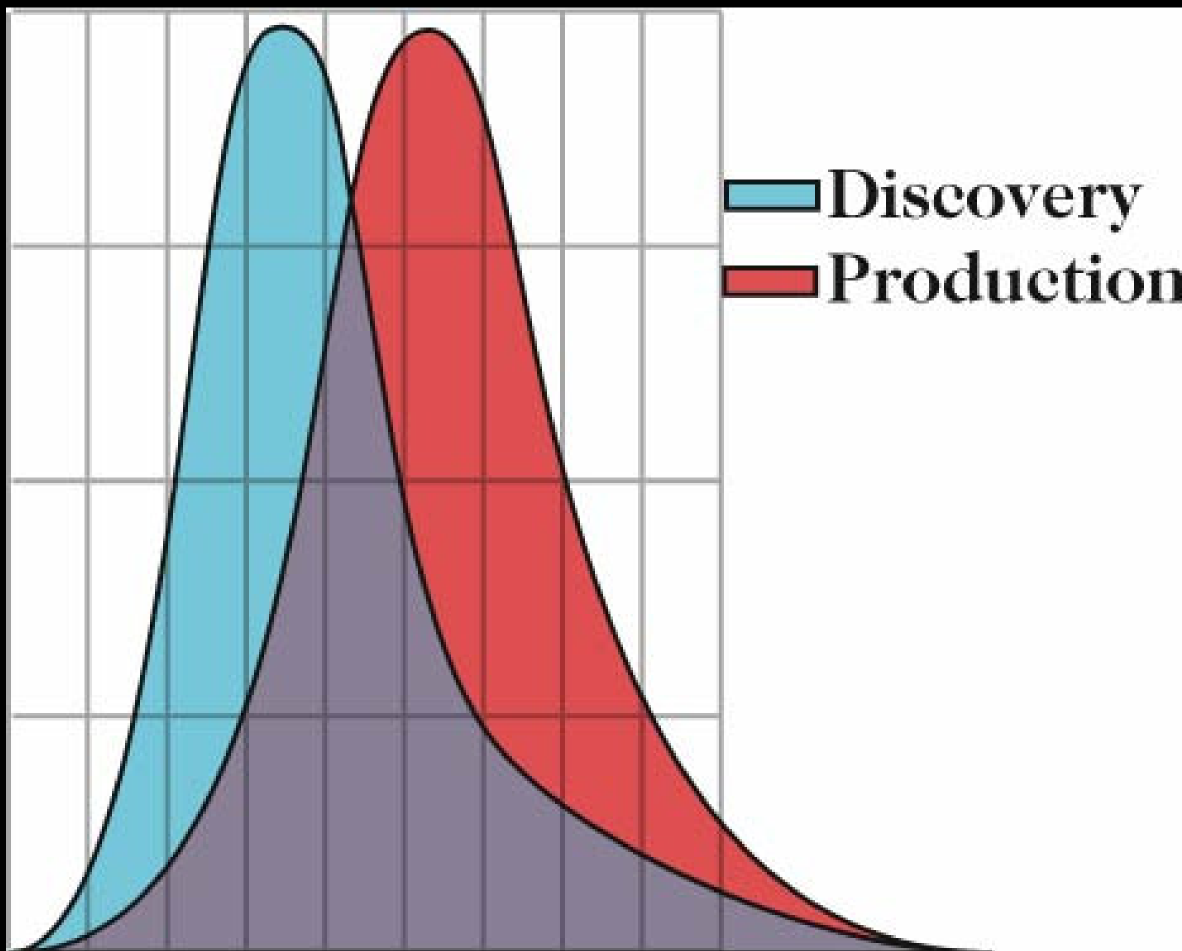
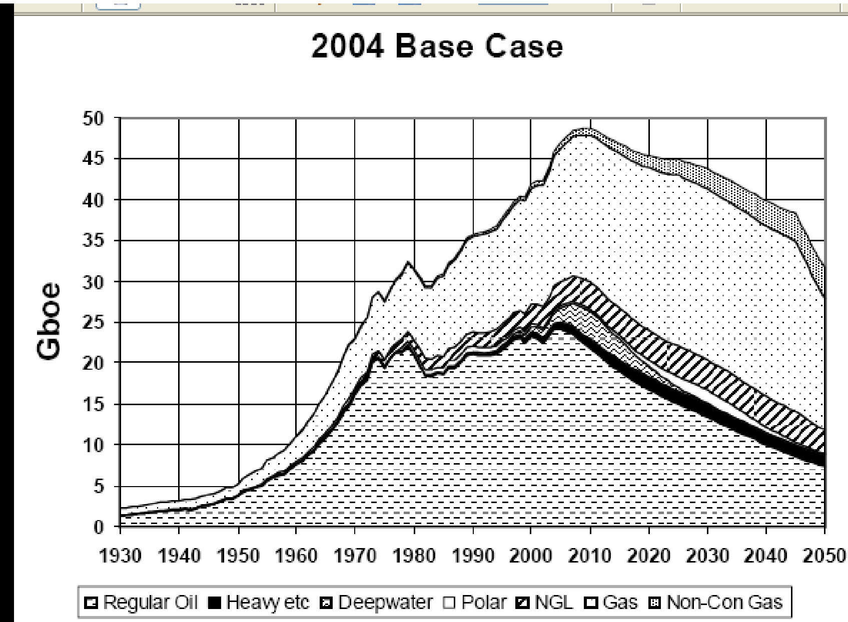
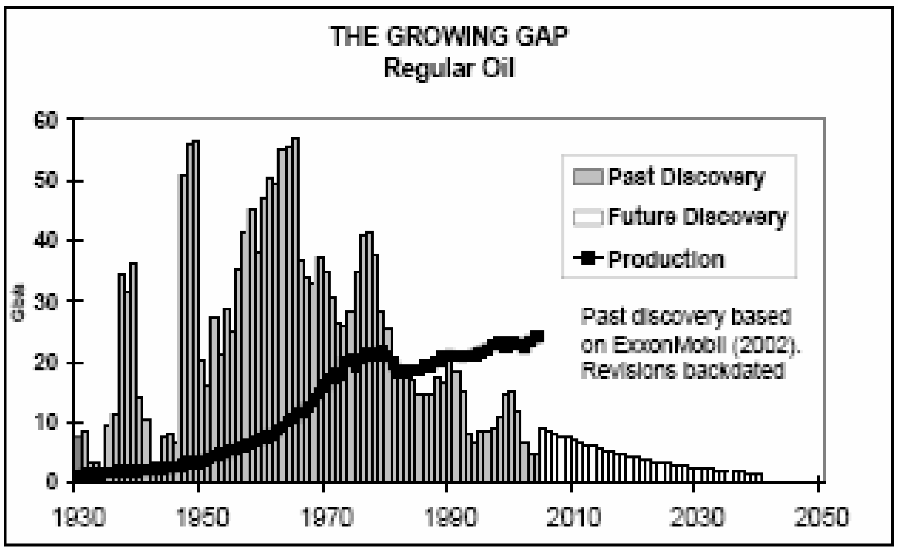
Discovery must predate production

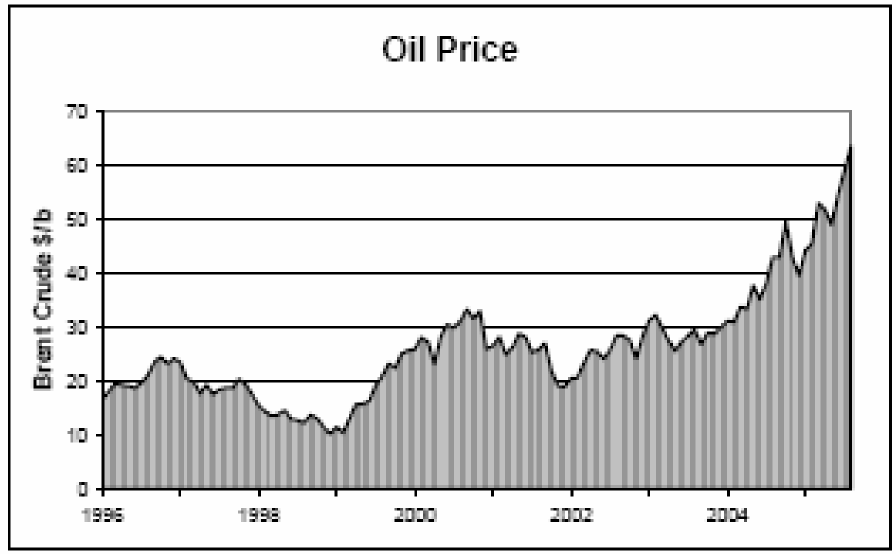


For Central Limit Theorem: http://www.stat.sc.edu/~west/javahtml/CLT.htr
See also http://mathworld.wolfram.com/CentralLimitTheorem.html
http://www.statisticalengineering.com/central_limit_theorem.htm

Oil and Gas Depletion According to source







ASPO Newsletter 57, September 2005 page 2 of 12

Oil Discovery vs production

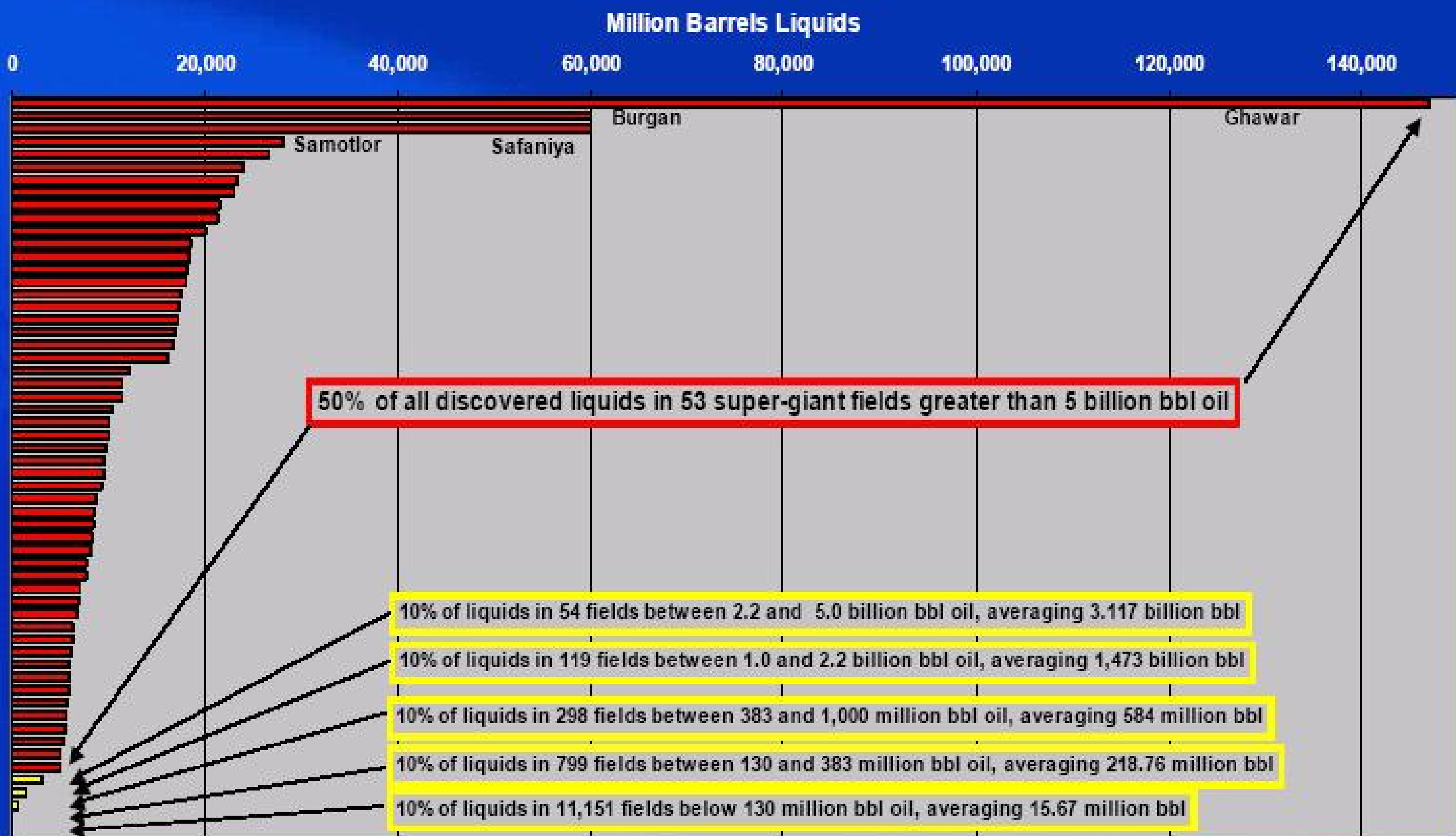
Oil Price

Not examinable

The Role of Giant Fields

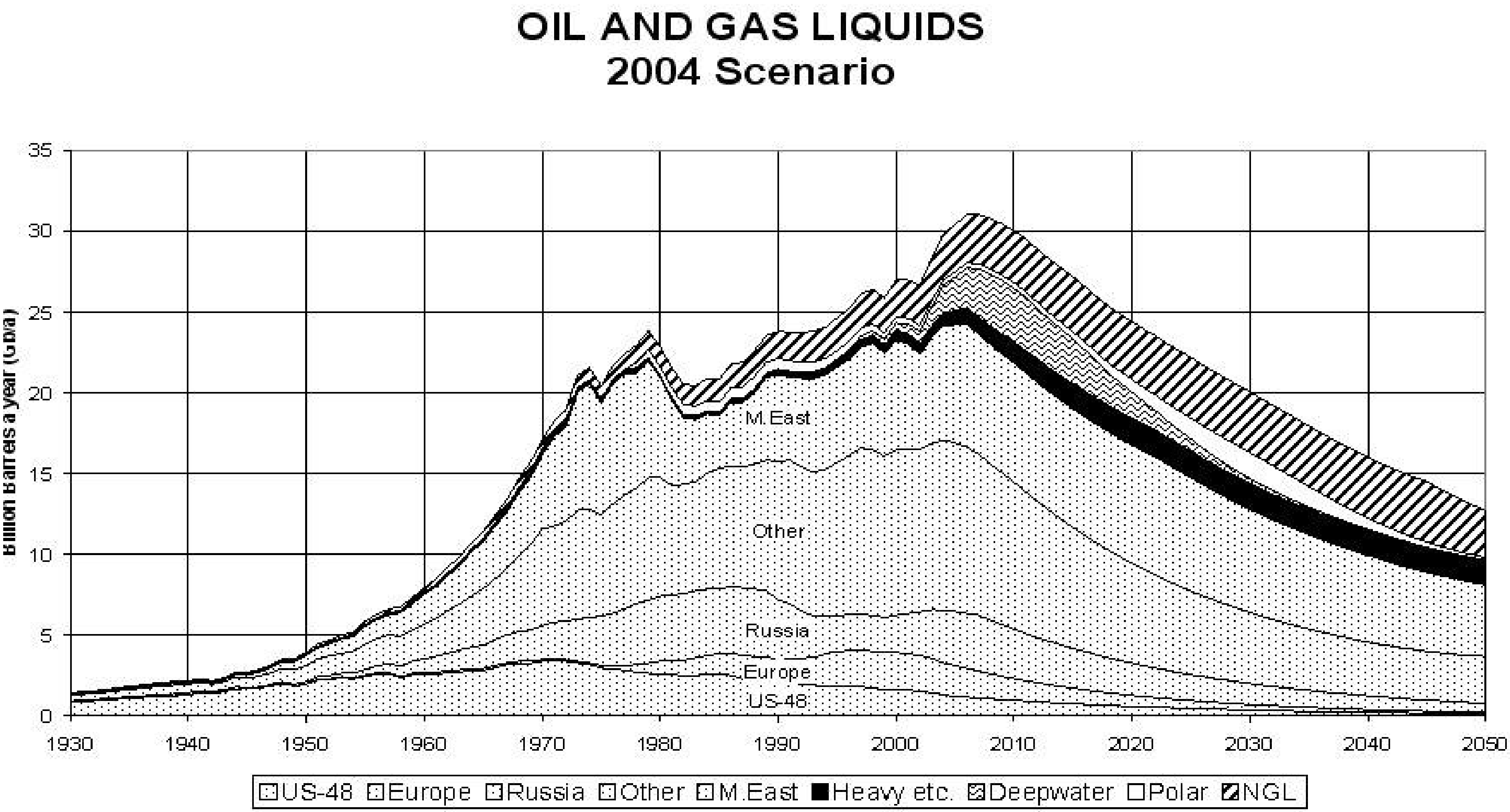
Liquids Field Size Distribution in 12,465 Oil-dominant Discoveries to End-2003

(excludes USA and Canada)



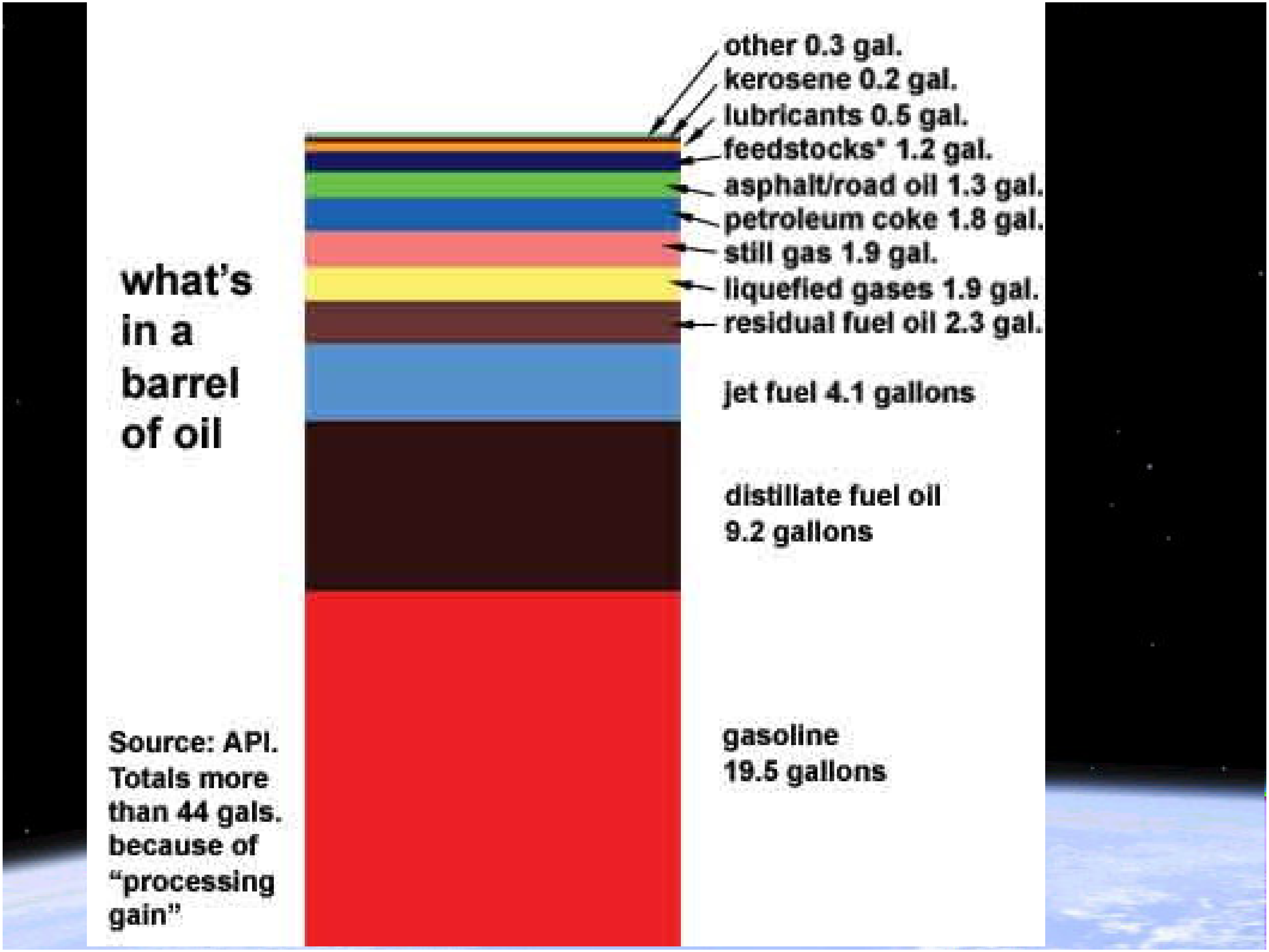
IHS ENERGY

The General Depletion Picture



Exercise

- Hypothesise the discovery of a new North Sea Oil field
- Calculate how far back (in years) the peak of global oil would be set.
- Assume Gaussian production curve


what's in a barrel of oil
other 0.3 gal.
kerosene 0.2 gal.
lubricants 0.5 gal.
feedstocks* 1.2 gal.
asphalt/road oil 1.3 gal.
petroleum coke 1.8 gal.
still gas 1.9 gal.
liquefied gases 1.9 gal.
residual fuel oil 2.3 gal.
jet fuel 4.1 gallons
distillate fuel oil 9.2 gallons
gasoline 19.5 gallons
Source: API. Totals more than 44 gals. because of "processing gain"

Not examinable

How much Oil in a bottle of tomato ketchup?

sh tomato ketchup. Researchers at the Swedish Institute for Food and Biotechnology analysed the production of tomato ketchup.

The study considered the production of inputs to agriculture, tomato cultivation and conversion to tomato paste (in Italy), the processing and packaging of the paste and other ingredients into tomato ketchup in Sweden and the retail and storage of the final product. All this involved more than 52 transport and process stages.

The aseptic bags used to package the tomato paste produced in the Netherlands and transported to Italy to be filled, placed in steel barrels, and then moved to Sweden.

The five layered, red bottles were either produced in the UK or Sweden with materials form Japan, Italy, Belgium, the USA and Denmark.

The polypropylene (PP) screw-cap of the bottle and plug, made from low density polyethylene (LDPE), was produced in Denmark and transported to Sweden.

LDPE shrink-film and corrugated cardboard were used to distribute the final product. Labels, glue and ink were not included in the analysis.

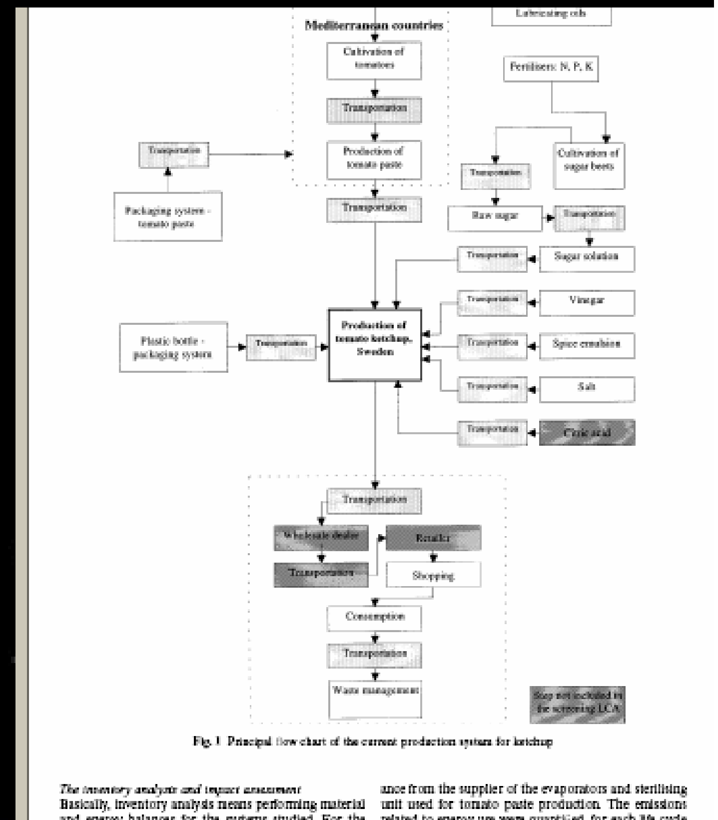
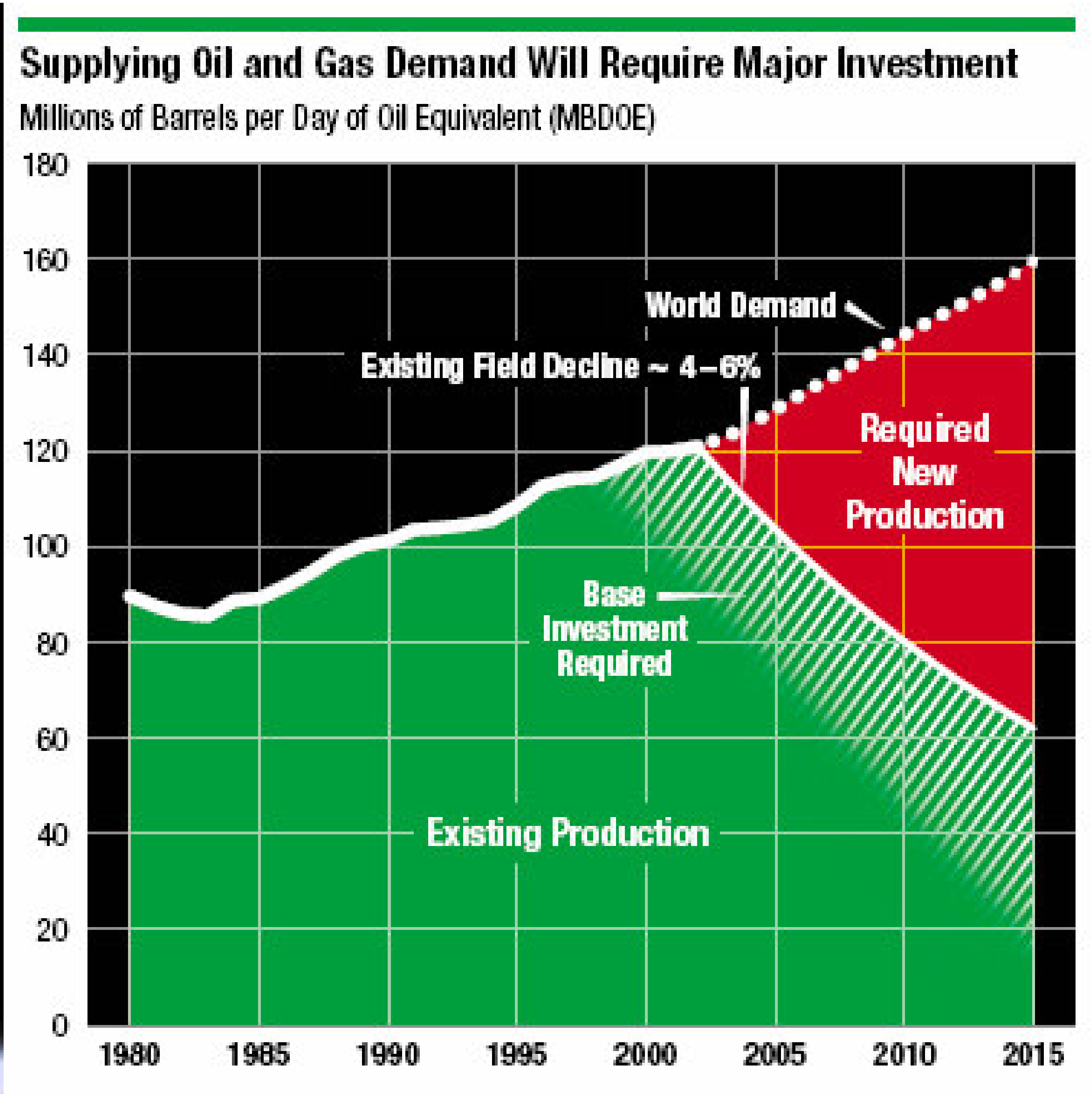


Fig. 1 Principal flow chart of the current production system for ketchup

http://www.321energy.com/editorials/church/church040205.html

- http://www.ciclodevida.ufsc.br/artigos/ciclodevida40.pdf

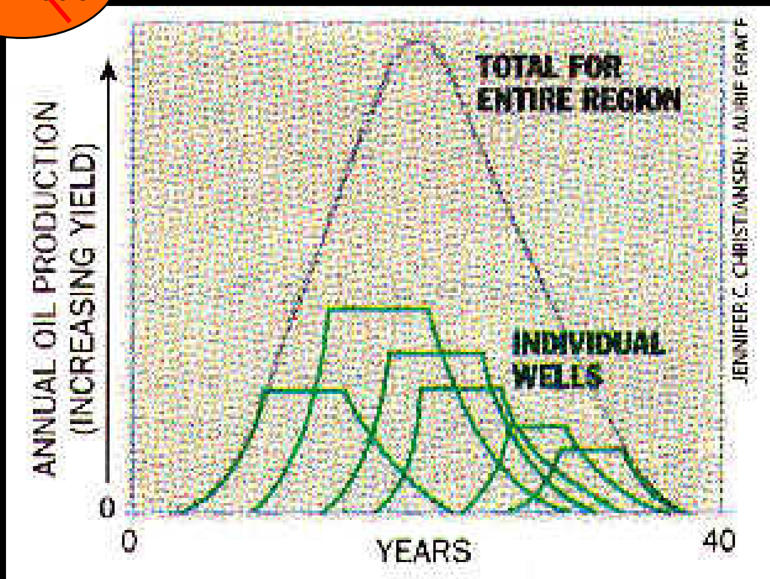
Optimism from an Oil Major

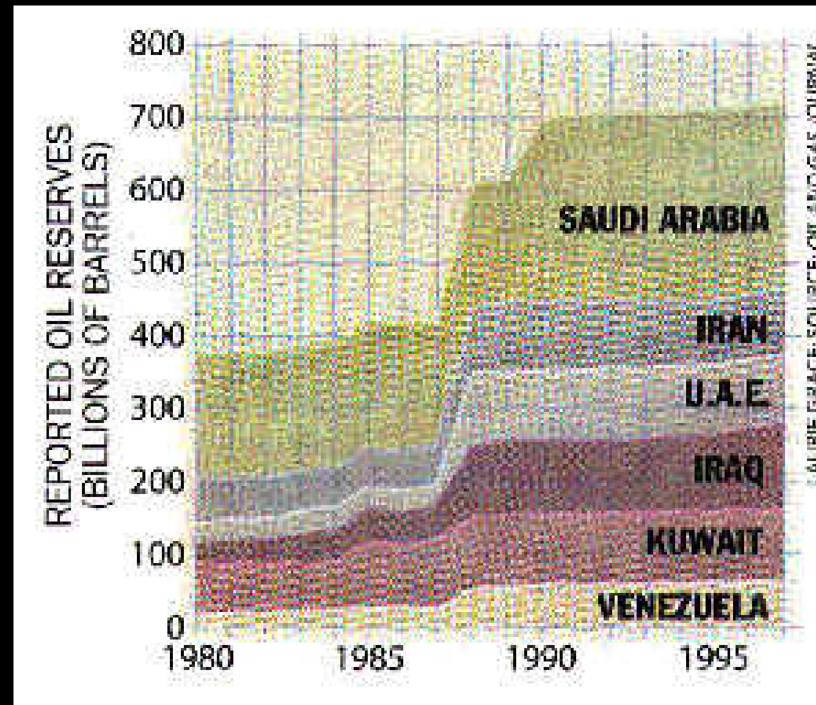


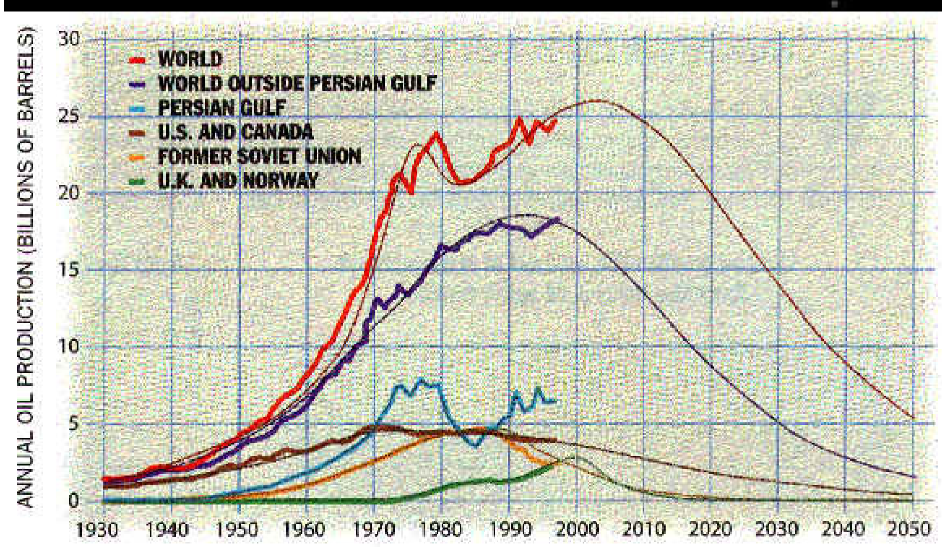
The Exxon view

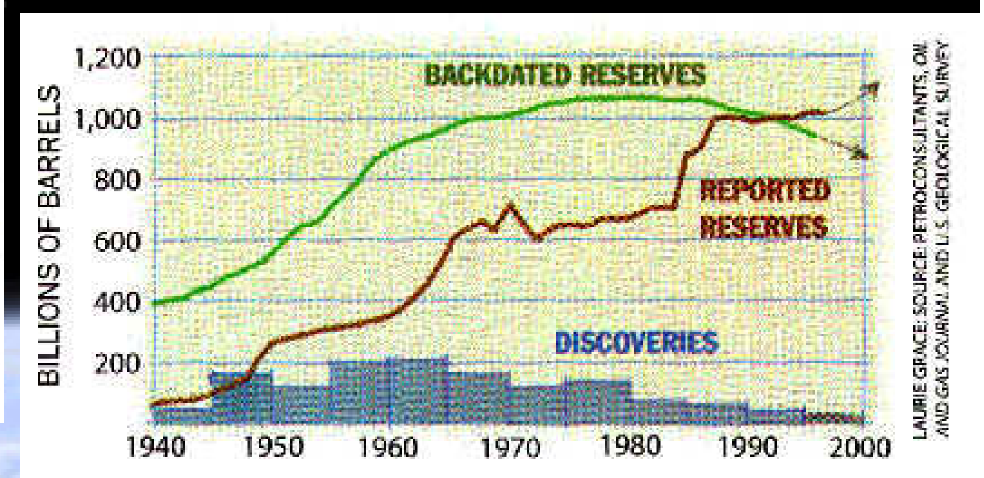
Not examinable

The limits to oil



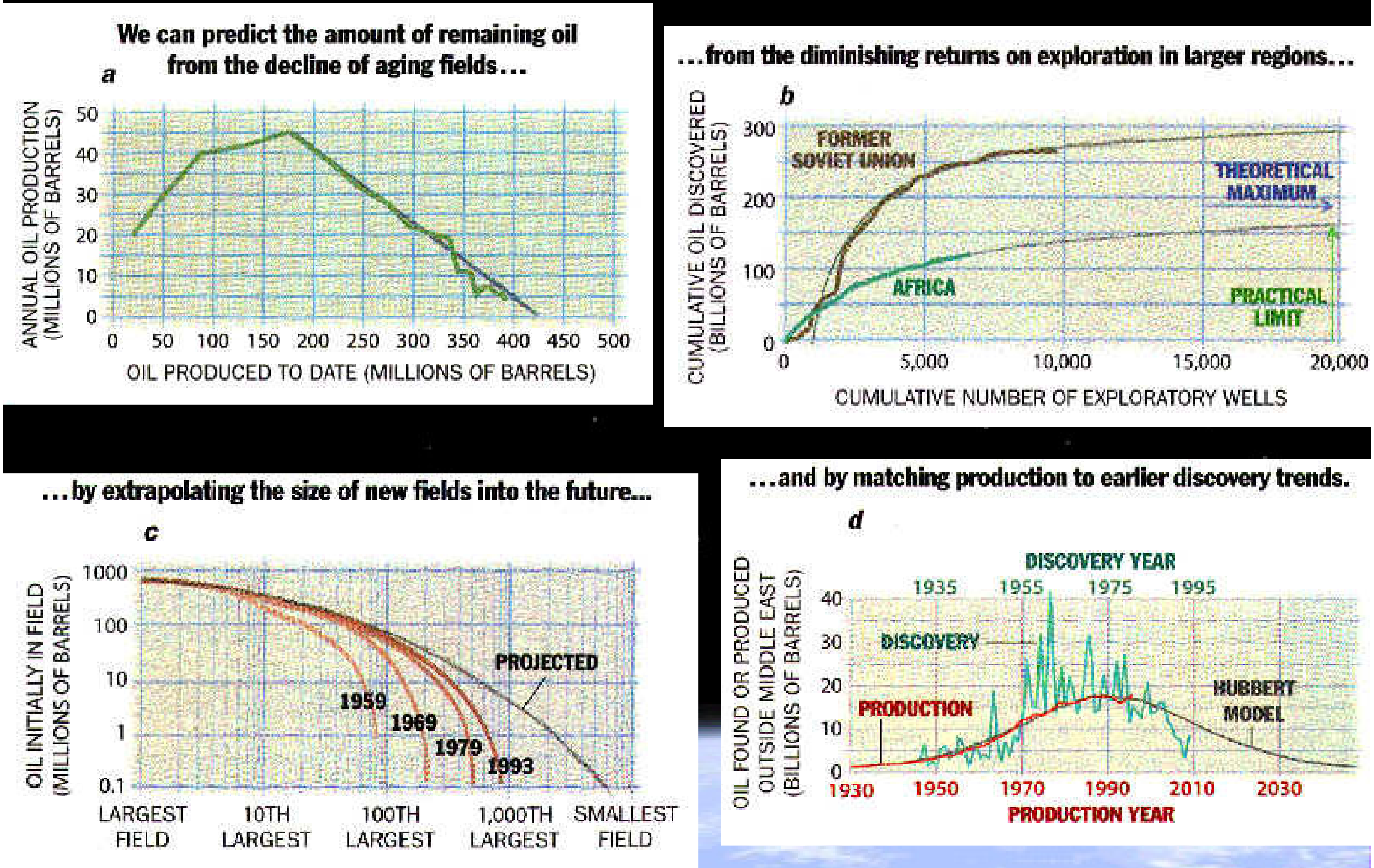






The Limits to Oil

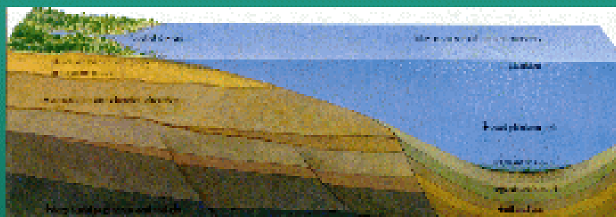
~~Not examinable~~



Not examinable

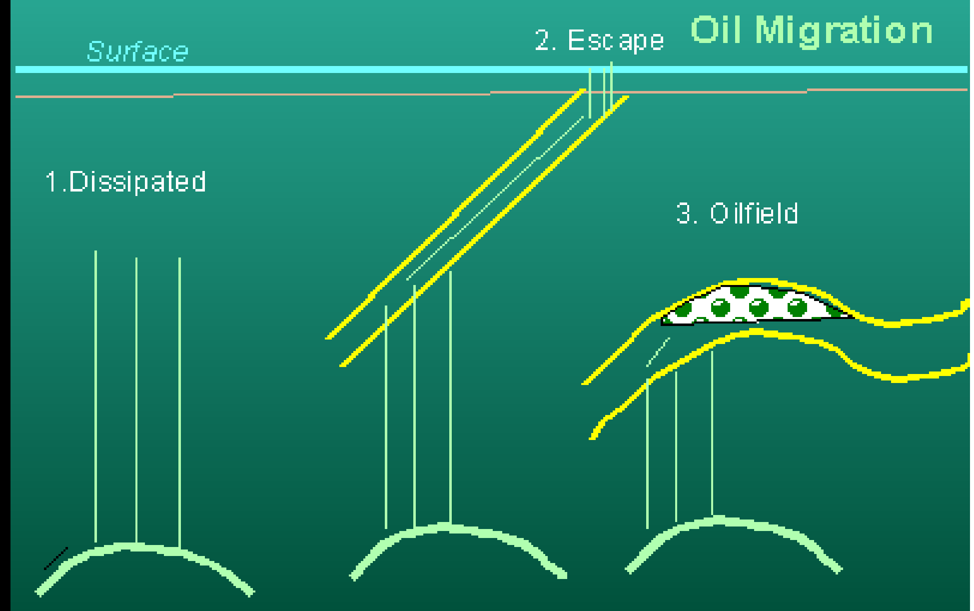
Limits to Oil

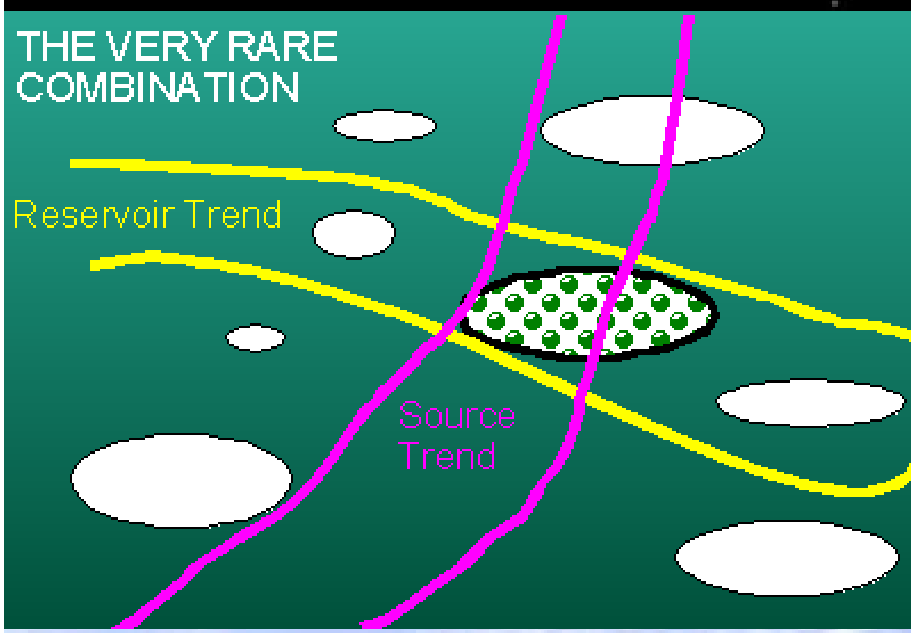
The stagnant trough



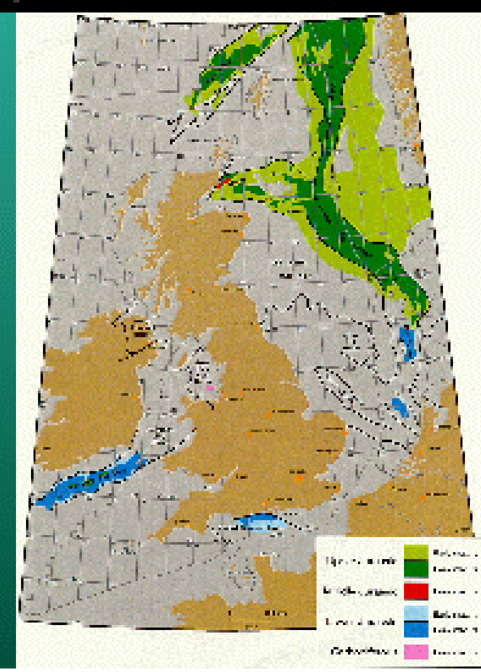
Conditions for prolific hydrocarbon generation

1. Algal flowering for oil; Plants for gas
2. A reducing environment
3. Critical balance of sediment influx
   to preserve and concentrate





North Sea oil generating trends

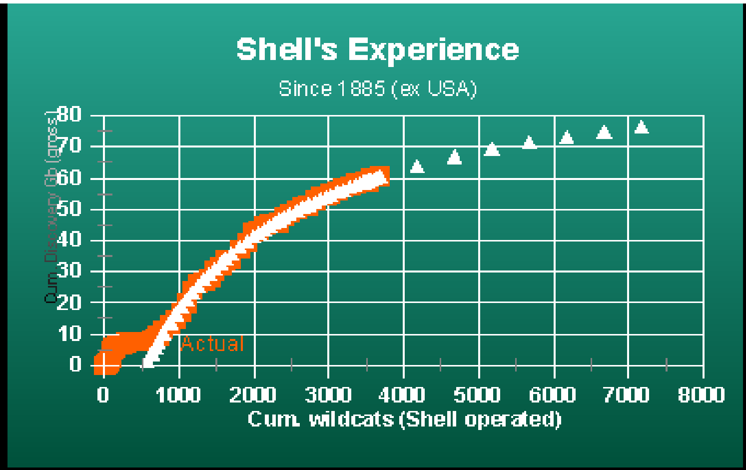


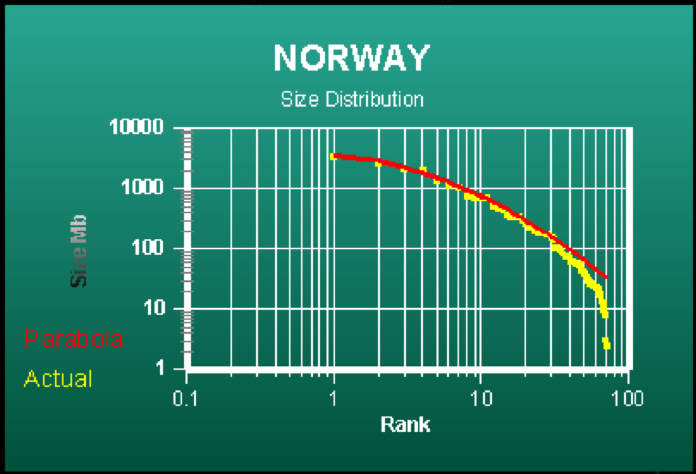
Not examinable

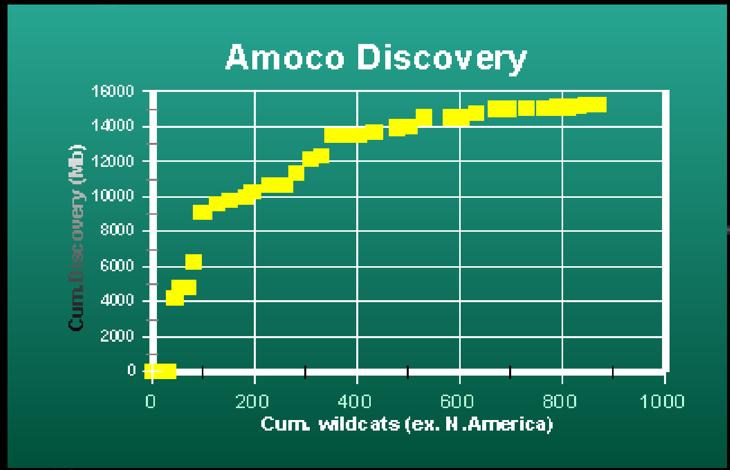
Causes of Confusion

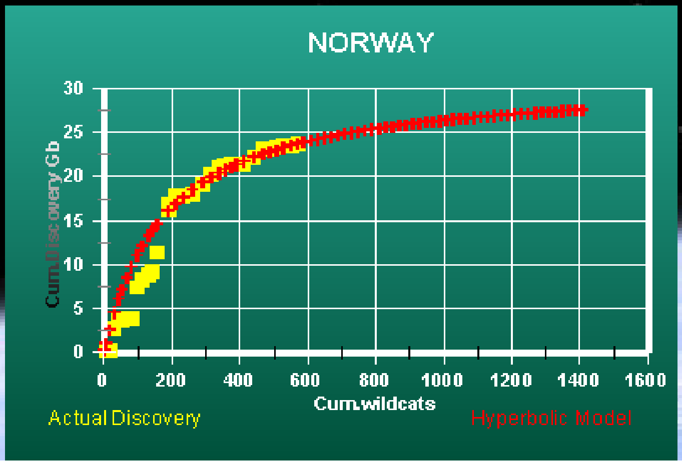
Many vested interests

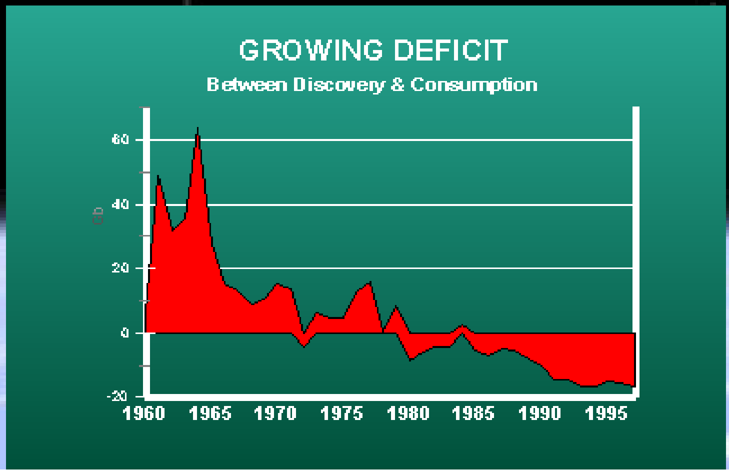
- Categories of oil and gas
  - Many different species - each with its own endowment and depletion rate
  - Peak driven by easy, cheap and fast to produce
- Nature of Reserve Estimates
  - Need best estimate not lowest
- Backdate revisions to discovery











What we learnt last lecture

- There are strong indications that global warming is happening, and that CO2 and a range of other GHGs are responsible
- Humanity is regarded by the majority of scientists as being a major cause of over-forcing the system
- Oil and gas underlie our society in all aspects and underpins the population.
- There possible non-biotic source for hydrocarbons, but big consensus believes them to be
  - a) rare
  - b) in decline
  - c) increasingly consolidated in fewer and fewer locations.

Exercise

- Hypothesise the discovery of a new North Sea Oil field
- Calculate how far back (in years) the peak of global oil would be set.
- Assume Gaussian production curve

The Science of Global Warming may still have surprises

Nature 439, 187-191 (12 January 2006) | doi:10.1038/nature04420

Methane emissions from terrestrial plants under aerobic conditions

Frank Keppler, John T. G. Hamilton, Marc Bra and Thomas Röckmann

'Methane is an important greenhouse gas and its atmospheric concentration has almost tripled since pre-industrial times

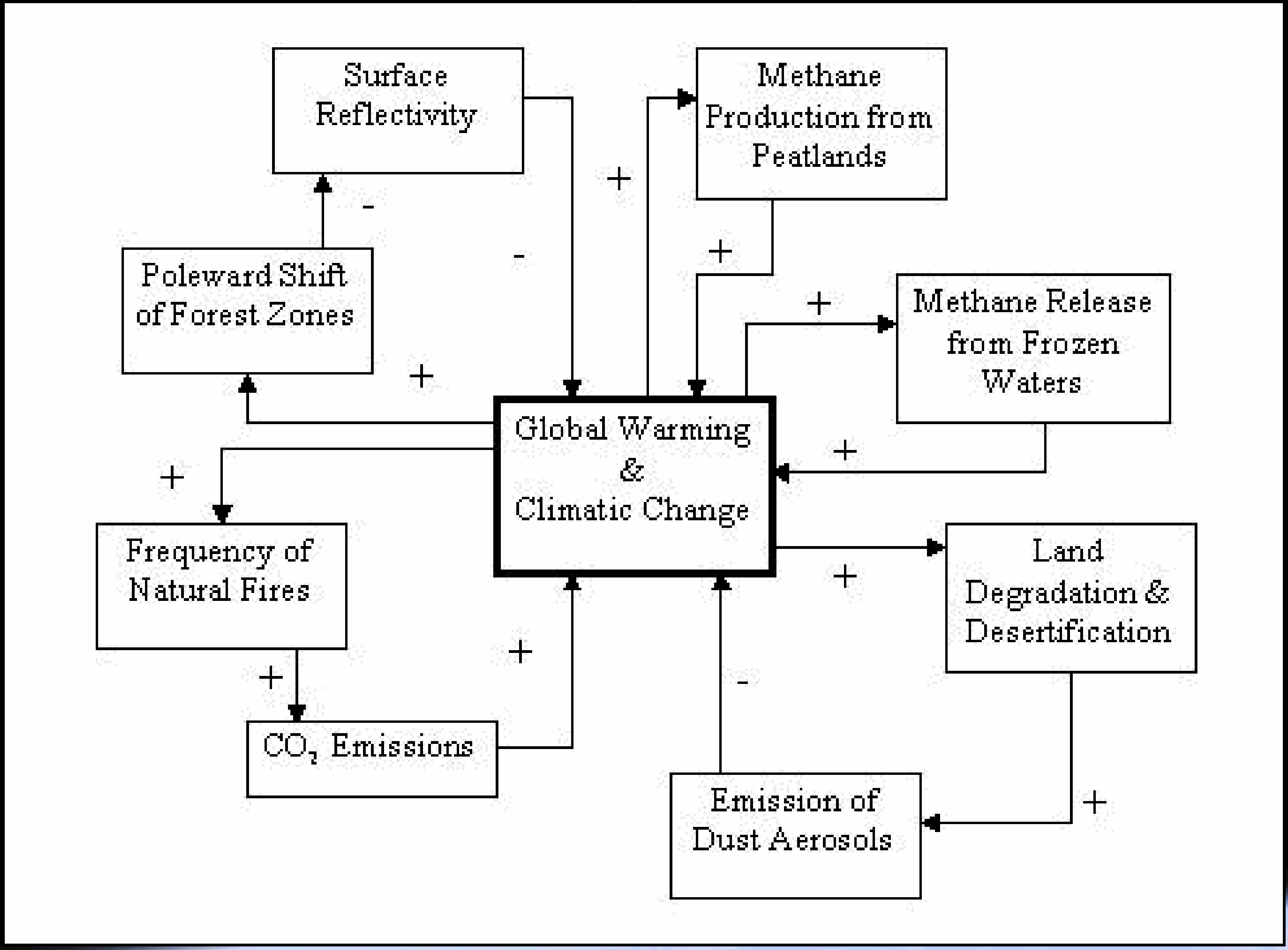
It plays a central role in atmospheric oxidation chemistry and affects stratospheric ozone and water vapour levels. Most of the methane from natural sources in Earth's atmosphere is thought to originate from biological processes in anoxic environments. Here we demonstrate using stable carbon isotopes that methane is readily formed *in situ* in terrestrial plants under oxic conditions by a hitherto unrecognized process.

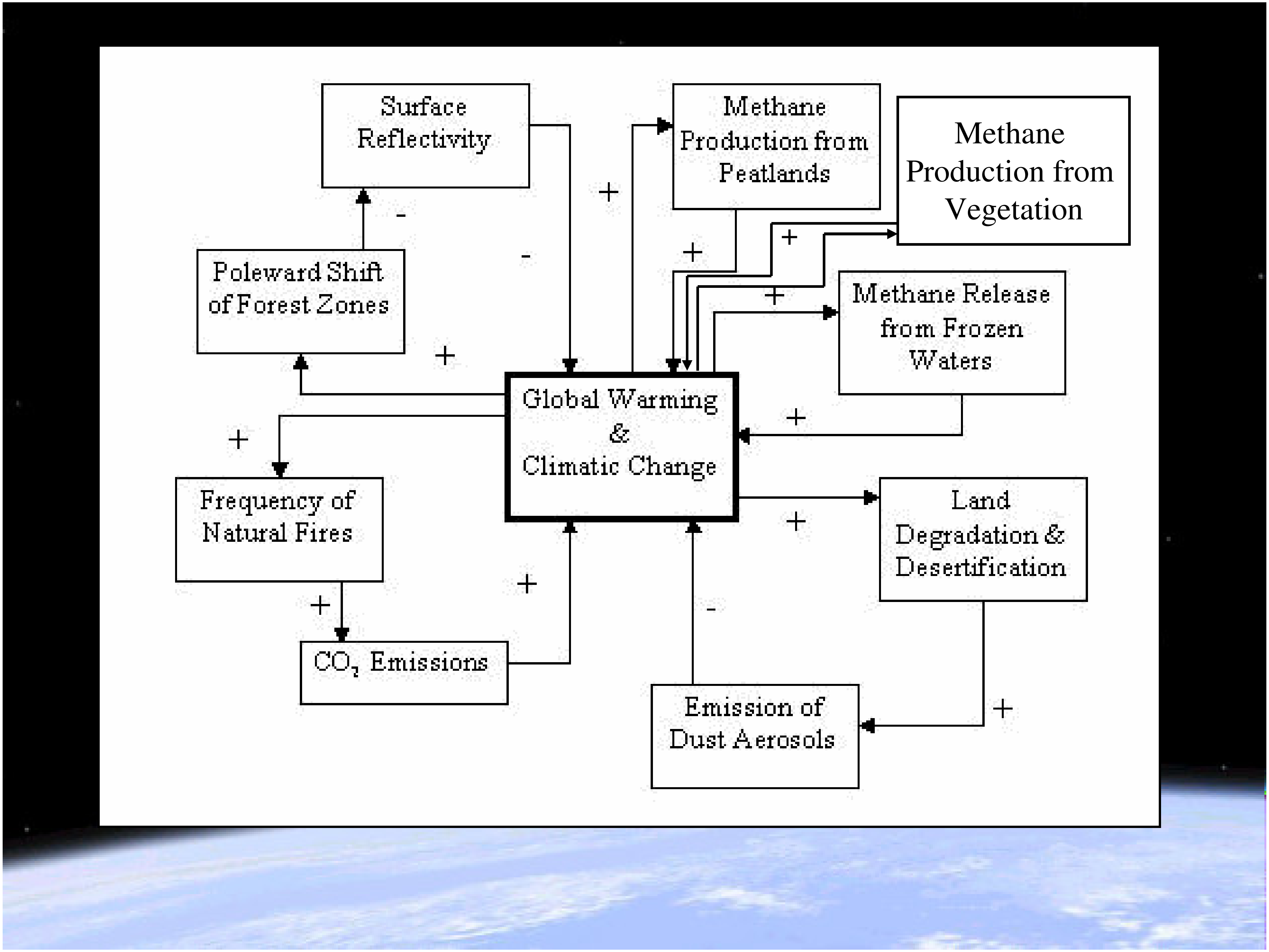
Keppler *et al*

Significant methane emissions from both intact plants and detached leaves were observed during incubation experiments in the laboratory and in the field. If our measurements are typical for short-lived biomass and scaled on a global basis, we estimate a methane source strength of 62–236 Tg yr^{-1} for living plants and 1–7 Tg yr^{-1} for plant litter (1 Tg = 10^{12} g).

We suggest that this newly identified source may have important implications for the global methane budget and may call for a reconsideration of the role of natural methane sources in past climate change'.

In its experiments, Keppler's team scrutinized the gaseous emissions of a variety of plants and their debris at normal atmospheric oxygen concentrations. A gram of dried plant material, such as fallen leaves, released up to 3 nanograms of methane per hour when the temperature was about 30°C. Each 10°C rise above that temperature, up to 70°C, caused the emission rate to approximately double. Living plants growing at their normal temperatures generated even larger quantities of methane, as much as 370 ng per gram of plant tissue per hour. Methane emission more than tripled when the plants, either living or dead, were exposed to sunlight. The team's experiments took place in sealed chambers with a well-oxygenated atmosphere, so it's unlikely that bacteria that thrive without oxygen generated the methane, says Keppler. Experiments on plants that were grown in water rather than in soil also resulted in methane emissions, another strong sign that the gas came from the plants and not soil microbes. From their data, the researchers estimate that the world's plants generate more than 150 million metric tons of methane each year, or about 20 percent of what typically enters the atmosphere


Surface Reflectivity
Methane Production from Peatlands
Poleward Shift of Forest Zones
Methane Release from Frozen Waters
Global Warming & Climatic Change
Frequency of Natural Fires
Land Degradation & Desertification
CO_2 Emissions
Emission of Dust Aerosols
-
-
+
+
+
+
+
+
+
+
+
-


Surface Reflectivity
Methane Production from Peatlands
Methane Production from Vegetation
Poleward Shift of Forest Zones
Methane Release from Frozen Waters
Global Warming & Climatic Change
Frequency of Natural Fires
Land Degradation & Desertification
CO_2 Emissions
Emission of Dust Aerosols
+
-

~~Not examinable~~

The Contrarian View

Why did the dinosaurs all die in Saudi Arabia? (Tommy Gold)

The case for Abiotic Oil

Hydrocarbons, as oil, gas and coal are called, occur on many other planetary bodies. They are a common substance in the universe. You find it in the kind of gas clouds that made systems like our solar system. You find large quantities of hydrocarbons in them.

Is it reasonable to think that our little Earth, one of the planets, contains oil and gas for reasons that are all its own and that these other bodies have it because it was built into them when they were born?

- http://www.wired.com/wired/archive/8.07/gold_pr.html
- http://www.gasresources.net/

Not examinable

Abiotic Oil

For almost a century, various predictions have been made that the human race is imminently going to run out of available petroleum. The passing of time has proven all those predictions to have been utterly wrong. It is pointed out here how all such predictions have depended fundamentally upon an archaic hypothesis from the 18th century that petroleum somehow (miraculously) evolves from biological detritus, and is accordingly limited in abundance. That hypothesis has been replaced during the past forty years by the modern Russian-Ukrainian theory of deep, abiotic petroleum origins which has established that petroleum is a primordial material erupted from great depth.

Therefore, petroleum abundances are limited by little more than the quantities of its constituents as were incorporated into the Earth at the time of its formation; and its availability depends upon technological development and exploration competence.

Statistical thermodynamic analysis has established clearly that hydrocarbon molecules which comprise petroleum require very high pressures for their spontaneous formation, comparable to the pressures required for the same of diamond. In that sense, hydrocarbon molecules are the high-pressure polymorphs of the reduced carbon system as is diamond of elemental carbon. Any notion which might suggest that hydrocarbon molecules spontaneously evolve in the regimes of temperature and pressure characterized by the near-surface of the Earth, which are the regimes of methane creation and hydrocarbon destruction, does not even deserve consideration.

Professor Emmanuil B. Chekaliuk, at All-Union Conference on Petroleum and Petroleum Geology, Moscow, 1968.

See also the extremely interesting **The Deep Hot Biosphere : The Myth of Fossil Fuels (Paperback)** Tommy Gold, Freeman Dyson

Carbon Content of fuels

bioenergy feedstocks: approx. 50% for woody crops
or wood waste;
approx. 45% for graminaceous (grass) crops or agricultural residues

coal (average) = 25.4 metric tonnes carbon per terajoule (TJ)
1.0 metric tonne **coal** = 746 kg carbon

oil (average) = 19.9 metric tonnes carbon / TJ
1.0 US gallon **gasoline** (0.833 Imperial gallon, 3.79 liter) = 2.42 kg carbon
1.0 US gallon **diesel/fuel oil** (0.833 Imperial gallon, 3.79 liter) = 2.77 kg carb

natural gas (methane) = 14.4 metric tonnes carbon / TJ
1.0 cubic meter **natural gas (methane)** = 0.49 kg carbon

Hydrogen (not a fuel, but a vector): 0% excluding production, transport

A carbon tax would be levied on all commercial forms of hydrocarbon fuels at a uniform rate, in relation to their carbon content. There are strong environmental arguments for fiscal instruments that discourage greenhouse gas emissions. The implementation of this tax by OECD countries (the highest hydrocarbon users) would significantly benefit the environment and supply a large part of the potential revenue that could be raised on a global scale.

Figures are regularly issued by many countries on the consumption of most forms of commercial energy and those for hydrocarbons can readily be converted, by means of a coefficient for each particular fuel, into carbon equivalents.

A uniform carbon tax on auto fuel of 4.8 cents per US gallon would represent US$ 17 per tonne of motor gasoline which, at an approximate carbon content of 0.81, would mean US$ 21 per tonne of carbon. Applied universally, this would raise about US$ 125 billion.

Governments would be free to collect the tax as they saw fit. For example, tax could be collected in the form of an excise tax per unit quantity of hydrocarbon fuel sold, the rate varying according to carbon content. This might encourage countries to impose additional taxes for domestic use on various hydrocarbon fuel. However, each country will be expected to raise a minimum tax by international agreement.

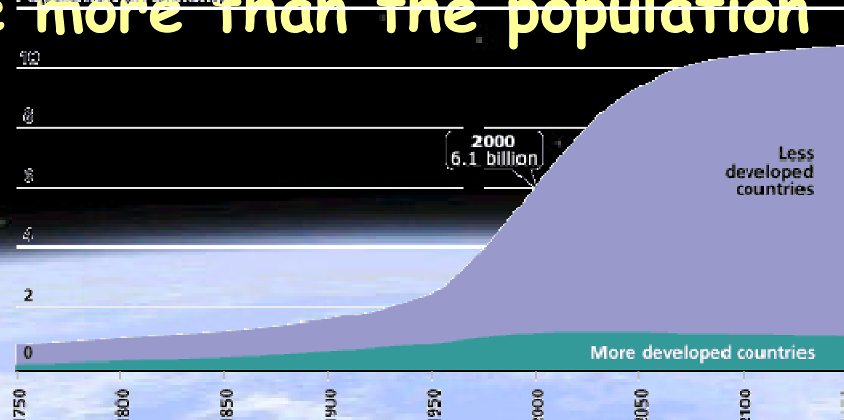
Specific excises, especially on sales of bulky commodities, are among the simplest and cheapest taxes to impose as the tax base is easily identified. Costs stay low because the commodities will often already be subject to specific taxes

Total Energy Use

- **In 1996 the total energy used in the world was 8380 mtoe (million tons of oil equivalent) which is about 400 million terajoules = 400 ExaJoules (EJ)= 4 x 10^{20} J.**

- ***Averaged over a year that's about 12TW***

- **The growth of the amount of energy used has been very rapid. It can been expressed as the product of two factors, the growth in the population and the growth in the energy used per person. It can be seen that it is the growth in energy use per person which has been and will be the driving force more than the population increase.**



http://www.dti.gov.uk/energy/inform/energy_stats/total_energy/index.shtml

Not examinable

I[illegible]tional Energy Outlook 2005

Report #: DOE/EIA-0484(2005) Released Date: July 2005

International Energy Annual 2002, DOE/EIA-0219(2002)

T[illegible]: World Total Primary Energy Consumption by Region, Reference Case, 1990-2025 (Quadrillion Btu)

	1990	2001	2002	2010	2015	2020	2025
Mature Market Economies							
North America 1.4	100.9	115.2	117.7	134.2	143.6	152.9	162.1
United States 1.3	84.6	96.3	98.0	110.6	117.6	125.1	132.4
Canada 1.6	11.1	12.8	13.1	15.6	16.9	17.8	18.8
Mexico 2.2	5.1	6.1	6.6	8.0	9.1	10.0	10.9
Western Europe 0.5	59.9	68.0	67.4	70.2	72.2	73.4	76.1
Mature Market Asia 0.7	22.7	28.0	28.4	30.4	31.5	32.5	33.6
Japan 0.5	18.3	21.9	22.0	22.9	23.6	24.1	24.7
Australia/New Zealand 1.4	4.5	6.1	6.5	7.5	7.9	8.4	8.8
Total Mature Market 1.1	**183.6**	**211.2**	**213.5**	**234.7**	**247.3**	**258.7**	**271.8**
Transitional Economies							
Former Soviet Union 1.6	60.9	42.0	42.4	49.7	53.9	57.2	61.0
Russia 1.4	39.1	27.7	27.5	31.3	33.5	35.7	37.9
Other FSU 1.9	21.8	14.3	14.9	18.4	20.4	21.5	23.1
Eastern Europe 1.7	15.3	11.4	11.2	13.3	14.5	15.6	16.7
Total Transitional 1.6	**76.2**	**53.4**	**53.6**	**63.0**	**68.4**	**72.8**	**77.7**
Emerging Economies							
Emerging Asia 3.5	51.5	84.7	88.4	133.6	155.8	176.3	196.7
China 4.1	27.0	40.9	43.2	73.1	86.1	97.7	109.2
India 3.3	8.0	13.8	14.0	19.6	22.7	26.0	29.3
South Korea 2.1	3.8	8.0	8.4	10.6	11.8	12.7	13.5
Other Asia 2.9	12.7	21.9	22.9	30.3	35.1	39.9	44.6
Middle East 2.5	13.1	20.9	22.0	28.7	32.4	35.6	38.9
Africa 2.7	9.3	12.5	12.7	16.7	19.3	21.4	23.4
Central and South America 2.3	14.5	21.2	21.2	26.8	30.4	33.2	36.1
Brazil 2.5	5.8	8.4	8.6	10.2	11.6	13.2	15.1
Other Central/South America 2.3	8.8	12.7	12.6	16.6	18.8	20.0	21.1
Total Emerging 3.2	88.4	139.2	144.3	205.8	237.8	266.6	295.1
Total World 2.0	348.2	403.9	411.5	503.5	553.5	598.1	644.6

Units

- **WATT** A metric unit used to measure the rate of energy generation or consumption. One horsepower is equal to 746 watts.
- **MEGAWATT** 10^6 W (MW) Gigawatt 10^9 W (GW) Common measure of generating capacity for large power plants. Typical windmill = 2MW. Typical nuclear power station – 1GW
- **JOULE** one watt of power operating for one second.
- **KILOWATT-HOUR** (kWh) A unit of energy equal to 3.6 million joules. It is the amount of energy generated by a one-kilowatt source operating for one hour.
- **PETAJOULE** Energy use on a large scale is often measured in petajoules. One metric ton of coal equivalent (U.N. standard) is approximately 29 billion joules, therefore one petajoule is equivalent to about 34,500 metric tons of coal.
- **PREFIXES:**
  - giga -- One billion (or 10^9)
    tera -- One trillion (or 10^{12})
    peta -- One thousand trillion (or 10^{15})
    exa -- One million million (or 10^{18})

~~Not examinable~~

Numbers and Conversion factors

- 1 British thermal unit (Btu) =1055.05585 joules (J)
  1 calorie (cal) =4.184 joules (J)
- Quad 1 Quadrillion BTU = 10^{15} Btu= 1.055 exa (10^{18}) J
- 1 exa (10^{18}) joule = 0.9478 quadrillion (10^{15}) Btu
- 1 Ton of oil equivalent (toe) = 40 MBtu = 42 GJ
- 1 barrel(42 gallons) of crude oil = 5 800 000 Btu
  1 gallon of gasoline = 124 000 Btu
  1 gallon of heating oil or diesel fuel = 139 000 Btu
  1 cubic foot of natural gas = 1 026 Btu
  1 therm = 100 000 Btu
  1 gallon of propane = 91 000 Btu
  1 short ton of coal = 20 681 000 Btu
  1 kilowatthour of electricity = 3412 Btu = 3.61×10^{6} J
  1 TW over one year = 8.76×10^{15} J
  1 EJ in a year ≡0.0317 TW (3600/24/7/52)

Current Burn Rate = 12.8TW

Numbers and Conversion Factors

- 1 million barrel of crude oil per day (bbl/day)

  = 1MBPD

  = 5.8 x 10^{12} Btu per day

  =80m tons coal per year

  = 1/5 ton per year UO_2

  = 2.23 x EJ/year

Not examinable

Conversions

Product Unit	Equivalent
Liquid Fuels	
42 U.S. gallons	1 barrel
1 cubic meter	6.289 barrels
159 liters	1 barrel
Gaseous Fuels	
35.315 cubic feet	1 cubic meter
Liquefied Natural Gas (LNG)	
1 metric ton	48,700 cubic feet of natural gas
Solid Fuels	
1 long ton	1.120 short tons
1 metric ton	1.10231136 short tons

What will fill in the missing energy?

- Within our lifetimes, energy consumption will increase at least two-fold, from our current burn rate of 12.8 TW to 20 – 30 TW by 2050

- The challenge for science is to meet this energy need in a secure, sustainable and environmentally responsible way.

Where does that 30TW come from?

- International energy consumption in 1998:

	population(m)	KWh/ year/capita
Norway	4.42	25304
Canada	30.30	16349
Sweden	8.85	15492
USA	269.09	13388
Japan	126.49	8008
France	58.85	7175
UK	59.24	5800
Saudi Arabia	20.74	5153
Russia	146.91	4873
S. Africa	41.40	4509
Brazil	165.87	1850
Mexico	95.68	1644
Turkey	64.75	1439
Egypt	61.67	900
China	1238.60	871
India	979.67	415
Sudan	28.35	47

Postulate population of 10bn each using 10,000 kW/h per year

≡1.141 kW each

$= 1.14 \times 10^{13}$ W

= 11TW

Not examinable

Total Primary Energy Consumption by Region, Reference Case, 1990-2025
W)

		1990	2001	2002	2010	2015	2020	2025
Mature Market Economies								
North America	1.4	3.4	3.9	3.9	4.5	4.8	5.1	5.4
United States	1.3	2.8	3.2	3.3	3.7	3.9	4.2	4.4
Canada	1.6	0.4	0.4	0.4	0.5	0.6	0.6	0.6
Mexico	2.2	0.2	0.2	0.2	0.3	0.3	0.3	0.4
Western Europe	0.5	2.0	2.3	2.3	2.3	2.4	2.5	2.5
Mature Market Asia	0.7	0.8	0.9	1.0	1.0	1.1	1.1	1.1
Japan	0.5	0.6	0.7	0.7	0.8	0.8	0.8	0.8
Australia/New Zealand	1.4	0.2	0.2	0.2	0.3	0.3	0.3	0.3
Total Mature Market	**1.1**	6.1	7.1	7.1	7.9	8.3	8.7	9.1

Not examinable

ansitional Economies

Former Soviet Union	1.6	2.0	1.4	1.4	1.7	1.8	1.9	2.0
Russia	1.4	1.3	0.9	0.9	1.0	1.1	1.2	1.3
Other FSU	1.9	0.7	0.5	0.5	0.6	0.7	0.7	0.8
Eastern Europe	1.7	0.5	0.4	0.4	0.4	0.5	0.5	0.6
Total Transitional	**1.6**	2.5	1.8	1.8	2.1	2.3	2.4	2.6
Emerging Economies								
Emerging Asia	3.5	1.7	2.8	3.0	4.5	5.2	5.9	6.6
China	4.1	0.9	1.4	1.4	2.4	2.9	3.3	3.7
India	3.3	0.3	0.5	0.5	0.7	0.8	0.9	1.0
South Korea	2.1	0.1	0.3	0.3	0.4	0.4	0.4	0.5
Other Asia	2.9	0.4	0.7	0.8	1.0	1.2	1.3	1.5
Middle East	2.5	0.4	0.7	0.7	1.0	1.1	1.2	1.3
Africa	2.7	0.3	0.2	0.3	0.3	0.3	0.4	0.4
Cent. and S Am.	2.3	0.5	0.7	0.7	0.9	1.0	1.1	1.2
Brazil		0.2	0.3	0.3	0.3	0.4	0.4	0.5
Other Cen/SAm	2.3	0.3	0.4	0.4	0.6	0.6	0.7	0.7
Total Emerging	3.2	3.0	4.7	4.8	6.9	8.0	8.9	9.9
Total World	2.0	11.6	13.5	13.8	16.8	18.5	20.0	21.6

» TW

What did we learn last lecture?

- Numbers: 80m bbl/day ≡ 30bn bbl /year
  ≡ 6400 tons coal /year
  ≡ 16 tons UO2 /year
  ≡ 178.4 EJ /year
  ≡ 5.7 TW over a year
  ≡ 44.5% total energy usage
- Units (use TW and EJ converting from non-SI units)
- Maybe there is non-biotic hydrocarbon genesis but it does not alter hydrocarbon scarcity issue if costs are taken into account (why is that?)
- World uses 12.8TW, but needs 20-30TW by 2025
- No single source can supply that yet

Not examinable

Helpful hints

Not examinable

- Any slide with this on is not examinable
- Exam questions will NOT be essays
- They will be numerical, and explore concepts.
- First problem sheet will follow exam format (out on Monday)

Not examinable

More on that crazy hydrocarbon genesis proposal…

- The spontaneous genesis of hydrocarbons that comprise natural petroleum have been analyzed by chemical thermodynamic-stability theory. The constraints imposed on chemical evolution by the second law of thermodynamics are briefly reviewed, and the effective prohibition of transformation, in the regime of temperatures and pressures characteristic of the near-surface crust of the Earth, of biological molecules into hydrocarbon molecules heavier than methane is recognized.

- For the theoretical analysis of this phenomenon, a general, first-principles equation of state has been developed by extending scaled particle theory and by using the technique of the factored partition function of the simplified perturbed hard-chain theory. The chemical potentials and the respective thermodynamic Affinity have been calculated for typical components of the H–C system over a range of pressures between 1 and 100 kbar (1 kbar 5 100 MPa) and at temperatures consistent with those of the depths of the Earth at such pressures.

The evolution of multicomponent systems at high pressures: VI. The thermodynamic stability of the hydrogen–carbon system: The genesis of hydrocarbons and the origin of petroleum
J. F. Kenney†‡§, Vladimir A. Kutcherov¶, Nikolai A. Bendeliani, and Vladimir A. Alekseevi

Not examinable

More on that crazy hydrocarbon genesis proposal….

- The theoretical analyses establish that the normal alkanes, the homologous hydrocarbon group of lowest chemical potential, evolve only at pressures greater than '30 kbar, excepting only the lightest, methane.

- The pressure of 30 kbar corresponds to depths of 100 km. For experimental verification of the predictions of the theoretical analysis, a special high-pressure apparatus has been designed that permits investigations at pressures to 50 kbar and temperatures to 1,500°C and also allows rapid cooling while maintaining high pressures. The high-pressure genesis of petroleum hydrocarbons has been demonstrated using *only* the reagents solid iron oxide, FeO, and marble, CaCO3, 99.9% pure and wet with triple distilled water.

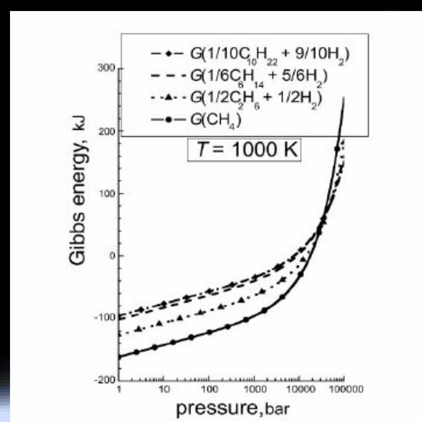
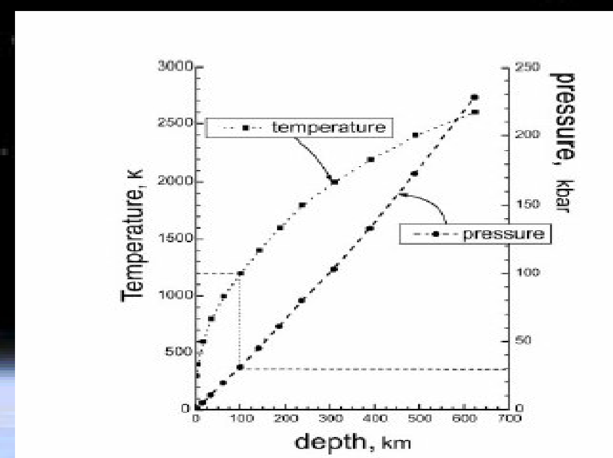


Fig. 2. Gibbs energies of methane and of the H–C system $[(1/n)C_nH_{2n+2} + (n-1)/nH_2]$.



The evolution of multicomponent systems at high pressures: VI. The thermodynamic stability of the hydrogen–carbon system: The genesis of hydrocarbons and the origin of petroleum

J. F. Kenney†‡§, Vladimir A. Kutcherov¶, Nikolai A. Bendelianii, and Vladimir A. Alekseevi

Where is this to come from?

From biomass, 7 - 10 TW:

This is the maximum amount of biomass energy available from the entire agricultural land mass of the planet.

From nuclear, 8 TW:

To deliver this TW value with nuclear energy will require the construction of 8000 new nuclear power plants. Over the next 45 years, this would require the construction of one new nuclear power plant every two days.

- **Powering the Planet: the Challenge for Science in the 21st Century - Professor Daniel Nocera**
- 25 January 2006 17:30 - 25 January 2006 18:30
  Location: G16, Sir Alexander Fleming Building

Where is this to come from?

From wind, 2.1 TW:

This energy is harvested by saturating the entire class 3 (the wind speed required for sustainable energy generation, 5.1 m/s at 10 m above the ground) and greater global land mass with wind mills.

From hydroelectric, 0.7 - 2.0 TW:

This energy is achieved by placing dams in all remaining rivers on the earth.

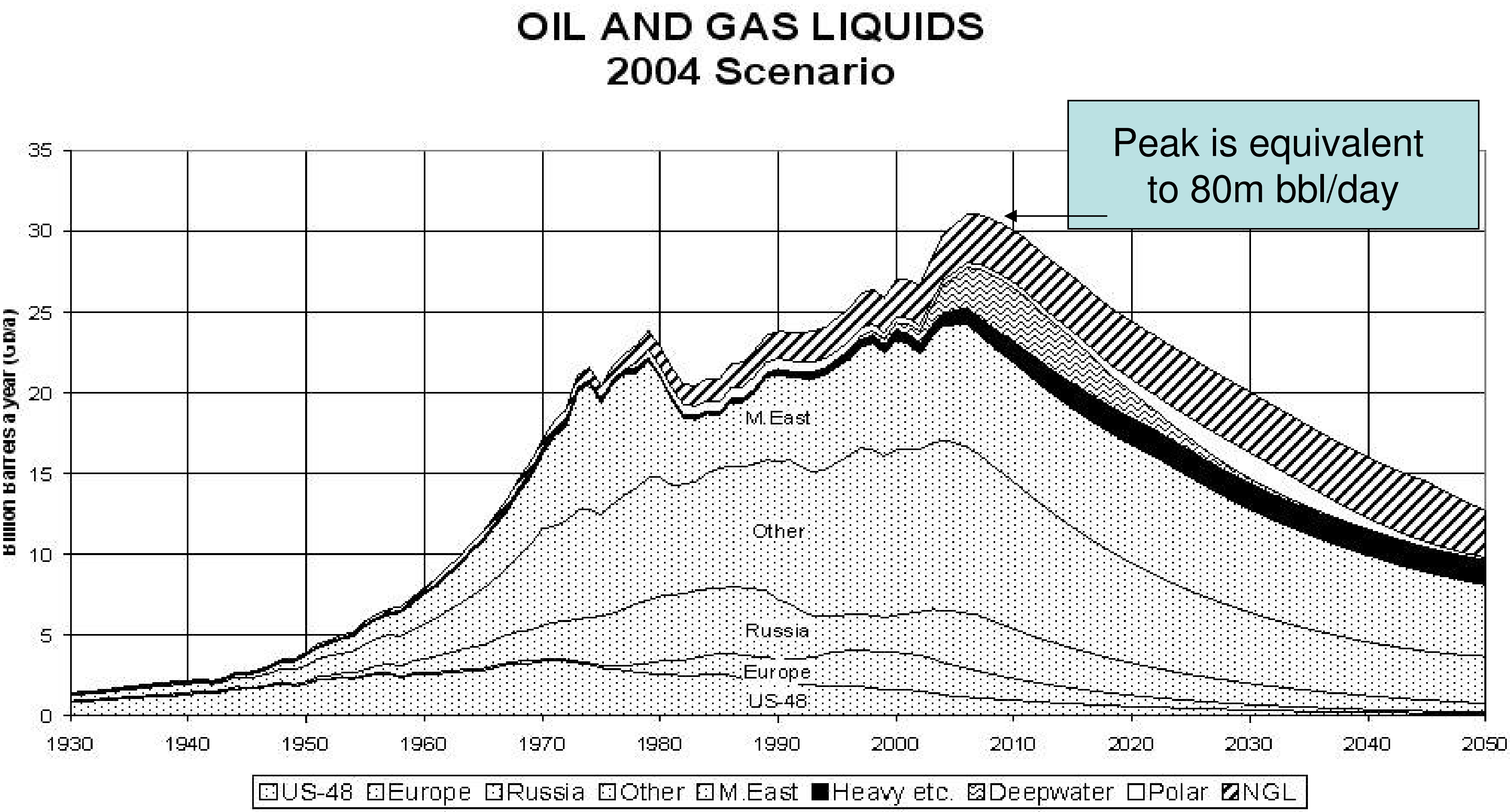
- **Powering the Planet: the Challenge for Science in the 21st Century - Professor Daniel Nocera**
- 25 January 2006 17:30 - 25 January 2006 18:30
  Location: G16, Sir Alexander Fleming Building

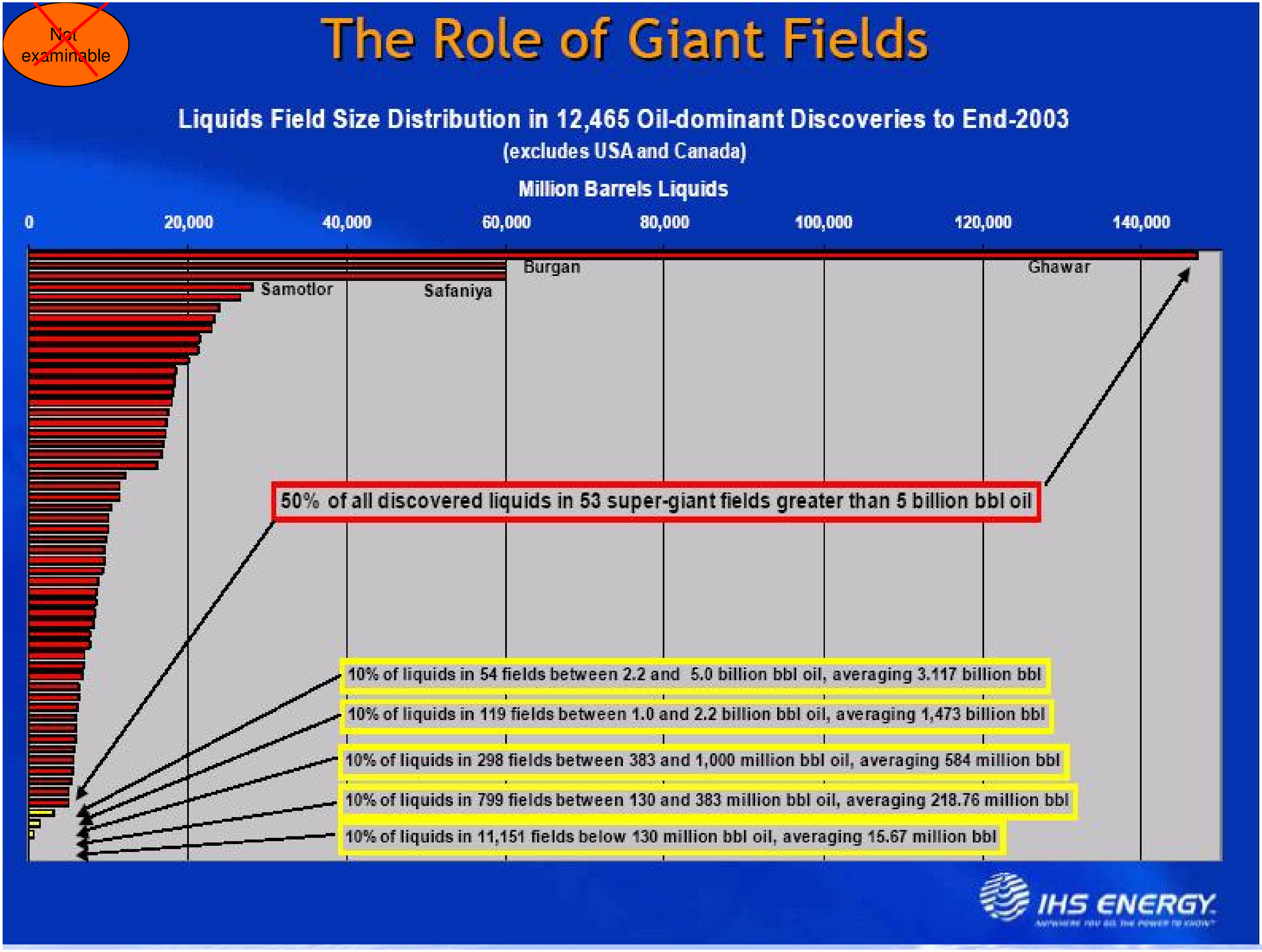
Not examinable

Under the untenable scenarios of the bulleted points listed above, an energy supply for 2050 is barely attained. The message is pretty clear. The additional energy needed for 2050, over the current 12.8 TW energy base, is simply not attainable from long discussed sources – the global appetite for energy is simply too much.

- Petroleum-based fuel sources (i.e., coal, oil and gas) could be increased. However, deleterious consequences resulting from external drivers of economy, the environment, and global security dictate that this energy need be met by renewable and sustainable sources.

The General Depletion Picture




Not examinable
The Role of Giant Fields
Liquids Field Size Distribution in 12,465 Oil-dominant Discoveries to End-2003
(excludes USA and Canada)
Million Barrels Liquids
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
Burgan
Ghawar
Samotlor
Safaniya
50% of all discovered liquids in 53 super-giant fields greater than 5 billion bbl oil
10% of liquids in 54 fields between 2.2 and 5.0 billion bbl oil, averaging 3.117 billion bbl
10% of liquids in 119 fields between 1.0 and 2.2 billion bbl oil, averaging 1,473 billion bbl
10% of liquids in 298 fields between 383 and 1,000 million bbl oil, averaging 584 million bbl
10% of liquids in 799 fields between 130 and 383 million bbl oil, averaging 218.76 million bbl
10% of liquids in 11,151 fields below 130 million bbl oil, averaging 15.67 million bbl
IHS ENERGY

What is the hydrocarbon equivalent?

World consumes 80m bbl/day≡29bn bbl/year (= 29 BBPD

= 4.64×10^{14} Btu per day

=6400m tons coal per year

= 40 ton per year UO_2

= 178.4 x EJ/year equivalent to 5.6TW

To match needs, hydrocarbon production must grow by over 6% per year

(Prove this)

Not examinable

Total energy costs

- **Nuclear power is currently one of the most expensive forms of electricity:**

Source of energy	Cost per kilowatt-hour
Energy Efficiency	0-5 cents
Hydroelectric	2-8 cents
Coal	5-6 cents
Wind	5-8 cents
Oil	6-8 cents
Solar Thermal	9 cents
Nuclear	**10-12 cents**
Solar Photovoltaic	15-20 cents

These numbers are aggregated over many sources and will be challenged in subsequent lectures. In particular, 'total costs' are rarely that.

Energy Return on Investment

The EROI is the ratio of the gross energy extracted to the energy used in the extraction process itself.

The EROI hunting and gathering is 10 to 20.

Agriculture requires greater inputs of energy compared to hunting and gathering, so EROI for agriculture often less than that for hunting and gathering… but agriculture allows greater density of population and economic displacement activities – allowing greater energy inputs and greater energy surplus.

Energy efficiency of service industries can be far higher than that of manufacturing, so as societies mature, energy density can decrease…

Energy Quality – an example

- The amount of solar energy intercepted by the Earth every *minute* is greater than the amount of fossil fuel the world uses every *year. (prove it)*
- Tropical oceans absorb 530 EJ of solar energy each year, equivalent to 1,600 times the world's annual energy use. *(prove it)*
- Annual photosynthesis by the vegetation in the Unites States is 49.58EJ, equivalent to nearly 60% of the USA's annual fossil fuel use. The land area of the lower 48 United States intercepts 49485EJ per year, = 500 times of the USA's annual energy use.

But absorbed energy is 0.006EJ per hectare per year.

But plants, on average, capture only about 0.1% of the solar energy reaching the Earth. This means that the actual plant biomass production in the United States is just 6.18×10^{13} J per hectare per year.

… the *quality* of solar energy is low

So in trying to solve the 3 'perfect storm' issues

- We must look at globally applicable solutions
- Apply a full lifetime economic costs
  - R&D costs honestly amortised
  - Capital cost honestly amortised
  - Fuel costs honestly calculated
  - O&M costs with real (not wishful) numbers including cost of pollution associated
  - Cost of post-operation : decommissioning, fuel storage etc
- So for solar cells, we must understand the full EROI by including production costs ($ and EJ)
- For nuclear, we must apply full reprocessing, storage etc
- We must also internalise reasonable insurance costs
- And costs of instability/ dependency on too few sources

Biomass

- At present 10.4 % of the total land area or 2.95 % of the total terrestrial globe surface are cultivated. According to Food and Agricultural Organisation data of the UNO (F.A.O.) the world's land reserves accounts for 13.4 billion hectares.

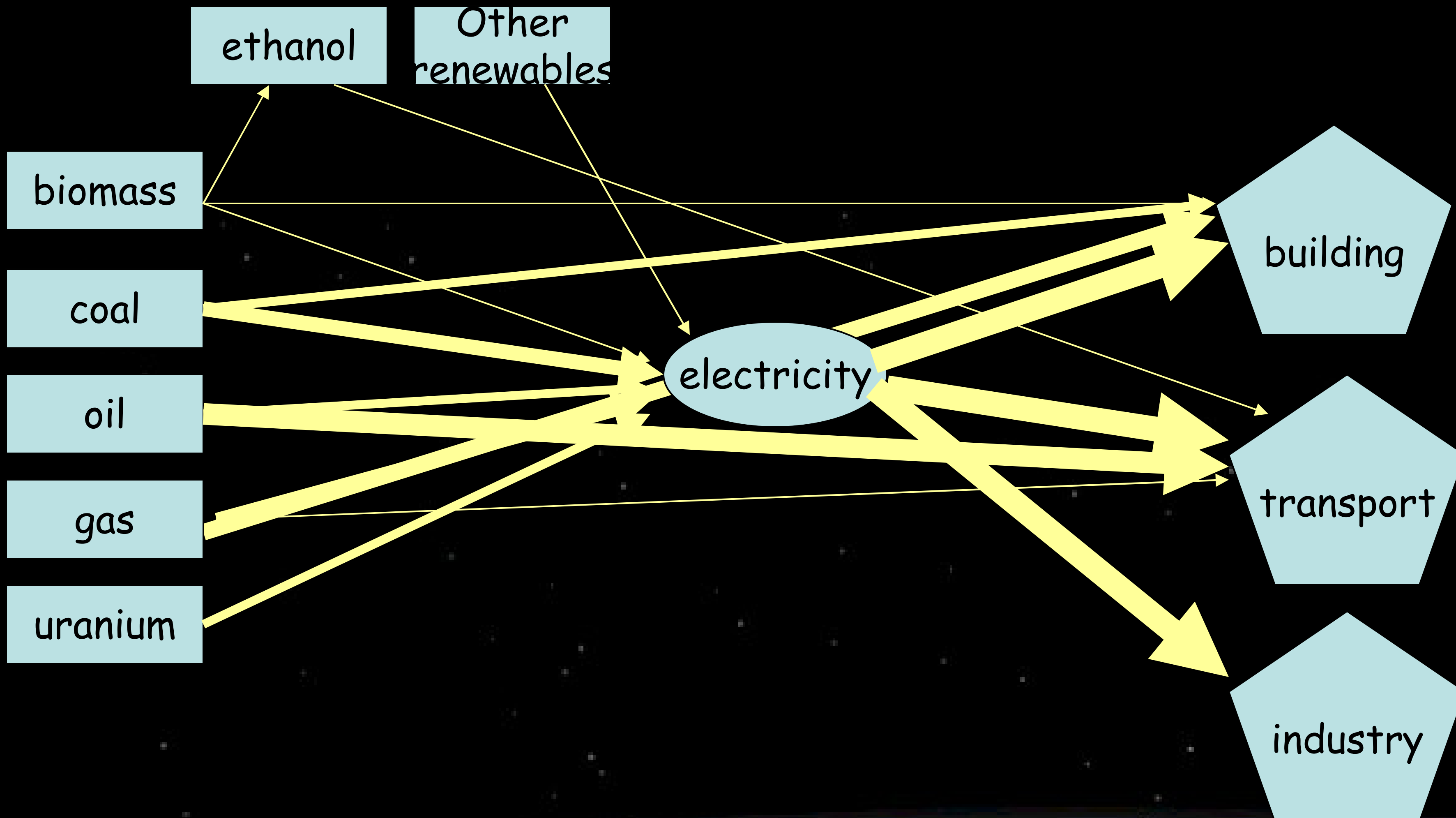
- Out of them:
- Cultivated areas (arable land and plantations) account for about 1.5 billion hectares (11 %);

- Pastures account for 3.2 billion hectares - 24 %;
- Forest and shrubs account for 4.1 billion hectares (41 %);
- Other lands (sands, stone space, lands intended for building) account for 4.4 billion hectares (34 %)
- Let's assume 10bn Ha are available, ignoring need for food

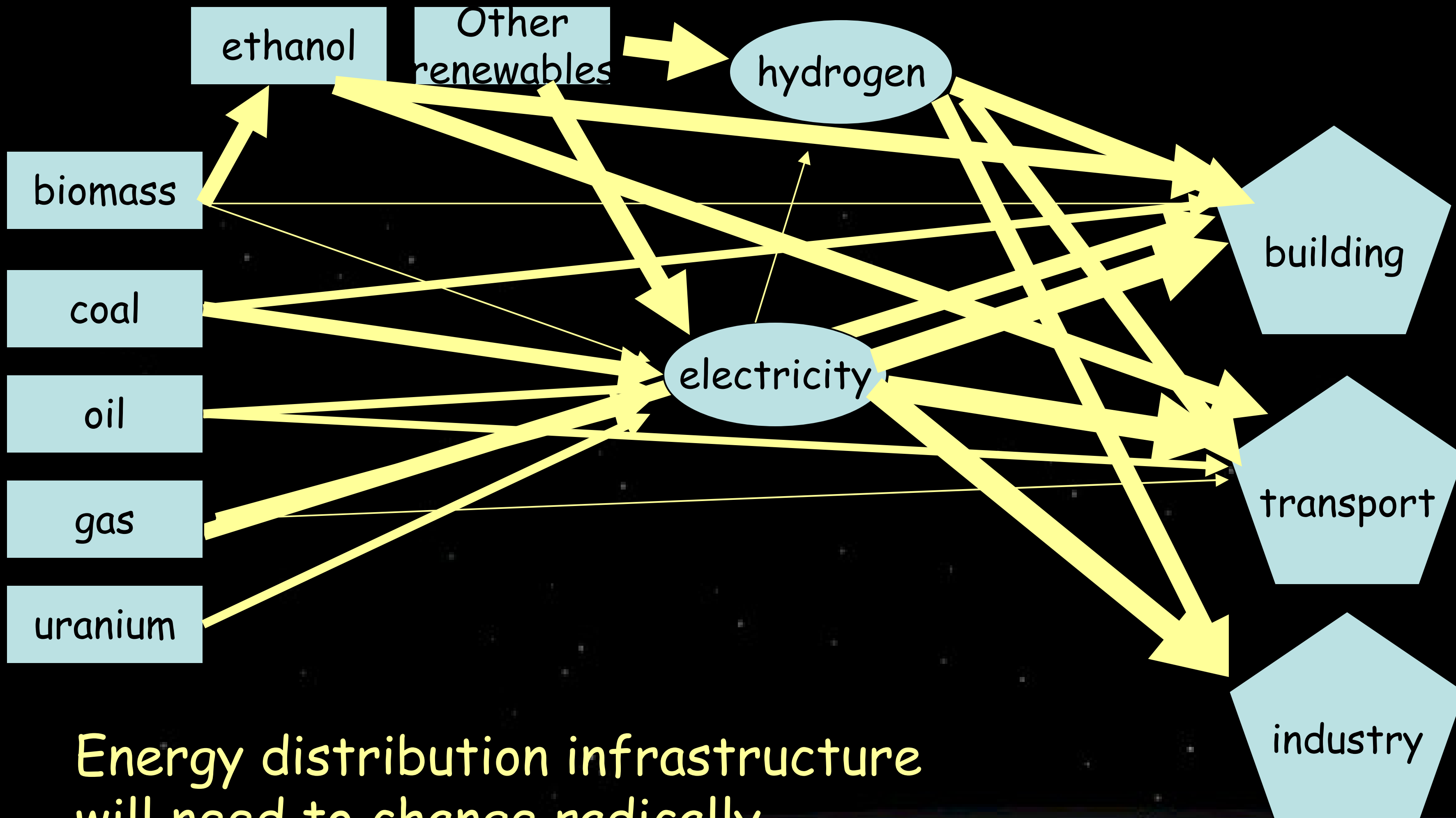
- = 1×10^{14} m^2. If we convert all sunlight to biomass, we get about 2×10^{16}W = 20,000TW….however….that is not feasible.

- If photosynthesis efficiency is 0.1% and we can spare 1% 'forest+ scrub' for biomass we get (what? Calculate it!) in electrical power…..See Nelson lectures.

Biomass - and other renewables



Biomass - and other renewables



Energy distribution infrastructure will need to change radically

This must be included in proper assessment of costs

Biomass in the US

US Petroleum Imports Current: 25 EJ 2020 (AEO): 38 EJ

Biomass production example
Land Area: All Conservation Reserve Program Lands
Biomass Production: 1.3 - 2.0 EJ switchgrass ≡0.04- 0.06TW over the year

Biofuel production
Biomass Input: 2.0 EJ switchgrass ≡ 0.06TW over the year

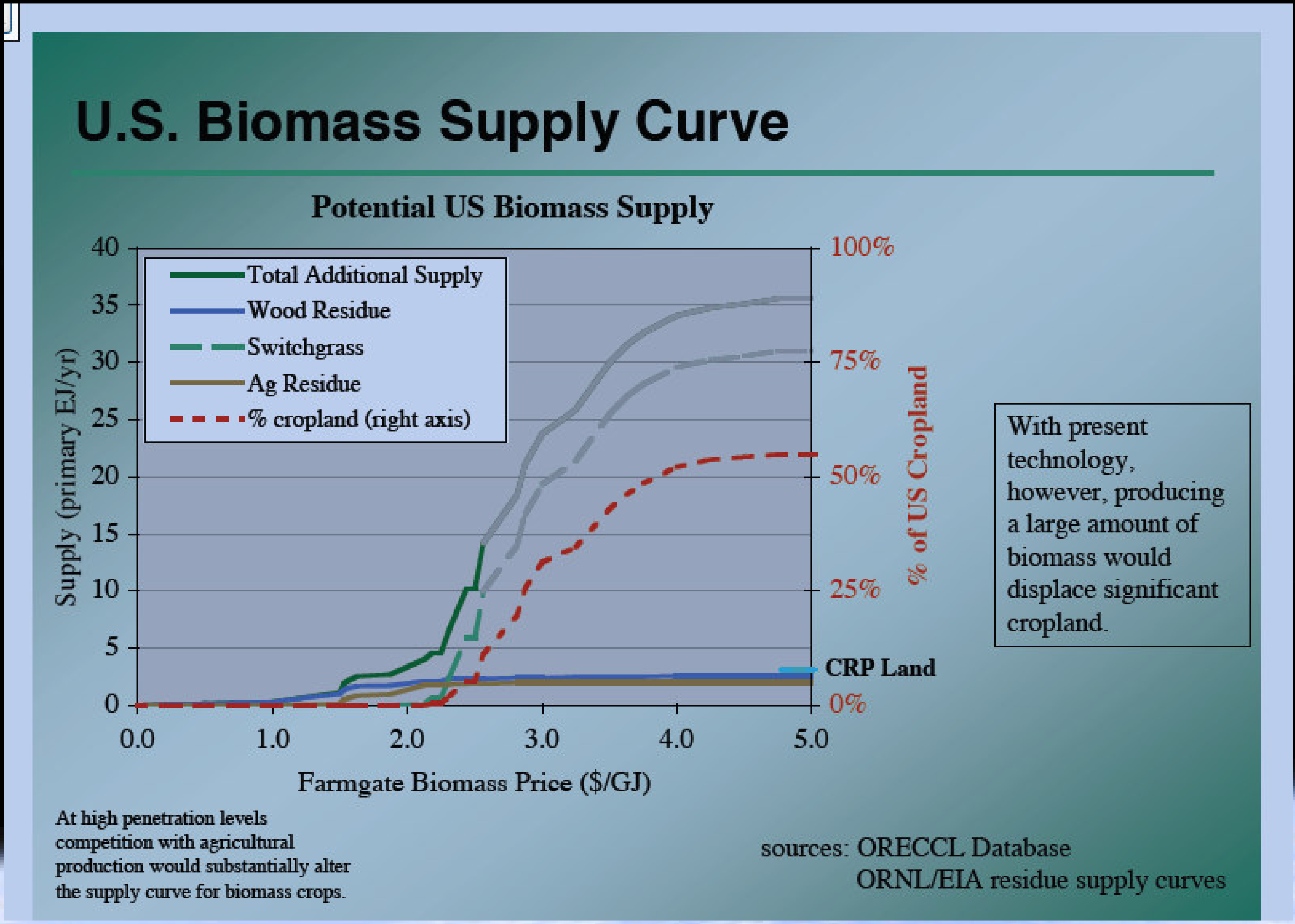
Ethanol Production: 1 EJ ≡ 0.03TW over the year

1 EJ is
59 million tonnes switchgrass
2,500 million bushels of corn)
~160 million barrels of oil (boe)
8.2 billion US gallons gasoline (LHV)
12.5 billion US gallons ethanol (LHV)

Adapted from: Steven Smith JGCRI – College Park, MD
April 2004 *GCEP Energy Workshop, Stanford,* (source: ORECCL Database)
And 2010 ethanol technology: NREL, Golden Colorado

Not examinable

To go beyond 1-2 EJ/year cuts into farmland



Not examinable

Nuclear Power around the world

Nuclear Power (1993)

Country	Nuclear as Percentage of Gross Electricity Generation (rounded)	Gross Electricity Generation (million kWh)	Gross Capacity (MW)
France	78%	368,188	59,020
Belgium	60%	41,927	5,485
Sweden	43%	61,395	9,912
Spain	36%	56,060	7,020
S. Korea	36%	58,138	7,616
Ukraine	33%	75,243	12,818
Germany	29%	153,476	22,657
Japan	28%	249,256	38,541
United Kingdom	28%	89,353	11,894
United States	19%	610,365	99,061
Canada	18%	94,823	15,437
Russia	12%	119,186	21,242
World Totals*	**18%**	**2,167,515**	**340,911**

* World totals include countries not individually listed. Source: *Energy Studies Yearbook: 1993* (New York: United Nations, 1995).