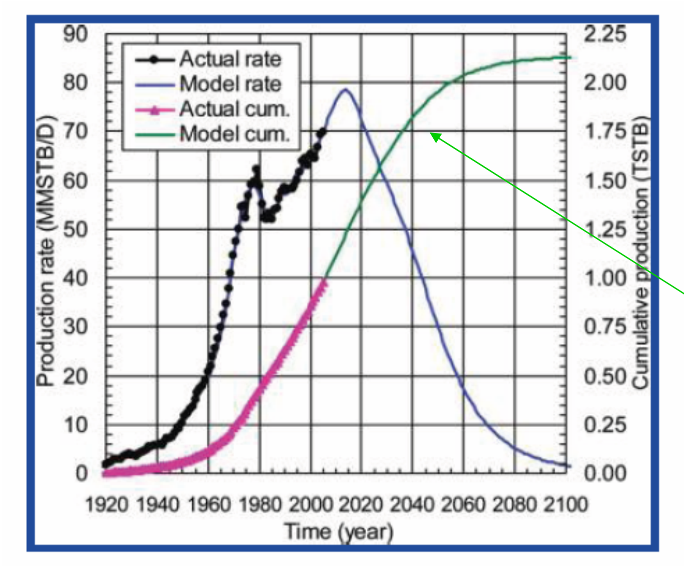
Mathematics of Resource Use

It is unlikely that an industry will go from full production of a resource to zero production the next year. It is reasonable to assume that production will follow an exponential growth while a resource is easy to find and relatively cheap to produce. As the resource becomes harder to find, prices rise, production rates peak, and then begin to decrease.



The area beneath this curve is the total amount of resource available.

Global *Oil* Production Predicted to Peak Next Decade !



Hubbert-like analysis applied to 47 major oil producing countries leads to conclusion that global production of oil will peak near 2014.

Actual production curve shows effects of economic and geo-political events

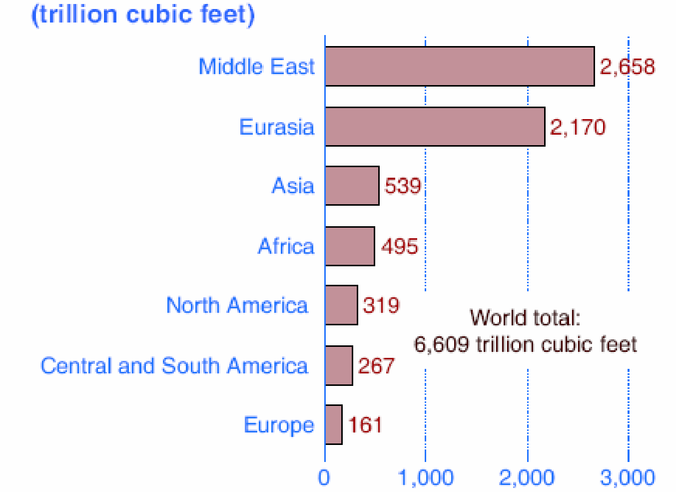
Cumulative (cum.) production curve indicates known oil reserves are ~ 2.1 TSTN (trillion stock tank barrels), **half of which have been produced**

Nashawi *et al.,* Energy Fuels, 2010

http://pubs.acs.org/doi/abs/10.1021/ef901240p

Natural Gas

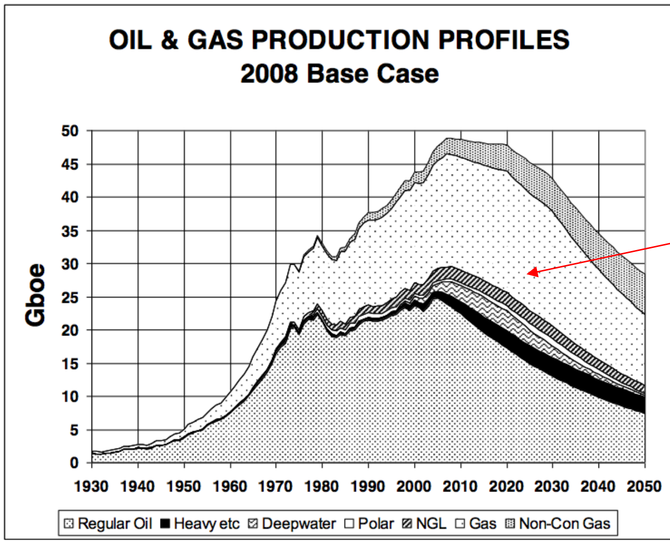
Figure 58. World natural gas reserves by geographic region as of January 1, 2010 (trillion cubic feet)



- Most reserves in Middle East & Russia.

http://www.eia.gov/oiaf/ieo/pdf/nat_gas.pdf

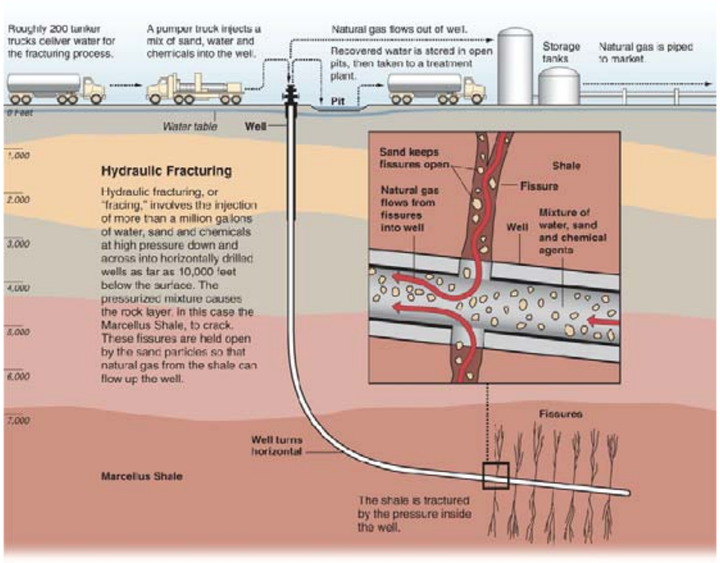
Natural Gas



- Most reserves in Middle East & Russia.
- Hubbert" analysis indicates peak of gas production around 2020

http://gailtheactuary.files.wordpress.com/2010/11/colin-campbell-april-2009-forecast.png

Natural Gas



- Most reserves in Middle East & Russia.
- Hubbert" analysis indicates peak of gas production 2020
- Fracking (drilling operation that involves pumping chemical brine underground to loosen deposits of natural gas from shale) is becoming more and more prevalent, including Marcellus Shale in Penn, NY, and NJ

Image: http://tpzoo.files.wordpress.com/2010/06/marcellus_hydraulic_graphic_090514.gif

Fracking in the news:

http://cleantechnica.com/2011/04/18/fracking-and-the-terrible-horrible-no-good-very-bad-week/
http://somd.com/news/headlines/2011/13587.shtml

Cap and Trade vs Carbon Tax

From an economic point of view, these two policies are vastly different

Cap and trade regulates ______________

Carbon tax regulates ________________

Comparison of Architectures for Greenhouse Gas Regulation

Instrument	*Economic wisdom*	*Allocation*	*Monitoring*	*Enforcement*
General approach:				
Cap and Trade (Kyoto)	**Pro:** Best way to empower market forces to control a "threshold" problem, but **Con:** tight quantity limits could force the economy to bear high costs **Con:** Identification and agreement on a dangerous threshold are not imminent	**Con:** Perhaps impossible to negotiate an allocation that would not cause some major emitting nations to withdraw	**Pro:** Easy to monitor permit trades; easy to monitor emissions if trading is restricted to fossil fuel CO_2 only **Con:** Kyoto Protocol includes six greenhouse gases—impossible to monitor all fluxes reliably if trading	**Pro:** Can rely on national legal systems in "liberal" nations if buyer liability is the rule. **Con:** If sellers are liable for non-compliance then system will require international enforcement institutions of unprecedented strength
Coordinated taxes	**Pro:** Most Efficient instrument when managing a "stock" problem; risks of climate change are mainly a function of the slowly growing "stock" of CO_2 in the atmosphere	**Pro:** Easier to allocate commitments because not distributing semi-permanent assets	**Con:** Very difficult to monitor real impact of taxes that are applied to economies in tandem with other tax and investment policies	**Con:** Requires strong and intrusive international institutions

The Collapse of the Kyoto Protocol
and the Struggle to Slow Global Warming
David G. Victor, Princeton University Press, 2001

Regional Greenhouse Gas Initiative "RGGI"
http://www.rggi.org/home

- RGGI caps CO_2 emissions from region's fossil fuel power plants (> 25 Mega Watt)
  - Regional CO_2 emissions held constant from 2009 through 2014
  - Beginning 2014 regional CO_2 emissions decrease for a total reduction of 10% by 2018
  - All fossil fuel fired facilities must own allowances equal to their annual CO_2 emissions
- 10 States are part of RGGI
  - Each state has an emissions cap
  - Regional market for CO_2 emission allowances
- Maryland joined on 20 April 2007
  - Bill passed in Annapolis
  - Participation governed by Md Dept of the Environment (MDE)
- Eleven auctions have been held; 3 more scheduled this year
  - Auction info: http://www.rggi.org/market/co2_auctions/results
  - $162.5 million has been generated for Md

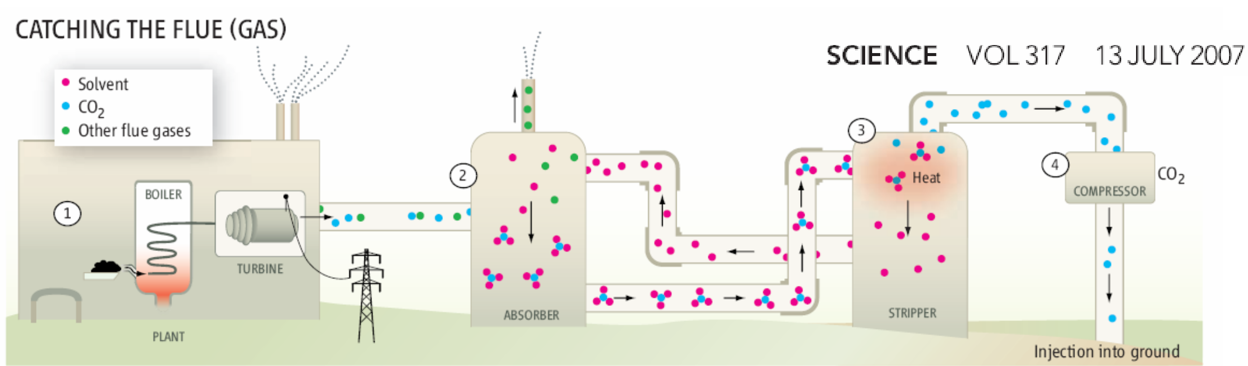
State	Emissions Cap (Tons CO_2)
CT	10,695,036
DE	7,559,787
MA	26,660,204
ME	5,948,902
NH	8,620,460
NJ	22,892,730
NY	64,310,805
RI	2,659,239
VT	1,225,830
MD	*37,505,984*
TOTAL	**188,078,977**

Maryland RGGI Revenue and Allocation

Revenue as of March 2011 Millions of $	% (Original %)	Allocation
38.2	46 (17.5)	Energy efficiency projects
84.2	50 (17)	Low income electricity assistance
43.5	23 (23)	General Rebates
13.9	6.5 (10.5)	Clean energy, education, & climate programs
6.0	3.0 (3.5)	Administration
162.5	100.0	Maryland Total: $ 162.5 million

http://www.env-ne.org/public/resources/pdf/ENE_Auction_Tracker_110317.pdf

Carbon Capture & Sequestration



How a retrofit works. (1) Most coal plants burn coal to create steam, running a turbine that produces electricity. After treatment for pollutants, the flue gas, a mixture of CO_2 (blue) and other emissions (green), goes out a smokestack. To collect CO_2 for storage, however, the mixture of gases is directed to an absorber (2), where a solvent like MEA (pink) bonds with the CO_2 molecules. The bonded CO_2–solvent complexes are separated in the stripper (3), which requires heat. More energy is needed for the next step (4), which produces a purified CO_2 stream for ground storage as well as solvent molecules that can be reused. (Schematic not to scale.)

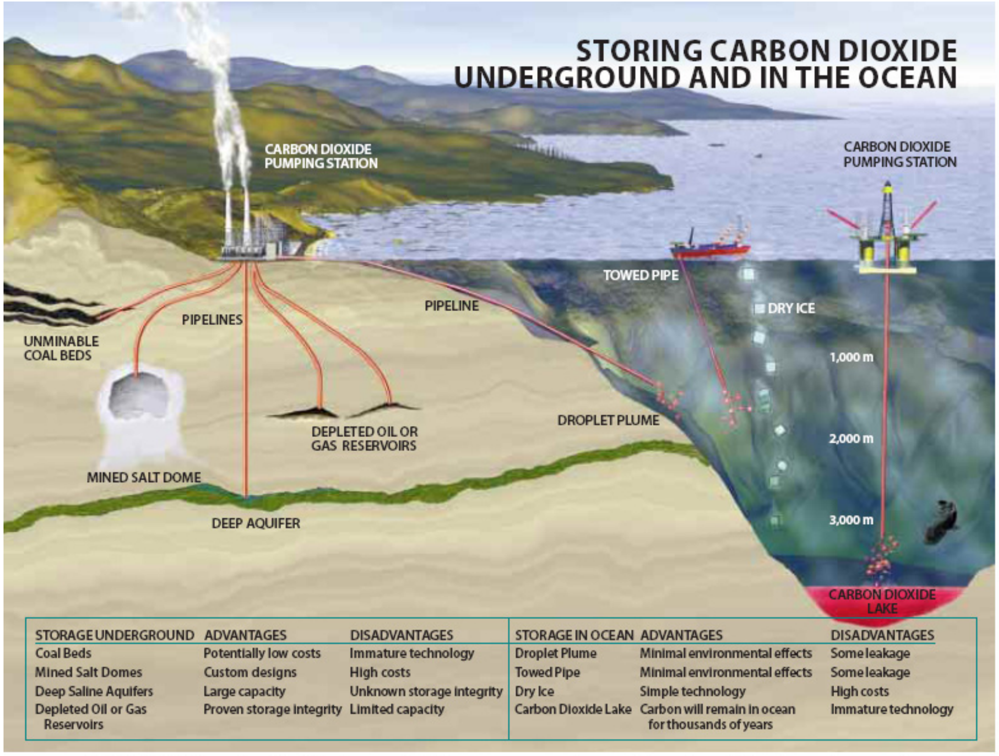
MEA-monoethanolamine $(CH_2CH_2OH)NH_2$ in an aqueous solution will absorb CO_2 to form ethanolammonium carbamate.

$$2RNH_2 + CO_2 + H_2O \rightarrow (RNH_3)_2CO_2$$

MEA is a weak base so it will re-release the CO_2 when heated

Kintisch, *Science*, 2007

Where to Place the Sequestered Carbon?



STORAGE SITES for carbon dioxide in the ground and deep sea should help keep the greenhouse gas out of the atmosphere where it now contributes to climate change. The various options must be scrutinized for cost, safety and potential environmental effects.

Herzog *et al*., *Scientific American*, 2000

Carbon Sequestration in Action:

Sleipner, Norway

National Geographic, June 2008

- Captures ~90% of CO_2 that is generated
- CO_2 pumped into 200 m thick sandstone layer 720 m below sea floor
- Project initiated in response to $50 ton tax on CO_2 emissions instituted by Norwegian Government in 1996
- Investment in capital cost paid off in about one and a half years !

CO_2 Capture and Storage (CCS) Costs:

CCS component	Cost range
Capture from a power plant	15–75 US\$/tCO_2 net captured
Capture from gas processing or ammonia production	5–55 US\$/tCO_2 net captured
Capture from other industrial sources	25–115 US\$/tCO_2 net captured
Transportation	1–8 US\$/tCO_2 transported per 250km
Geological storage	0.5–8 US\$/tCO_2 injected
Ocean storage	5–30 US\$/tCO_2 injected
Mineral carbonation	50–100 US\$/tCO_2 net mineralized

http://www.ipcc.ch/pdf/presentations/briefing-montreal-2005-11/presentation-special-report-co2.ppt

WMO

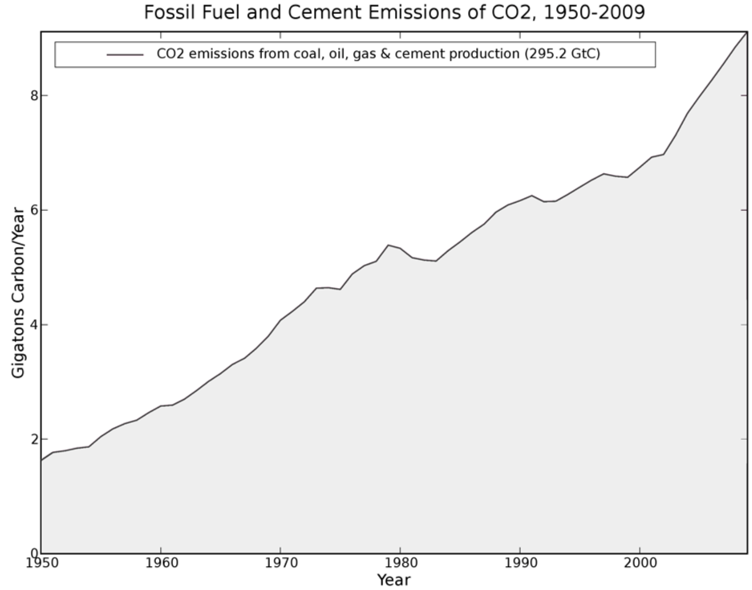
INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

Carbon Dioxide Capture and Storage

UNEP

Fossil Fuel Emissions: Population & Standard of Living

Fossil Fuel and Cement Emissions of CO2, 1950-2009



- **Many sources of future emissions of fossil fuel (e.g., central to IPCC forecasts)**
- **Some postulate can not decouple studies of future climate & population projections (e.g., http://www.atmos.umd.edu/IMO-Population-Kalnay.pdf)**
- **Changes in the standard of living also likely to be extremely important**