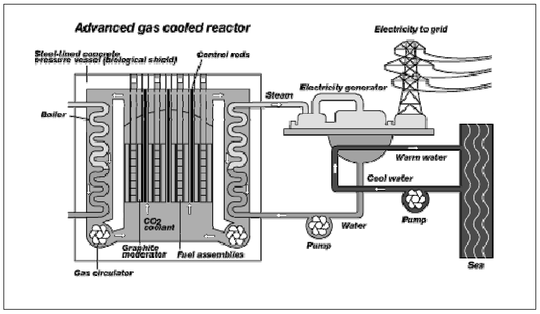
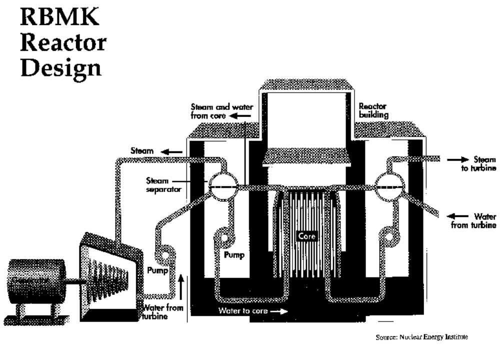
AGR



Not examinable

RBMK



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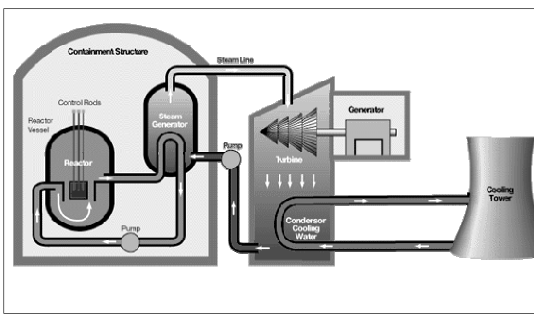
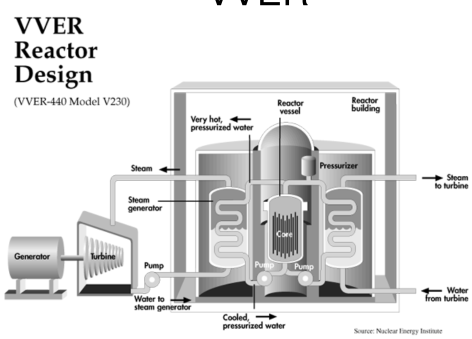
IM Gas reactor



Not examinable

VVER



What we learnt last lecture

Need to go from 12.8TW to 20-30TW

- From biomass, 7 - 10 TW:
- From nuclear, 8 TW:
- From wind, 2.1 TW:
- From hydroelectric, 0.7 - 2.0 TW:

- These numbers come from Nocera, and are not universally accepted.

- Biomass, 0.03TW…increases cut into food production and cause environmental damage
- Hydrocarbons: 80m bbl/day≡29bn bbl/year (= 29 BBPD
  = 178.4 x EJ/year equivalent to 5.6TW so to match needs, hydrocarbon production must grow by over 6% per year

Real issue is Energy Retrun on Investment (EROI), with 'I' covering full life-cycle honest costings

Modular Pebble bed reactor

In the 1950's, Dr Rudolf Schulten:

idea was to compact silicon carbide coated uranium granules into hard billiard-ball-like graphite spheres to be used as fuel for a new high temperature, helium cooled type of reactor.

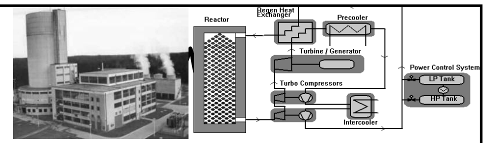
The idea took root in due course of the AVR, a 15 MW (megawatt) demonstration pebble bed reactor, was built in Germany. It operated successfully for 21 years.

PBMR

'The Pebble Bed Modular Reactor (PBMR) is a small, safe, clean, cost efficient, inexpensive and adaptable nuclear power plant.'

The PBMR is a nuclear power plant that uses coated uranium particles encased in graphite to form a fuel sphere (60mm in diameter). In addition, the PBMR design makes use of helium as the coolant and energy transfer medium to a closed cycle gas turbine and generator.

Not examinable



1- 2: The helium enters the reactor at a temperature of about 500°C (932°F) and moves downward between the hot fuel spheres. It picks up the heat from the fuel spheres which have been heated by the nuclear reaction. The helium then leaves the reactor at a temperature of about 900°C (1 652°F).

2- 3: The helium then moves through the High Pressure Turbine (HTP). This turbine forms part of the High Pressure Turbo Unit and drives the High Pressure Compressor with the aid of the expanded helium within it.

3- 4: Next the helium moves through the Low Pressure Turbine, which is part of the Low Pressure Turbo Unit. The Low Pressure Turbine drives the Low Pressure Compressor.

4- 5: The helium then moves through the Power Turbine. This turbine drives the generator.

5- 6: At this point, the helium is still at a high temperature. It passes through the recuperator in this state. Heat is transferred between the high temperature (stream) from the Power Turbine and the low temperature (stream) returning to the reactor.

6- 7: The helium is now cooled by means of a pre-cooler. This increases the density of the helium and improves the efficiency of the compressor.

7- 8: The helium is then compressed by the Low Pressure Compressor.

8- 9: The helium is cooled in the inter-cooler. This process increases the density and improves the efficiency of the compressor.

9- 10: The High Pressure Compressor then compresses the helium.

10- 11: The cold, high-pressure helium steam passes through the recuperator where it is pre-heated. The helium then returns to the reactor.

PBMR

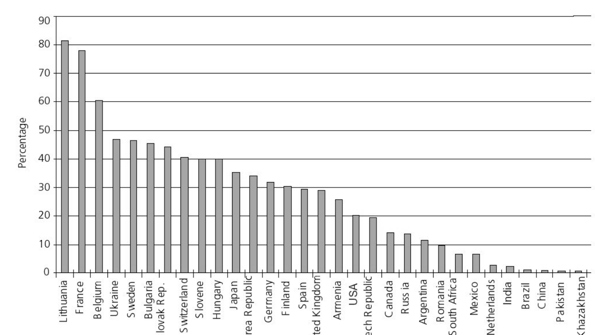
Refuelling of the reactor

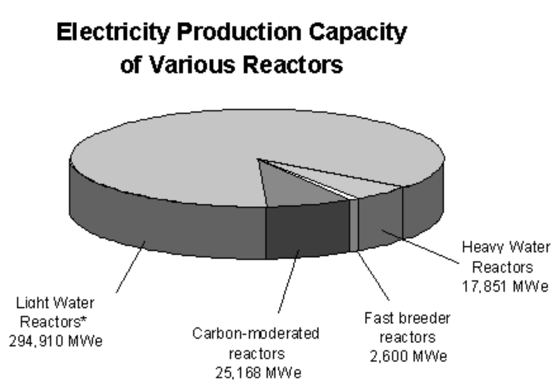
The reactor will be refuelled while the plant is operating. This removes any requirement to shut down the reactor for refuelling. The availability of the plant is be increased by this functionality.

Furthermore, the fuel spheres are circulated through the core several times before they are depleted. This means that the burnup of the uranium within the reactor is more even and results in effective use of uranium in the reactor.

Not examinable

Global nuclear electricity





But, there is a problem…

Recall that world consumes 80m bbl/day≡29bn bbl/year (= 29 BBPD
= 4.64 x 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

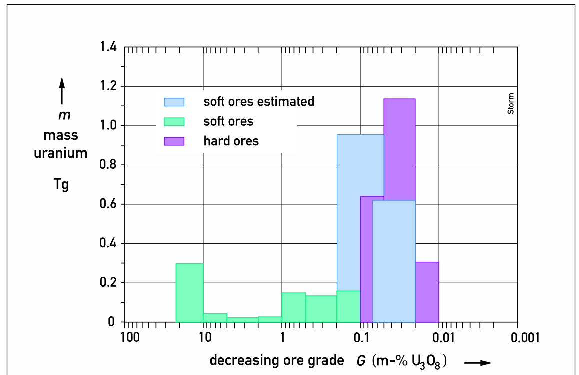
According to official data, the world known recoverable uranium resources per 1-1-2003 are 3.537 million metric tonnes.

- At the current consumption rate (some 68000 metric tonnes per year) these resources will be depleted at about 2050-2055.
- 'Recoverable' means: 'Reasonably Assured Resources plus Inferred Resources' to US$ 80 per kilogram uranium.
- As the uranium prices are rising, the uranium industry expects larger resources become 'recoverable', for instance to a price of 130 US$/kg U.

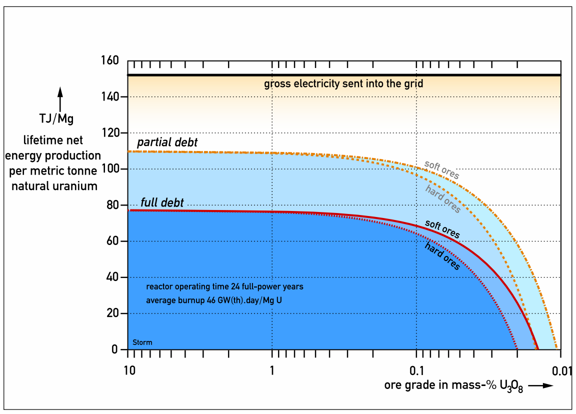
Uranium resources: an economic resource is not the same as an energy resource, J.W. Storm van Leeuwen, 12 November 2005
The official figures of the recoverable uranium resources are from OECD NEA and IAEA and published by,
among others, the World Nuclear Association WNA (formerly: The Uranium Institute). www.world-nuclear.org/info/inf75.htm

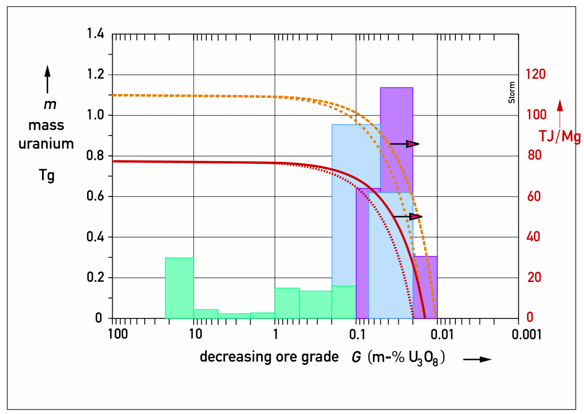
And so….?

- WNA suggests that, if all estimates of conventional resources are considered, the total resources may amount to about 9.7 million metric tonnes = 9.7 Tg ie some 140 years uranium supply at the current consumption rate.
- But only 3.537 Tg currently classified as 'recoverable'.

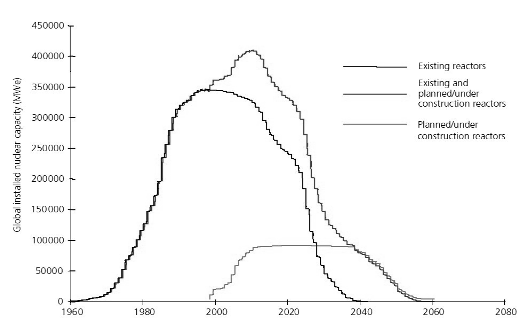


The world known recoverable uranium resources as function of decreasing ore grade.
The total in the diagram amounts to 4.5 Tg, more than the official figure of 3.6 Tg. Source: WNA.

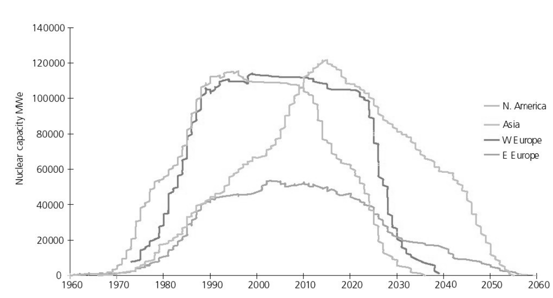




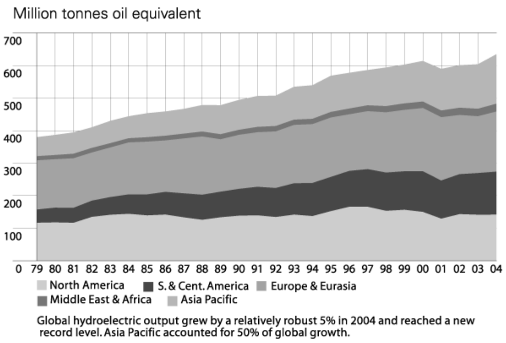
Nuclear realities



Global Nuclear realities



Hydroelectricity consumption by area



=29EJ

=0.9TW

Global hydroelectric output grew by a relatively robust 5% in 2004 and reached a new record level. Asia Pacific accounted for 50% of global growth.

- 1 Ton of oil equivalent (toe) = 40 MBtu = 42 GJ
- http://www.bp.com/sectiongenericarticle.do?categoryId=9003079&contentId=7005864

Wind

- The potential energy in the winds that blow across the United States each year could produce more than 4400 Terawatt hours of electricity—more than one and one-half times the electricity consumed in the United States in 2000. The total available global wind resource today that is technically recoverable is 53,000 Terawatt hours per year (ie about 6TW - about half the world's entire electricity consumption in 1998.)
- Optimistic, but more realistic projections claim wind could supply 10% of the world's needs within 20 years.

(how many windmills?)

Wind

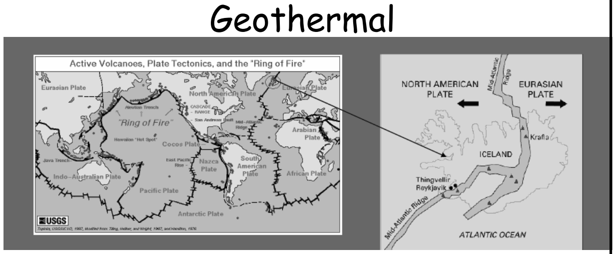
- Wind power was the fastest growing energy source in the world last year, and grew by an average of 40% worldwide between 1994 and 1998. Yet its global contribution to electricity needs is still only 0.15%. In Denmark, wind provides almost 10% of the country's electricity, and the country's target is 50% by 2030.
- The cost of Denmark's wind energy fell by two-thirds between 1981 and 1995, and it's claimed* by 2020 the cost of wind power globally will be competitive with all today's new generating technologies.
- *EWEA

Not examinable

Wind Power

Rank	Country	Pop (M)	Total cap inst 2004 (MW)	Total (W/capita
1	Denmark	5.33,	117	588.1
2	Spain	39.48,	263	209.7
3	Germany	82.016,	629	202.8
4	Ireland	3.733	9	91.6
5	Luxembourg	0.43	5	87.5
6	Austria	8.06	6	75.8
7	Netherlands	15.81,	78	68.2
8	Portugal	10.05	22	52.2
9	Sweden	8.94	42	49.7
10	Greece	10.54	65	44.3
11	New Zealand	4.01	68	42.5
12	Norway	4.51	60	35.6
13	USA	285.96,	740	23.6
14	Australia	19.33	80	19.7
15	Italy	57.61,	125	19.5
16	Costa Rica	4.07	11	8.0
17	Finland	5.28	21	5.8
18	UK	59.18	881	5.0
19	Canada	31.04	411	4.2

Geothermal



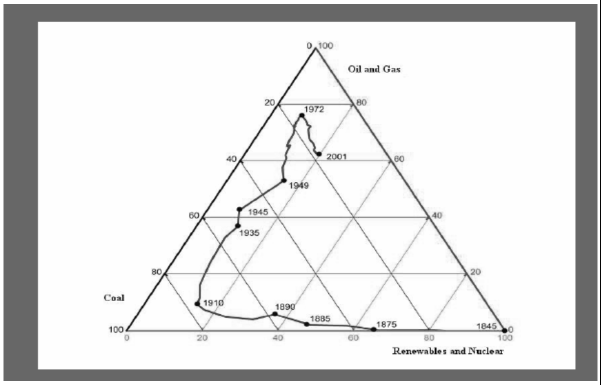
Heat and electricity production from geothermal sources accounts for about 60% of the total energy consumption in Iceland and the amount of electricity or space heating produced from fossil resources is negligible. The ratio of hydroelectric to geothermal *electricity* in Iceland is roughly 4:1.

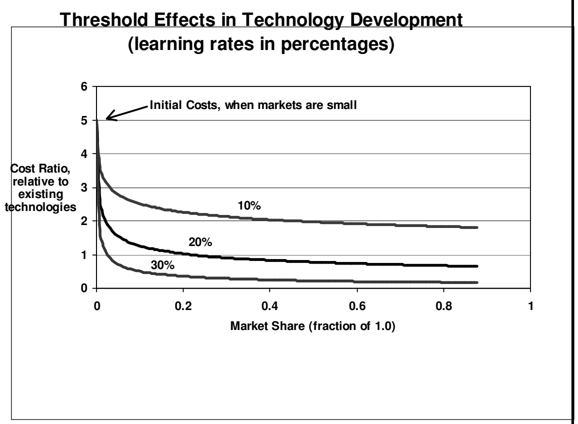
Typically, geothermal power is converted into electricity through turbines operating on the flash steam or the binary Rankine cycle. Geothermal heat is a huge energy resource.

Geothermal

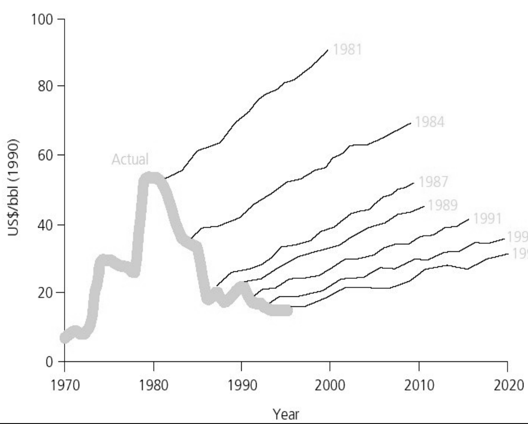
- It has been estimated that the total worldwide harnessable power using turbines (steam >150°C) is about 1.3TW and that lower temperature geothermal resources may provide about twice that using binary systems [Stefansson, 1998]. Extraction of H2 and HS2 in geothermal installations could increase these numbers.
- For comparison, the total installed power of all electricity generators in the world is about 3.3 TWe

Oil-coal-renewable trajectory of US

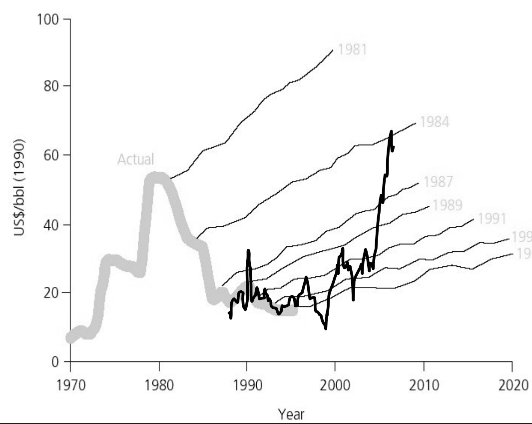




Oil price projections – they are always wrong.

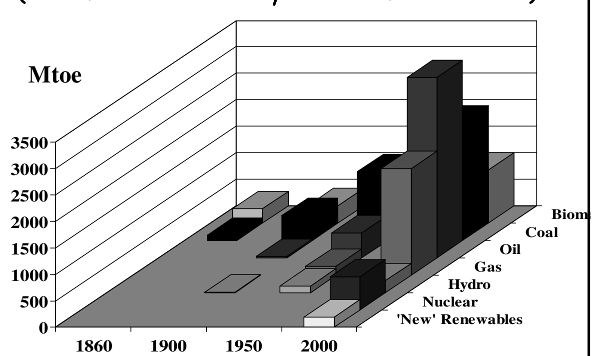


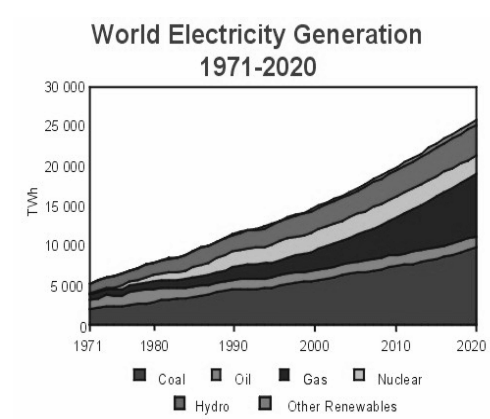
Oil price projections – they are always wrong.



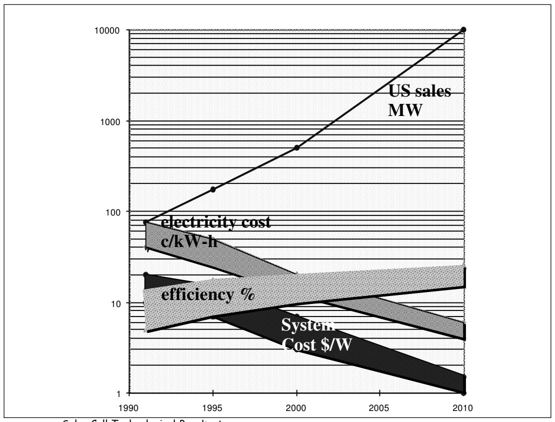
World Primary Energy Supply Mix, 1860-2000

(The future is rarely 'more of the same')

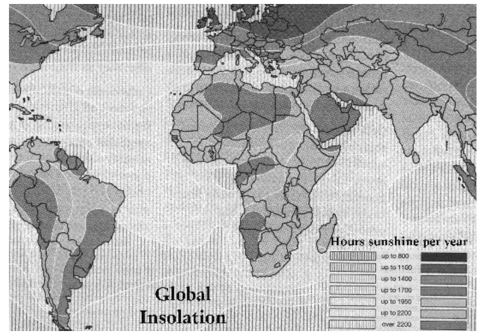




Commercialization barriers.



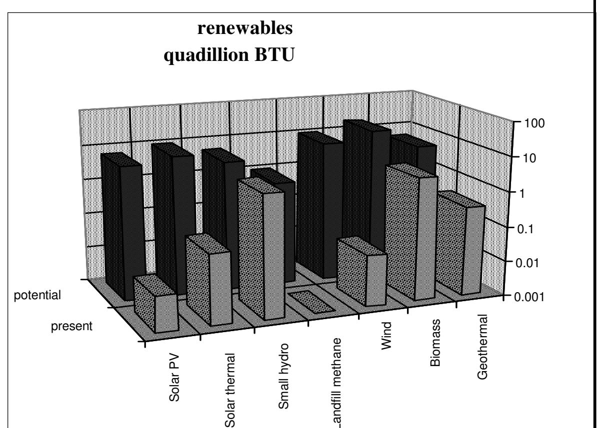
Solar Cell Technological Breakout



Theoretical Energy Limits EJ/year

Type of energy	Theoretical potential	Technical potential (secondary energy)	Possibly utilizable (secondary energy)	Relationship of technical potential to world secondary energy use
Solar radiation	791370	586	88	2.8
Wind energy	8793	94	32	0.45
Biomass	2931	191	158	0.95
Hydropower	158	70	47	0.35
Geothermal	1114	64	18	0.3
Others (OTEC, Wave energy, Tidal energy)	733	32	15	
Total		**1037**	**358**	**5**

(Based on J.Nitsch (1988). Energy Supply Structures and the Importance of Gaseous Energy Carriers, In Hydrogen as an Energy Carrier (Ed. Carl-Jochen Winter), Springer Verlag p.13-29).



UK Energy Goals: White Paper 2003

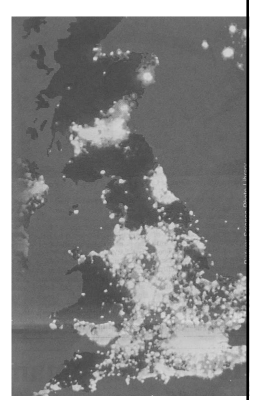
•to put ourselves on a path to cut the UK's carbon dioxide emissions - the main contributor to global warming - by some 60% by about 2050, as recommended by the RCEP, with real progress by 2020;

• to maintain the reliability of energy supplies;

• to promote competitive markets in the UK and beyond, helping to raise the rate of sustainable economic growth and to improve our productivity; and

• to ensure that every home is adequately and affordably heated.

Current UK energy demands

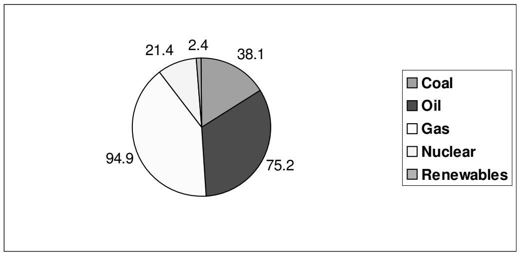


- UK primary energy consumption in 2000 = 231.9 million tonnes of oil equivalent = 2700 TWh
- Projected to rise by 10% by 2020
- Use of gas and oil increasing
- Use of coal and nuclear decreasing
- Production of all primary sources down

http://www.wired-gov.net/EDP8203R7W/WGLaunch.aspx?ARTCL=36403&ALERT_TYPE=16

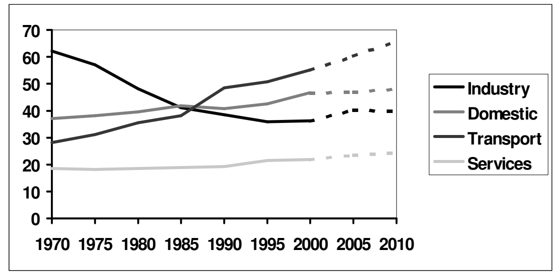
UK primary energy mix

Primary energy consumption by fuel (mtoe), 2000



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 1020 J. UK consumption = 232 mtoe = 11EJ .≡ 0.35TW

Final energy demand by sector, 1970-2010 (mtoe)



Climate change drivers

- UK target under Kyoto Protocol
  - reducing greenhouse gas(GHG) emissions by 12.5% below 1990 levels by 2008-2012
- Current trends
  - GHG emissions fell by 14% between 1990 and 2000, driven by economic changes:
  - switch from manufacturing to services
  - energy efficiency improvements
  - 'dash for gas'

Climate Change Programme

- Underlying trend for emissions to rise after 2010 due to
  - retirement of nuclear power stations
  - continuing growth in transport emissions
- Policy measures to ensure continued emissions reductions
  - Climate Change Levy (and agreements)
  - Renewables Obligation (10% by 2010)
  - voluntary agreements on vehicle emissions

Framework has been proven to work in mitigation of acid rain- where SOX and NOX have been monitored and regulated.

Regulating Acid Rain

- Coal burning is the single largest man-made source of sulphur dioxide accounting for about 50% of annual global emissions, with oil burning accounting for a further 25 to 30%.
- In 1979, the United Nations Economic Commission for Europe (UNECE) implemented the Convention on Long-Range Transboundary Pollution. In 1985 most UNECE members adopted the Protocol on the Reduction of Sulphur Emissions, agreeing to reduce sulphur dioxide emissions by 30% (from 1980 levels) by 1993.
- In 1988 a Directive was introduced for European Community (EC) countries which required power stations to reduce emissions of sulphur dioxide and nitrogen oxides. For the UK, reductions of sulphur dioxide by 60% by 2003 and nitrogen oxides by 30% by 1998 (against 1980 levels) have been set.
- The UK is well on course to exceed both targets through new gas-fired power stations (which have lower emissions) replacing coal fired power stations, and flue gas desulphurisation equipment fitted to some of the existing coal-fired power stations.

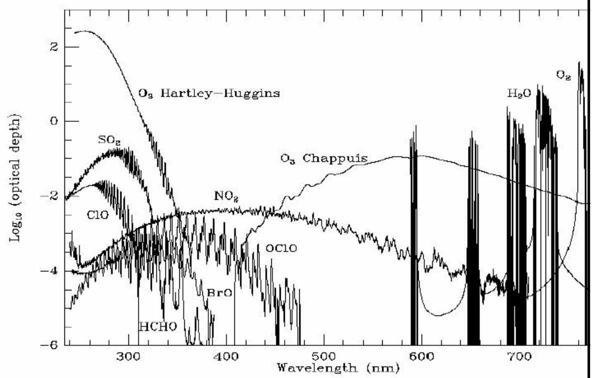
http://www.ace.mmu.ac.uk/eae/Acid_Rain/Older/Sulphur_Dioxide.html

Regulating Acid Rain

- In June 1994, a number of European countries signed the Second Protocol for sulphur. Most of the western European countries agreed to reduce sulphur emissions by between 70 and 80% by the year 2000 (against 1980 levels) whilst eastern European countries generally have a lower target of between 40 and 50% (against 1980 levels).
- Overall, emissions of sulphur dioxide in Europe are estimated to have fallen by 25-30% between 1980 and 1990, and by 40% by the year 2000. Further falls in sulphur dioxide emissions are expected over the next decade.
- Physics contibutes through measuring, modelling and monitoring

http://www.ace.mmu.ac.uk/eae/Acid_Rain/Older/Sulphur_Dioxide.html

Gases Observable in UV/VIS/NIR



DOAS – Differential Optical Absorption Spectroscopy

The Principle of the DOAS and DUVAS Technique

Like all absorption techniques DOAS makes use of the absorption of electromagnetic radiation by matter. Quantitatively the absorption of radiation is expressed by the Beer-Lambert law:

$I(\lambda) = I_0(\lambda) \exp(-x\, c\, \sigma(\lambda))$

where $I_0(\lambda)$ denotes the initial intensity of a light source

$I(\lambda)$ is the intensity of the radiation after it has passed through a layer of thickness x,

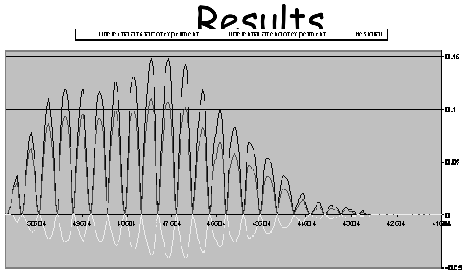
where the species to be measured is present at the concentration c; $\sigma(\lambda)$ denotes the absorption cross section at the wavelength λ which can be measured in the laboratory. Once $\sigma(\lambda)$ is known, the trace gas concentration c can be calculated by:

$c = D/\, \sigma(\lambda)\, x$ where D, the optical depth = $\ln (I_0(\lambda)/I(\lambda))$

This neglects:

Extinction due to Rayleigh scattering
Extinction due to Mie scattering
Absorption by other molecules present in the atmosphere.

Results

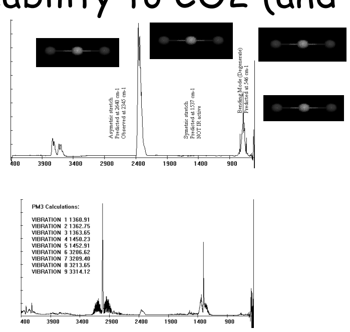


Sulphur dioxide data, higher scan (blue) is earlier in time, lower scan (purple) is approx ten minutes later while scan under x-axes (yellow) is the scaled residual between the two higher scans

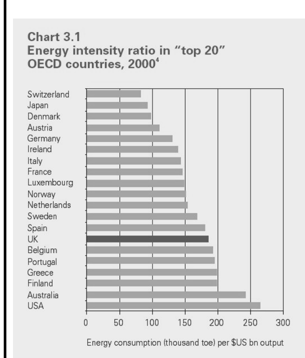
How to implement

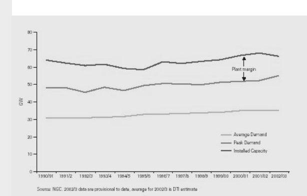
- US Example of pollution credit trading: The Clean Air Act Amendments of 1990 was partly directed at acid rain. How to reduce sulphur dioxide levels to 10 million tons below 1980 levels?
- The key feature of the Acid Rain Program is the use of economic incentives through the SO2 allowance system. Each allowance authorizes the emission of one ton of SO2. Once allocated, allowances become marketable commodities and may be bought, sold, or traded.
- At the end of each year, units included in the program must hold a quantity of allowances equal to or greater than its annual emissions.

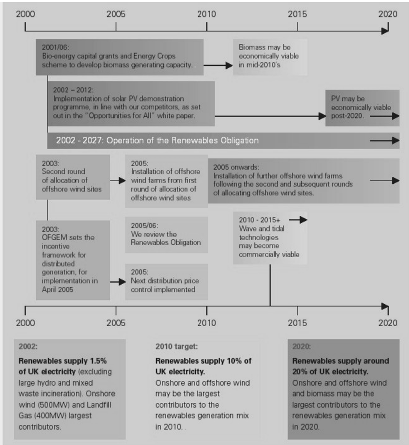
Applicability to CO2 (and CH4)



Gifs from http://science.widener.edu/svb/ftir/intro_ir.html







Wind energy:
UK 330 MWe,
Germany 2.9 GWe
Denmark 1.4 GWe
By the end of 1998 the total installed capacity for the whole of Europe was 6.3 GWe.

Allowing for the variability of the wind this is equivalent to a source of about one third of the installed capacity - i.e. about 110 MWe for the UK and 2.1 GWe for Europe.

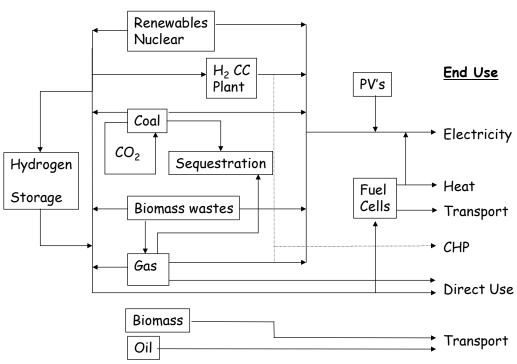
Elasticity

UK projections: at 2p/kWh the contribution from renewables would be about 20 TWh per annum;

…at a price of 3 p/kWh this figure rises to 170 TWh per annum.

Beyond the RCEP 2050 Scenarios

+ Hydrogen + Fuel cells + Carbon Sequestration



Our ambition is for the world's developed economies to cut emissions of greenhouse gases by 60% by around 2050.

We therefore accept the Royal Commission on Environmental Pollution's (RCEP's) recommendation that the UK should put itself on a path towards a reduction in carbon dioxide emissions of some 60% from current levels by about 2050.

Until now the UK's energy policy has not paid enough attention to environmental problems. Our new energy policy will ensure that energy, the environment and economic growth are properly and sustainably integrated.

…But an extensive review by the Intergovernmental Panel on Climate Change suggests that action aimed at stabilising carbon dioxide atmospheric concentrations at no more than 550ppm would lead to an average GDP loss for developed countries of around 1% in 20506.

It suggests that the cost impact of effectively tackling climate change would be very small - equivalent in 2050 to just a small fraction (0.5-2%) of the nation's wealth, as measured by GDP, which by then will have tripled as compared to now.

Kyoto

The Kyoto Protocol commits the UK to reduce greenhouse gas emissions by 12.5 per cent below 1990 levels between 2008 and 2012. The Government's own Climate Change Programme … and towards 20 per cent reduction in carbon dioxide emissions by 2010. Provisional data for 2002 point to a reduction of UK carbon dioxide emissions of 3.5 per cent between 2001 and 2002. Total greenhouse gas emissions in 2002 are estimated to have been between 14 and 15 per cent below the 1990 level…

On the environment, the White Paper sets out the Government's ambition that the world's developed economies should cut emissions of greenhouse gases by 60 per cent by around 2050 and puts the UK on a path towards cutting carbon dioxide emissions by 60 per cent by 2050, with real progress by 2020.

Renewables

To hit the 10% target we will need to install approximately10,000MW of renewables capacity by 2010, an annual build rate of over 1250MW. Only 1200MW of renewables capacity has been installed in total so far (excluding large hydro).

The measures we have already put in place will make a major difference to the rate at which capacity is installed. But they were only introduced last year and it will take a few years before these measures impact fully.

Our analysis and consultation has shown that we need to strengthen our policy if we are to ensure that the measures we have put in place have the maximum impact.

The End of Nuclear?

We do not propose new nuclear build...
… our priority is to strengthen the contribution that energy efficiency and renewable energy sources make to meeting our carbon commitment.

We believe that such ambitious progress is achievable, but uncertainties remain. While nuclear power is currently an important source of carbon free electricity, the current economics of nuclear power make it an unattractive option for new generating capacity and there are also important issues for nuclear waste to be resolved.

This white paper does not contain proposals for building new nuclear power stations. However, we do not rule out the possibility that at some point in the future new nuclear build might be necessary if we are to meet our carbon targets.

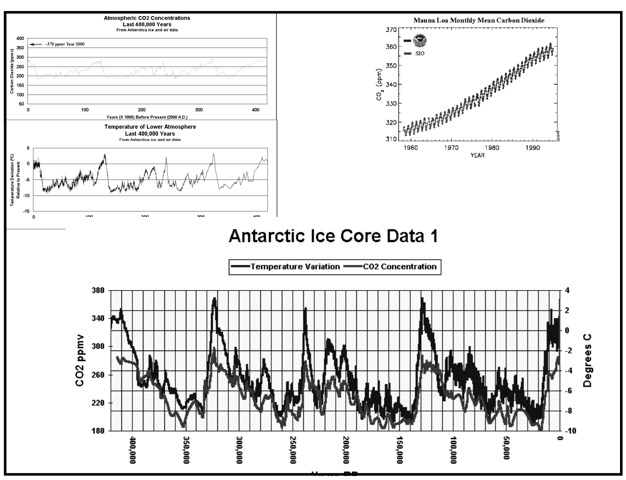
Before any decision to proceed with the building of new nuclear power stations, there would need to be the fullest public consultation and the publication of a white paper setting out the Government's proposals.

Climate Change

- This section is dealt with in detail by Dr Czaja. Here we explore the overall issues.

What we learnt last lecture

- Oil price projections always wrong: so cost comparisons always wrong
- The future is never the same as the past
- Costs for renewables generally goes down driven by the learning curve
- The cost of coal ought to include CO2 mitigation
- Sequestration isn't totally insane
- Global warming driven by legislation: legislation enabled by technology
- "Acid rain" provides excellent model: SO2 etc can be monitored by DUVAS
- CH4 and CO2 can be monitored by FTIR
- UK is an appropriate model for legislation-driven, technology-backed actions
- UK roadmap provided by UK Govt Energy White Paper, and RCEP
- IPCC will provide scientific framework with buy-in from most of the world's climate scientists
- Is nuclear on the way back?



JAMES HANSEN NASA Goddard Institute for Space Studies,

Heating up the sea, air and ice

- **Climate forcings, sensitivity, response time and feedbacks** ***A climate forcing*** is an imposed perturbation of the Earth's energy balance. If the sun brightens, that is a positive forcing that warms the Earth. Aerosols (fine particles) blasted by a volcano into the upper atmosphere reflect sunlight to space, causing a negative forcing that cools the Earth's surface. These are natural forcings. Human-made gases and aerosols are also important forcings.

  Climate sensitivity is the response to a specified forcing, after climate has had time to reach a new equilibrium, including effects of fast feedbacks. A common measure of climate sensitivity is the global warming caused by a doubling in atmospheric CO2 concentration. Climate models suggest that doubled CO2 would cause 3 °C global warming, with an uncertainty of at least 50%. Doubled CO2 is a forcing of about 4 W/m2, implying that global climate sensitivity is about 3/4 °C per W/m2 of forcing.

  Climate response time is the time needed to achieve most of the climate response to an imposed forcing, including the effects of fast feedbacks. The response time of the Earth's climate is long, at least several decades, because of the thermal inertia of the ocean and the rapid mixing of waters within the upper few hundred meters of the ocean.

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Climate sensitivity and response time depend upon ***climate feedbacks***, which are changes in the planetary energy balance induced by the climate change that can magnify or diminish climate response. Feedbacks do not occur immediately in response to a climate forcing; rather, they develop as the climate changes.

Fast feedbacks come into play quickly as temperature changes. For example, the air holds more water vapor as temperature rises, which is a positive feedback magnifying the climate response, because water vapor is a greenhouse gas. Other fast feedbacks include changes of clouds, snow cover, and sea ice. It is uncertain whether the cloud feedback is positive or negative, because clouds can increase or decrease in response to climate change. Snow and ice are positive feedbacks because, as they melt, the darker ocean and land absorb more sunlight.

Slow feedbacks, such as ice sheet growth and decay, amplify millennial climate changes. Ice sheet changes can be treated as forcings in evaluating climate sensitivity on time scales of decades to centuries.