Natural Gas:

Extraction and energy conversion technologies

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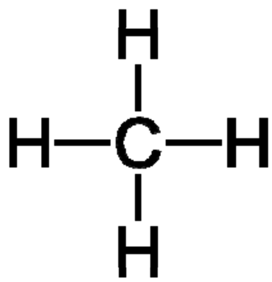
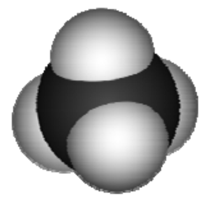
What we will talk about…

- What is natural gas and why is it a good (or bad) energy source
- How is it extracted, particularly what is 'fracking' and 'unconventional resources'.
- How gas is converted to final energy uses.

What is natural gas?





Mostly Methane
Typically of "Thermogenic" orgin

Why is Natural Gas A 'Good' Energy Source:

- Carbon efficiency vs. other fossil fuels
  - C-H bond energy ~410 kJ/mol
  - C-C bond energy ~350 kJ/mol

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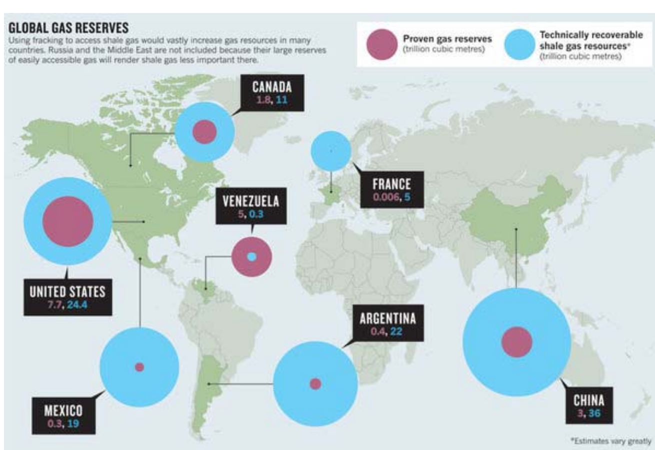
  - Gas = ~ 20% (by quantity) C atoms vs. long chain hydrocarbons ~33% vs. Coal 60%+

About the same

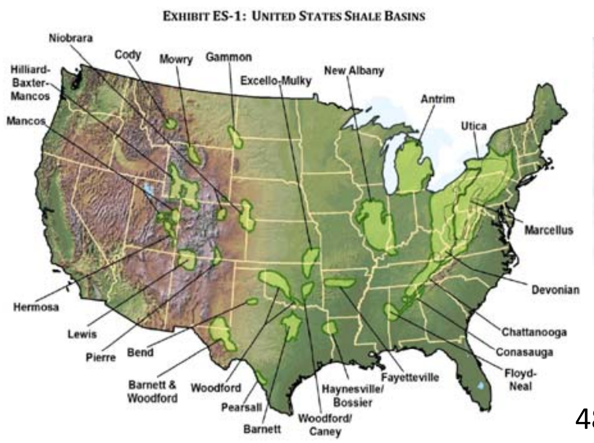
- Greater potential conversion efficiency
  - 95%+ for heating (vs. 70-85% for solid fuels)
  - ~60% for electricity (vs. 30-35% typical for coal plants)

Why is Natural Gas A 'Good' Energy Source:

- Energy Security:



From a U.S. perspective:



Marcellus field alone:
84 tcf – (USGS, 2011)
489 tcf – (Engelder, 2009)
65 –400 years at current consumption
(1 tcf = 1 trillion cubic feet)

Why is Natural Gas a 'Good' Energy Source:

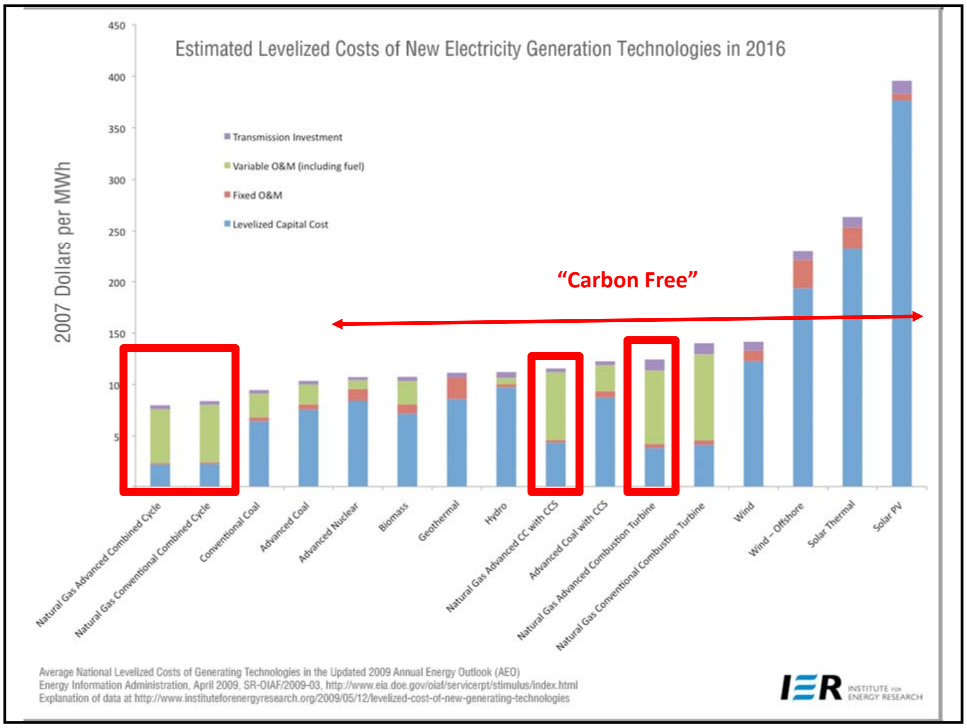
Fossil Fuel Emission Levels
- Pounds per Billion Btu of Energy Input

Pollutant	Natural Gas	Oil	Coal
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0.000	0.007	0.016

Lower non-carbon pollutants than other fossil fuels

Why is Natural Gas a 'Good' Energy Source:

- Cost: Approximate Cost Per GJ (Nov. 2011)
  - Wood $1.40 ($22/ton)
  - Coal $1.80 ($41/ton)
  - Gas $2.71 ($2.86/MMBTU)
  - Oil $16.08 ($98.13/bbl)



Why is Natural Gas a ‘Good’ Energy Source:

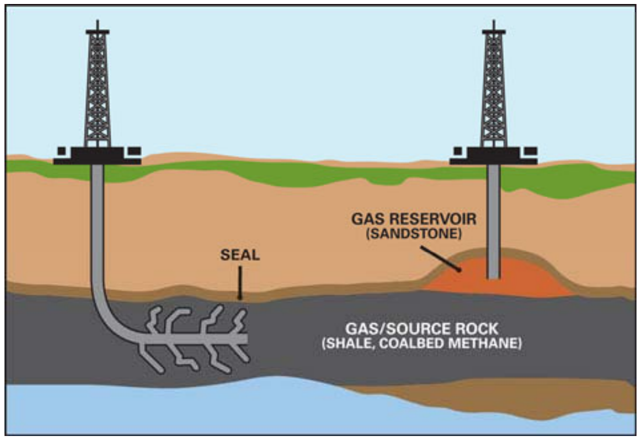
- Carbon Efficiency
- Energy Conversion Efficiency
- National Energy Security
- Lower non-carbon pollutant emissions
- Cost

Why is Natural Gas a ‘Bad’ Energy Source:

- Still emits fossil carbon:
  - "Global warming aside, there is no compelling reason to ban hydraulic fracturing" -Terry Engelder in *Nature*.
- Low energy to volume ratio
- Gaseous at room temperature, requires pipelines and pressurized tanks
- Explosive
- Extraction Issues…

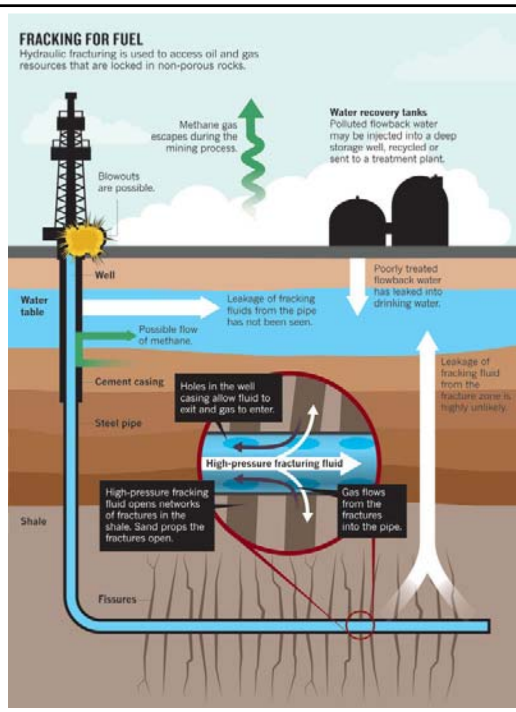
How is Natural Gas Extracted

Unconventional *vs*. Conventional



Is Fracking New?

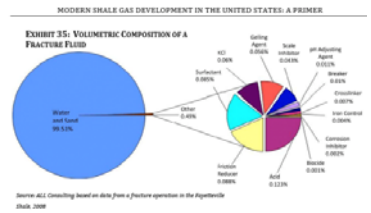
DTE Energy



Unconventional Gas Extraction and Potential Hazards

http://www.nytimes.com/interactive/2011/02/27/us/fracking.html

Fracking Fluids and Toxicity



- Large quantities of water (20,000,000 gal/well)
- Regulatory uncertainty – exempt from Safe Drinking Water Act, not required to disclose chemicals
- Undisclosed chemicals (0.5% = 20-40,000 gal)
  - Biocide, acids, scale inhibitors, friction reducers, surfactants.
  - Fluid returns to surface 1/5 right away, rest slowly over life of the well.
  - Water also extracts natural salts, heavy metals, hydrocarbons, and radioactive materials (much like mine drainage)
  - Some chemicals toxic at ppb levels
- Fluid disposal

Contamination of Groundwater:

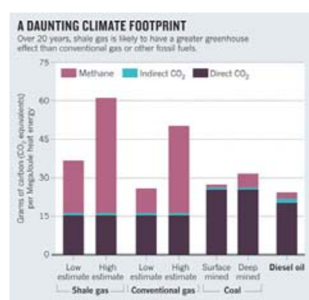
- From the surface ponds containing fluids, yes.
- From the well casing breaks, likely.
- From the deep fractures, very unlikely.
- One study finds traces of shale gas in 75% of water wells within 1 km of Marcellus shale in Pensylvania (Osborn, 2011).

Surface Footprint:

- 5-15 acres/square mile (512 acres)
- Substantial industrial development
- Heavy equipment on nearby roads and use of local infrastructure
- Noise

Is the climate footprint reduced?

- **<u>Increased Methane Leakage</u>** is a major concern:
  - 3.6-7.9% of methane leaked (vs 1.7-6% for conventional wells)
  - Over 20 year period, one study finds the greenhouse gas impact comparable to that of coal or oil, largely due to this methane release (for heat generation, Howarth, 2011)
  - Carbon emissions reduced at least 50%, even considering increased leakage.
  - Impact could readily be reduced through proper regulatory pressure to collect gas released during flowback period



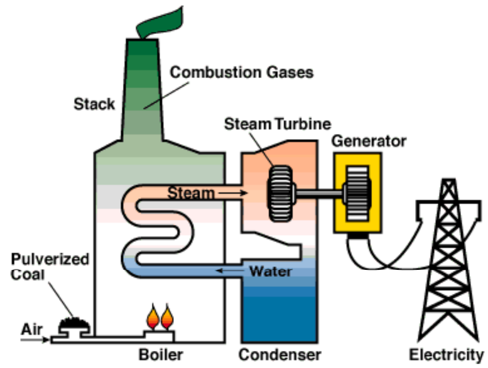
Production rate declines?

What Technologies are Available for Energy Conversion?

- To Electricity
- To Heat
- To Automotive Fuel

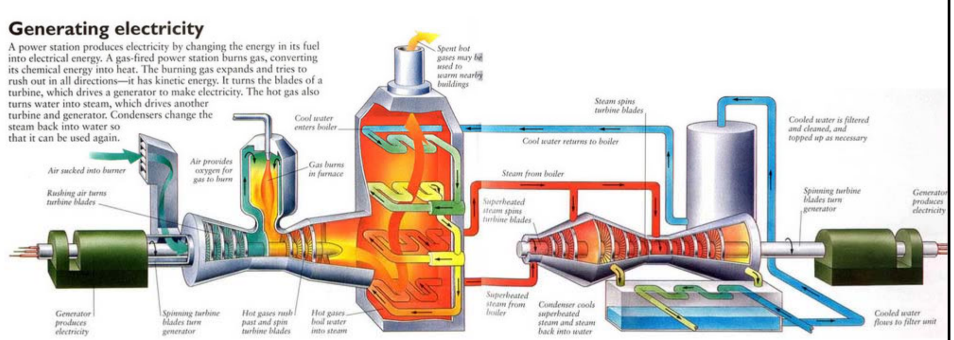
Typical Combustion Power Plant:

- 30-35% efficient
- Low grade heat typically wasted.
- Heat source coal, nuclear fission, gas, etc.
- Startup usually days.



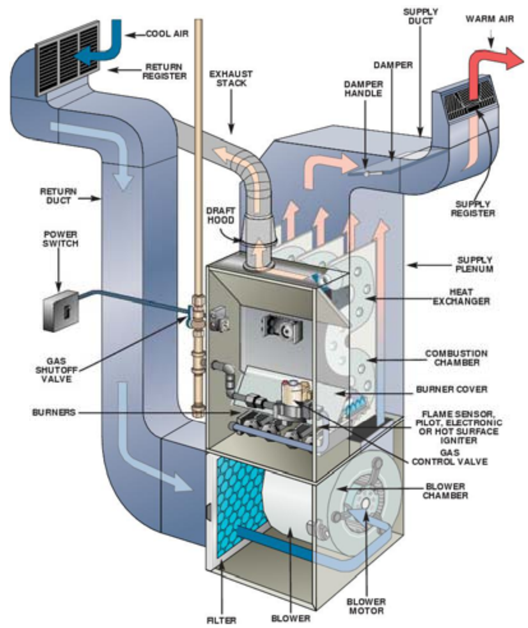
Combined Cycle Gas Turbines

Up to 60% efficiency (VERY high)
Startup in minutes to hours



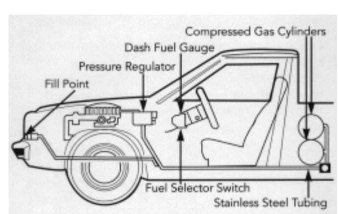
Heat:

- Condensing gas furnaces 95%+ Efficient



Transportation

- Infrastructure Challenges
- Shorter Vehicle Range
- Potential Hazards
- Retrofit performance lower
- Substantial cost savings
- Possible rapid refueling



Good Summary:

"Natural gas has been used as a domestic and industrial fuel source for over a century. It contains more energy per pound than coal. When burned, it produces almost none of the mercury, sulfur dioxide, and particulates that burning coal produces, nor does it require destructive mountain-top mining and other approaches inherent in coal production. As a cleaner source of energy, and as a bridge to a carbon constrained future, natural gas has many desirable qualities. Despite these benefits, more research is needed to assess the mechanisms of water contamination and possible methane losses to the atmosphere." – Jackson, 2011

Fracking Reading

- Nature: http://www.nature.com/nature/journal/v477/n7364/full/477271a.html#/point-yes-it-x27-s-too-high-risk
- Proceedings of the National Academies of Science: http://www.pnas.org/content/108/20/8172.short
- NY Times Article Series: http://www.nytimes.com/interactive/us/DRILLING_DOWN_SERIES.html
- Scientific American Articles: http://www.scientificamerican.com/article.cfm?id=safety-first-fracking-second
- Duke White Paper: http://www.nicholas.duke.edu/cgc/HydraulicFracturingWhitepaper2011.pdf

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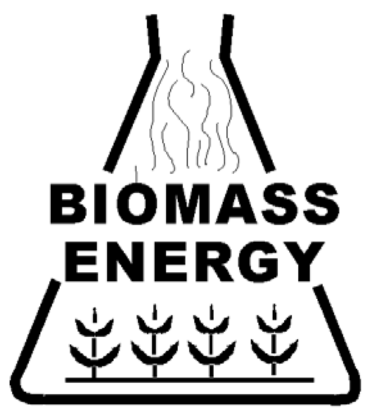
Biomass::

Types, Advantages/Disadvantages, and (very briefly) energy conversion technologies

Biomass… Not ethanol conversion

- Types of biomass and advantages/disadvantages of use.
- Is it carbon neutral?
- Growing/Harvesting
- Conversion to final energy use



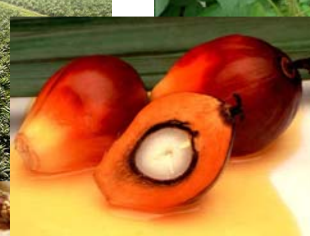
Types of Biomass

- Terrestrial plants
  - Carbohydrate/lipid
  - Cellulosic
    - Woody – Trees, willows
    - Non Woody – switchgrass, corn
- Algae
- Waste Streams
  - Municipal waste
  - Agricultural Process Waste – corn stover, lawn clippings, tree tops, sawdust, hulls
  - Animal dung

Lipid/Carbohydrate Crops

-Sugar cane, corn kernel, soy, palm oil, rapeseed, cotton seed, etc.
-Advantages/Disadvantages?



Cellulosic Crops

- Woody – Trees, willows
- Non Woody – switchgrass, corn (whole plant)
- Process Waste – corn stover, lawn clippings, tree tops, sawdust, hulls
- Advantages/disadvantages?

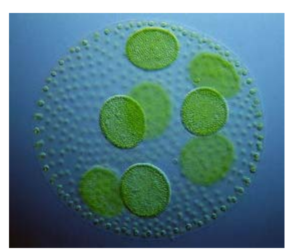
Energy Plantation Challenges

Energy Plantation Challenges

- Land use competition
- Loss of soil carbon
- Fresh water issues
- Availability of cropland
- Fertilizer, genetic engineering,
- Tillage vs perennial crops
- Food prices and famine

Algal crops

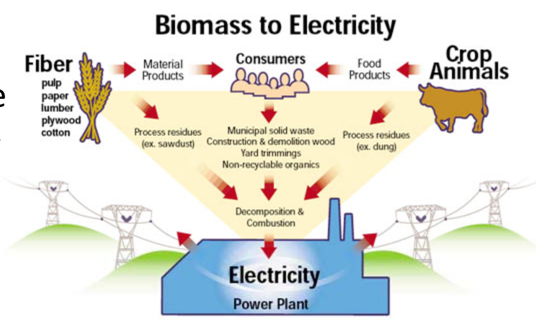
- Water pollution
- Very high lipid production (up to 60% by mass)
- 5000-20,000 gal/yr/acre
- Biosecurity
- Genetic modifications



Waste Streams

Large percentage (7-44% found) of U.S. energy needs is currently thrown away

- Animal dung
- Municipal solid waste
  - 10-20 MJ/person/day
  - Conversion profitable
- Agricultural process waste
  - Corn stover = 1.3 billion dry tons in U.S. 'wasted'



Agricultural Byproducts and wastes

- 30% of global commercial energy use (of which 30% is techically recoverable)
- Not profitable
- Issues with moving wastes around (biosecurity and fertility)

Biomass Advantages

- Can be Carbon neutral over moderate time period, no additional greenhouse effect
- Widely available and globally distributed
- Several ready conversion methods to liquid fuels
- From a U.S. perspective, national security
- Inexpensive, self replicating “equipment” for sunlight harvest

Biomass Disadvantages

- Must be carefully controlled to ensure sustainability
- Competition with crops and food.
- Rather an inefficient way to harvest sunlight
- Ecosystem destruction
- Fertilizer/pesticide use (possible)
- Low conversion efficiency (typical combustion designs similar to coal fired plant)

Are Bio-fuels GHG neutral?

Table 1A – Comparison of GHG Well-to-Wheel Emissions by Stage from Gasoline and Ethanol-Fueled Vehicles – Grams (CO_2 equivalent) Per Kilometer Driven

	Making Feedstock	Refining Fuel	Vehicle Operation (Burning Fuel)	Net Land Use Effects: GREET Feedstock Uptake Credit	Net Land Use Effects: Land Use Change	Total GHG	Change in net GHGs vs. Gasoline
Gasoline	11	47	220	0		278	
Pure Corn Ethanol	72	121	215	-188		221	-20%
Corn Ethanol with Our Land Use Change Emissions	72	121	215	-188	316	536	93%
Biomass Ethanol	29	26	215	-188		83	-70%
Biomass Ethanol with our carbon charge	29	26	215	-188	336	418	50%

Source: Calculated with GREET 1.7(4) using default assumptions for 2015 scenario. Gasoline is a combination of conventional and reformulated gasoline. Ethanol emissions remove emissions of 15% gasoline from E85 fuels. GREET assumes 7.15 km/liter for ethanol (and rates for gasoline adjusted for higher energy content). The table deletes from Making Feedstock column the GREET 2.5 grams/km estimate of emissions from land conversion for corn ethanol but includes credit for direct soil carbon gain by switching cropland to switchgrass. Land use change emissions are amortized over 30 years. The land use change estimate for biomass assumes switchgrass produced on average-yielding U.S. corn fields, at 18 MT/ha (*S33*) without feed by-product. Numbers in columns may not sum due to rounding.

Searchinger, 2008 , in Science

Sunlight Harvest efficiency

- Sunlight incoming is not all PAR (45% is)
- Theoretical maximum conversion 11%
- Typical 3-6%
- Most not used to create biomass (just used for life processes of plant)
- Typical 0.1-2% efficient, with crops 1-2%

PV is more efficient!

Conversion technologies

- Combustion… Challenge: Solid fuel (fuels burn as a gas, feed systems work better with fluids)
- Conversion to liquid fuels or hydrogen… challenges in economics and chemical/biological process design.
- Conversion to hydrogen… challenges in storage and transport.

Biomass Summary*

- Global biomass production = 220 billion oven dry tons… 4500 exajoules/yr
- Leave Ecosystems, produce food, grow high yield biomass, 270-446 exajoules/yr
- Total world primary energy use ~ 400 exajoules/year

Exa= 10^{18}

*Includes Bio-diesel, vegetable oil, ethanol, wood, manure, combustible organics