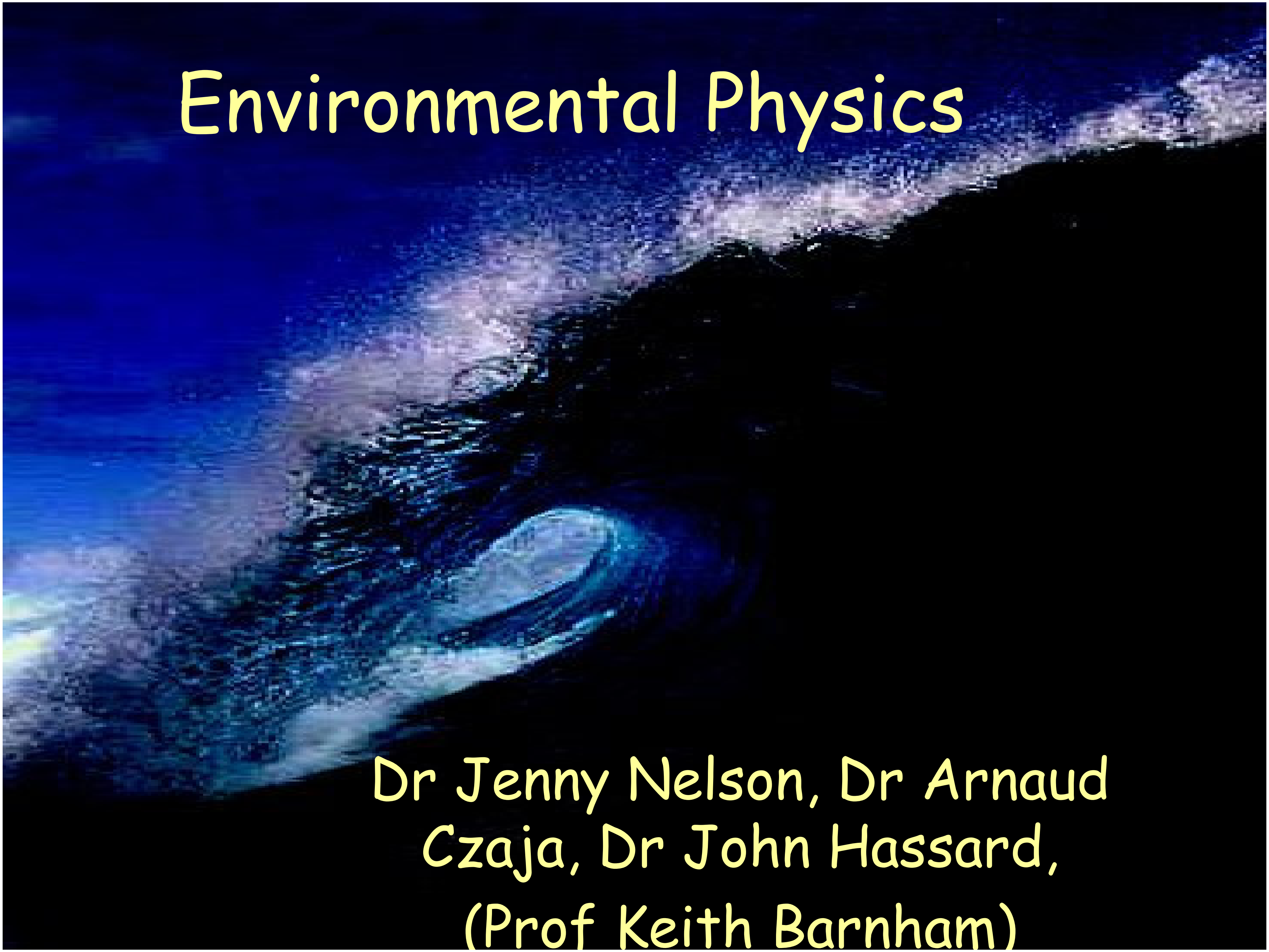
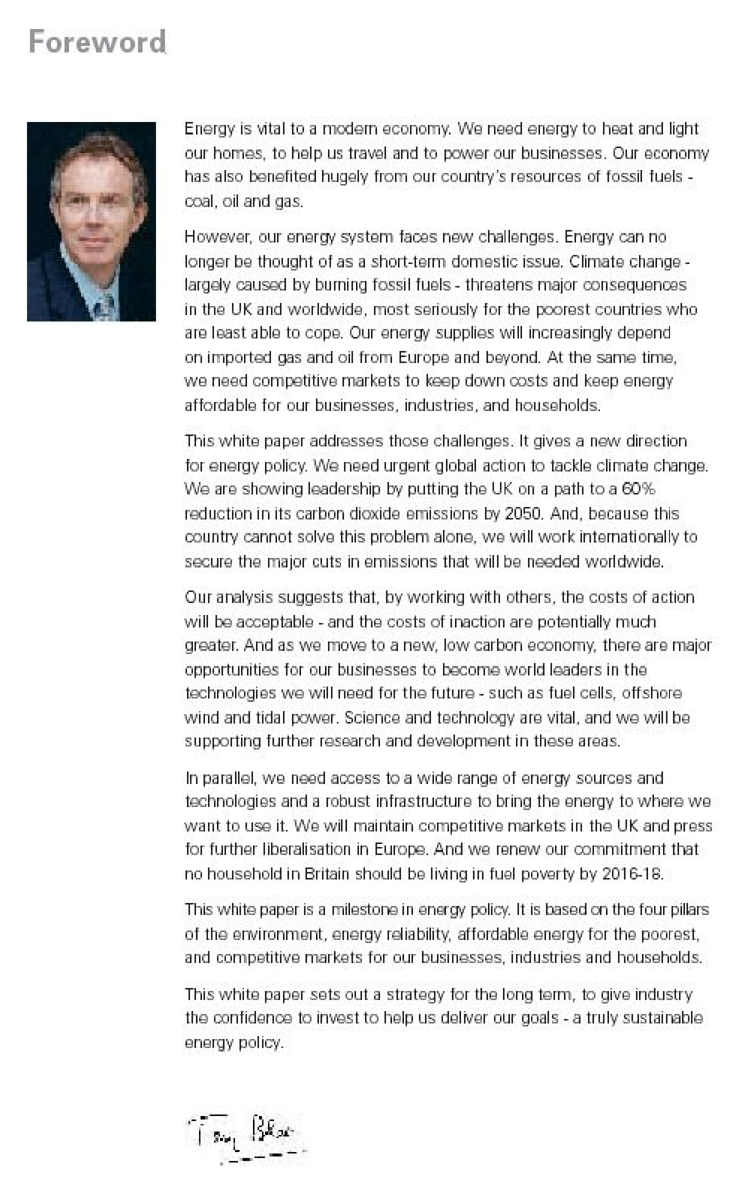


Environmental Physics

Dr Jenny Nelson, Dr Arnaud Czaja, Dr John Hassard,
(Prof Keith Barnham)

The Perfect Approach



Foreword

Energy is vital to a modern economy. We need energy to heat and light our homes, to help us travel and to power our businesses. Our economy has also benefited hugely from our country's resources of fossil fuels - coal, oil and gas.

However, our energy system faces new challenges. Energy can no longer be thought of as a short-term domestic issue. Climate change - largely caused by burning fossil fuels - threatens major consequences in the UK and worldwide, most seriously for the poorest countries who are least able to cope. Our energy supplies will increasingly depend on imported gas and oil from Europe and beyond. At the same time, we need competitive markets to keep down costs and keep energy affordable for our businesses, industries, and households.

This white paper addresses those challenges. It gives a new direction for energy policy. We need urgent global action to tackle climate change. We are showing leadership by putting the UK on a path to a 60% reduction in its carbon dioxide emissions by 2050. And, because this country cannot solve this problem alone, we will work internationally to secure the major cuts in emissions that will be needed worldwide.

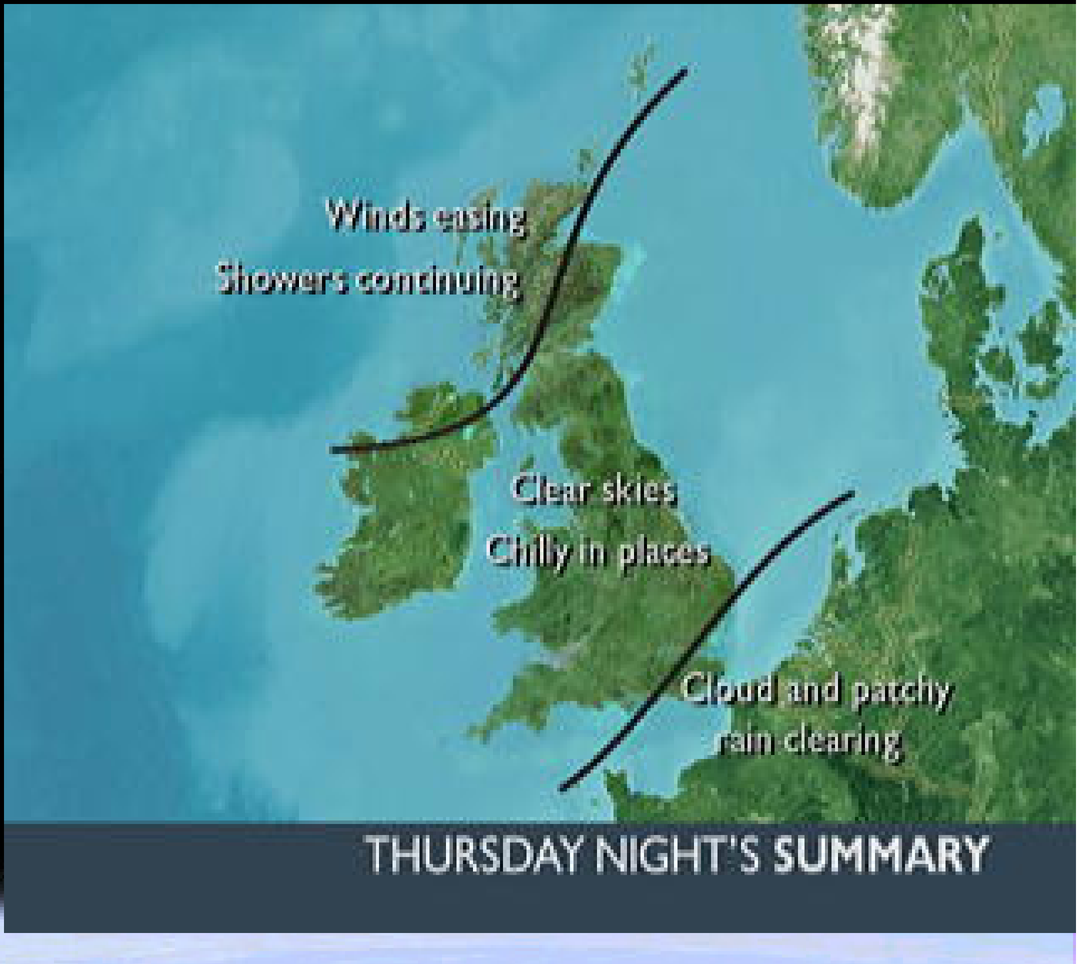
Our analysis suggests that, by working with others, the costs of action will be acceptable - and the costs of inaction are potentially much greater. And as we move to a new, low carbon economy, there are major opportunities for our businesses to become world leaders in the technologies we will need for the future - such as fuel cells, offshore wind and tidal power. Science and technology are vital, and we will be supporting further research and development in these areas.

In parallel, we need access to a wide range of energy sources and technologies and a robust infrastructure to bring the energy to where we want to use it. We will maintain competitive markets in the UK and press for further liberalisation in Europe. And we renew our commitment that no household in Britain should be living in fuel poverty by 2016-18.

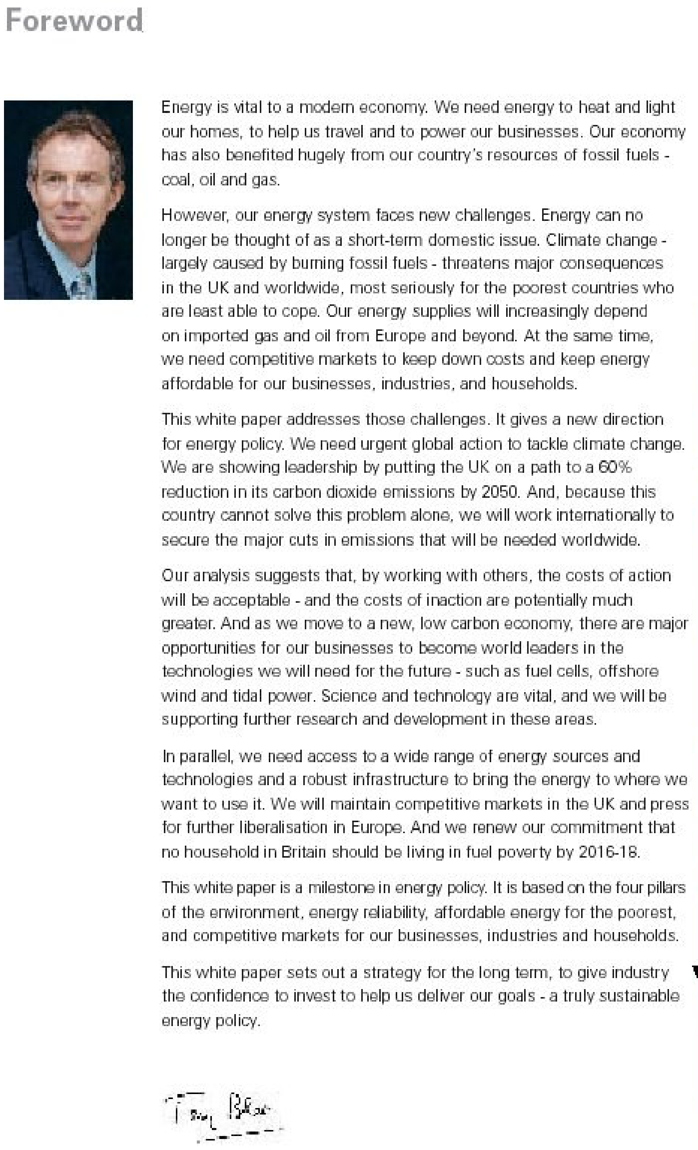
This white paper is a milestone in energy policy. It is based on the four pillars of the environment, energy reliability, affordable energy for the poorest, and competitive markets for our businesses, industries and households.

This white paper sets out a strategy for the long term, to give industry the confidence to invest to help us deliver our goals - a truly sustainable energy policy.

Tony Blair



The Perfect Storm



Foreword

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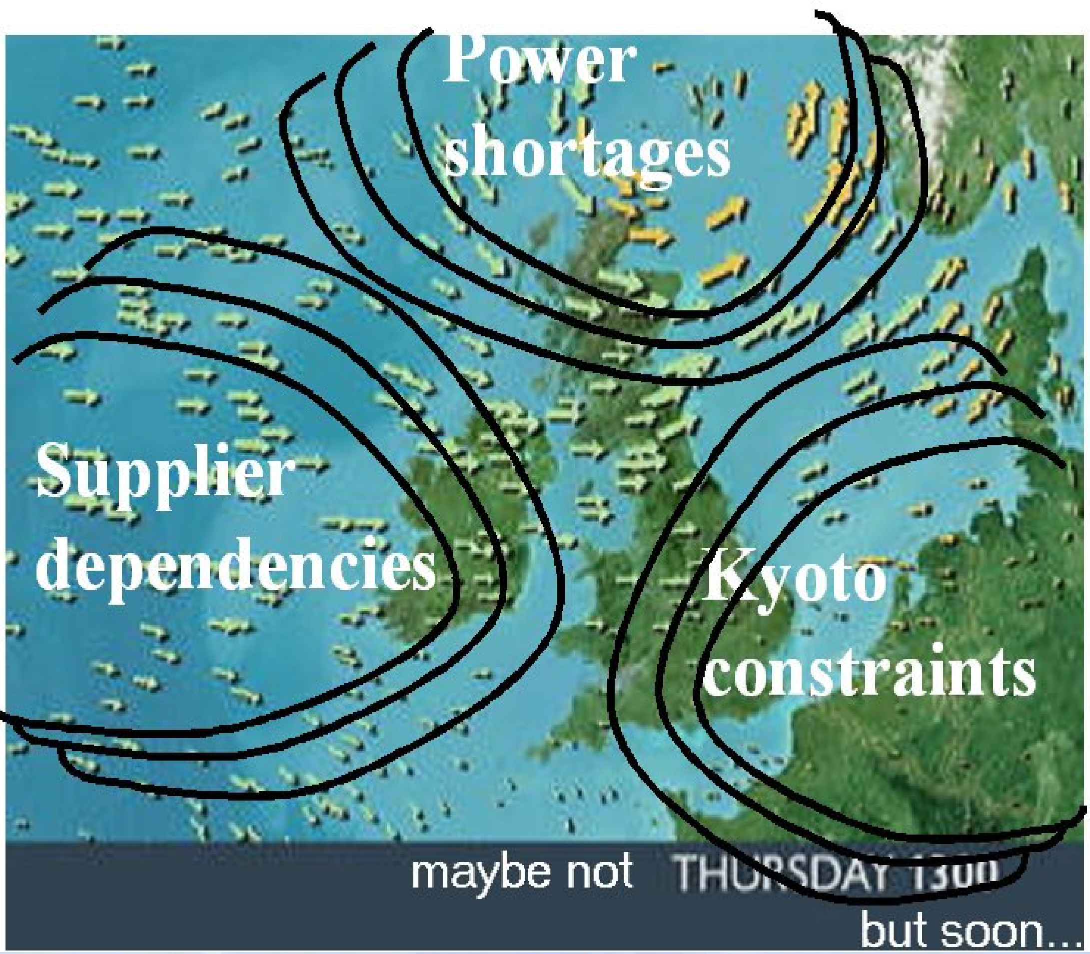


maybe not

but soon...

Aims and Objectives

Aims:

- To introduce students to the application of core physics concepts to issues related to energy and the environment, with special focus on: energy production use and conversion; factors influencing the Earth's temperature; environmental monitoring techniques. The course should develop students' problem solving abilities, provide practice in the applications of physics and help to develop a critical awareness of the wider context of aspects of science and technology.

Objectives:

- To understand the physical basis of the main sources of energy for human use.
- To be familiar with the factors influencing energy consumption and its true costs in the past and the issues determining future trends.
- To understand how spectroscopy and detection technology may be used for monitoring environmental processes and pollutants.
- To be able to discuss the main factors influencing Earth's temperature
- To understand the origin and action of the "greenhouse effect"
- To understand the influences of CO2 and water vapour feedback on radiative forcing and Earth temperature
- To understand the origin of winds and ocean currents
- To understand how solar energy can be converted into thermal, kinetic, electrical or chemical energy, and the function of a photovoltaic cell
- To calculate the efficiency of solar thermal and solar photovoltaic energy converters using heat engine models
- To understand the production of electricity from wind, wave, tidal and hydroelectric resources.

Why this course for physicists?

Physicists are meant to have a better than average chance of being able to identify problems, apply rigorous analysis to quantifying, and identifying interdependencies within that problem, establishing a set of solutions and the consequences of those solutions.

All three components of that 'perfect storm' of problems have the potential to **massively disrupt our society**. All three have their roots in science and technology. All three have the roots of solutions in science and technology – and how these can be applied.

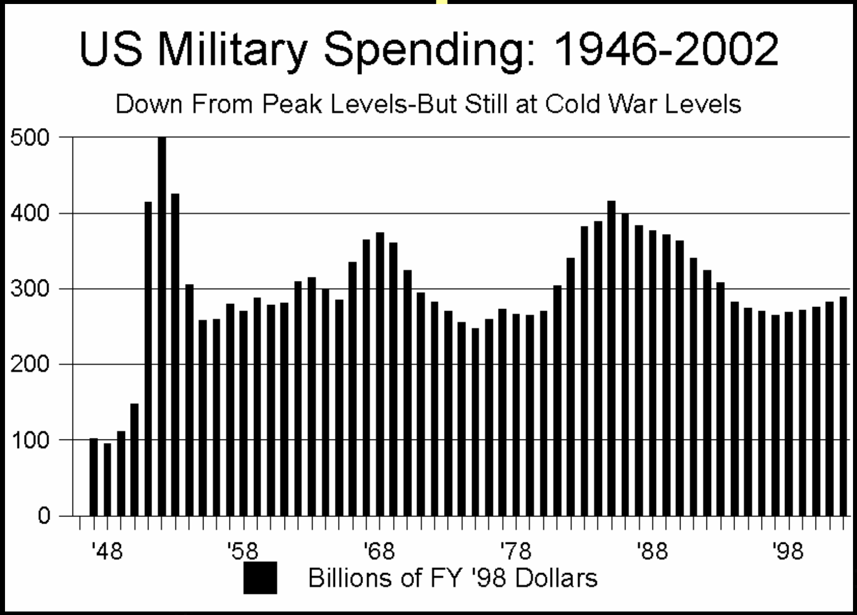
Our goal is to understand what is known, and what is not known about the environment now, and projecting into the future.

- To anticipate risks and opportunities by examining the underlying physical principles
- To see how physics reality, and its inherent uncertainties, guide, limit and constrain political and social response
- To apply our alleged relative sophistication in unbiased analysis to what might be the most serious threats to society presently around

Risk and Risk Perception

- "perfect storm' of problems have the potential to massively disrupt our society'

This would normally result in society trying to find ways to mitigate. However, 'risk perception' is not the same as 'risk' and it is a physicist's job – with other disciplines – to try to make the two converge to allow rational and cost effective measures to be formulated and executed.



US Military Spending: 1946-2002

Down From Peak Levels-But Still at Cold War Levels

Clinton approved an increase for the Pentagon of $112 billion over 6 years . . .
. . .
and $6.6 billion for Star Wars deployment over 6 years to the Pentagon budget

and 1-year Pentagon budget boost is $12.6 billion in fiscal year 2000 alone . . .

and that the combined annual military budgets of the Pentagon's rogue states -- North Korea, Iraq and Iran -- totals less than $9 billion

Let's look at the perceived threat has been addressed over the last 50 years.

Risk Perception

Personal risks: Ralph Hertwig, PhD, of the University of Basel "People can arrive at relatively accurate estimates as long as they rely on their personal experiences of the frequencies of such events ....However, when they start sampling from the virtual world as created by the mass media, they are more likely to arrive at distorted estimates of likelihood."

The findings suggest that people aren't horribly off the mark as long as they do not rely on media reports and stick to what's happened to people they know. *Journal of Experimental Psychology: Learning, Memory and Cognition* (APA).

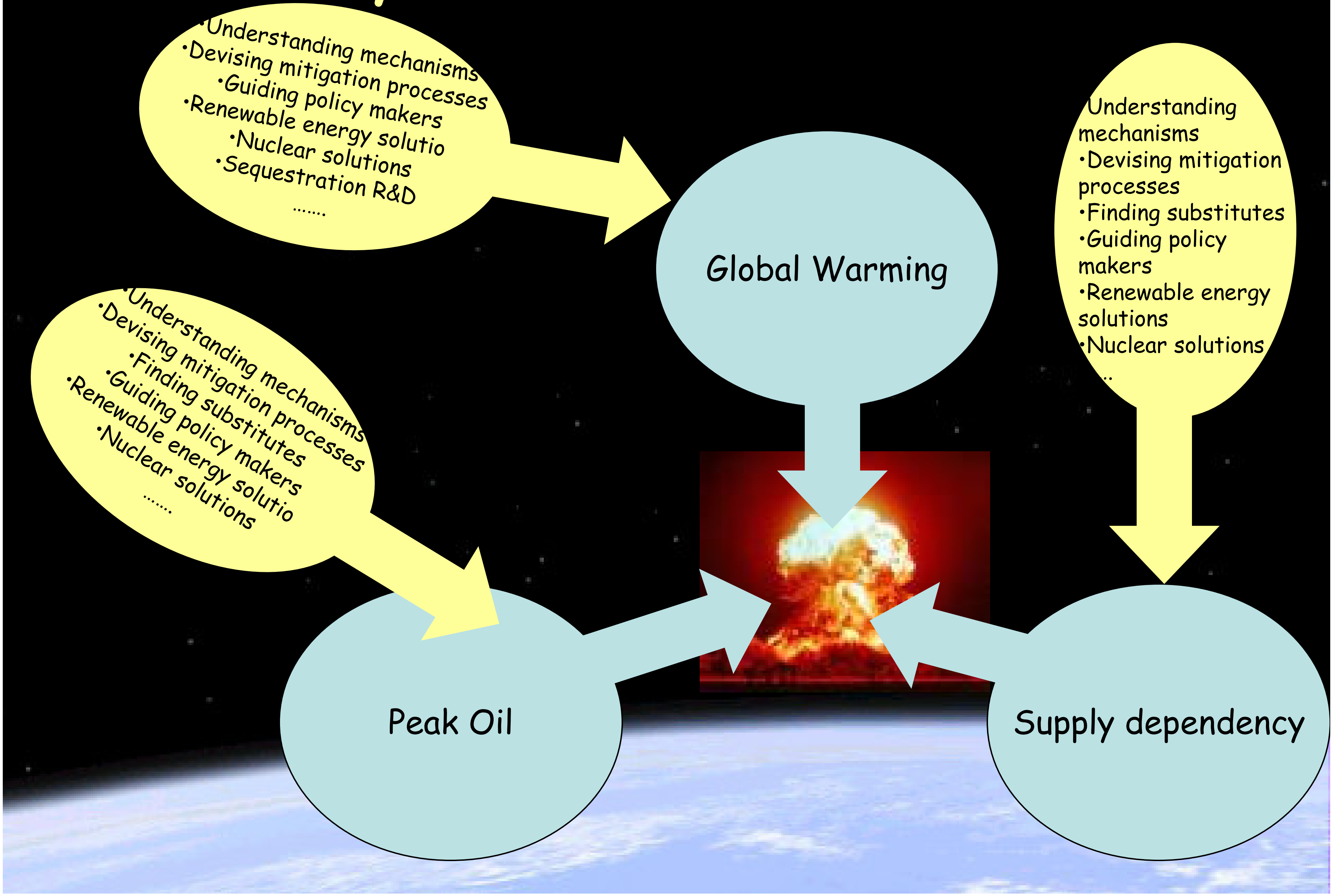
“Regressed-frequency mechanism" assumes that people base their health risks on automatically encoded frequency information arising from a goulash of various exposures –Because it's hard to reliably process all that information, however, people's estimates shift toward the average value in a category, a statistical phenomenon called "regression toward the mean."

As a result, small frequencies (such as dying from vitamin overdose) are overestimated and large frequencies (such as dying from rectal cancer) are underestimated.

The implications for our response to potentially catastrophic events is profound

http://www.apa.org/releases/healthrisks.html see also *Journal of Experimental Psychology: Learning, Memory and Cognition* published by the American Psychological Association (APA).

How Physicists Can Contribute



- Understanding mechanisms
- Devising mitigation processes
- Guiding policy makers
- Renewable energy solutio
- Nuclear solutions
- Sequestration R&D

…….

Global Warming

- Understanding mechanisms
- Devising mitigation processes
- Finding substitutes
- Guiding policy makers
- Renewable energy solutio
- Nuclear solutions

…….

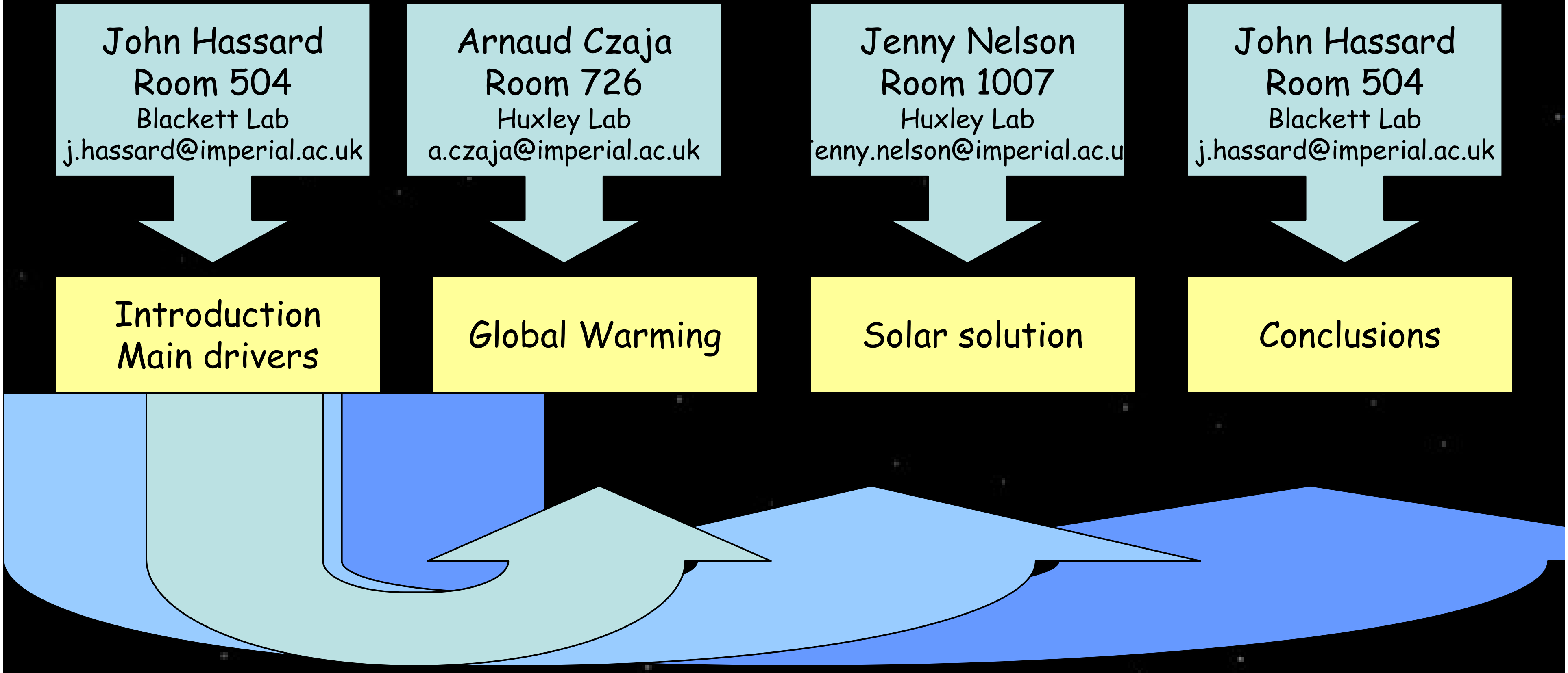
Peak Oil

- Understanding mechanisms
- Devising mitigation processes
- Finding substitutes
- Guiding policy makers
- Renewable energy solutions
- Nuclear solutions

..

Supply dependency

Course Structure



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Introduction
Main drivers

Global Warming

Solar solution

Conclusions

Tue 9-10, Thur 10-11

Tue 9-10, Thur 10-11, Fri 16-17

Tue 9-10, Thur 10-11, Fri 16-17

Tue 9-10, Thur 10-11, Fri 16-17

Course synopsis

A. Energy consumption, resources, trends Introduction World population and energy usage Energy consumption details Future trends in resources, population and energy usage Environmental Spectroscopy, methods in the atmosphere and water; Measuring Greenhouse Gas Emissions: Ground based techniques; Satellite observations.	JH 1-7
B. What controls the Earth surface temperature? The “greenhouse effect”: pristine form The “greenhouse effect” modified: role of convection and surface evaporation Surface temperature response to CO2 increase Water vapour feedback Role of atmospheric circulation: the tropics Role of ocean circulation: the Gulf Stream and the sea-ice albedo feedback **C. Production of winds and currents** The atmospheric heat engine The ocean is not a heat engine!	AC 8-14
D. Conversion of solar energy The solar resource. Absorption of sunlight in matter and Solar Conversion routes. Solar Thermal energy conversion. Semiconductor background. Solar photovoltaic energy conversion. Implementation of photovoltaic energy conversion. Solar chemical energy conversion. Photosynthesis Biomass.	JN 15-22
E. Wind, Wave, Tidal and Hydroelectric power. **G. Conclusions**	JH 23-26

Published on Tuesday, September 21, 2004 by the Inter Press Service

Global Warming May Spawn More Super-Storms

by Stephen Leahy

BROOKLIN, Canada - Hurricane Ivan, the incredibly powerful storm that killed at least 120 people in the Caribbean and southern United States, may be a harbinger of the Earth's hotter future, say experts.

"As the world warms, we expect more and more intense tropical hurricanes and cyclones," said James McCarthy, a professor of biological oceanography at Harvard University.

Large parts of the world's oceans are approaching 27 degrees C or warmer during the summer, greatly increasing the odds of major storms, McCarthy told IPS.

Despite the recent destructive series of hurricanes and tornadoes, global warming is off the radar scree

When water reaches such temperatures, more of it evaporates, priming hurricane or cyclone formation. Once born, a hurricane needs only warm water to build and maintain its strength and intensity.

Over the last 100 years, the Earth has warmed by about .6 degrees C

E-mail this to a friend

Russia cuts Uk

Russia has begun cu gas supplies to Ukra energy price disput has become a majo row.

Ukraine has rejecte p ced fourfold p political

Europe / Brussels

Dispute likely to b

By Thomas Catan
Published: January 2 2006 17:

Russia's row with energy suppli

With

Life After the Oil Crash

"Deal With Reality or Reality Will Deal With You"

Dear Reader,

Civilization as we know it is coming to an end soon. This is not the wacky proclamation of a doomsday cult, apocalypse bible prophecy sect, or conspiracy theory society. Rather, it is the scientific conclusion of the best paid, most widely-respected geologists, physicists, and investment bankers in the world. These are rational, professional, conservative individuals who are absolutely terrified by a phenomenon known as global "Peak Oil."

"Are We 'Running Out'? I Thought There Was 40 Years of the Stuff Left"

Oil will not just "run out" because all oil production foll curve. This is true whether we're talking about a country, or on the planet as a whole.

THE OIL A IS OVER

Is Global Warming Making Hurricanes Worse?

ographic News

and slash leave

WORLD

Ukraine refuses Moscow g

EST (01:43 GMT)

Saturday, Decem

MOSCOW, R state-contr monopoly s Ukraine had on the term deliveries setting the close the t Day.

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Gazprom sp told The Ass had sent its signed cont

Web Exclusive | Nation

Is Global Warming Fueling Katrina?

Warm ocean temperatures are a ke ingredient for monster hurricanes, prompting some scientists to believe that global warming is exacerbating our storm troubles

By JEFFREY KLUGER

From CNN.com: Special Report: Hurricane Season

d Monday, Aug. 29, 2005

e StoryServer 5.0 Sun Dec 18 09:03:35

e people of New Orleans are surely

on about wind vortices, the coriolis

16641,1101280102,00.html

From
Person
Charles Lin
solo flight acr
Atlantic landed
the cover of the
Man of the Year
1927

Energy Bulletin

news by category:

- ⊟ Resources
  - ⊞ Crude Oil
  - ⊞ Natural Gas
  - ☐ Tar Sands
  - ☐ Shale Oil
  - ☐ Coal
  - ☐ Methane Hydrates
  - ☐ Nuclear
  - ☐ Other Resource Depletion
  - ⊞ Renewables
- ⊟ Regions

Published on 15 Mar 2005 by US Congressional Record. Archived on 16

Peak Oil Presentation in the US Cong

by Roscoe Bartlett

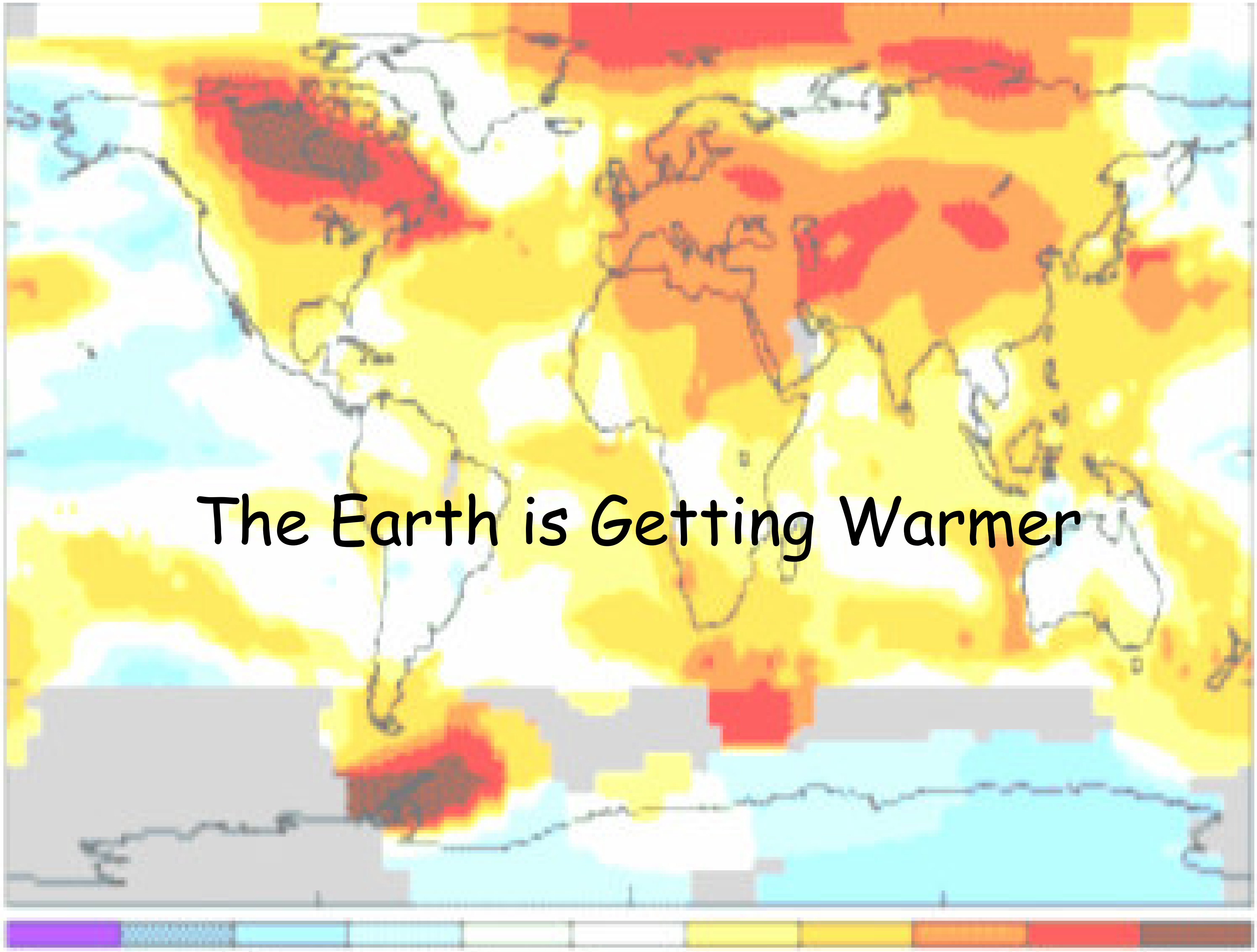
[Conservative Congressman Roscoe Bartlett, Chairman of the Projection Forces Subcommittee of the Armed Services Committee, gave an hour long presentation on Peak Oil to the US Congress on Monday. This is the full transcript. We hope to get a hold of the graphs used by Mr. Bartlett and will update this article to include them if they come to hand.

Update 4 April: Video of the presentation is now available, as well as a PDF version with graphics, see: www.energybulletin.net/5080.html

-AF]

OIL DEMANDS -- (House of Representatives - M

H1409]



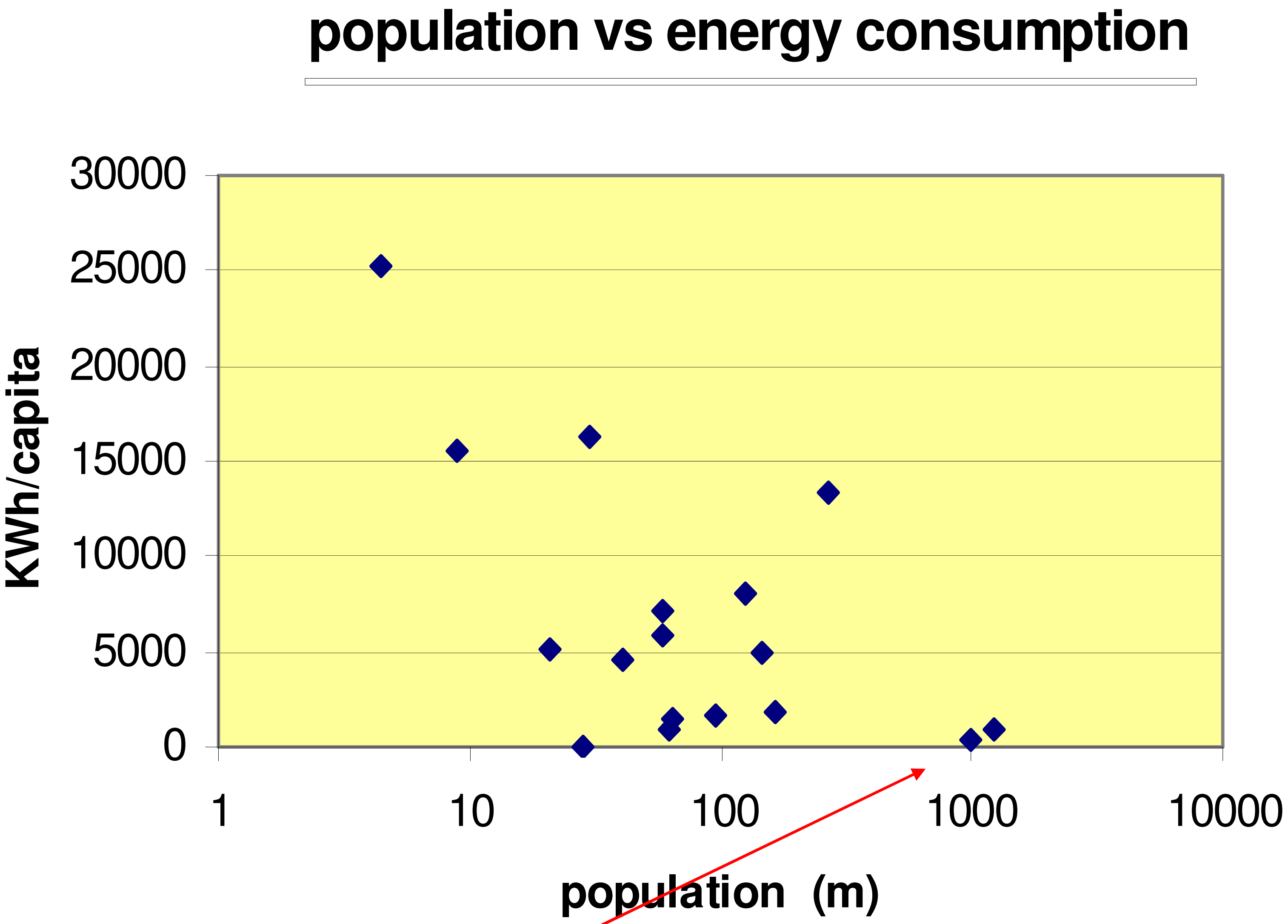
The Earth is Getting Warmer

How big is the problem ?

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

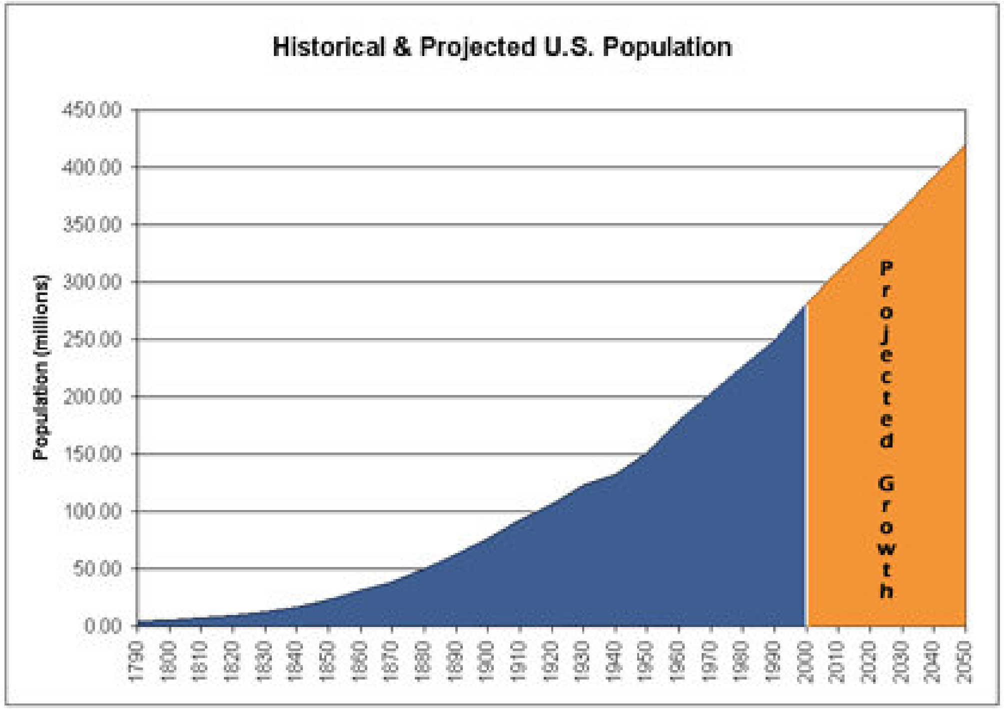
http://earthtrends.wri.org/searchable_db/index.cfm?theme=6&variable_ID=351&action=select_countries



Countries will aspire to Western standards by raising their energy consumption

The problem is not the developing world

A very large proportion of historical GHGs came from the developed world



Some countries are still growing fast, and per capita use is also increasing

But the solution must encompass the developing world

GHGs= Green House Gases

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.**

- **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 tional Energy Outlook 2005

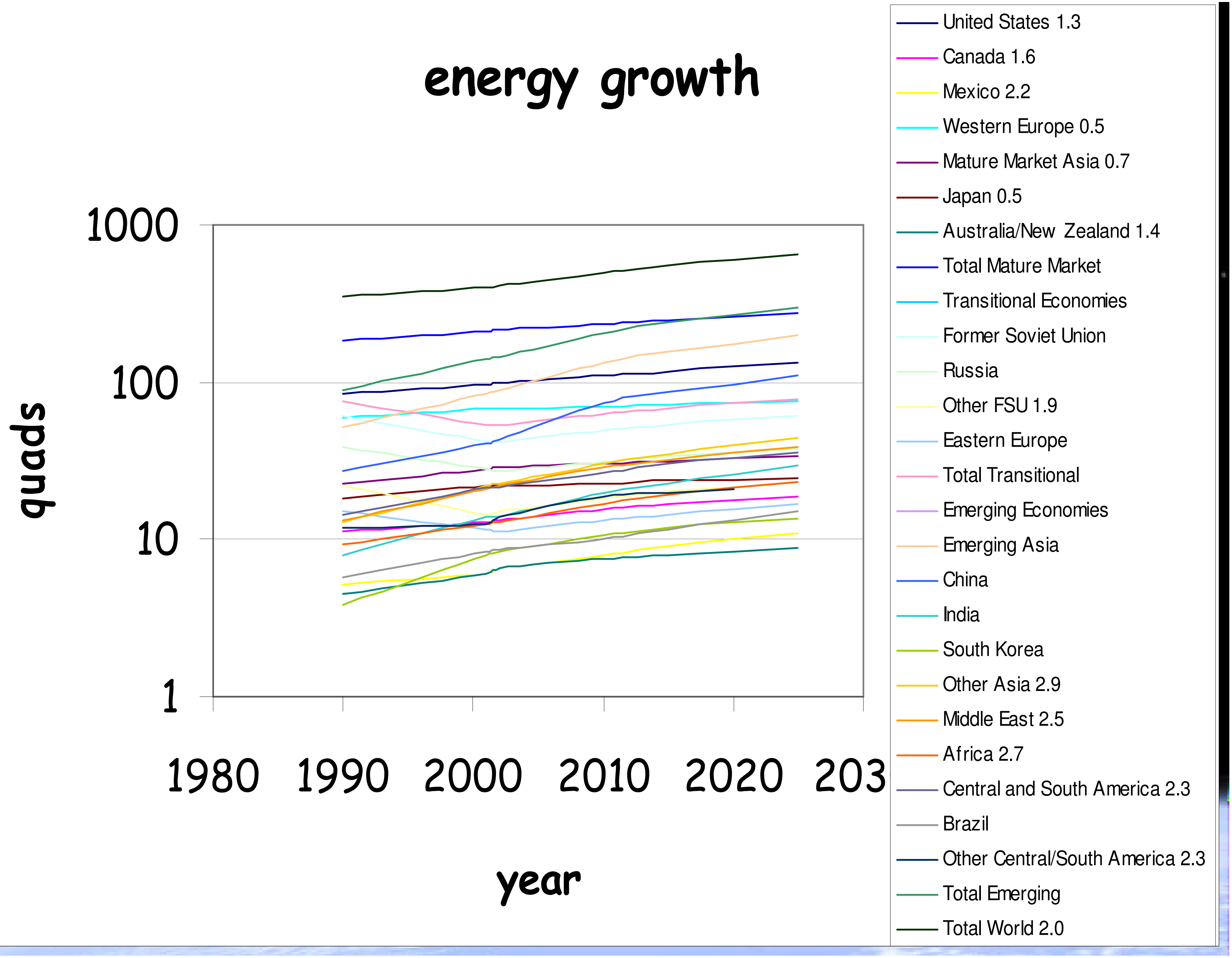
Report #: DOE/EIA-0484(2005) Released Date: July 2005

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

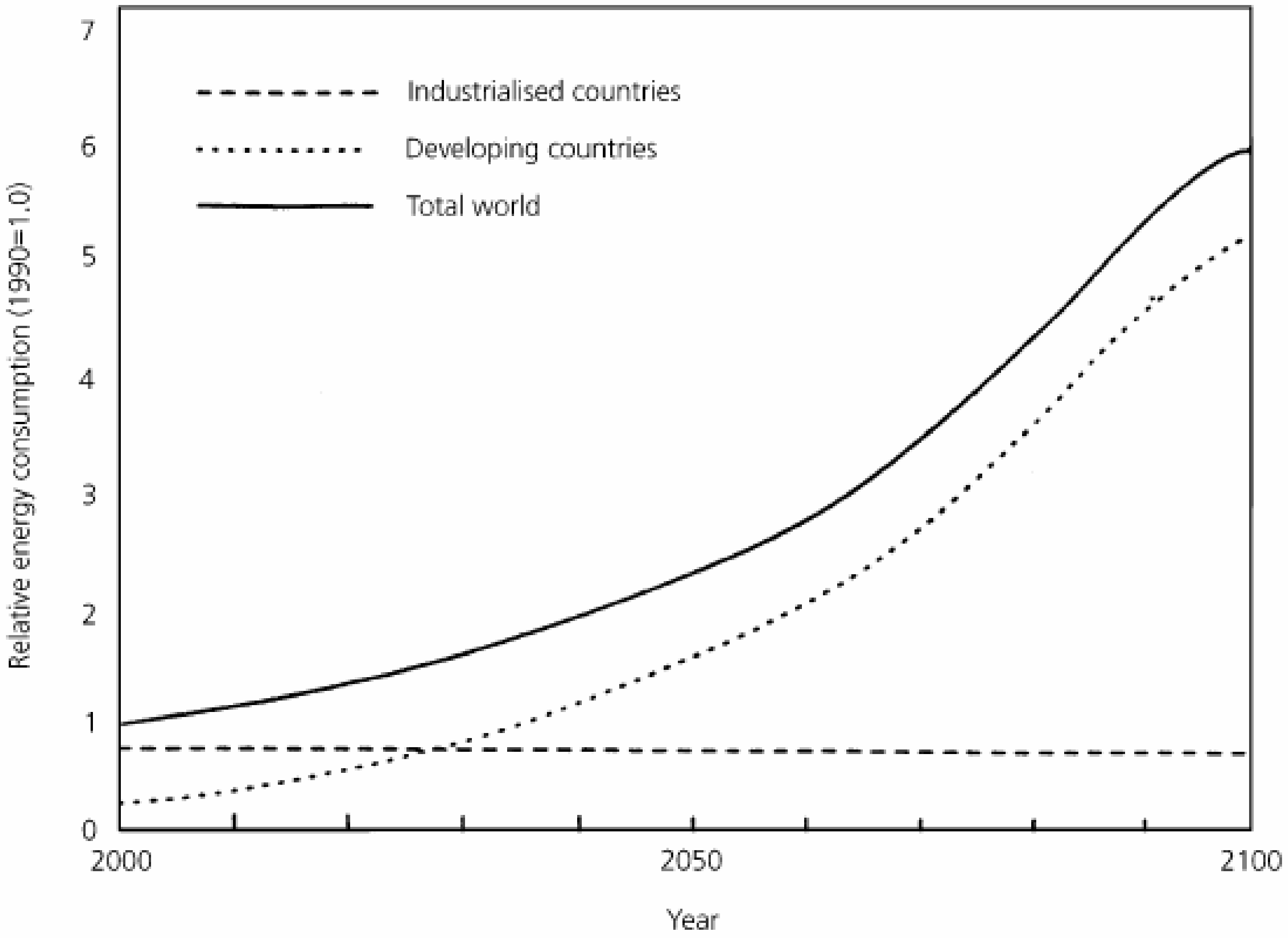
T . World Total Primary Energy Consumption by Region, Reference Case, 1990-2025 (Quadrillion Btu)

		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

energy growth



Relative energy consumption 2000-2100



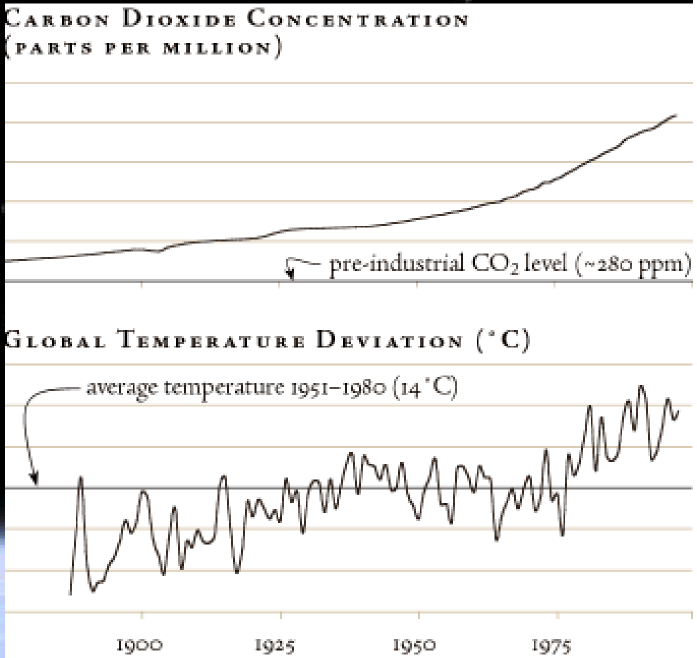
Global Warming

- This section introduces the concepts of global warming.
- It will be explored fully by Dr Czaja later in the course.
- The Solar Solution to renewable energy production will be detailed by Dr Nelson in the third part of the course

In 1896, Svante Arrhenius, a Swedish chemist, was the first to advance the theory that emissions of carbon dioxide (CO_2) would intensify the Earth's natural greenhouse effect and thus warm the planet.

> *"One may now ask, How much must the carbonic acid vary according to our figures, in order that the temperature should attain the same values as in the Tertiary and Ice ages respectively?*

"A simple calculation shows that the temperature of the Arctic regions would rise about 8 degrees or 9 degrees Celsius, if the carbonic acid increased 2.5 to 3 times its present value. In order to get the temperature of the ice age between the 40th and 50th parallels, the carbonic acid in the air should sink to 0.62 to 0.55 of present value (lowering the temperature 4 degrees to 5 degrees Celsius)."



http://earthobservatory.nasa.gov/Library/Giants/Arrhenius/arrhenius_2.html
http://www.longman.co.uk/tt_secsci/resources/scimon/arrhenius/arrh_main.htm

Since then, carbon dioxide and other so-called greenhouse gases have been building up rapidly in our atmosphere, primarily due to deforestation and the burning of coal, oil and gasoline in power plants, automobiles and factories.

These polluting activities release more than 25 billion tons of carbon dioxide into our atmosphere annually, and natural processes are unable to absorb all of what we emit, hence the 30 percent rise in atmospheric carbon dioxide since pre-industrial times, and the 145 percent rise in the second most important greenhouse gas, methane.

Dr Czaja will give us the facts.

http://www.bp.com/genericsection.do?categoryId=92&contentId=7005893
http://earthguide.ucsd.edu/globalchange/global_warming/03.html
http://www.eia.doe.gov/

What we learnt last lecture

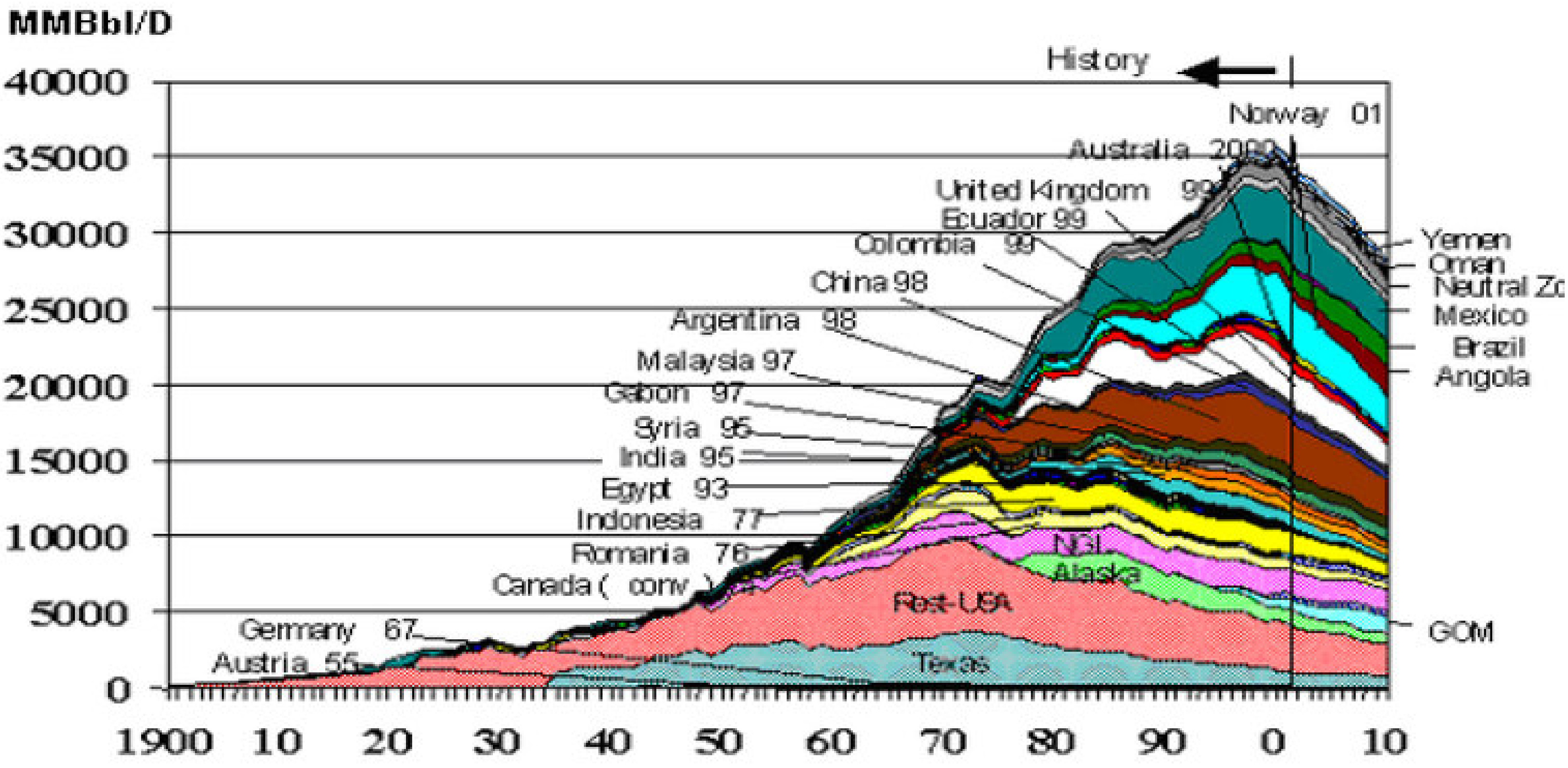
1) Convergence almost unique in human history of three forces which get to the heart of our society. According to the consensual view:
  - Primary energy resource depletion has begun
  - Remaining energy sources potentially unstable
  - The consequences of using those resources is altering the climate perhaps irrevocably, certainly to the detriment of the environment

2) Science has crucial role to play in establishing a solution, if there is one.

First job is to understand the problem (Dr Czaja) and then to provide a solution (Dr Nelson)

Oil Has Peaked in Most Places

Non-OPEC, non-FSU Oil Production Has Peaked and is Declining

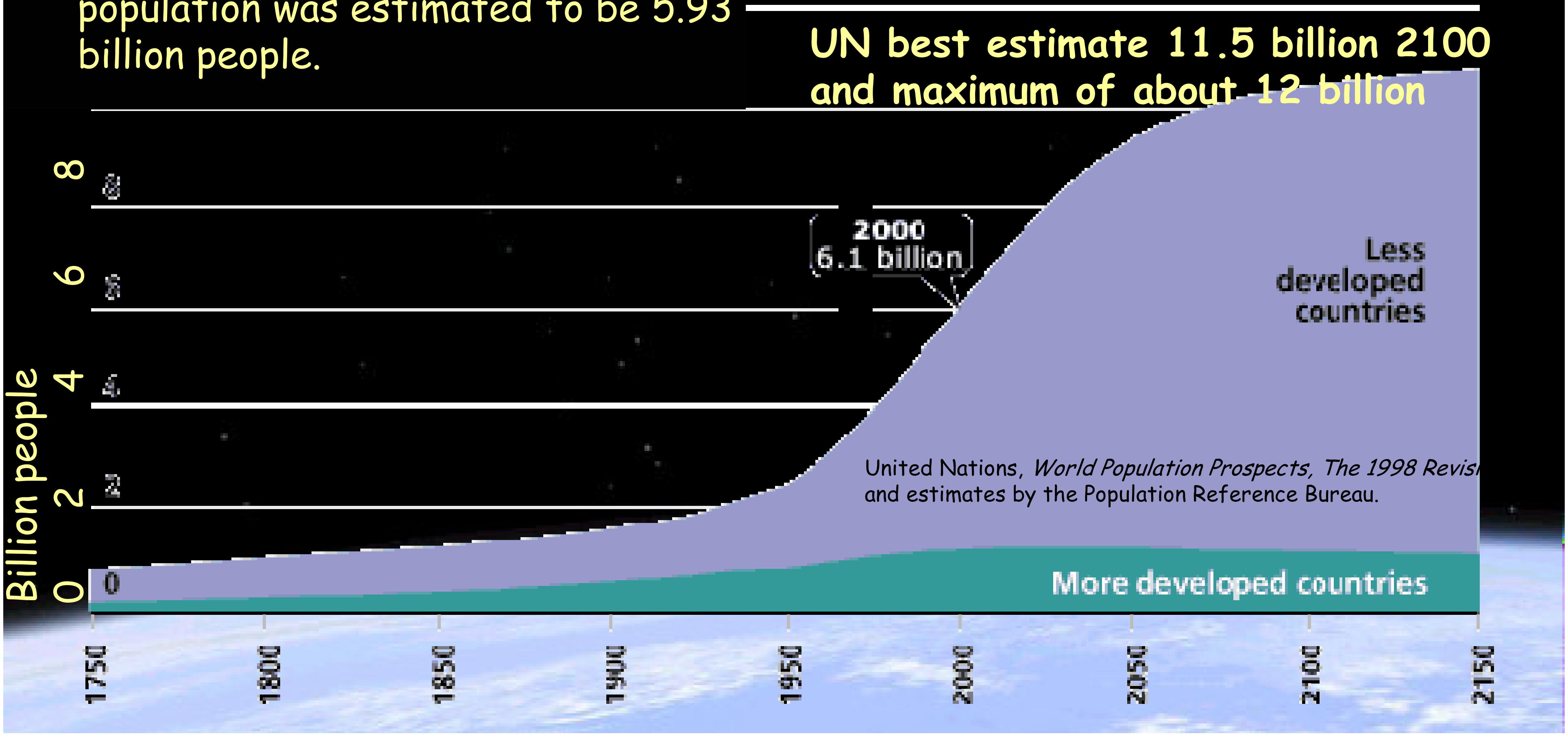


Population Pressure

In the 2400 years between 1600 BC and 800 AD, the population tripled from 0.06 billion to 0.2 billion, but in the last hundred years the population has more than tripled from 1.5 billion in 1890 to 5.3 billion in 1990. In mid-1998 the total world population was estimated to be 5.93 billion people.

The population growth rate was about 0.04% per year over the first period but was 0.7% in 1890, and between 1975 and 1990 was 1.72% per year.

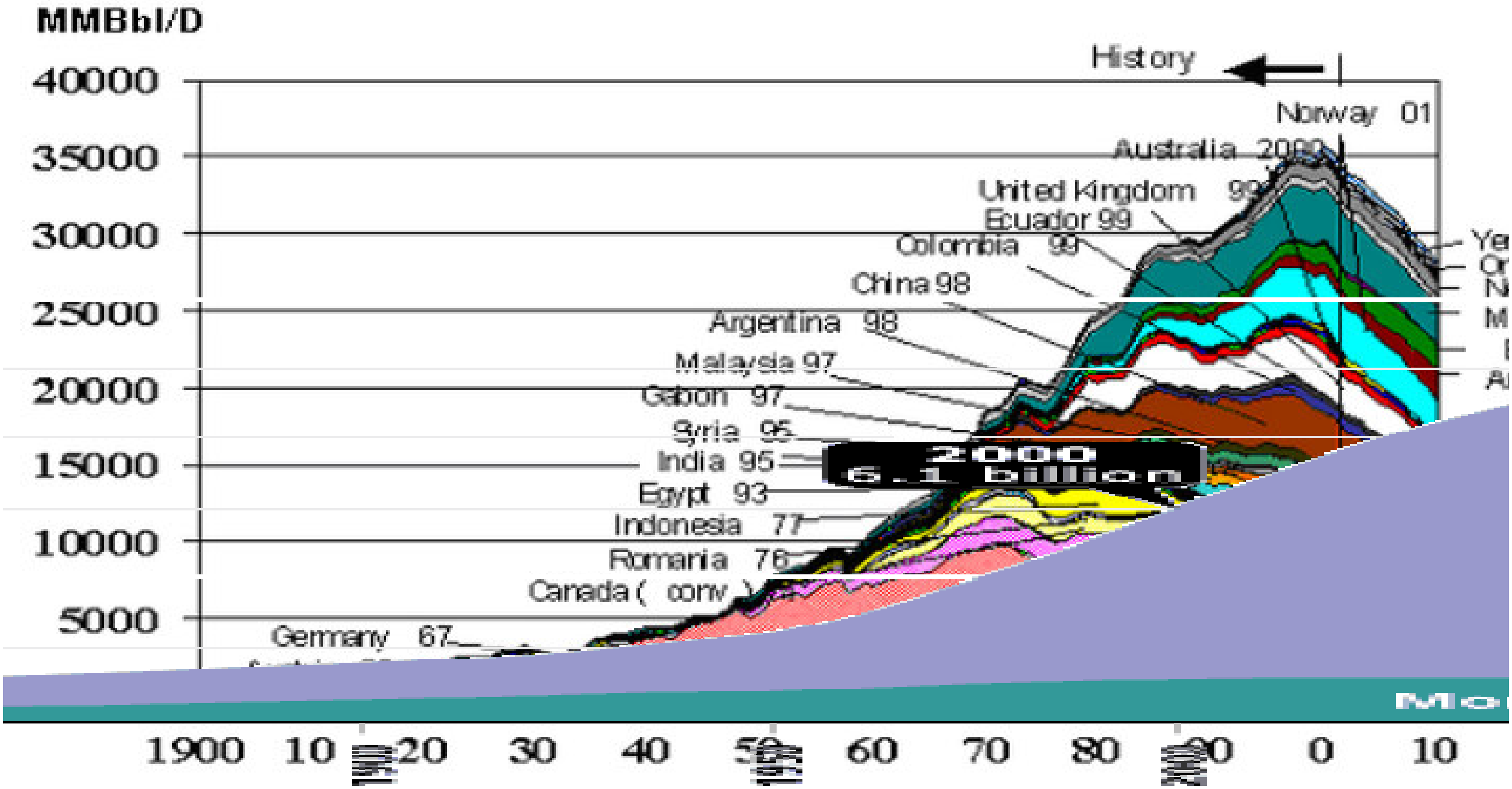
For 1990 - 1995. the annual growth rate has decreased substantially being 1.48%

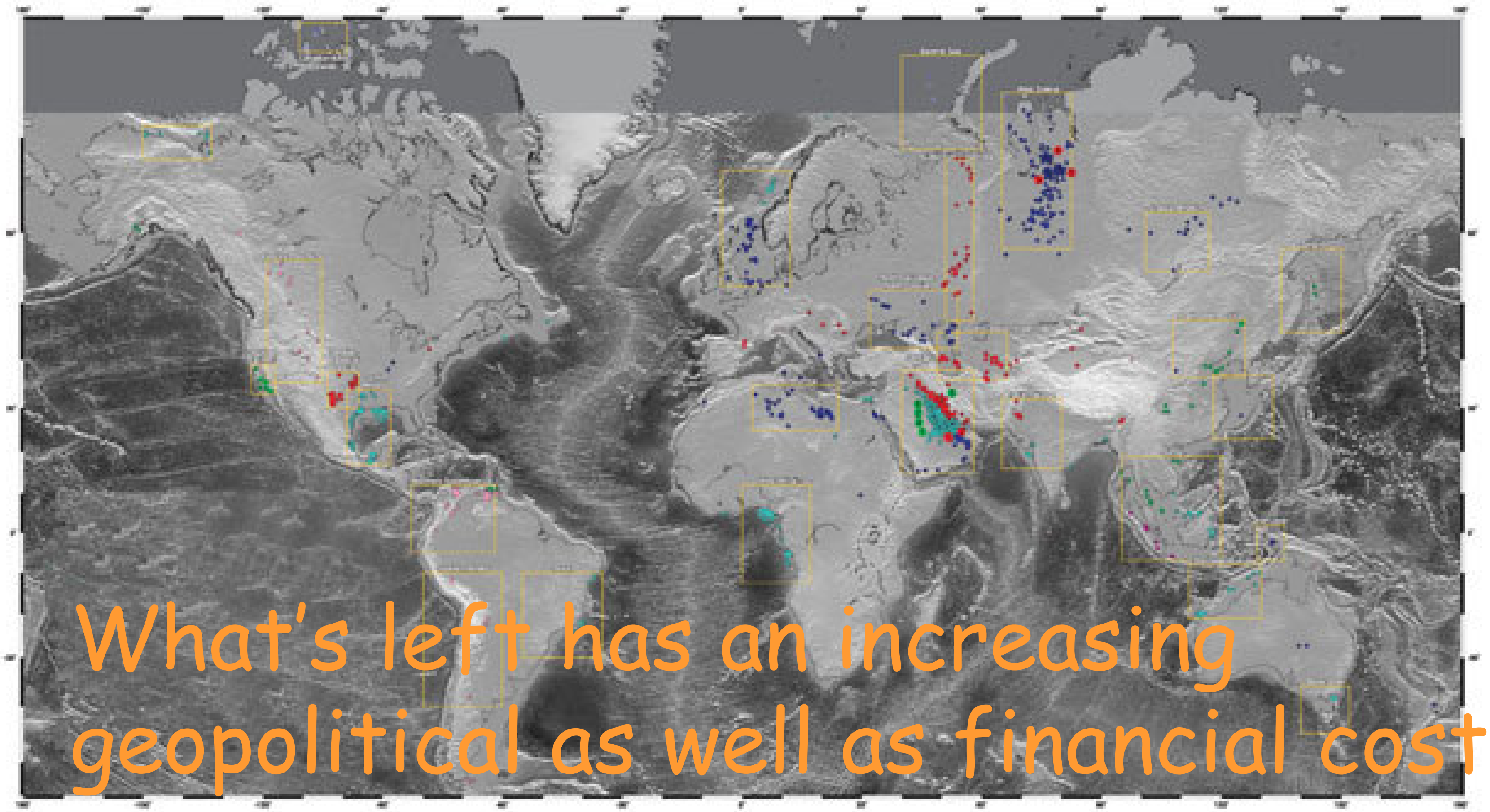


UN best estimate 11.5 billion 2100 and maximum of about 12 billion

United Nations, *World Population Prospects, The 1998 Revisi* and estimates by the Population Reference Bureau.

Non-OPEC, non-FSU Oil Production Has Peaked and is Declining





What's left has an increasing geopolitical as well as financial cost

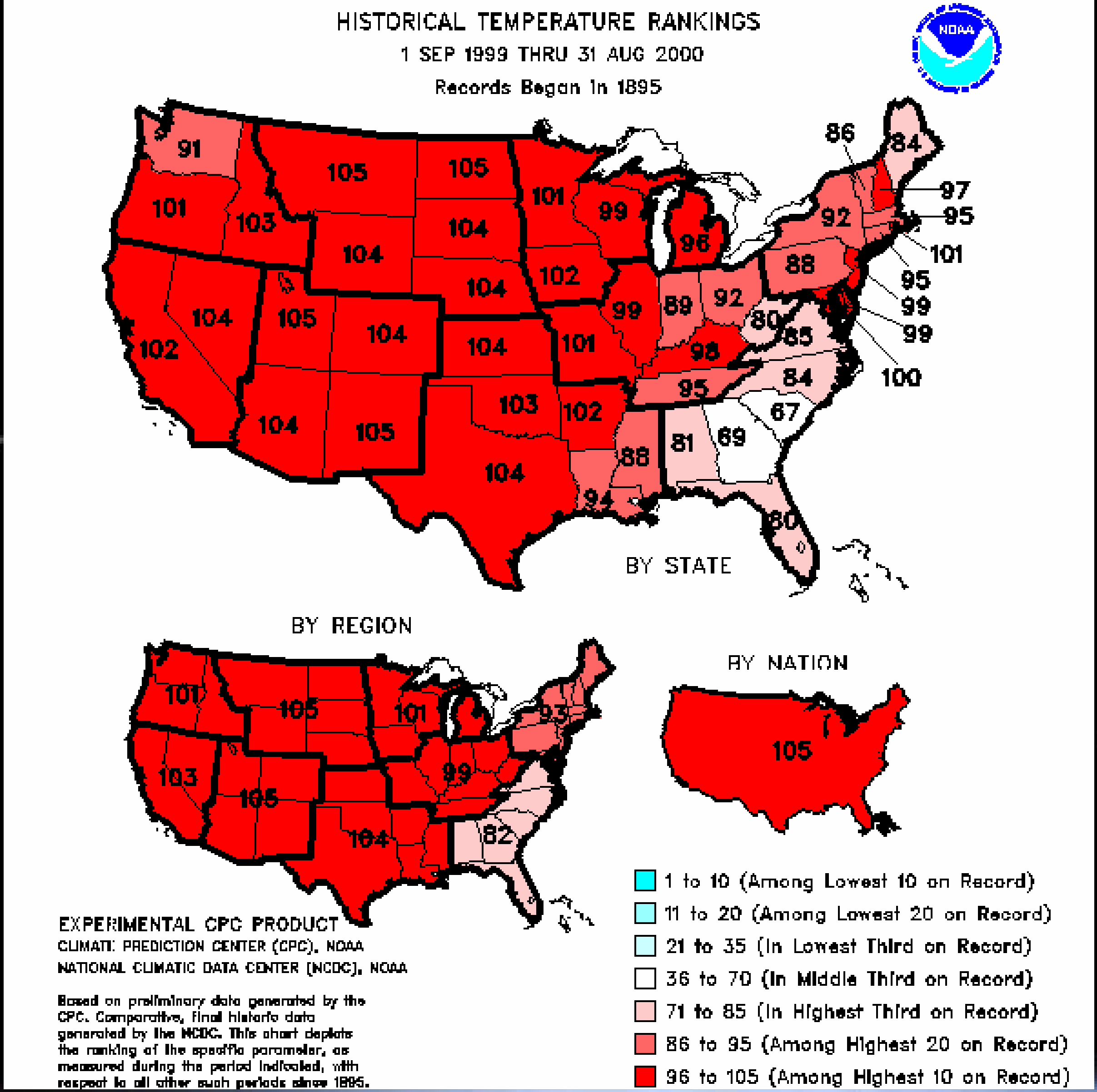
- The world's 877 giant oil and gas fields are those with 500 million bbl of ultimately recoverable oil or gas equivalent. Remarkably, almost all of these 877 giant fields, which by some estimates account for 67% of the world's petroleum reserves, cluster in 27 regions, or about 30%, of the earth's land surface

~~Not examinable~~

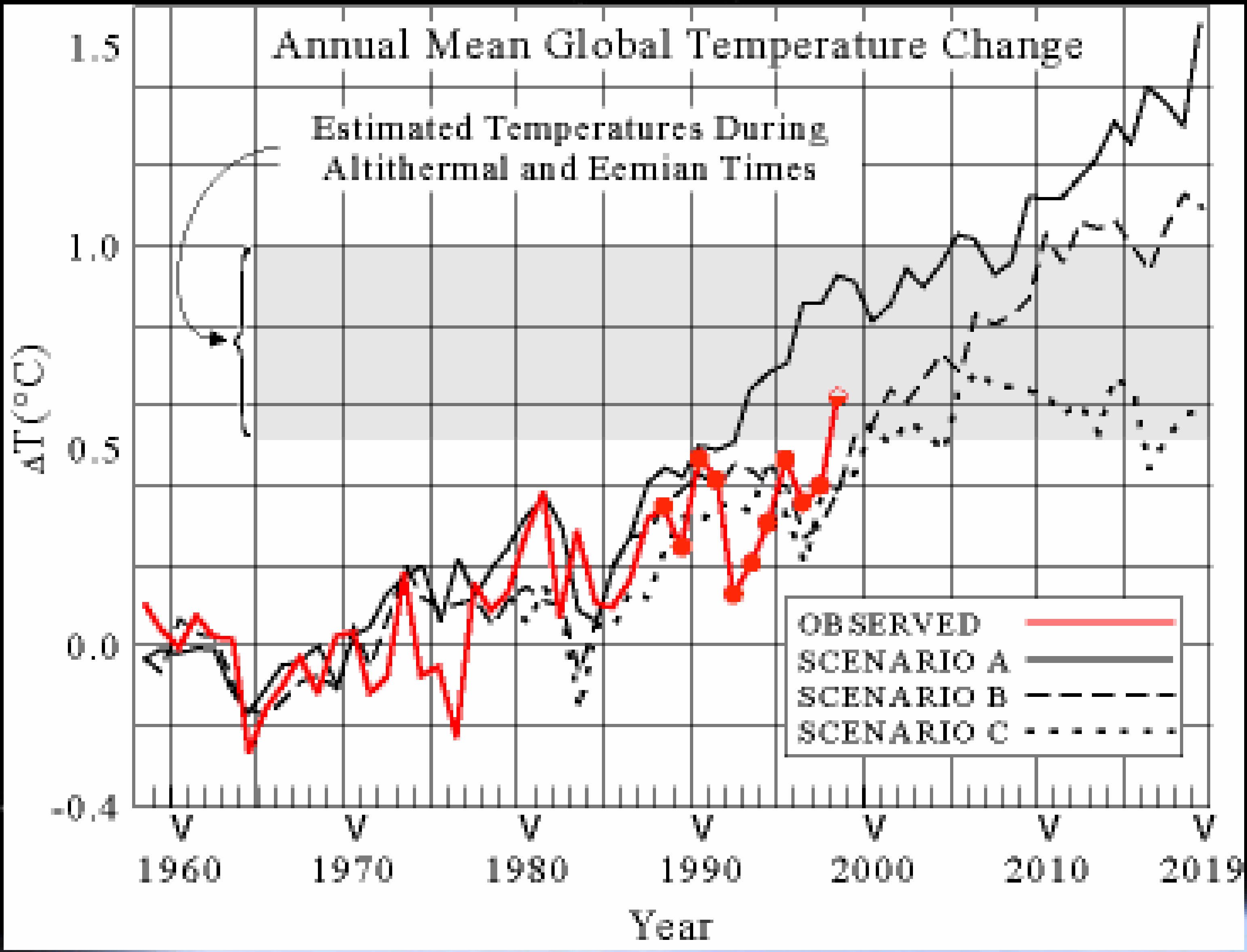
www.climatehotmap.org

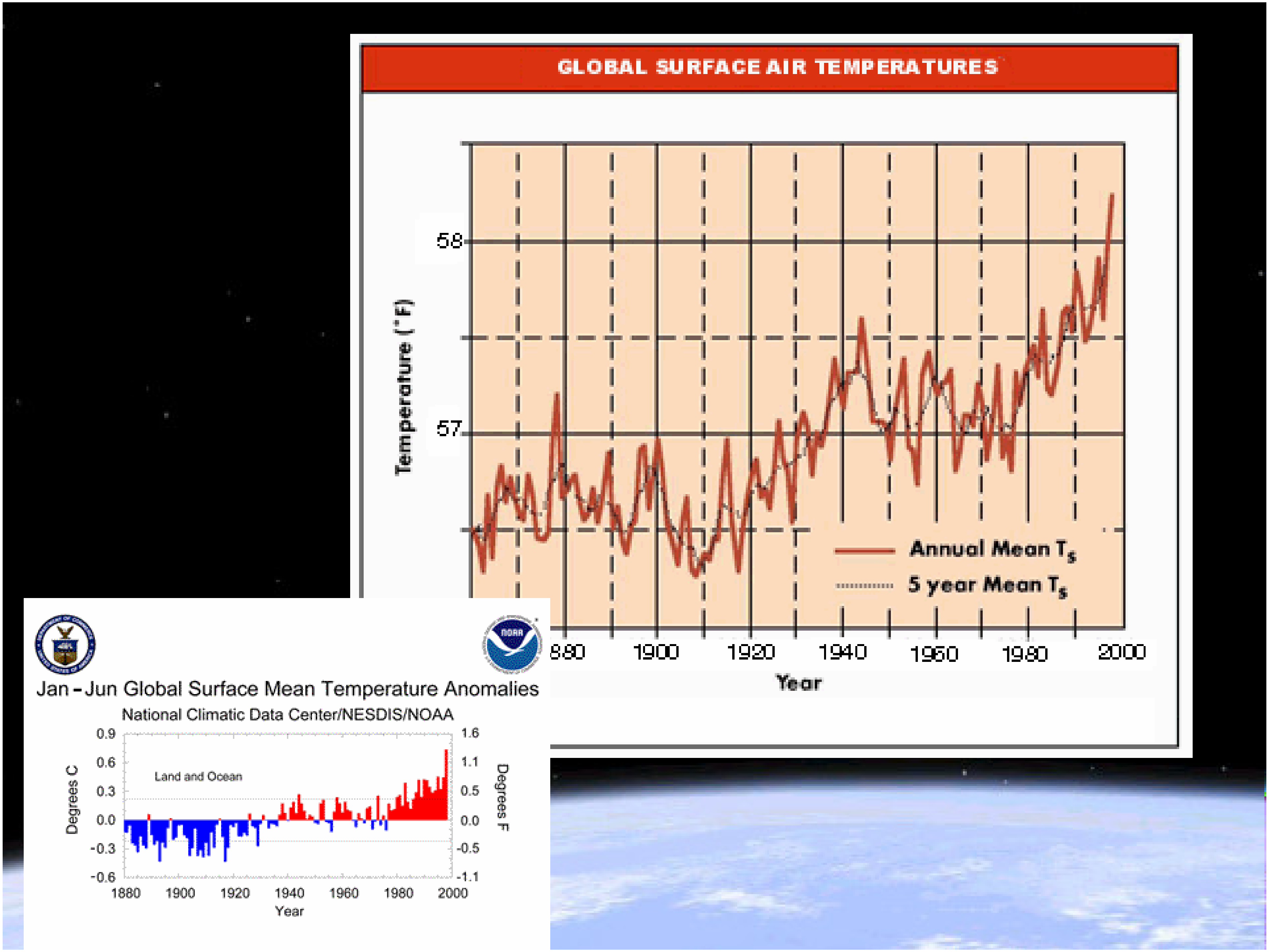
~~Not examinable~~

Most of the hottest years on record have occurred in the last 15 years.

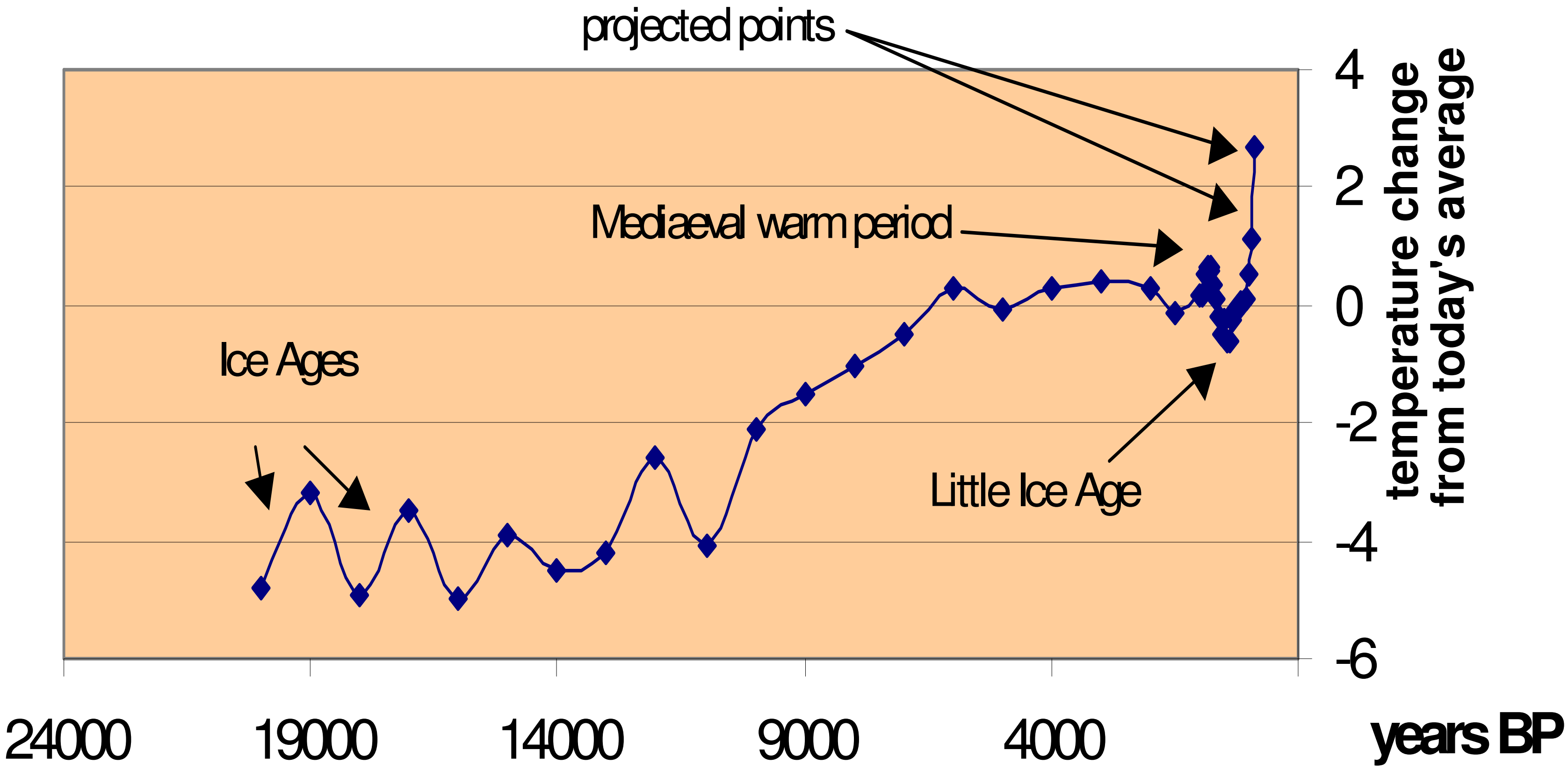


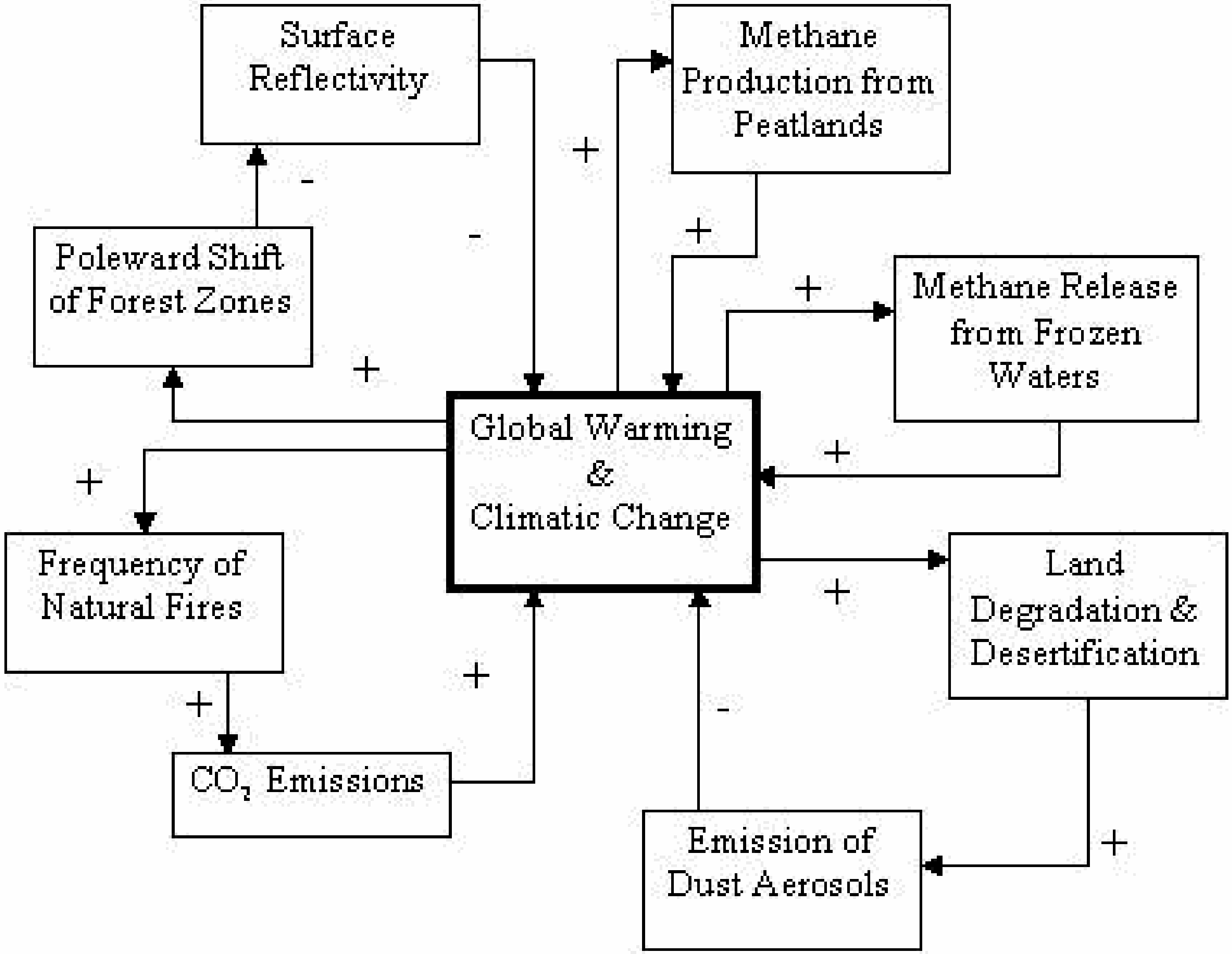
2005 has been one of the hottest on record, with eight of the past 10 years at the top of the charts in terms of high temperatures.
NASA's Goddard Institute for Space Studies has concluded that 2005 is the warmest year in recorded history,
while the National Oceanic and Atmospheric Administration and the U.K. Meteorological Office call it the second-hottest after 1998.
All three groups agree that 2005 is the hottest year on record for the Northern Hemisphere, at roughly 1.3 degrees Fahrenheit above historical averag


Annual Mean Global Temperature Change
Estimated Temperatures During
Altithermal and Eemian Times
ΔT(°C)
1.5
1.0
0.5
0.0
-0.4
OBSERVED
SCENARIO A
SCENARIO B
SCENARIO C
1960
1970
1980
1990
2000
2010
2019
Year


GLOBAL SURFACE AIR TEMPERATURES
Temperature (°F)
58
57
880
1900
1920
1940
1960
1980
2000
Year
Annual Mean T_s
5 year Mean T_s
Jan - Jun Global Surface Mean Temperature Anomalies
National Climatic Data Center/NESDIS/NOAA
Land and Ocean
Degrees C
0.9
0.6
0.3
0.0
-0.3
-0.6
Degrees F
1.6
1.1
0.5
0.0
-0.5
-1.1
1880
1900
1920
1940
1960
1980
2000
Year

Global Average Temperatures





Surface Reflectivity

Methane Production from Peatlands

Poleward Shift of Forest Zones

Methane Release from Frozen Waters

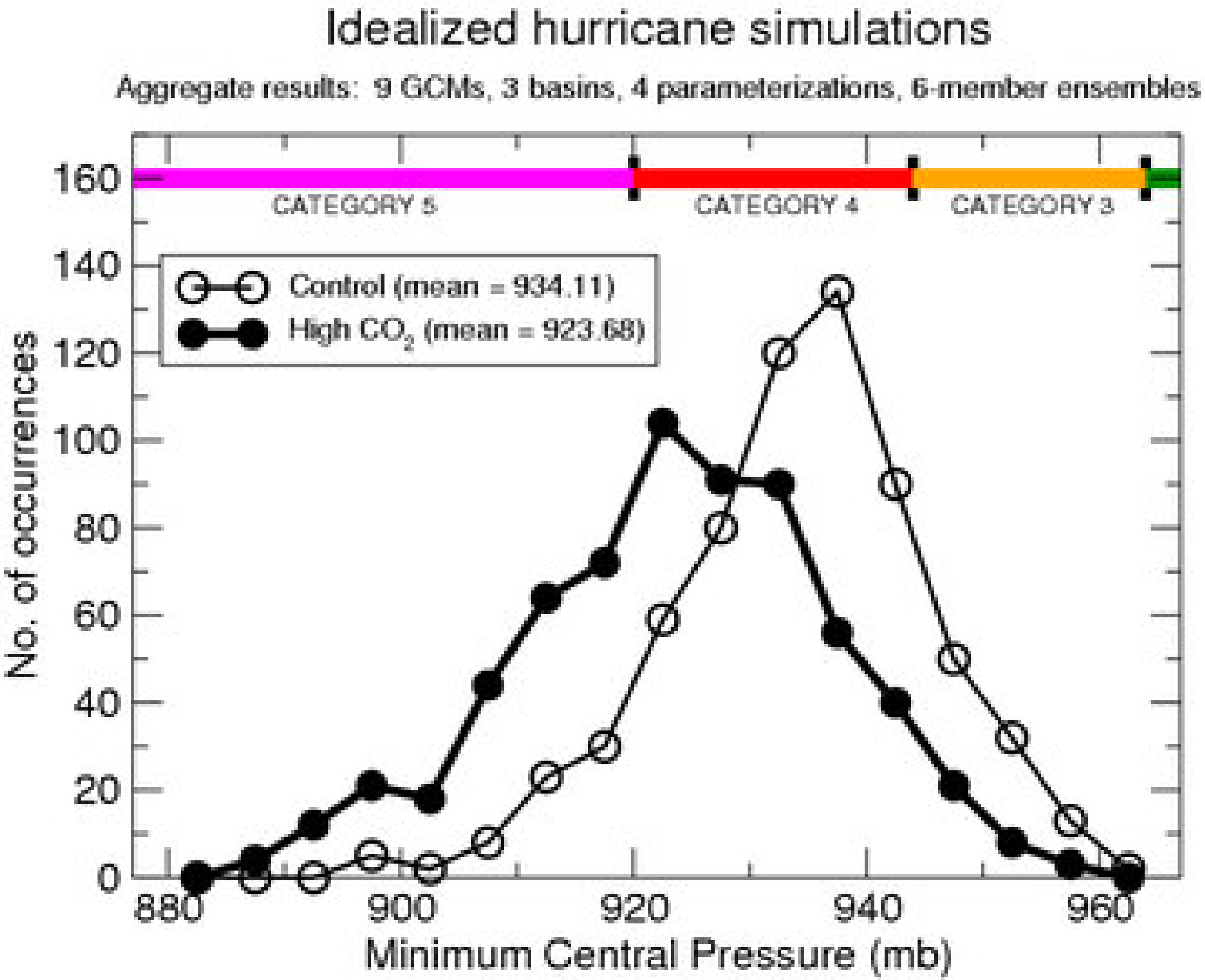
Global Warming & Climatic Change

Frequency of Natural Fires

Land Degradation & Desertification

CO_2 Emissions

Emission of Dust Aerosols

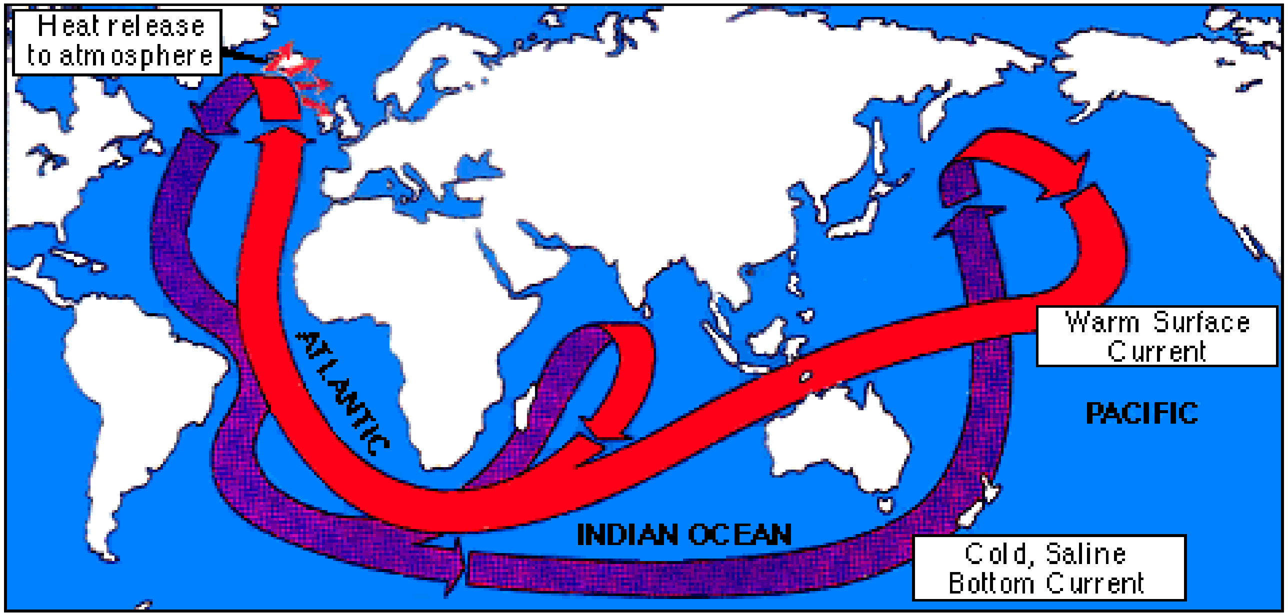


Idealized hurricane simulations

Aggregate results: 9 GCMs, 3 basins, 4 parameterizations, 6-member ensembles

It is certain that uncertainties remain - these are reflected in the range or results in the many scenarios.

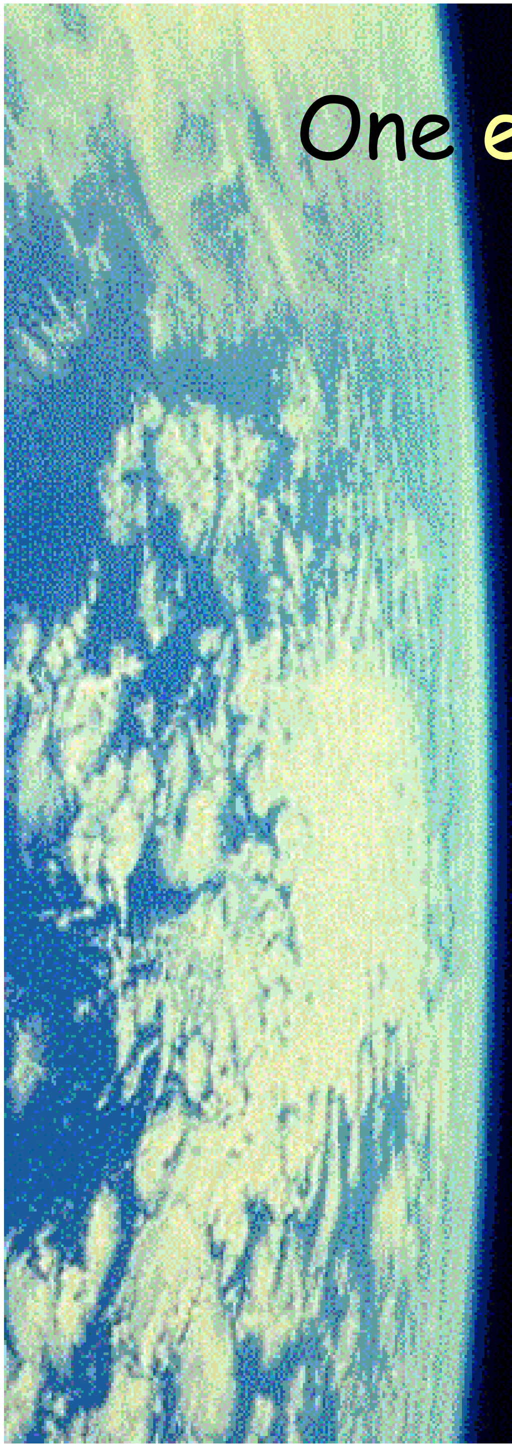
These are due to the complexity of the science, and the uncertainties about other possible contributors.



The present large-scale ocean current system determines climate to a great extent. The huge "conveyor belt" reacts extremely sensitively to global temperature changes accompanying each increase and decrease in the content of carbon dioxide in the atmosphere. - Broecker

http://www.ldeo.columbia.edu/edu/dees/ees/climate/slides/ocean_index.html

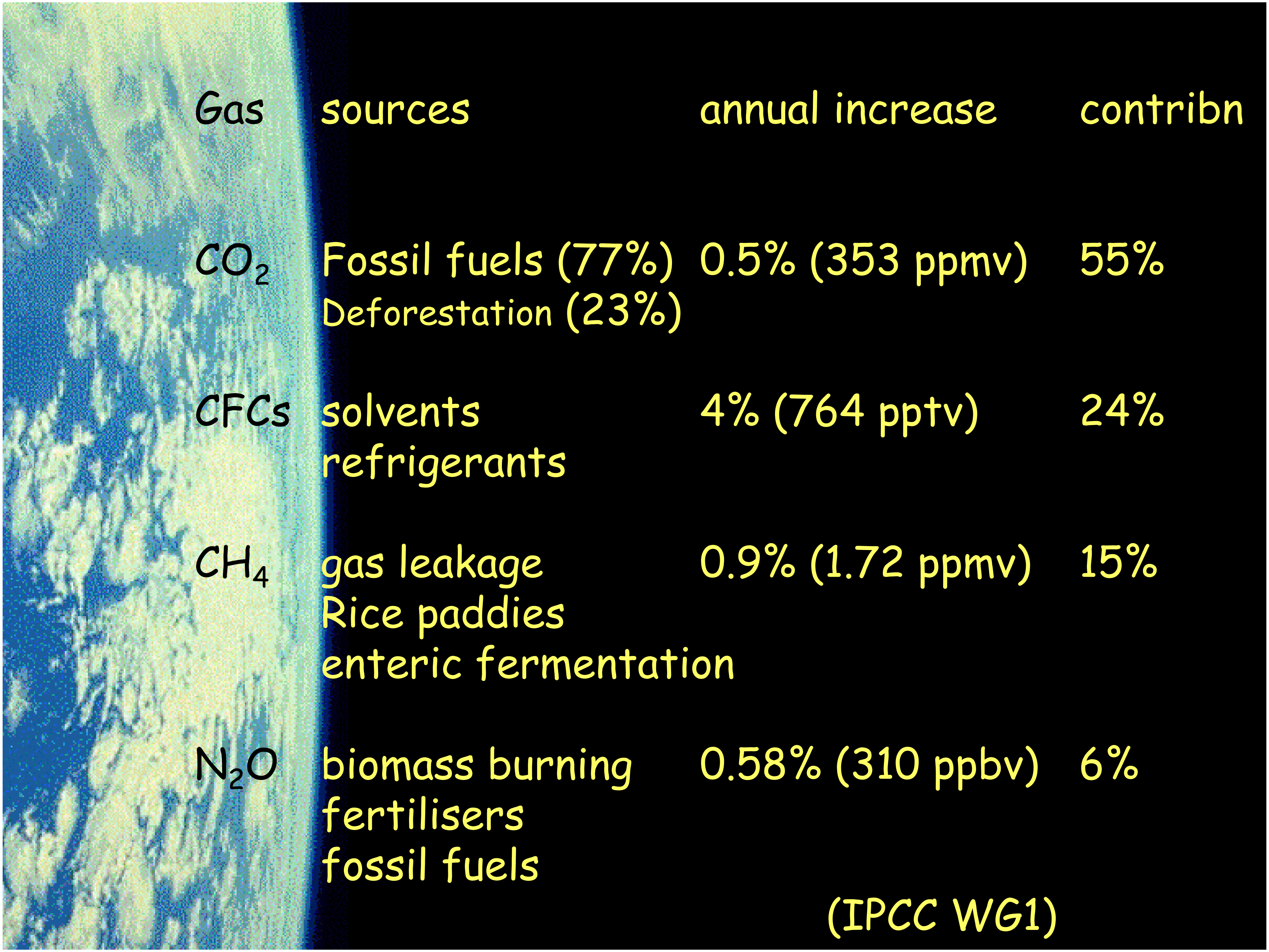
One example of unproven hypotheses



Global surface temperature has increased about 0.5C since 1975, and it is commonly assumed that this warming will continue or accelerate.

Scientists at the Goddard Institute for Space Studies argue that observed warming has been driven mainly by non-CO_2 greenhouse gases. It would be practical to halt the growth of these gases.

They suggest a scenario in which an international focus on reducing air pollution, especially tropospheric ozone and black carbon aerosols, which would help unite the interests of developed and developing countries and slow global warming.



Gas	sources	annual increase	contribn
CO_2	Fossil fuels (77%) Deforestation (23%)	0.5% (353 ppmv)	55%
CFCs	solvents refrigerants	4% (764 pptv)	24%
CH_4	gas leakage Rice paddies enteric fermentation	0.9% (1.72 ppmv)	15%
N_2O	biomass burning fertilisers fossil fuels	0.58% (310 ppbv)	6%

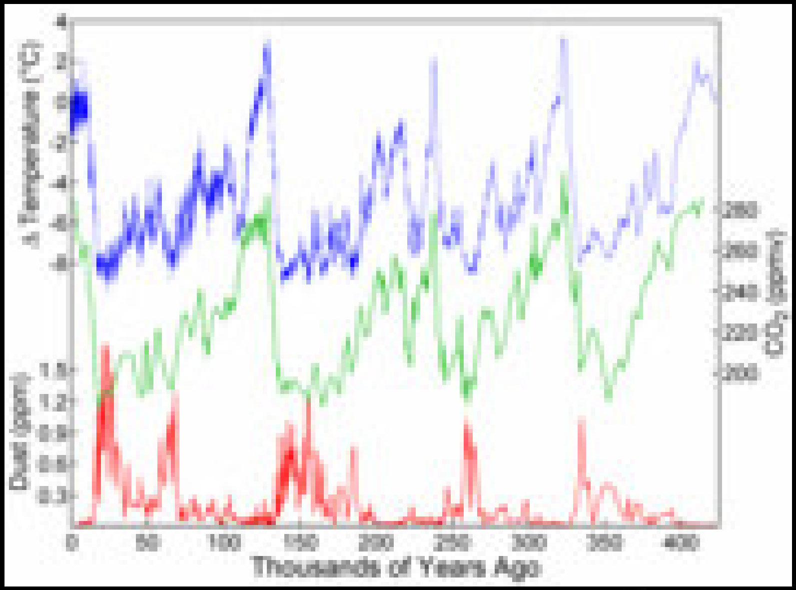
(IPCC WG1)

~~Not examinable~~

Another claimed effect: Solar variability

It has been suggested that there are natural cycles in the sun which can explain present day global warming.

It is clear there are short term variations and a 11.3 year sunspot cycle.



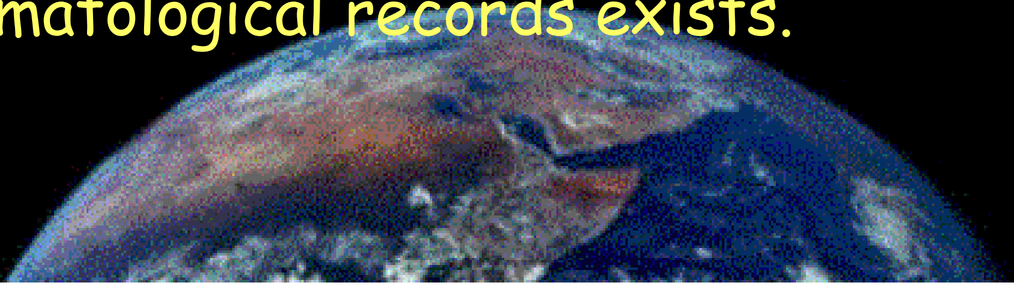
There are also long term cycles.

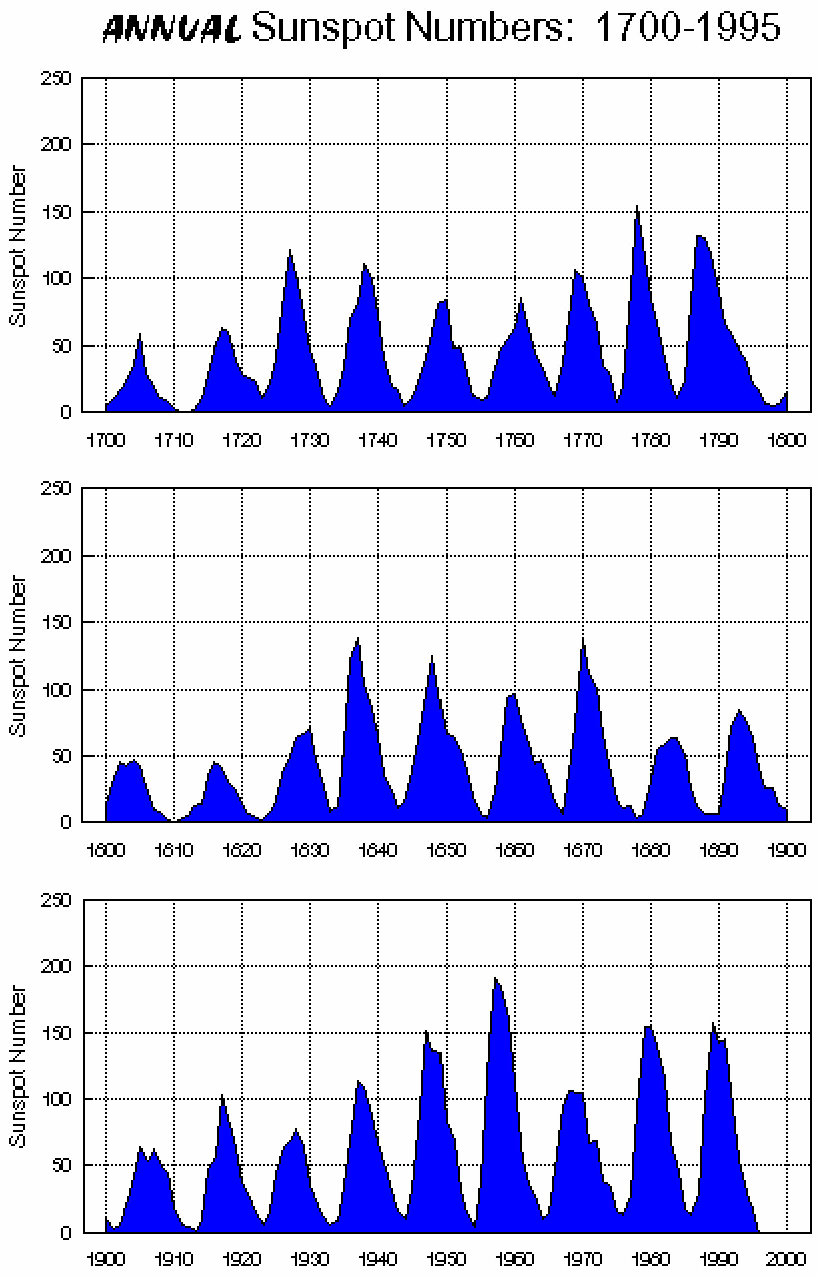
Understanding the correlations is difficult

Unfortunately for the solar cycle theorists,
150 years x 2 degrees/50,000 years = 0.006 degrees.

Space weather may also in the long term affect the Earth's climate. Solar ultra-violet, visible and heat radiation are the primary factors for the Earth's climate, including global average temperatures, and these energy sources appear to be quite constant.

However, some scientists have claimed correlations between the solar magnetic activity, which is reflected in the sunspot frequency, and climate parameters at the Earth. Sunspot activity has been recorded through several hundreds of years which makes it possible to compare their variable frequency to climate variations to the extent that reliable climatological records exists.





ANNUAL Sunspot Numbers: 1700-1995

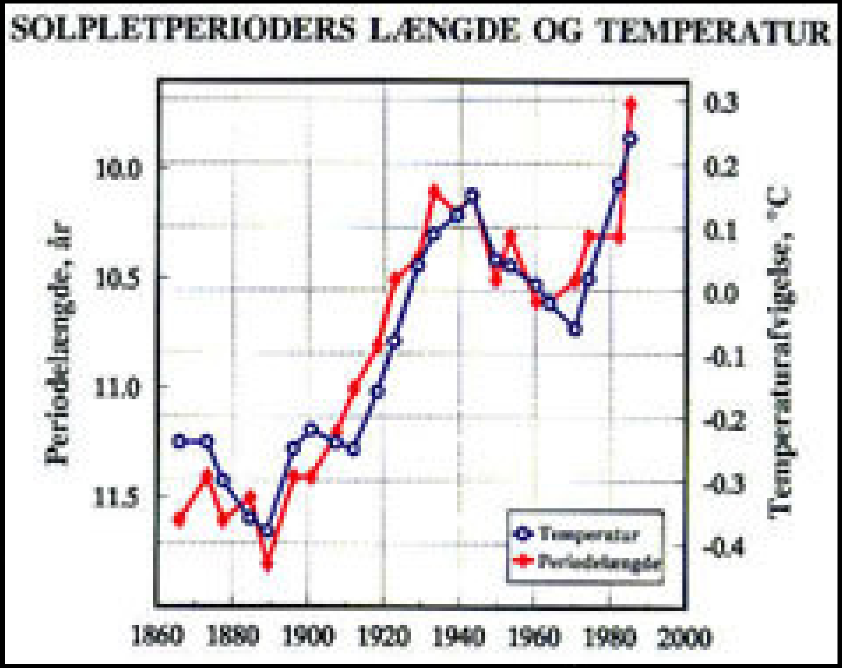
Reduced Sunspot Activity Predicted for Next Decade

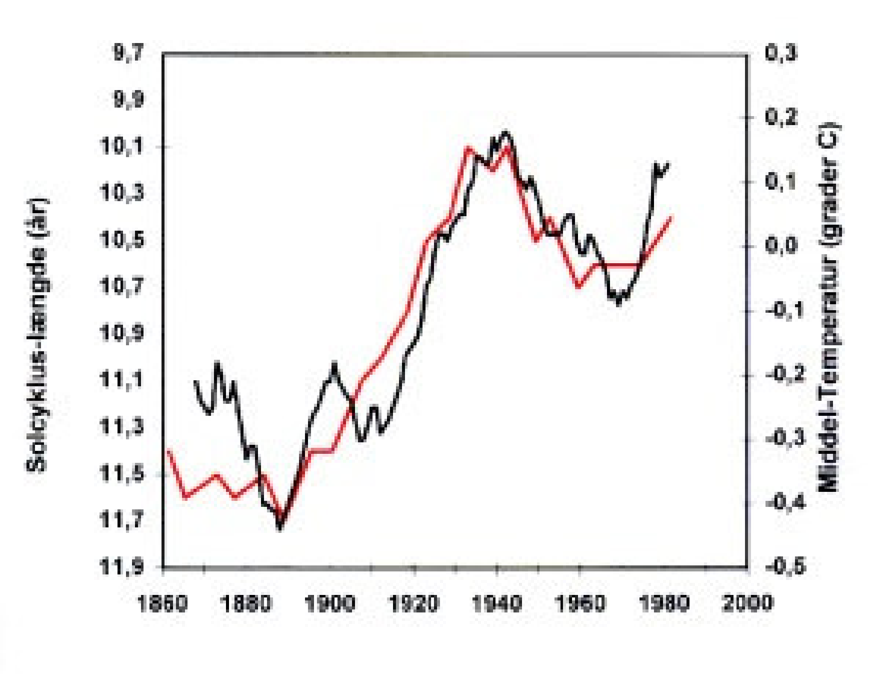
YALE News Release

For Release: Jan. 14, 1997

Yale and NASA Astronomers Predict Decline in Sunspots, Which Could Bring Cooler Weather, Fewer Electronic Disruptions

The optimistic prediction, which contradicts that of many other scientists, will be reported Jan. 14 1997 at a meeting of the American Astronomical Society in Toronto, Canada, by Kenneth Schatten of Goddard Space Flight Center/NASA in Greenbelt, Maryland. He and Sabatino Sofia, chairman of the Yale astronomy department, inferred the magnitude of magnetic fields just below the sun's surface from observations with solar telescopes in Stanford and Big Bear, CA

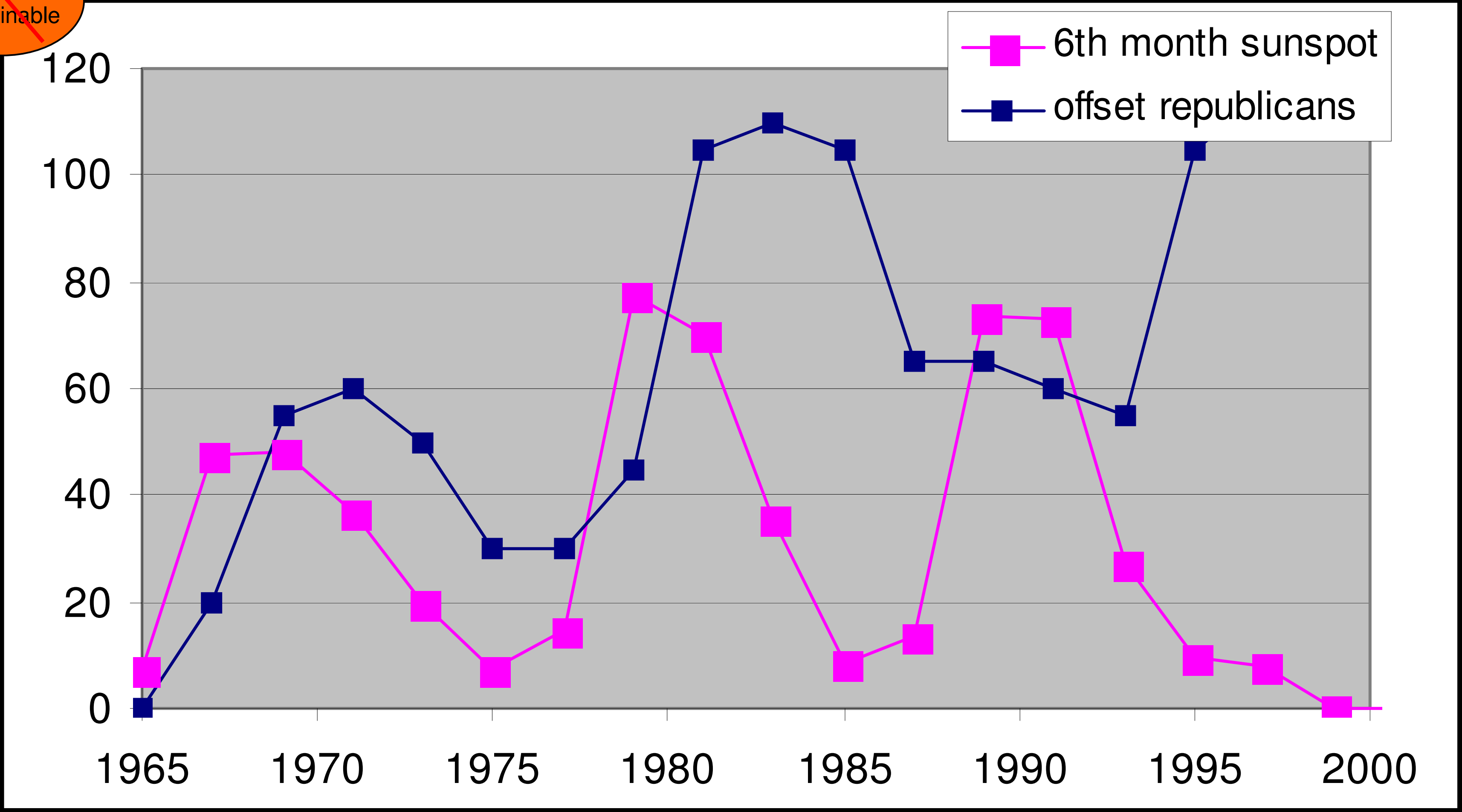




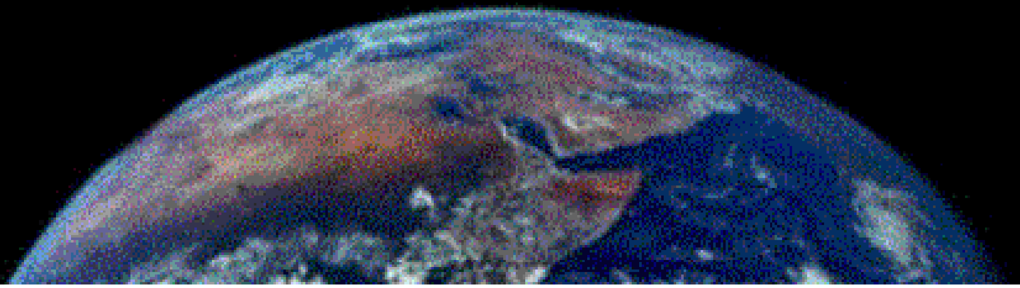
The red curve illustrates the solar activity, which is generally increasing through an interval of 100 years, since the cycle length has decreased from around 11.5 years to less than 10 years. Within the same interval the Earth's average temperature as indicated by the blue curve has increased by approximately 0.7 degree C. It is even claimed that the finer structures in the two curves have similar appearances.

(Reference: Friis-Christensen, E., and K. Lassen,
Length of the solar cycle: An indicator of solar activity closely associated with climate, Science, 254, 698-700, 1991).

~~Not examinable~~



Unfortunately, it's very easy to find correlations, not all of which make sense



More Variabilities….

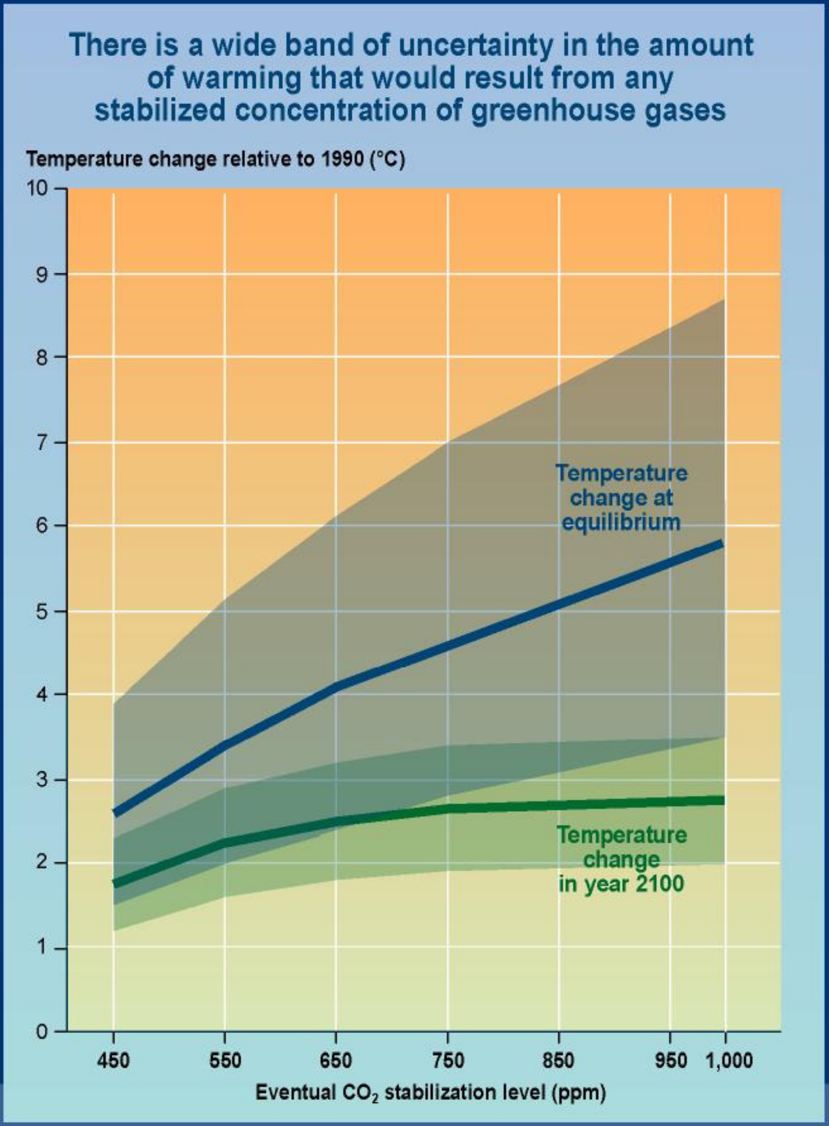
There are clearly also long term solar variations. One such is the Milankovitch orbital and the North Atlantic Oscillation periodicities. Some long term catastrophic changes in Global climate are unassociated with these.

For example, ‘Heinrich’ events occurred between 14000 and 70000 years ago. These are characterised by specific layers of rich carbonate deposits and clear evidence of low salinity, very cold water, and planktonic foraminifer, associated with brief and intense periods of glacial calving.

The N. Atlantic thermohaline circulation would have been stopped by these effects.

Global Warming: what's the truth?

- The rational way to see through this morass of claim, counterclaim, politics, ignorance, prejudice, commercial interests…
  - Go Back to Basics: look at the physics
  - Try to consider as many issues as possible without being blinded by the extraneous detail
  - Think for yourselves
  - Attend Czaja's lectures



There is a wide band of uncertainty in the amount of warming that would result from any stabilized concentration of greenhouse gases

SYR - FIGURE 6-2

Things you should know

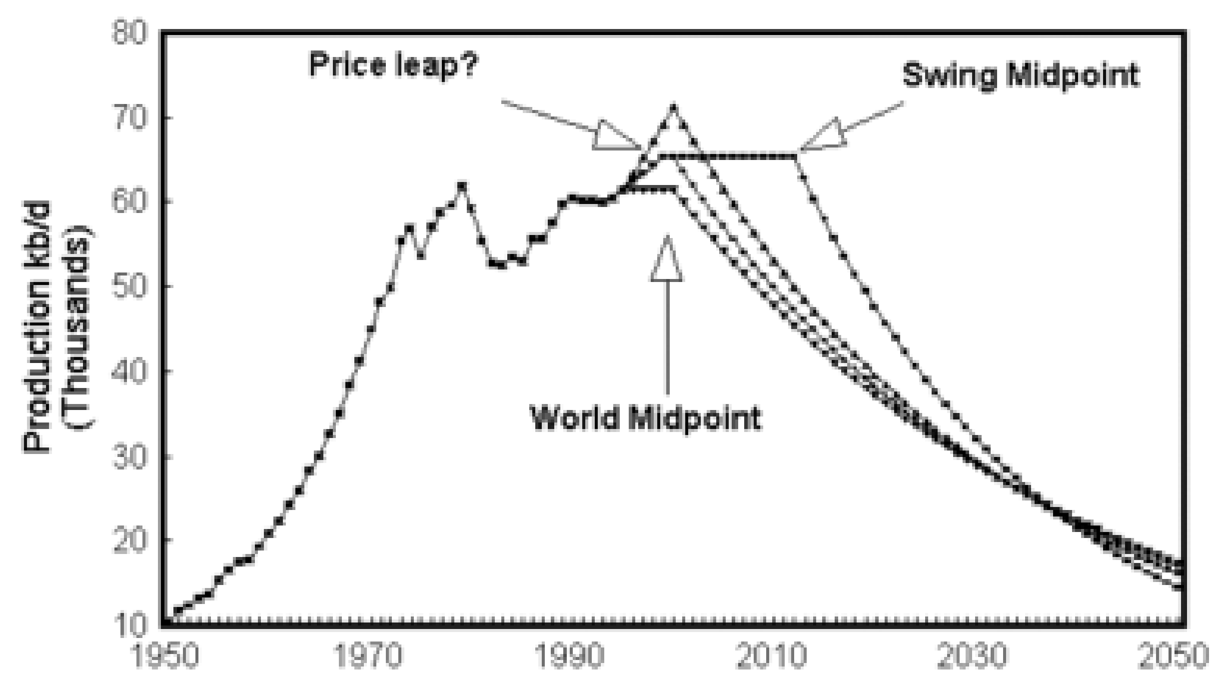
1) There are clear signs of global warming.

The near-consensus is that it is mostly anthropogenic

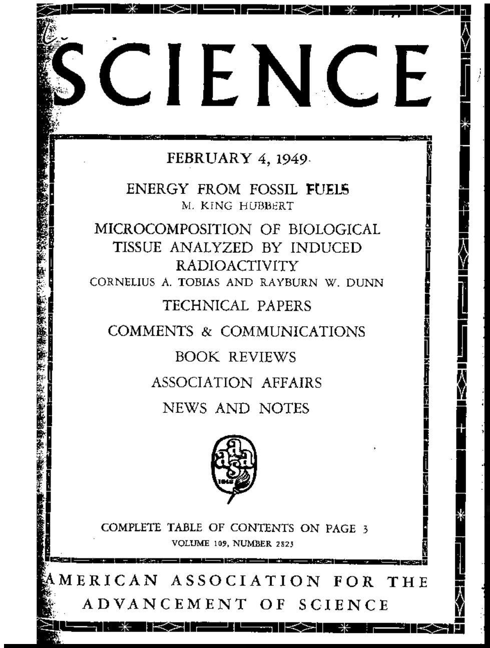
2) There are very large uncertainties

Oil Peak

- This section introduces the concepts of peak oil
- The underlying science will be not be covered extensively in this physics course.
- But the consequences of it being true will be.



Dr. C.J. Campbell/Petroconsultants
http://www.oildepletion.org/
http://www.energiekrise.de/
http://www.peakoil.net



SCIENCE

FEBRUARY 4, 1949

ENERGY FROM FOSSIL FUELS
M. KING HUBBERT

MICROCOMPOSITION OF BIOLOGICAL TISSUE ANALYZED BY INDUCED RADIOACTIVITY
CORNELIUS A. TOBIAS AND RAYBURN W. DUNN

TECHNICAL PAPERS
COMMENTS & COMMUNICATIONS
BOOK REVIEWS
ASSOCIATION AFFAIRS
NEWS AND NOTES

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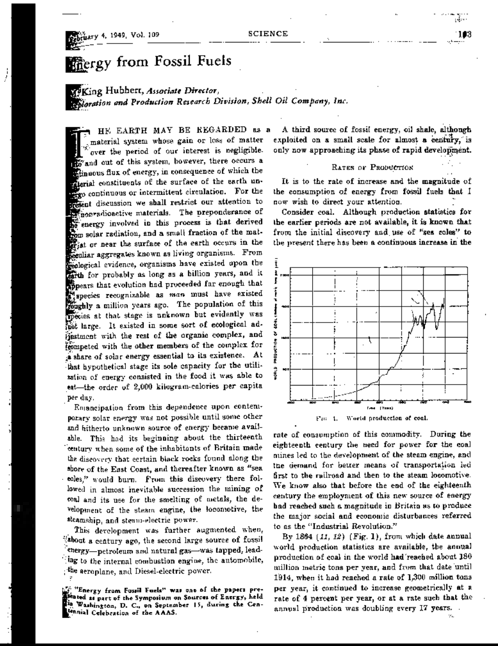
VOLUME 109, NUMBER 2823

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE



Energy from Fossil Fuels

M. King Hubbert, *Associate Director,*
Exploration and Production Research Division, Shell Oil Company, Inc.

THE EARTH MAY BE REGARDED as a material system whose gain or loss of matter over the period of our interest is negligible. Into and out of this system, however, there occurs a continuous flux of energy, in consequence of which the material constituents of the surface of the earth undergo continuous or intermittent circulation. For the present discussion we shall restrict our attention to the nonradioactive materials. The preponderance of the energy involved in this process is that derived from solar radiation, and a small fraction of the matter at or near the surface of the earth occurs in the peculiar aggregates known as living organisms. From geological evidence, organisms have existed upon the earth for probably as long as a billion years, and it appears that evolution had proceeded far enough that a species recognizable as *man* must have existed roughly a million years ago. The population of this species at that stage is unknown but evidently was not large. It existed in some sort of ecological adjustment with the rest of the organic complex, and competed with the other members of the complex for a share of solar energy essential to its existence. At that hypothetical stage its sole capacity for the utilization of energy consisted in the food it was able to eat—the order of 2,000 kilogram-calories per capita per day.

Emancipation from this dependence upon contemporary solar energy was not possible until some other and hitherto unknown source of energy became available. This had its beginning about the thirteenth century when some of the inhabitants of Britain made the discovery that certain black rocks found along the shore of the East Coast, and thereafter known as "sea coles," would burn. From this discovery there followed in almost inevitable succession the mining of coal and its use for the smelting of metals, the development of the steam engine, the locomotive, the steamship, and steam-electric power.

This development was further augmented when, about a century ago, the second large source of fossil energy—petroleum and natural gas—was tapped, leading to the internal combustion engine, the automobile, the aeroplane, and Diesel-electric power.

A third source of fossil energy, oil shale, although exploited on a small scale for almost a century, is only now approaching its phase of rapid development.

Rates of Production

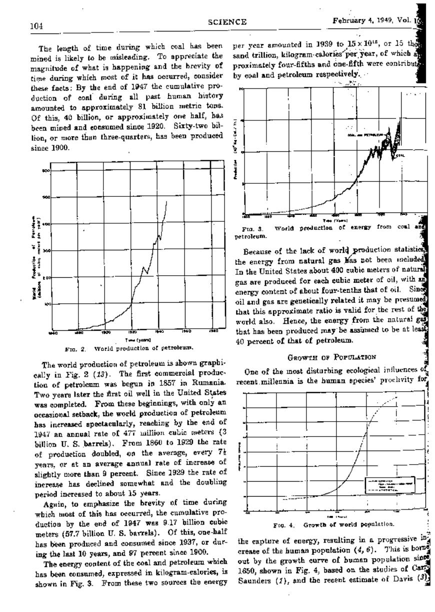
It is to the rate of increase and the magnitude of the consumption of energy from fossil fuels that I now wish to direct your attention.

Consider coal. Although production statistics for the earlier periods are not available, it is known that from the initial discovery and use of "sea coles" to the present there has been a continuous increase in the rate of consumption of this commodity. During the eighteenth century the need for power for the coal mines led to the development of the steam engine, and the demand for better means of transportation led first to the railroad and then to the steam locomotive. We know also that before the end of the eighteenth century the employment of this new source of energy had reached such a magnitude in Britain as to produce the major social and economic disturbances referred to as the "Industrial Revolution."

FIG. 1. World production of coal.

By 1864 (*11, 12*) (Fig. 1), from which date annual world production statistics are available, the annual production of coal in the world had reached about 180 million metric tons per year, and from that date until 1914, when it had reached a rate of 1,300 million tons per year, it continued to increase geometrically at a rate of 4 percent per year, or at a rate such that the annual production was doubling every 17 years.

"Energy from Fossil Fuels" was one of the papers presented as part of the Symposium on Sources of Energy, held in Washington, D. C., on September 15, during the Centennial Celebration of the AAAS.



The length of time during which coal has been mined is likely to be misleading. To appreciate the magnitude of what is happening and the brevity of time during which most of it has occurred, consider these facts: By the end of 1947 the cumulative production of coal during all past human history amounted to approximately 81 billion metric tons. Of this, 40 billion, or approximately one half, has been mined and consumed since 1920. Sixty-two billion, or more than three-quarters, has been produced since 1900.

FIG. 2. World production of petroleum.

The world production of petroleum is shown graphically in Fig. 2 (*13*). The first commercial production of petroleum was begun in 1857 in Rumania. Two years later the first oil well in the United States was completed. From these beginnings, with only an occasional setback, the world production of petroleum has increased spectacularly, reaching by the end of 1947 an annual rate of 477 million cubic meters (3 billion U. S. barrels). From 1860 to 1929 the rate of production doubled, on the average, every 7½ years, or at an average annual rate of increase of slightly more than 9 percent. Since 1929 the rate of increase has declined somewhat and the doubling period increased to about 15 years.

Again, to emphasize the brevity of time during which most of this has occurred, the cumulative production by the end of 1947 was 9.17 billion cubic meters (57.7 billion U. S. barrels). Of this, one-half has been produced and consumed since 1937, or during the last 10 years, and 97 percent since 1900.

The energy content of the coal and petroleum which has been consumed, expressed in kilogram-calories, is shown in Fig. 3. From these two sources the energy per year amounted in 1939 to 15×10^{15}, or 15 thousand trillion, kilogram-calories per year, of which approximately four-fifths and one-fifth were contributed by coal and petroleum respectively.

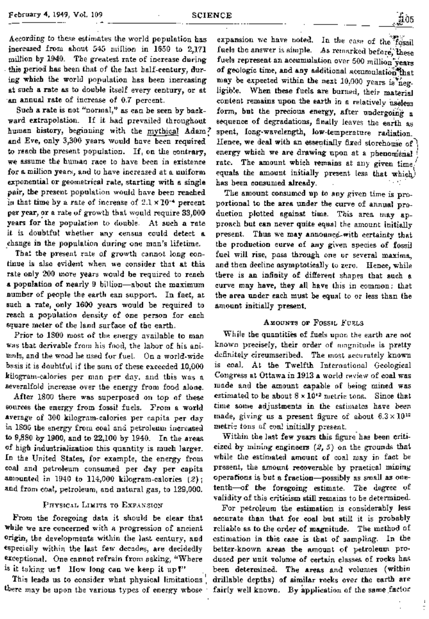
FIG. 3. World production of energy from coal and petroleum.

Because of the lack of world production statistics the energy from natural gas has not been included. In the United States about 400 cubic meters of natural gas are produced for each cubic meter of oil, with an energy content of about four-tenths that of oil. Since oil and gas are genetically related it may be presumed that this approximate ratio is valid for the rest of the world also. Hence, the energy from the natural gas that has been produced may be assumed to be at least 40 percent of that of petroleum.

Growth of Population

One of the most disturbing ecological influences of recent millennia is the human species' proclivity for the capture of energy, resulting in a progressive increase of the human population (*4, 6*). This is borne out by the growth curve of human population since 1650, shown in Fig. 4, based on the studies of Carr-Saunders (*1*), and the recent estimate of Davis (*3*).

FIG. 4. Growth of world population.



According to these estimates the world population has increased from about 545 million in 1650 to 2,171 million by 1940. The greatest rate of increase during this period has been that of the last half-century, during which the world population has been increasing at such a rate as to double itself every century, or at an annual rate of increase of 0.7 percent.

Such a rate is not "normal," as can be seen by backward extrapolation. If it had prevailed throughout human history, beginning with the mythical Adam? and Eve, only 3,300 years would have been required to reach the present population. If, on the contrary, we assume the human race to have been in existence for a million years, and to have increased at a uniform exponential or geometrical rate, starting with a single pair, the present population would have been reached in that time by a rate of increase of 2.1×10^{-4} percent per year, or a rate of growth that would require 33,000 years for the population to double. At such a rate it is doubtful whether any census could detect a change in the population during one man's lifetime.

That the present rate of growth cannot long continue is also evident when we consider that at this rate only 200 more years would be required to reach a population of nearly 9 billion—about the maximum number of people the earth can support. In fact, at such a rate, only 1600 years would be required to reach a population density of one person for each square meter of the land surface of the earth.

Prior to 1800 most of the energy available to man was that derivable from his food, the labor of his animals, and the wood he used for fuel. On a world-wide basis it is doubtful if the sum of these exceeded 10,000 kilogram-calories per man per day, and this was a severalfold increase over the energy from food alone.

After 1800 there was superposed on top of these sources the energy from fossil fuels. From a world average of 300 kilogram-calories per capita per day in 1800 the energy from coal and petroleum increased to 9,880 by 1900, and to 22,100 by 1940. In the areas of high industrialization this quantity is much larger. In the United States, for example, the energy from coal and petroleum consumed per day per capita amounted in 1940 to 114,000 kilogram-calories (*2*); and from coal, petroleum, and natural gas, to 129,000.

Physical Limits to Expansion

From the foregoing data it should be clear that while we are concerned with a progression of ancient origin, the developments within the last century, and especially within the last few decades, are decidedly exceptional. One cannot refrain from asking, "Where is it taking us? How long can we keep it up?"

This leads us to consider what physical limitations there may be upon the various types of energy whose expansion we have noted. In the case of the fossil fuels the answer is simple. As remarked before, these fuels represent an accumulation over 500 million years of geologic time, and any additional accumulation that may be expected within the next 10,000 years is negligible. When these fuels are burned, their material content remains upon the earth in a relatively useless form, but the precious energy, after undergoing a sequence of degradations, finally leaves the earth as spent, long-wavelength, low-temperature radiation. Hence, we deal with an essentially fixed storehouse of energy which we are drawing upon at a phenomenal rate. The amount which remains at any given time equals the amount initially present less that which has been consumed already.

The amount consumed up to any given time is proportional to the area under the curve of annual production plotted against time. This area may approach but can never quite equal the amount initially present. Thus we may announce with certainty that the production curve of any given species of fossil fuel will rise, pass through one or several maxima, and then decline asymptotically to zero. Hence, while there is an infinity of different shapes that such a curve may have, they all have this in common: that the area under each must be equal to or less than the amount initially present.

Amounts of Fossil Fuels

While the quantities of fuels upon the earth are not known precisely, their order of magnitude is pretty definitely circumscribed. The most accurately known is coal. At the Twelfth International Geological Congress at Ottawa in 1913 a world review of coal was made and the amount capable of being mined was estimated to be about 8×10^{12} metric tons. Since that time some adjustments in the estimates have been made, giving us a present figure of about 6.3×10^{12} metric tons of coal initially present.

Within the last few years this figure has been criticized by mining engineers (*2, 5*) on the grounds that while the estimated amount of coal may in fact be present, the amount recoverable by practical mining operations is but a fraction—possibly as small as one-tenth—of the foregoing estimate. The degree of validity of this criticism still remains to be determined.

For petroleum the estimation is considerably less accurate than that for coal but still it is probably reliable as to the order of magnitude. The method of estimation in this case is that of sampling. In the better-known areas the amount of petroleum produced per unit volume of certain classes of rocks has been determined. The areas and volumes (within drillable depths) of similar rocks over the earth are fairly well known. By application of the same factor

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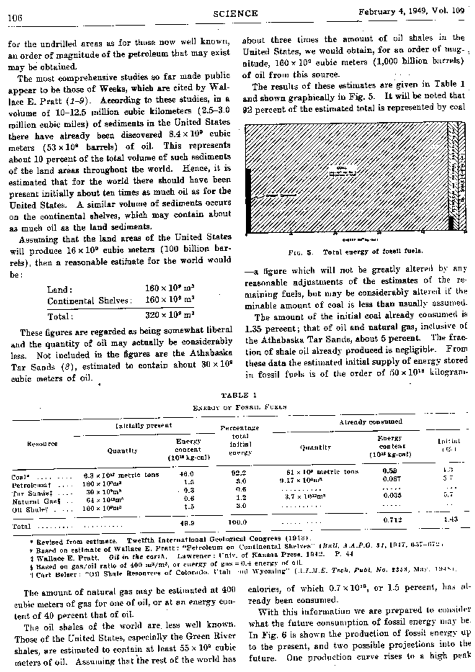


for the undrilled areas as for those now well known, an order of magnitude of the petroleum that may exist may be obtained.

The most comprehensive studies so far made public appear to be those of Weeks, which are cited by Wallace E. Pratt (*1–9*). According to these studies, in a volume of 10–12.5 million cubic kilometers (2.5–3.0 million cubic miles) of sediments in the United States there have already been discovered 8.4×10^9 cubic meters (53×10^9 barrels) of oil. This represents about 10 percent of the total volume of such sediments of the land areas throughout the world. Hence, it is estimated that for the world there should have been present initially about ten times as much oil as for the United States. A similar volume of sediments occurs on the continental shelves, which may contain about as much oil as the land sediments.

Assuming that the land areas of the United States will produce 16×10^9 cubic meters (100 billion barrels), then a reasonable estimate for the world would be:

Land:	160×10^9 m³
Continental Shelves:	160×10^9 m³
Total:	320×10^9 m³

These figures are regarded as being somewhat liberal and the quantity of oil may actually be considerably less. Not included in the figures are the Athabaska Tar Sands (*8*), estimated to contain about 30×10^9 cubic meters of oil.

The amount of natural gas may be estimated at 400 cubic meters of gas for one of oil, or at an energy content of 40 percent that of oil.

The oil shales of the world are less well known. Those of the United States, especially the Green River shales, are estimated to contain at least 55×10^9 cubic meters of oil. Assuming that the rest of the world has about three times the amount of oil shales in the United States, we would obtain, for an order of magnitude, 160×10^9 cubic meters (1,000 billion barrels) of oil from this source.

The results of these estimates are given in Table 1 and shown graphically in Fig. 5. It will be noted that 92 percent of the estimated total is represented by coal

FIG. 5. Total energy of fossil fuels.

—a figure which will not be greatly altered by any reasonable adjustments of the estimates of the remaining fuels, but may be considerably altered if the minable amount of coal is less than usually assumed.

The amount of the initial coal already consumed is 1.35 percent; that of oil and natural gas, inclusive of the Athabaska Tar Sands, about 5 percent. The fraction of shale oil already produced is negligible. From these data the estimated initial supply of energy stored in fossil fuels is of the order of 50×10^{15} kilogram-calories, of which 0.7×10^{15}, or 1.5 percent, has already been consumed.

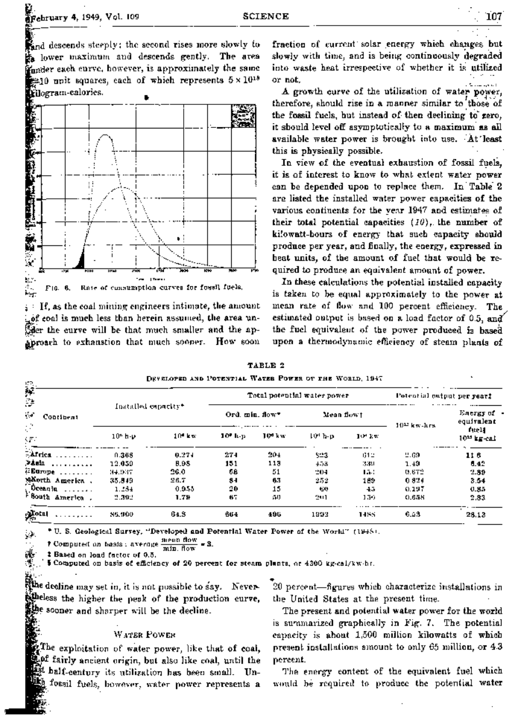
With this information we are prepared to consider what the future consumption of fossil energy may be. In Fig. 6 is shown the production of fossil energy up to the present, and two possible projections into the future. One production curve rises to a high peak

TABLE 1

Energy of Fossil Fuels

Resource	Initially present		Percentage total initial energy	Already consumed		Initial
	Quantity	Energy content (10^{15} kg-cal)		Quantity	Energy content (10^{15} kg-cal)	
Coal*	6.3×10^{12} metric tons	46.0	92.2	81×10^9 metric tons	0.59	1.3
Petroleum†	160×10^9 m³	1.5	3.0	9.17×10^9 m³	0.087	5.7
Tar Sands‡	30×10^9 m³	0.3	0.6	....	.....	...
Natural Gas§	64×10^{12} m³	0.6	1.2	3.7×10^{12} m³	0.035	5.7
Oil Shale¶	160×10^9 m³	1.5	3.0	....	.....	..
Total	....	49.9	100.0	....	0.712	1.43

* Revised from estimate. Twelfth International Geological Congress (1913).
† Based on estimate of Wallace E. Pratt: "Petroleum on Continental Shelves" (*Bull. A.A.P.G. 31*, 1947, 657–672).
‡ Wallace E. Pratt. *Oil in the earth.* Lawrence: Univ. of Kansas Press, 1942. P. 44
§ Based on gas/oil ratio of 400 m³/m³, or energy of gas = 0.4 energy of oil.
¶ Carl Belser: "Oil Shale Resources of Colorado, Utah and Wyoming" (*A.I.M.E. Tech. Publ. No. 2358*, May, 1948).



and descends steeply; the second rises more slowly to a lower maximum and descends gently. The area under each curve, however, is approximately the same ≅10 unit squares, each of which represents 5×10^{15} kilogram-calories.

FIG. 6. Rate of consumption curves for fossil fuels.

If, as the coal mining engineers intimate, the amount of coal is much less than herein assumed, the area under the curve will be that much smaller and the approach to exhaustion that much sooner. How soon the decline may set in, it is not possible to say. Nevertheless the higher the peak of the production curve, the sooner and sharper will be the decline.

Water Power

The exploitation of water power, like that of coal, is of fairly ancient origin, but also like coal, until the last half-century its utilization has been small. Unlike fossil fuels, however, water power represents a fraction of current solar energy which changes but slowly with time, and is being continuously degraded into waste heat irrespective of whether it is utilized or not.

A growth curve of the utilization of water power, therefore, should rise in a manner similar to those of the fossil fuels, but instead of then declining to zero, it should level off asymptotically to a maximum as all available water power is brought into use. At least this is physically possible.

In view of the eventual exhaustion of fossil fuels, it is of interest to know to what extent water power can be depended upon to replace them. In Table 2 are listed the installed water power capacities of the various continents for the year 1947 and estimates of their total potential capacities (*10*), the number of kilowatt-hours of energy that such capacity should produce per year, and finally, the energy, expressed in heat units, of the amount of fuel that would be required to produce an equivalent amount of power.

In these calculations the potential installed capacity is taken to be equal approximately to the power at mean rate of flow and 100 percent efficiency. The estimated output is based on a load factor of 0.5, and the fuel equivalent of the power produced is based upon a thermodynamic efficiency of steam plants of 20 percent—figures which characterize installations in the United States at the present time.

The present and potential water power for the world is summarized graphically in Fig. 7. The potential capacity is about 1,500 million kilowatts of which present installations amount to only 65 million, or 4.3 percent.

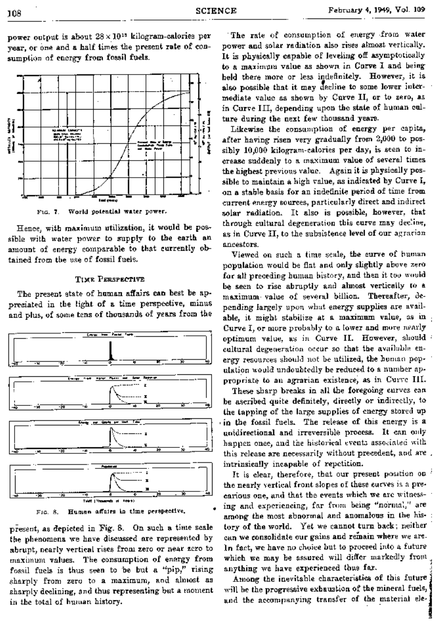
The energy content of the equivalent fuel which would be required to produce the potential water

TABLE 2

Developed and Potential Water Power of the World, 1947

Continent	Installed capacity*		Total potential water power				Potential output per year‡	
			Ord. min. flow*		Mean flow†			
	10^6 h-p	10^6 kw	10^6 h-p	10^6 kw	10^6 h-p	10^6 kw	10^{12} kw-hrs	Energy of equivalent fuel§ 10^{15} kg-cal
Africa	0.368	0.274	274	204	823	612	2.69	11.6
Asia	12.059	8.98	151	113	453	339	1.49	6.42
Europe	34.937	26.0	68	51	204	153	0.672	2.89
North America	35.849	26.7	84	63	252	189	0.824	3.54
Oceania	1.284	0.955	20	15	60	45	0.197	0.85
South America	2.392	1.79	67	50	201	150	0.658	2.83
Total	86.900	64.8	664	496	1992	1488	6.53	28.13

* U. S. Geological Survey, "Developed and Potential Water Power of the World" (1945).
† Computed on basis: average $\frac{\text{mean flow}}{\text{min. flow}} = 3$.
‡ Based on load factor of 0.5.
§ Computed on basis of efficiency of 20 percent for steam plants, or 4300 kg-cal/kw-hr.



power output is about 28×10^{15} kilogram-calories per year, or one and a half times the present rate of consumption of energy from fossil fuels.

FIG. 7. World potential water power.

Hence, with maximum utilization, it would be possible with water power to supply to the earth an amount of energy comparable to that currently obtained from the use of fossil fuels.

Time Perspective

The present state of human affairs can best be appreciated in the light of a time perspective, minus and plus, of some tens of thousands of years from the present, as depicted in Fig. 8. On such a time scale the phenomena we have discussed are represented by abrupt, nearly vertical rises from zero or near zero to maximum values. The consumption of energy from fossil fuels is thus seen to be but a "pip," rising sharply from zero to a maximum, and almost as sharply declining, and thus representing but a moment in the total of human history.

FIG. 8. Human affairs in time perspective.

The rate of consumption of energy from water power and solar radiation also rises almost vertically. It is physically capable of leveling off asymptotically to a maximum value as shown in Curve I and being held there more or less indefinitely. However, it is also possible that it may decline to some lower intermediate value as shown by Curve II, or to zero, as in Curve III, depending upon the state of human culture during the next few thousand years.

Likewise the consumption of energy per capita, after having risen very gradually from 2,000 to possibly 10,000 kilogram-calories per day, is seen to increase suddenly to a maximum value of several times the highest previous value. Again it is physically possible to maintain a high value, as indicated by Curve I, on a stable basis for an indefinite period of time from current energy sources, particularly direct and indirect solar radiation. It also is possible, however, that through cultural degeneration this curve may decline, as in Curve II, to the subsistence level of our agrarian ancestors.

Viewed on such a time scale, the curve of human population would be flat and only slightly above zero for all preceding human history, and then it too would be seen to rise abruptly and almost vertically to a maximum value of several billion. Thereafter, depending largely upon what energy supplies are available, it might stabilize at a maximum value, as in Curve I, or more probably to a lower and more nearly optimum value, as in Curve II. However, should cultural degeneration occur so that the available energy resources should not be utilized, the human population would undoubtedly be reduced to a number appropriate to an agrarian existence, as in Curve III.

These sharp breaks in all the foregoing curves can be ascribed quite definitely, directly or indirectly, to the tapping of the large supplies of energy stored up in the fossil fuels. The release of this energy is a unidirectional and irreversible process. It can only happen once, and the historical events associated with this release are necessarily without precedent, and are intrinsically incapable of repetition.

It is clear, therefore, that our present position on the nearly vertical front slopes of these curves is a precarious one, and that the events which we are witnessing and experiencing, far from being "normal," are among the most abnormal and anomalous in the history of the world. Yet we cannot turn back; neither can we consolidate our gains and remain where we are. In fact, we have no choice but to proceed into a future which we may be assured will differ markedly from anything we have experienced thus far.

Among the inevitable characteristics of this future will be the progressive exhaustion of the mineral fuels, and the accompanying transfer of the material ele-

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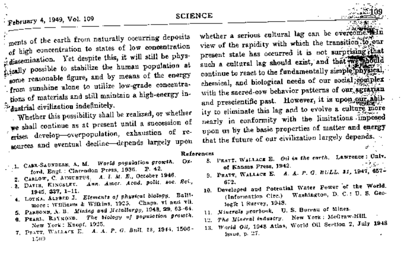

ments of the earth from naturally occurring deposits of high concentration to states of low concentration dissemination. Yet despite this, it will still be physically possible to stabilize the human population at some reasonable figure, and by means of the energy from sunshine alone to utilize low-grade concentrations of materials and still maintain a high-energy industrial civilization indefinitely.

Whether this possibility shall be realized, or whether we shall continue as at present until a succession of crises develop—overpopulation, exhaustion of resources and eventual decline—depends largely upon whether a serious cultural lag can be overcome. In view of the rapidity with which the transition to our present state has occurred it is not surprising that such a cultural lag should exist, and that we should continue to react to the fundamentally simple physical, chemical, and biological needs of our social complex with the sacred-cow behavior patterns of our agrarian and prescientific past. However, it is upon our ability to eliminate this lag and to evolve a culture more nearly in conformity with the limitations imposed upon us by the basic properties of matter and energy that the future of our civilization largely depends.

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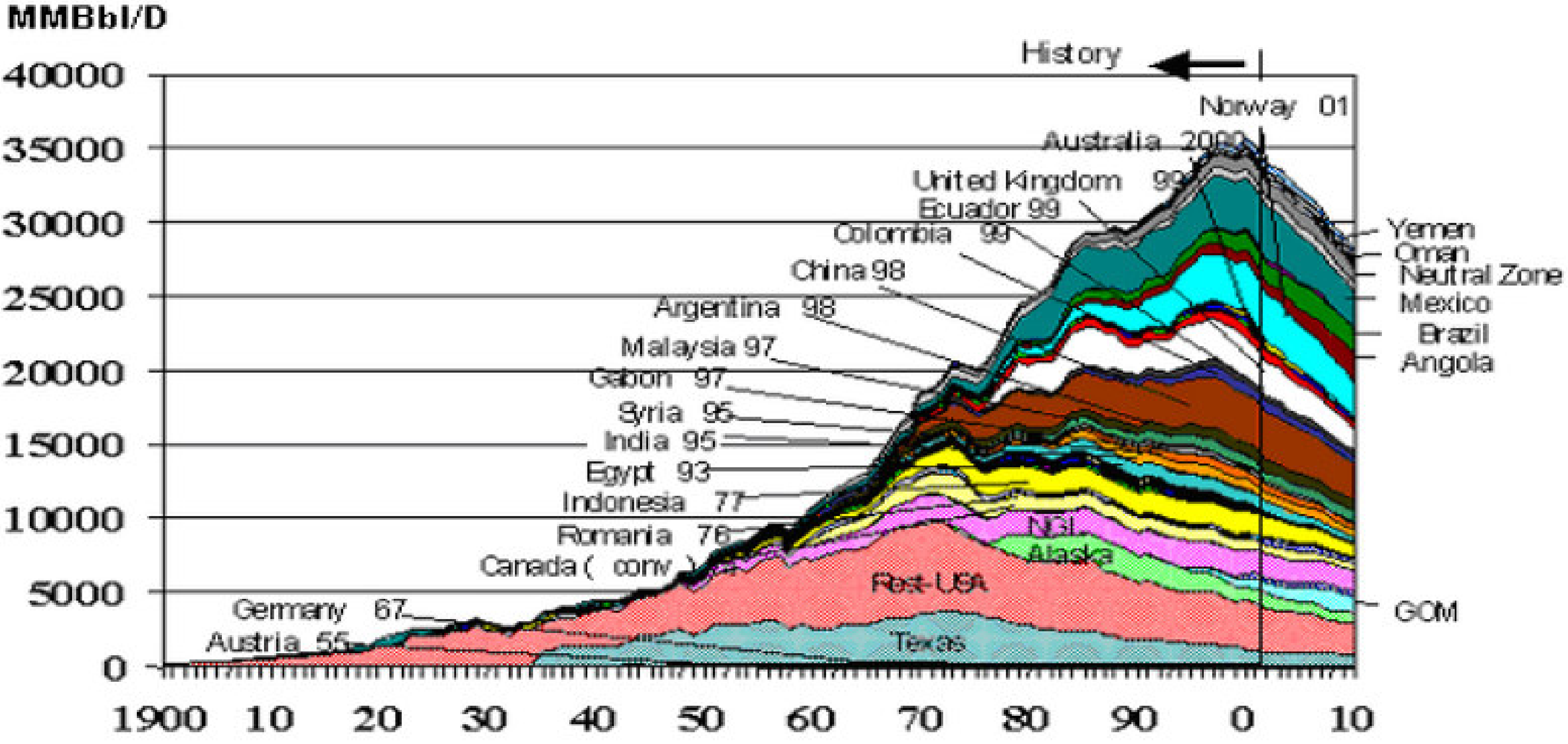
According to conventional geological theory, Oil Has Peaked in Most Places

Non-OPEC, non-FSU Oil Production Has Peaked and is Declining



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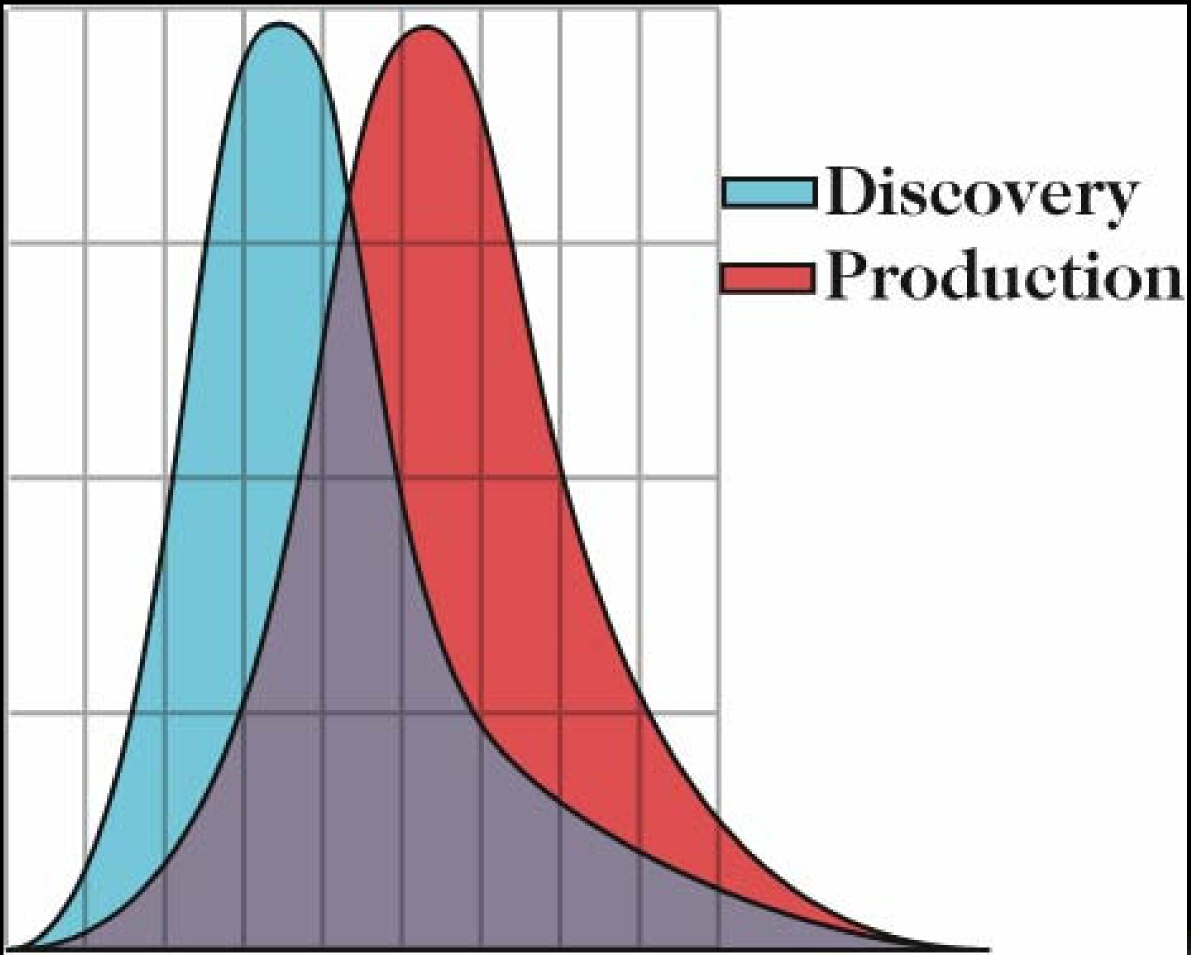
Discovery must predate production



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