- “The key to foreign policy is to rely on reliance.”
- “I will have a foreign handed foreign policy.”
- “I don’t care what the polls say. I don’t. I’m doing what I think what’s wrong.”
- “I know what I believe. I will continue to articulate what I believe, and what I believe-I believe what I believe is right.”

-George W.

"The position of this country as the leading producer of petroleum cannot be maintained economically…the Near East (Caspian Sea etc.) promises to be the leading producing area by 1970-1975…other regions…South America and the East Indies. At a still later date…the Arctic Circle will be developed."

"This loss of predominance in the production of petroleum will probably be the forerunner of an intensive program within the U.S. for the conversion of other raw materials such as natural gas, coal, and oil shale into motor fuels…"

-R.L. Huntington (1950)

Primary Resources

Most data from U.S. DOE (EIA)

Also: USGS, EPA, and IEA

Other resources to be listed.

Definition Blitzkrieg

- **Petroleum** – Gas or Oil
- **Natural Gas** – Naturally occurring hydrocarbon and non-hydrocarbon gasses
- **Associated NG** – in contact, but not in solution with oil.
- **Non-Associated NG** – not existing with oil.
- **Wet NG** –Unprocessed or semi-processed NG from strata containing condensable (heavy) hydrocarbons.

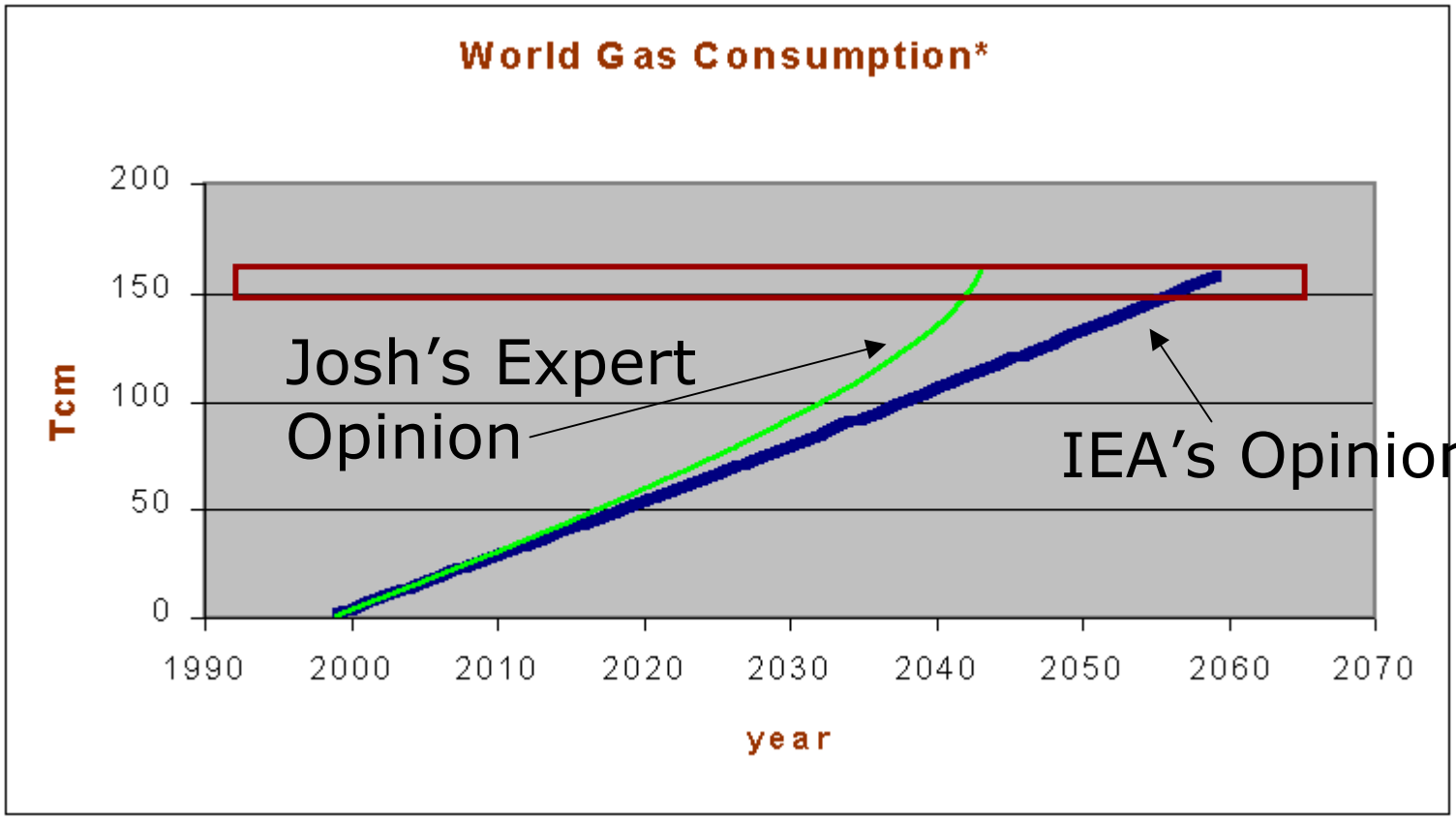
Oh yeah…there are more.

- **Dry NG** – Dehydrated. Also: containing little or no recoverable liquid hydrocarbons. Almost pure Methane.
- **Natural Gas Liquids –** Gaseous hydrocarbon mixtures at reservoir conditions, recoverable as liquids through condensation or absorption.
  - **Liquefied Petroleum Gas** – Usually Propane and Butane. Can be liquefied under moderate pressure at normal temperature.
  - **Natural Gasoline** – liquid hydrocarbons at STP…pentane and heavier. (extracted from NG or separated from oil)
- **Liquefied Natural Gas (LNG)** – I'll get to this.

The Big Picture

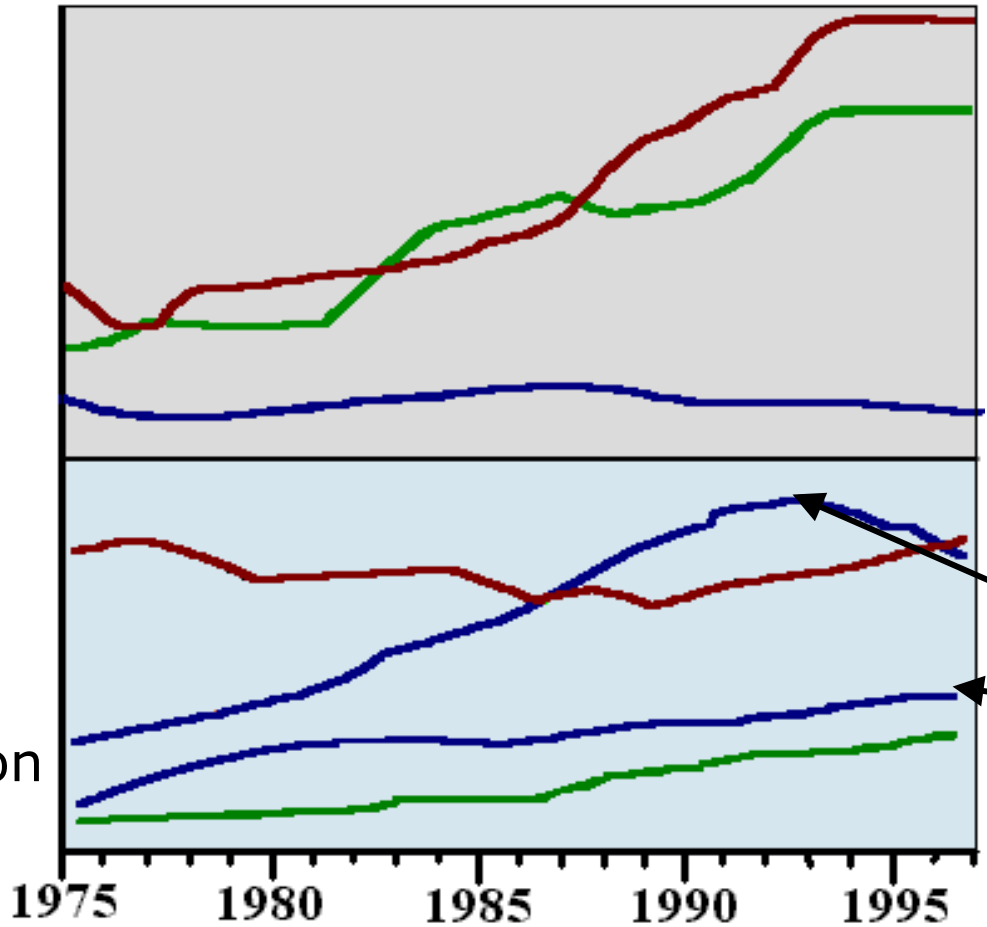
- World Proved Reserves of Dry Natural Gas (DOE)
  - 145.7-158.3 trillion cubic meters (1999)
- World Estimated Resources (Including Proved Reserves) (USGS)
  - 436.4 Tcm (1999)
- World Consumption (IEA)
  - 2.39 Tcm in 1999.
    - 2.7% per year expected increase.

- World Natural Gas Staying Power
  - 51-58 years based on proved reserves
  - 431 years based on estimated resources



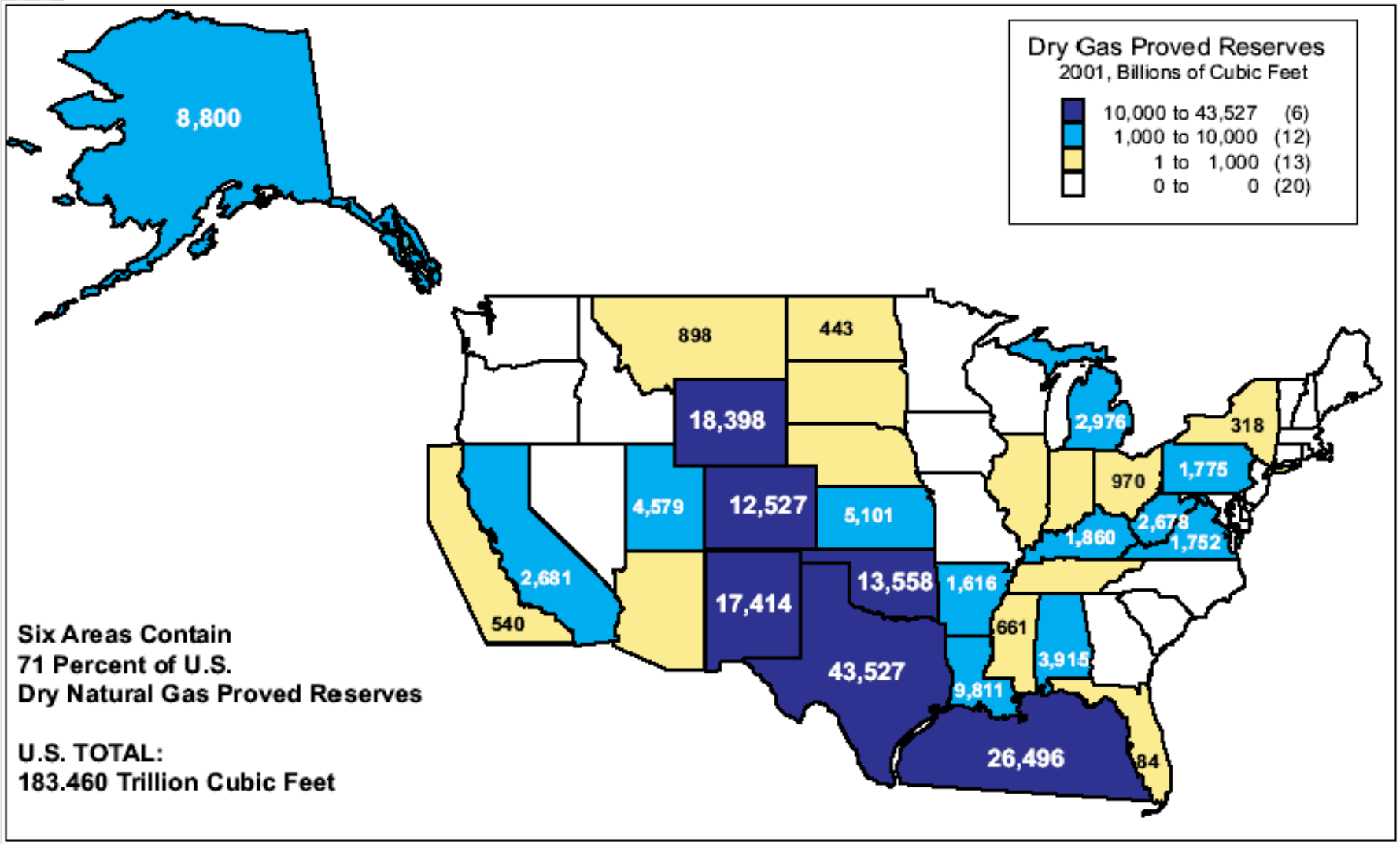
*Total consumption sum from 1999 to plotted year, increasing 2.7% per year.

Reserves VS. Consumption (DOE)



- Economic cipher or repair: Industrialized vs. Developing.

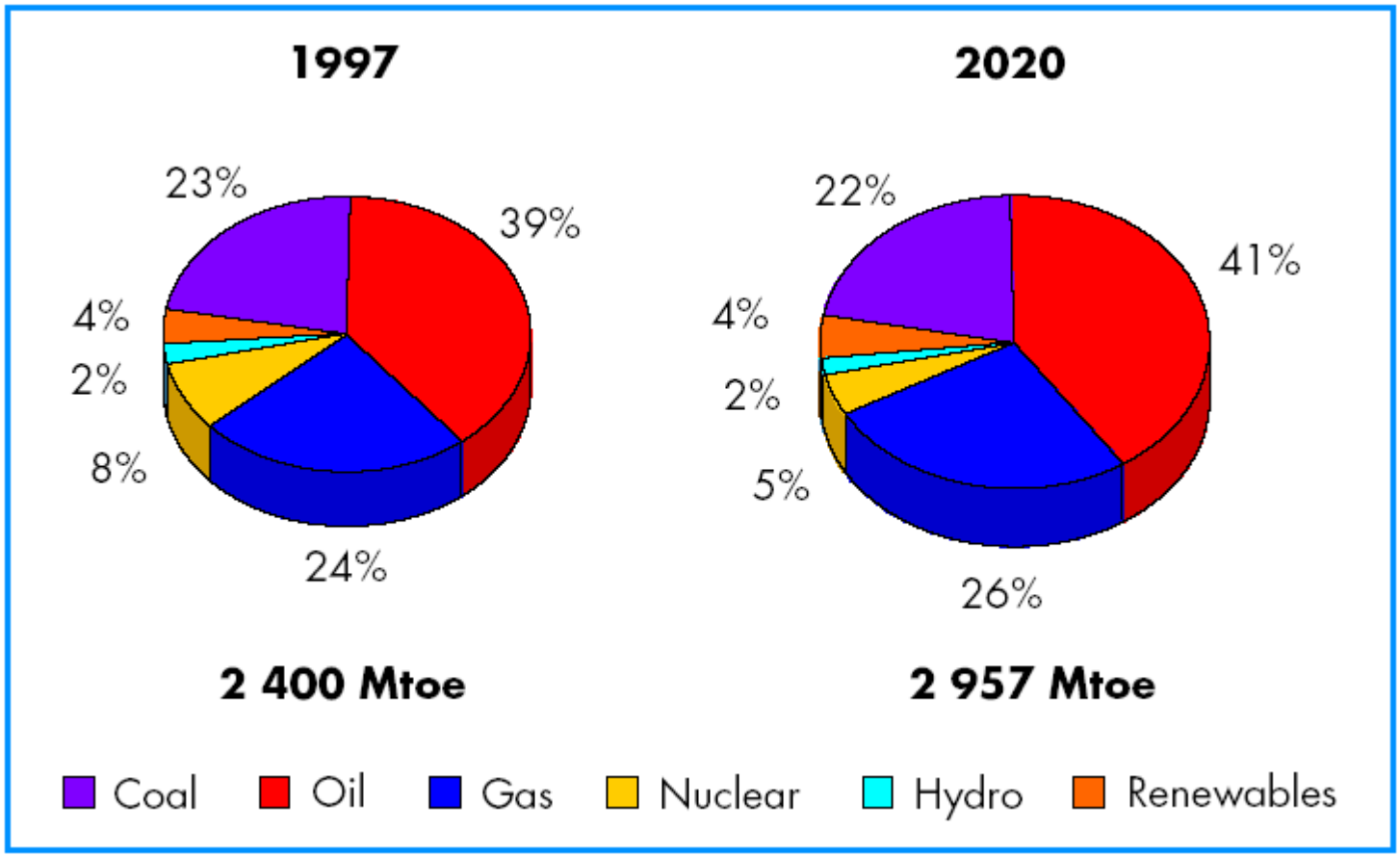
2001 Dry Natural Gas Proved Reserves (DOE)



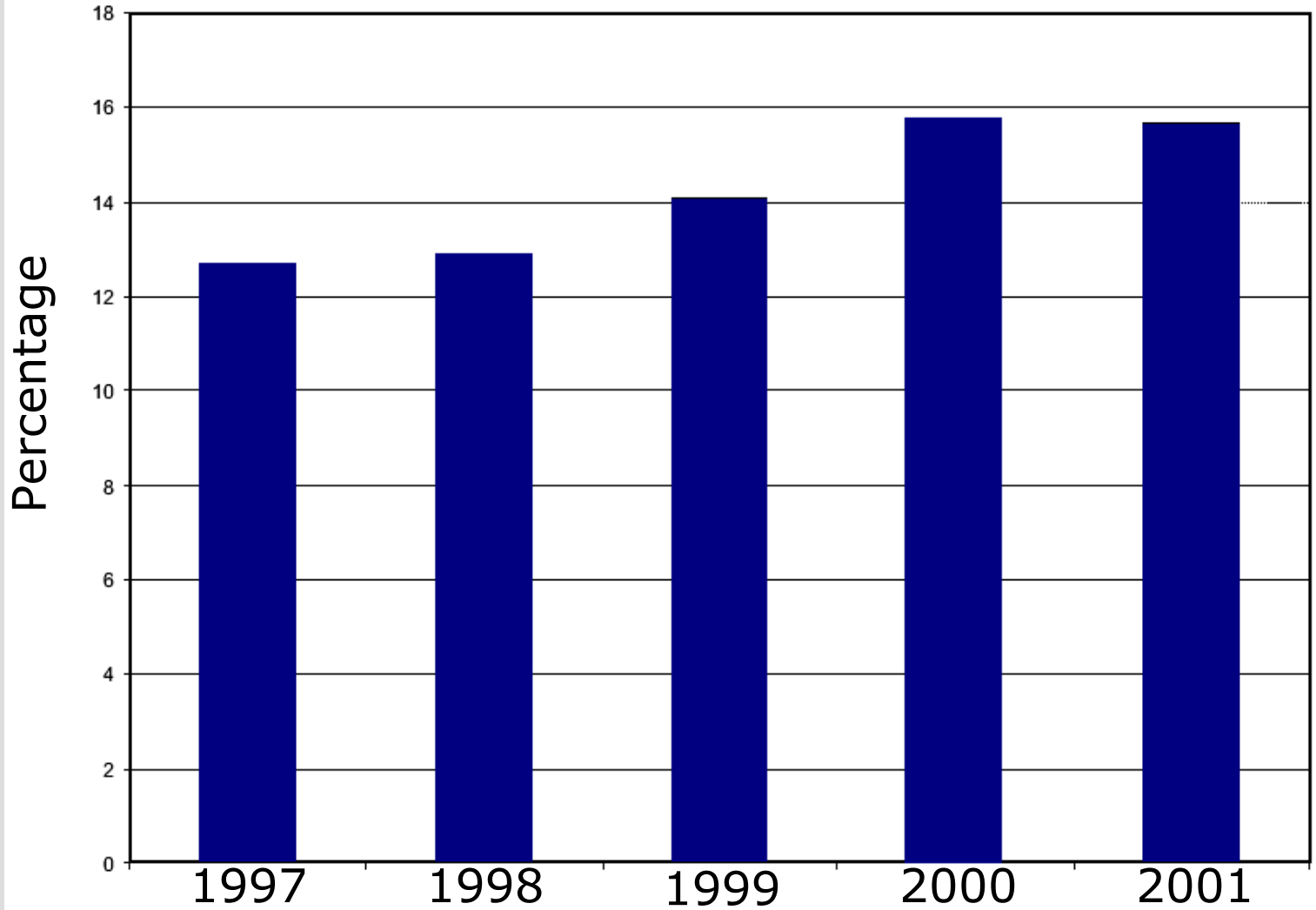
United States Proved Reserves (DOE)

Rank	Field	State
1	Ignacio-Blanco	NM & CO
2	Basin	NM
3	Prudhoe Bay	AK
4	Hugoton Gas Area	KS & OK & TX
5	Madden	WY
6	Wattenberg	CO
7	Carthage	TX
8	Jonah	WY
9	Raton Basin Gas Area	CO & NM

U.S. Energy Allocation (IEA)



Net U.S. Imports as Percentage of Total Consumption (DOE)



Yearly Percent Changes of World vs. United States 1997–2020 (IEA)

	United States	World
GDP	2.2	-
Population	0.75	-
Coal Use	0.85	-1.3
Oil	1.2	1.2
Gas	1.45	0.5
Nuclear	-1.6	-
Hydro & Other Renewables	1.1	1.7
Electricity Consumption	1.25	1.3
Transportation	1.7	-
CO2 Emissions	1.2	-
Heat		1.1

- CO2 increases at same rate as Renewables
- US: higher predicted gas use increase than the world

Pennsylvania Natural Gas (DOE)

Year	Marketed Production*	Consumption*
1998	3693	16641
1999	4951	18016
2000	0	18696
2001	0	16828

*Million cubic meters

- A bit imbalanced, don't you think?

What is Natural Gas?

Constituent	Typical % of gas	Chemical Structure	Heating Value (BTU/lb)
Methane	70-95	CH_4	23,571
Ethane	2.5-12	C_2H_6	21,876
Propane	1-6	C_3H_8	21,646
Butanes*	0.2-2.5	C_4H_{10}	21,293
Pentane	0.2-1	C_5H_{12}	20,877

*Butane includes iso and N varieties

- Don't forget H_2O, CO_2, H_2S, N_2, O_2 in small amounts

Associated and Non-Associated

- Reservoirs with Oil
  - Option 1: Fully dissolved gasses
  - Option 2: Gas cap
    - More gas than can be dissolved
      - Pressure (vapor pressure), Temperature, Quantities of gas
- Reservoirs without Oil

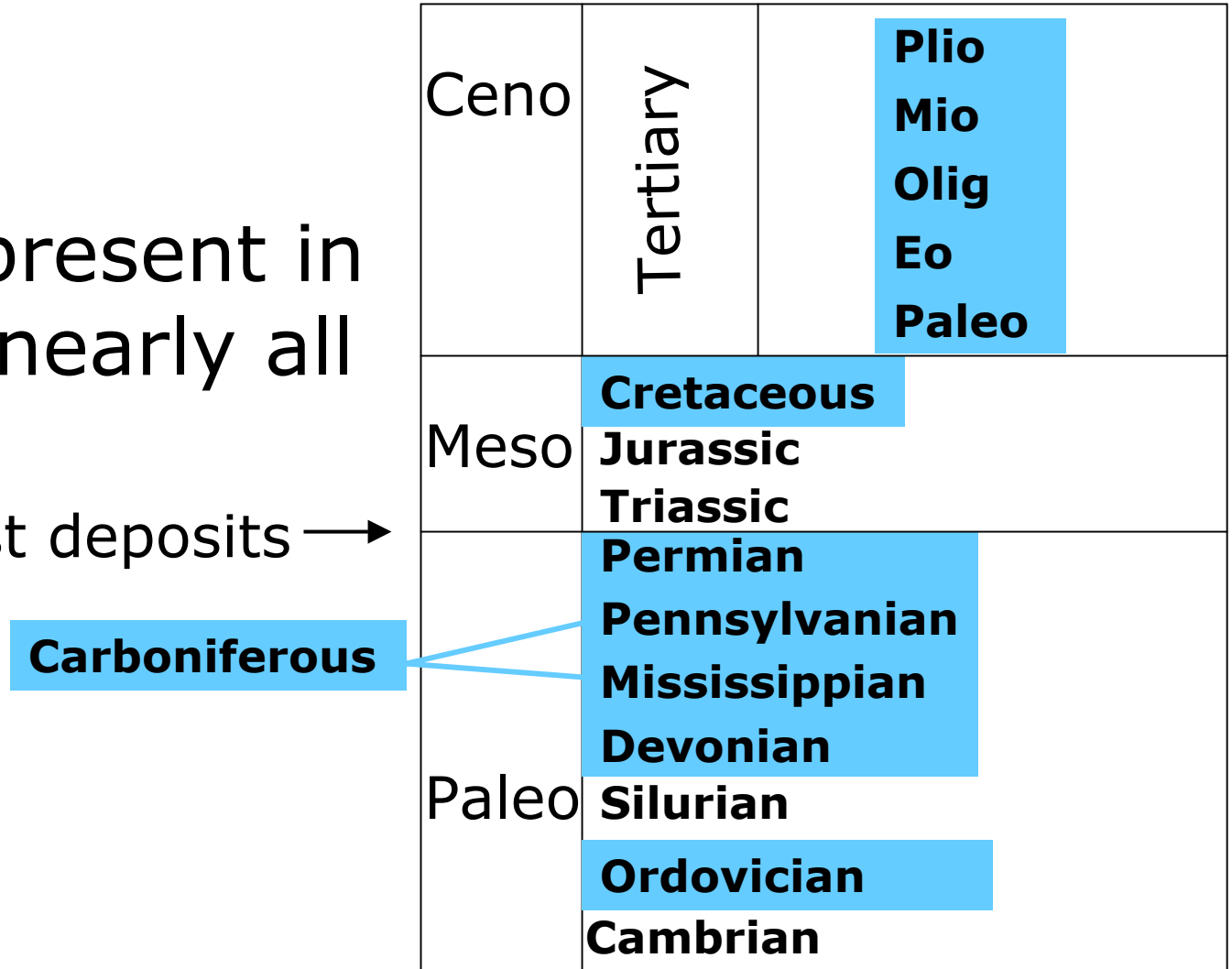
Liquefaction for Separation

Heavier

Hydrocarbon	Pressure (Psi)	Temperature (^{O}F)
Methane	500	-131
Ethane	500	60
Propane	85	60
Butane	26	60
Pentane	Liquid at STP	

PNG Geology

- Oil/Gas present in rocks of nearly all eras
  - Largest deposits →



Oil/Gas Formation

- Oil vs. Coal
  - Land Plants vs. Marine Animals (karogen)
- Oil vs. Gas
  - High hydrogen index (H/C) and low oxygen index (O/C) increases oil yield
  - High oxygen index and low hydrogen index increases gas yield
    - Indexes are a function of type of organic matter and water conditions (oxygen rich water)
    - Thus Humic (land plant) organic matter (high O/C) aids in coal seam methane formation.
- Source Rocks
  - Shale (mud, clay)

Oil/Gas Formation Cont.

Maturity Level	Vitrinite Reflectance (R_o %)	Tmax (°C)
Immature	0.4	420
Immature	0.5	430
Top of oil window	0.6	440
Peak of oil generation	0.8	450
Late oil generation	1.0	460
End oil generation, start gas generation	1.2	465
Gas Generation	1.35	470

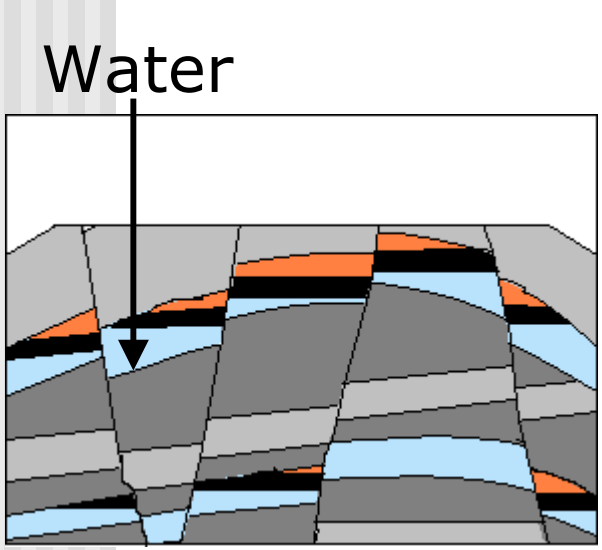
- Vitrinite reflectance is a function of light reflection from small coal-like particles in the shale source rock
- Thermal maturation leads to increased O/C and decreased H/C

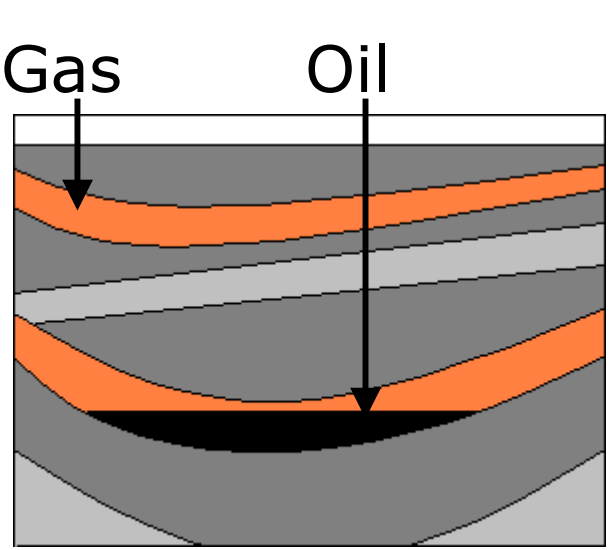
One More…

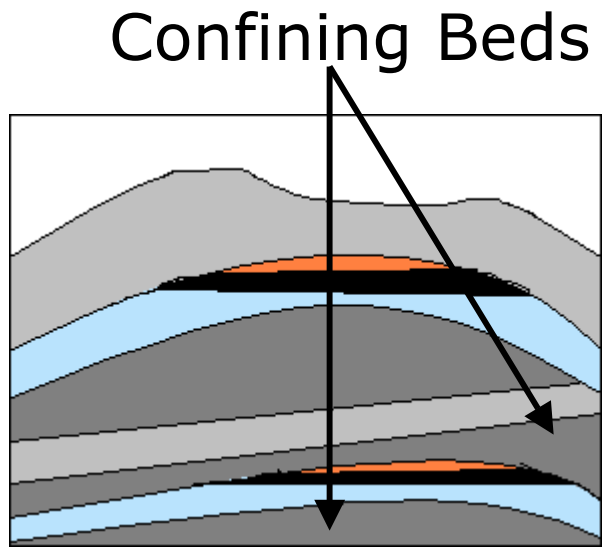
- Thus, Gas present with coal and oil formation:
  - Depends on oxygen index, thermal maturation, pressure, and vitrinite reflectance (in source rock situations)
  - With oil, the lightest hydrocarbons (gas) will separate out to create the gas cap.
  - Or, in very oxygen rich environments, petroleum seams can be entirely gas.

More Geology

- High porosity of sandstone and carbonate sedimentary deposits (shallow coastal environments are ideal)
  - Confining beds
    - Any low porosity layer (source rock)
  - Fault containment.
  - Vertical vs. Horizontal Conductivity







Liquefied Natural Gas (LNG)

- Most gas is inconveniently located and not economically feasible for pipeline transport across oceans.
- Enter LNG:
  - LNG – Almost pure Methane. Liquefied through temperature and pressure constraints. Occupies 1/600 of the volume of gaseous version.
  - Can be somewhat economically shipped by tanker.

LNG trade, where's it coming from? (DOE)

To	From								Total Imports
	USA	UAE	Algeria	Libya	Australia	Brunei	Indonesia	Malaysia	
North America									
USA	-	7.1	35.3	-	-	-	-	-	42.4
Europe									
Belgium	-	*	141.3	-	-	-	-	-	141.3
France	-	7.1	268.4	-	-	-	-	-	275.5
Spain	-	31.8	169.5	42.4	*	-	-	-	243.7
Turkey	-	-	77.7	-	3.5	-	-	-	81.2
Asia Pacific									
Japan	63.6	211.9	-	-	353.1	271.9	900.5	452.0	2,253.1
South Korea	-	-	-	-	3.5	35.3	300.2	123.6	462.5
Taiwan	-	-	-	-	-	-	70.6	49.4	120.1
Total Exports	63.6	257.8	692.2	42.4	360.2	307.2	1,271.3	625.1	3,619.7

*Less than 2 billion cubic feet.

Note: Sum of components may not equal total because of independent rounding.

Source: Energy Information Administration, Office of Oil and Gas, derived from the British Petroleum Company, *BP Statistical Review of World Energy 1997*.

*Billion cubic feet

Transportation LNG Losses (U.S. DOE)

From	To	Distance (approx. miles)	Gas Losses (as fraction of shipment)
Algeria	Everett, MA	3,303	1.7%
UAE	Everett, MA	7,871	4.1%
Australia	Everett, MA	11,874	6.2%
Venezuela/Trinidad	Everett, MA	2,075	1.1%
Algeria	Lake Charles, LA	4,962	2.6%
UAE	Lake Charles, LA	9,533	5.0%
Venezuela/Trinidad	Lake Charles, LA	2,275	1.2%
Persian Gulf	Japan	7,000 (1)	3.6%
Indonesia	Japan	2,400 (2)	1.3%
Alaska	Japan	3,200 (3)	1.7%

Note: Gas losses were derived based on an assumed tanker speed of 20 nautical miles per hour and gas losses of 0.25 percent per day.

CO2 Emissions From Fossil Fuel Combustion (IEA)

Brown Coal	Steam Coal	Heavy Fuel Oil	Diesel & Light Fuel Oil	Gasoline	Liquefied Petroleum Gas	Natural Gas
4.23	4.12	3.24	3.10	2.90	2.64	2.35

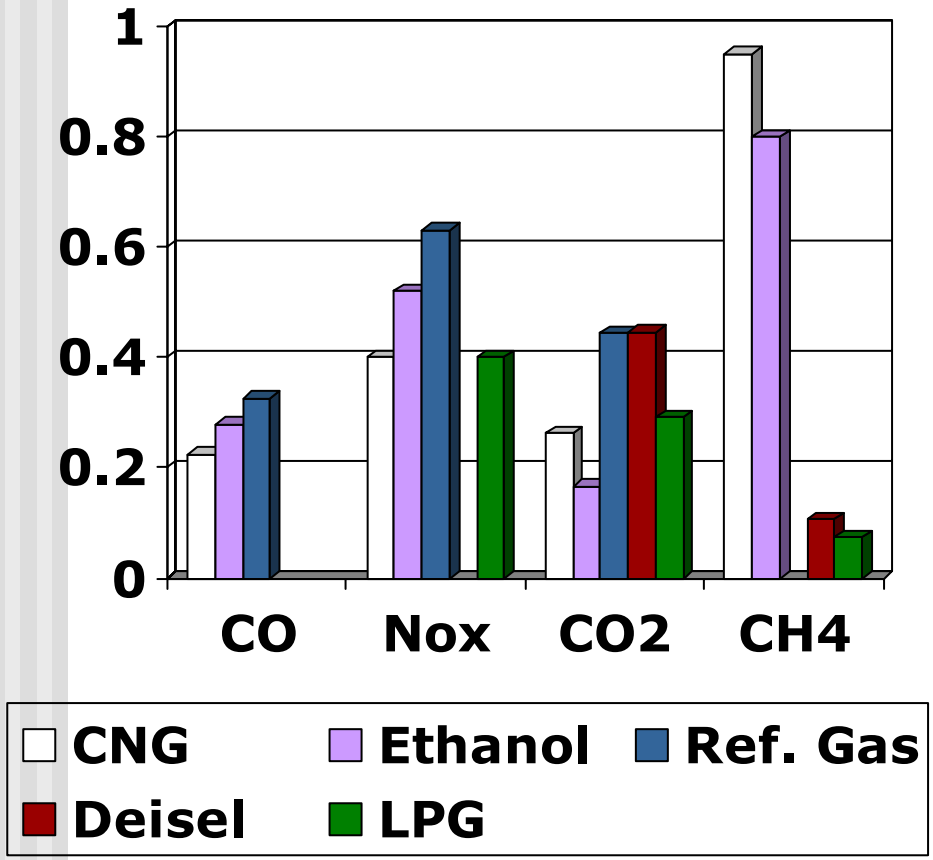
*Tonnes CO2 per tonne oil equivalent (Toe)

Percent Changes w/Respect to Gasoline

CNG → -19%

LPG (remember: propane and butane) → -9%

Other Emissions



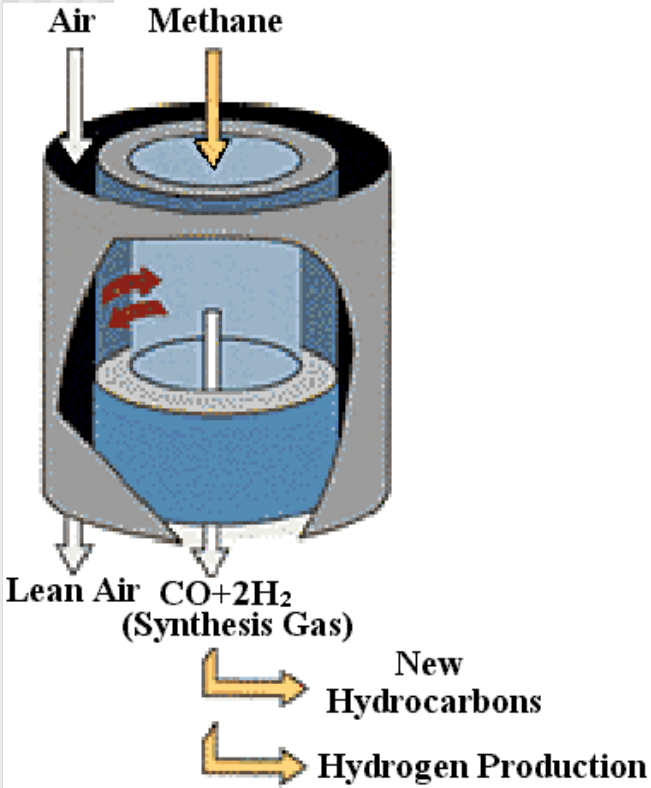
- While there seems to be some disagreement of actual values, the comparisons are most important.
- CNG, LPG, and Ethanol tend to produce lower CO, CO2, and NO_x emissions but higher CH4 (VOC) emissions.
  - They are cleaner overall.

CO2 in kg/mile – CO in 10g/mile – others in g/mile

Carbon Cycle and the Future

- Ethanol and the Carbon Cycle
- The Future:
  - Gas-to-Liquids Technology (GTL)
  - Better LNG Technology
  - Natural gas hydrates
    - More fuel than we can ever use (where have I heard this before?)
    - And it’s clean!!

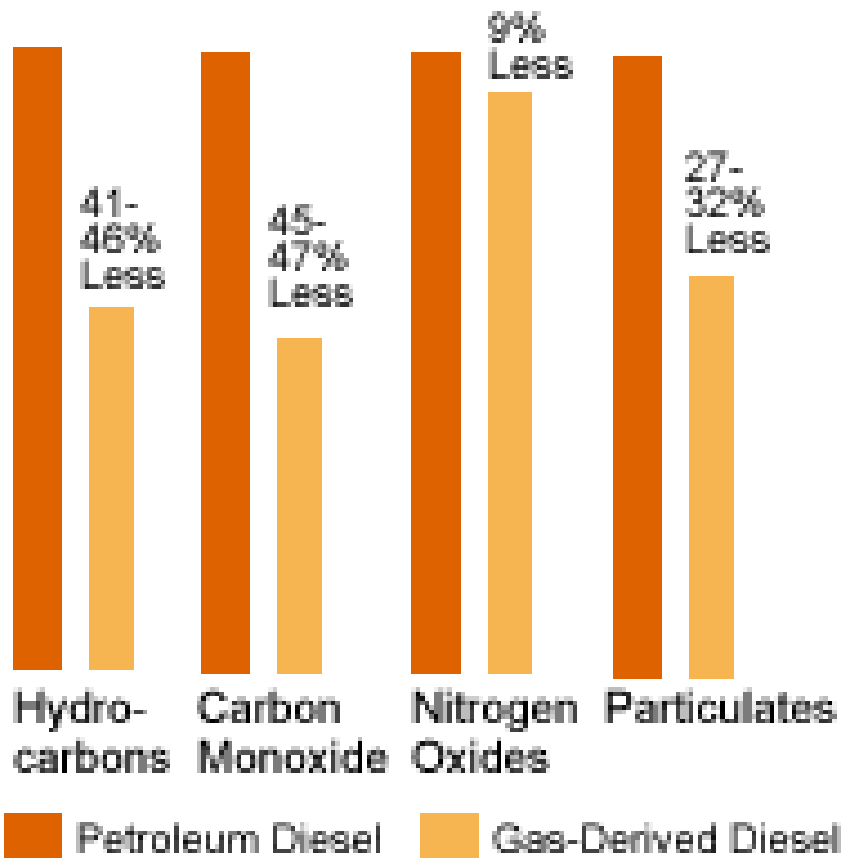
GTL Ceramic Membrane Technology



- Methane is partially oxydized to create "syngas" (CO and H_2). Syngas can be converted in a Fischer-Tropsch reactor into more complex, long-chain hydrocarbons.
- The more complex hydrocarbons are similar to those in crude oil. Syngas derived fuels, however, are cleaner than oil based.

- The partial pressure difference in oxygen, which occurs between the air side and the methane side of the membrane when synthesis gas is formed, "pushes" oxygen ions through the membrane.

Synthetic (GTL) Diesel vs. Oil Based Diesel (DOE)



- Ceramic Membrane Technology can operate at 25% less cost than other GTL technologies
- The synthetic hydrocarbons are stable liquids at STP. Easier transport than methane.

Thermoacoustic Natural Gas Liquefaction (LNG)

- The process uses direct gas burning to generate sound waves to drive a refrigerator. This process is designed for small-scale LNG generation at wellhead or other locations, at one-half the cost of traditional refrigeration at similar scale. The process has no moving parts, does not require electricity, and can be used at remote off-shore locations.

NG and Methane Hydrates

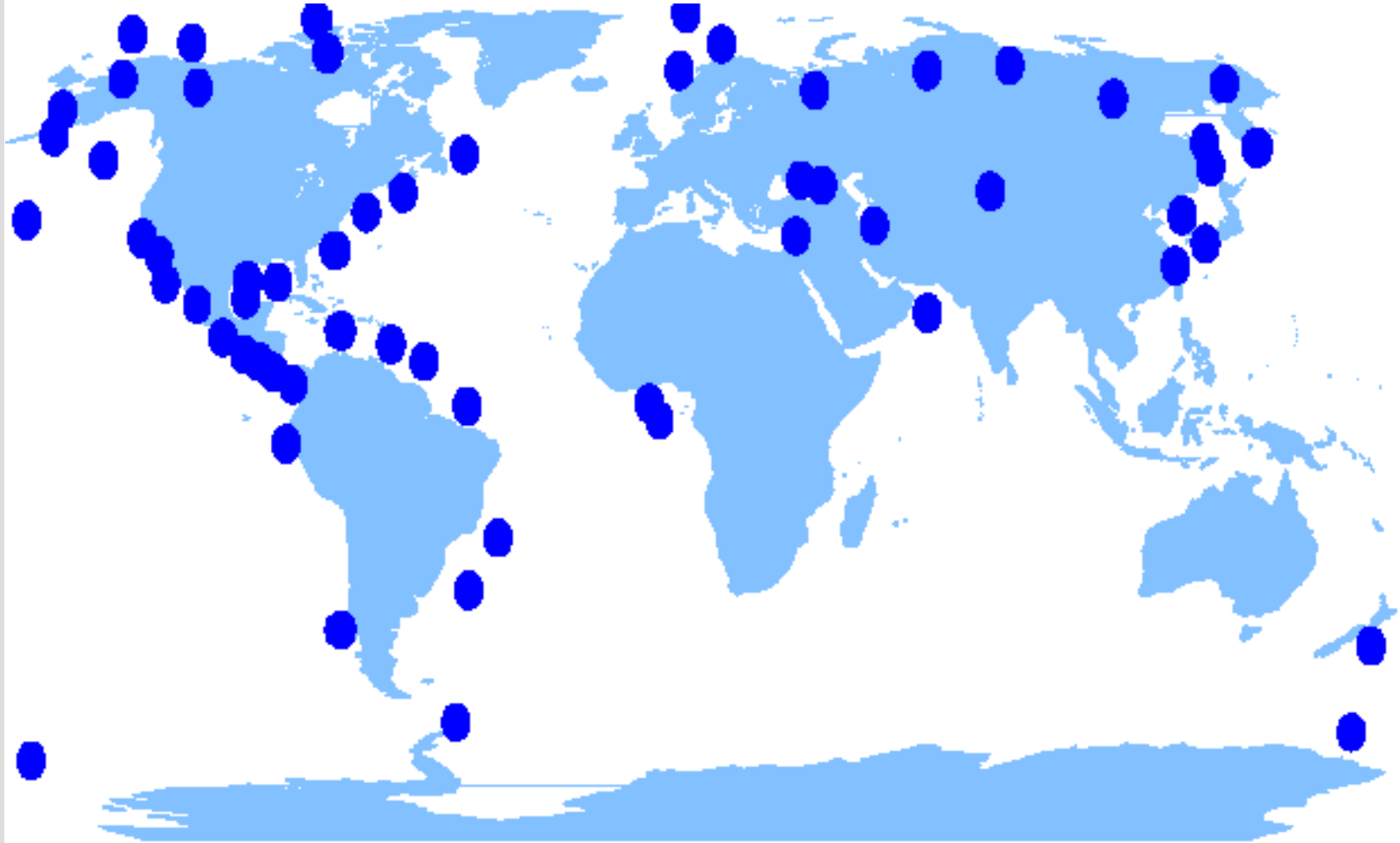
- Gas physically bonded to a water crystal lattice.
- Primarily formed in permafrost regions, although not a requirement. Sub-sea environment can be ideal.
- Gas hydrates that contain more than one kind of guest molecule are usually stable at higher ranges of temperatures than pure methane hydrate.

Carbon Allocation (DOE)

Reservoir	Organic Carbon	
	10^{13} Kilograms	Trillion short tons
Fossil Fuels (coal, oil, NG)	**5,000**	**55,116**
Soil	**1,400**	**15,432**
Dissolved OM (in water)	**980**	**10,803**
Land Biota	**830**	**9,149**
Peat	**830**	**9,149**
Detrital Organic Matter	**60**	**661**
Atmosphere	**3.6**	**40**
Marine Biota	**3**	**33**
Total all	**9,106.6**	**100,383**
Gas Hydrates	**10,000**	**110,230**

- That's a lot of Carbon. Carbon cycle?

Known Gas Hydrate Deposits

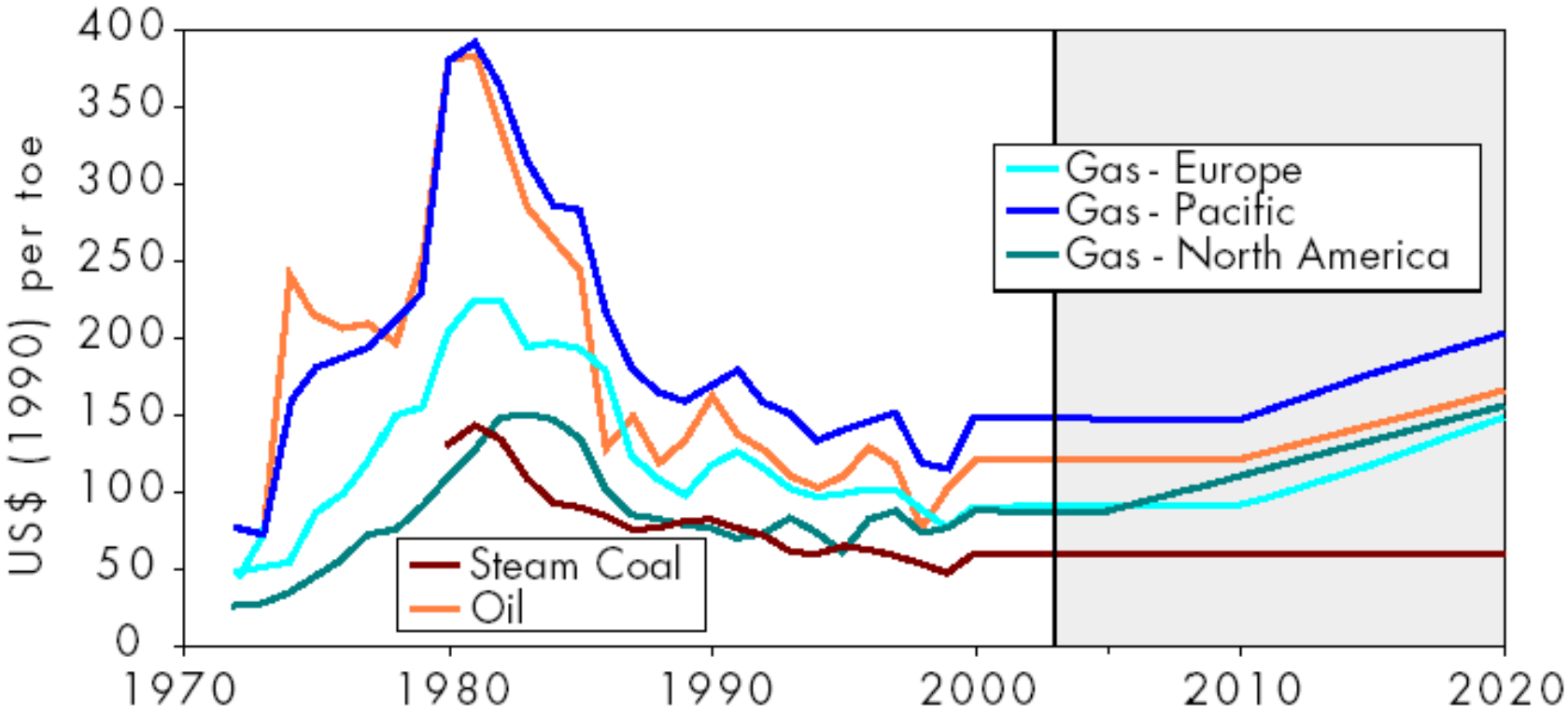


Hydrate Depth (IEA)

Energy Economics 101
(Shell's 2000 Gas to Power Map)

Trans-Caspian Project
Dauletabad (Turkmenistan) to India Project

Increasing Gas Prices (IEA)



- Will increased prices make the widespread distribution more profitable and lead to rapid increases in consumption?

Gas References

- Dennis and Drew.
- American Gas Association (1999) 1999 Gas Facts. Washington, DC, 122 pp.
- The Engineering Committee Interstate Oil Compact Commission (1951) Oil and Gas Production. OK, 128 pp.
- Hobson, G.D. (1954) Introductory Petroleum Geology. Great Britain, 130 pp.
- Shell (2000) Gas to Power Map.
- Paull, Charles K. and Dillon, William P. (2000) Natural Gas Hydrates*, Occurrence, Distribution, and Detection.* American Geophysical Union, DC, 315 pp.
- DOE, EIA, IEA, USGS, and EPA.