The global energy problem

Lennart Bengtsson
MPI for Meteorology, Hamburg
ESSC, University Reading

The Global energy problem
Why is it a problem?

- There is an urgent need in developing countries to improve living conditions. This requires more energy in suitable form, mainly in the form of electricity. Present available energy is insufficient.
- The inertia/complexity of energy producing systems favors the use of fossil fuel.
- The regenerative energies have limited possibilities
- The public is generally against nuclear energy
- The continued and increasing use of fossil fuel effects climate and have other negative environmental effects.

Some data

- Total solar irradiation at the surface: **7.3×10^{16}** W (0.11Mkm^2)
- Total kinetic energy: **1.4×10^{15}** W (5.5Mkm^2)
- Total energy from falling precipitation: **$1.5\text{-}2.3 \times 10^{13}$** W
- Total energy consumption: 4.2 GWh/sec (**1.52×10^{13}** W)
- The emission of energy from the interior of the Earth is 6×10^{13}W
- Total emission of CO_2: **1000** ton/sec

Hertz´ Schätzungen der Energieströme auf der Erdoberfläche, verglichen mit den zuverlässigsten Schätzungen (Satellitendaten und Modellberechnungen) aus dem Jahre 1999 (Leistungen in Watt)

	Hertz´ Schätzungen 1885	Heutige Modellberech-nungen
Strahlung der Sonne Einfallendes Sonnenlicht	$2.5*10^{17}$	$1.74*10^{17}$
Reflexion von Sonnenstrahlung durch die Erde	$9*10^{16}$	$5.3*10^{16}$
Rückstrahlung von der Erde	$1.6*10^{17}$	$1.21*10^{17}$
	Hydrologischer Kreislauf	
Leistung zur Wasserverdampfung der Erdoberfläche	$4.2*10^{16}$	$4.1*10^{16}$
Leistung bei Regenfall (Global) (h=2500m)	$4.4*10^{14}$	$4.3*10^{14}$
Leistung strömenden Wassers auf dem Festland	$1.5*10^{13}$ (h= 440m)	$2.3*10^{13}$ (h=1124m)
Leistung des Windes	$4*10^{15}$	$1.4*10^{15}$
Energieproduktion 2005 Energieverbrauch (geschätzt) 1999	1.5x $1.4*10^{13}$	

Energy production per capita for some selected countries in 2005. Unit: MWh/year

(Global average 20 MWh/year)

Global total 133 PWhg

US (Canada)	92 (98)
China (Chinese Taipei)	15 (54)
Sweden	67
Norway (Iceland)	81 **(143)**
Singapore	81
Eritrea	**2**

Content of my talk

- The production and use of energy in the world
- What are the sources?
- What are the prospects for regenerative energies?
- What are the prospects for nuclear energy?
- How long will the fossil fuel last?
- What options do we have. What are the consequences for climate?

What are the energy sources?

- A. Residuals of solar radiation
- Fossil fuels: peat, coal, oil, natural gas
- Non-fossil fuel: direct solar radiation, wind, hydro energy, biomass, tidal effects

- B. Residuals of nuclear radiation
- Geothermal energy
- Radioactive material uranium, thorium etc.

Definition of some energy units

- 1 Petawatthour (PWh) = 3.6 Exajoule
- 1 Mtoe = 11.63 TWh
- 1 barrel = 159 liters
- Exa = 10**18, Peta = 10**15, Tera= 10**12

Energy production in 1973 (left) and 2005(right)

- **Total 71 PWh**

- Fossil 87%
- Nuclear 1%
- Hydro 2%
- Combustion, waste 11%

- Others, wind solar etc.) 0.1%

- **Total 133 PWh**

- Fossil 81%
- Nuclear 6%
- Hydro 2%
- Combustion, waste 10%

- Others 0.5%

The production and use of energy in the world

- Information mainly from International Energy Agency (Key world energy statistics, 2007). Free download.
- TPES: Total production of primary energy
- TFC: Total final consumption

Global energy use in 2002 and the percentage change between 1973 and 2002. **TPES** is the production of primary energy and **TFC** the total final consumption

TPES in Twh		%
Coal	27924	60
Oil	43217	31
Gas	25272	222
Nuclear	8071	1369
Hydro	2605	204
Combustion	13002	66
Other	605	867
Sum	120696	69

Encrgy Transfcr
Conversion Losses
• Oil-Petrol
• Generation of Electricity
• Internal Use

of Which

Electricity	%
13.3%	
16054 Twh	259

TFC in Twh		%
Industry	= 26074	36
Transport	= 21364	90
Other Sections	= 32727	99
Non Encrgy Usc	= 2338	43
Sum	= 82503	54

of Which

Industry	= 6662	210
Transport	= 289	95
Othcrs	= 9103	318

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The following is required to produce 1 PWh
(Norway produced in 2005 2.72(0.43) PWh)

- **90** Mton oil
- **140** Mton coal
- **95** Gm**3 natural gas

- **9000 km**2** solar panels (rad. cond. typical of US)
- **150 000** wind generators (3MW capacity, 25%)
- **330 Mton** biomass (ca 40% water content)(0.5-1.5K/m**2, larger figure requires supply of reactive N)

- **6 Kton** natural uranium (0.7% enrichment)

Energy production per capita for some selected countries. Unit: MWh/year
(Global average 20 MWh/year)

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Regenerative energy sources
Solar energy

- Direct solar energy (electricity generation using photovoltaic solar cells) have conversion efficiency 10-20% (Weisz, 2004).

- Considering energy losses in transformers, power-equalization over time and efficiency losses for conversion or transmission would require and area of 9000 km^2 to generate 1 PWh/year using radiation conditions typical of US.

Regenerative energy sources
Biomass-energy

- 60 Gton carbon is produced annually of which some 25% may be in a form suitable for energy production.

- Modern agriculture can generate 1-1.5 $Kton/km^2$ but will require supply of reactive nitrogen. More realistic figure is 0.5 $Kton/km^2$.
- 1 PWh will thus require 7-800 000 km^2

- Assuming that 25% of the vegetated land area of 80 Mkm^2 can be used then a primary production of 25 PWh/year could be achieved

- Present global use together with waste (fossil fuel derivatives) amounts to some 13PWh

Regenerative energy sources
Wind energy

- The atmosphere is a very inefficient “engine” and only some 1% is converted to work (wind). Average energy density is 3W/m^2.
- Modern wind turbines can produce about 800KWh/m^2/year in good locations (Hill, 2002).
- Scaling this up means that we need 150 000 wind generators of 3MW capacity to generate 1 PWh/year electric energy
- Transition of energy into hydrogen gas or transmission losses may well double this figure
- Special problems are related to the large variability in production due to the weather.
- Present projections indicate a contribution of some 2 PWh at 2030.

Regenerative energy sources
Hydro energy

- Hydro-electricity provides presently 2.7 PWh/year or some 2% of the total energy (but some 16% of the electricity).

- Hydro electricity is totally limited and even the use of every drop of rain falling on land is actually less that the present TPES! (first calculated by H Hertz in 1885)

- Optimum extraction is probably at most 6-8 PWh/year

Regenerative energy sources
Additional sources

- **Tidal energy**
- It is estimate that 3000 GW is available but only some 2% (60 GW or 0.125TWh/year) can potentially be recovered from the tides.
- Total contribution is insignificant

- **Geothermal energy**
- Here there are huge potential possibilities but large practical problems as very high investments are needed to explore the heat at great depth.

- Present projections until 2030 will hardly come above 1 PWh/year

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What are the prospects for nuclear energy?

- Fission energy
- Do we have sufficient uranium and thorium
- Breeder reactors
- New types of nuclear power stations
- Fusion energy

Is there enough of fission fuel?

- There are presently **439** operational reactors in the world (2006-07) in 31 countries.
- **115** are planned or under construction and **223** are proposed
- Most reactors are using fuel from the U235 isotope.
- Available resources (less than $260/kgU amounts to 17Mton with an approximative energy content of 2750 PWh (equivalent to 400Gton coal) (Bodansky , 2004).
- It is expected that uranium ore costing more that $260 is much more abundant.
- Uranium ore in sea water can also be used.
- Cost of uranium ore in a minor component in energy production.

What other possibilities exist?

- Using thorium. This is about twice as abundant as uranium

- Using breeder reactors. This can increase the use of fuel by a factor of **50x or more**. Breeder reactors have been plagued by complex technical difficulties but advanced work is going on in several countries.

Mitsubishi to develop Japan's next fast breeder reactor
18 April 2007

The Japanese government has selected Mitsubishi Heavy Industries (MHI) as the core company to develop a new generation of fast breeder reactors, in an initiative promoted by the Japan Atomic Energy Agency (JAEA).

Concept of commercial FBR (sodium-cooled loop type) (Image: MHI)
The government bodies involved - the Ministry of Education, Culture, Sports, Science & Technology, and the Ministry of Economy, Trade and Industry, together with the Federation of Electric Power Companies of Japan and the JAEA - opted to concentrate responsibility and authority for fast breeder reactor (FBR) development into one core company, possessing "technological development capabilities and tangible achievements in this area."

Unlike most of the reactors used today for nuclear power generation, FBRs make maximum use of uranium resources by generating more fuel than they consume. They do this by using fast neutrons to "burn up" uranium and plutonium mixed oxide (MOX) fuel, which can be surrounded a uranium "blanket" in which slightly more plutonium is created than is used. The MOX fuel uses the plutonium recovered when spent fuel, including that from conventional light water reactors, is reprocessed.

Recycling plutonium could potentially provide a long-term stable energy supply, and the Japanese government sees the FBR as the main nuclear power generation system for the 21st century, superseding light-water reactors. Japan already has experience with fast reactors, with the Joyo prototype reactor, operating since 1977, and the Monju prototype FBR which started up in 1994. Monju has been off line since a sodium leakage in 1995 but it is slated for restart, possibly in 2008.

MHI has been actively engaged in FBR development since the 1960s. The company plans to establish a new unit by March 2008 to orchestrate engineering activities and carry out development, looking towards construction of a demonstration FBR by 2025 and a commercial reactor for introduction by 2050. The government has allocated 13 billion yen ($109 million) for development of the next generation reactor over the next year.

Further information

Mitsubishi Heavy Industries

Japan Atomic Energy Agency

WNA's Nuclear power in Japan information paper
WNA's Fast neutron reactors information paper

What are the prospects for fusion energy?

- This work is progressing but presently difficult to say whether it will lead to practical solutions or how long time this will take.
- An experimental reactor by the international ITER consortium will be constructed at Cadarache in France.
- Present plans call for an reactor to produce 500MW in 2016.

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Fossil energy
Oil projections

- 2006: **4076 Mton,** estimated increase 2030: **5800 Mton**
- Long term trend 0.9%/year but increasing in recent years
- Estimated reserves 150 Gton but could be twice as much
- Reserves may last **30-60** years but probably not much longer
- Total energy content: > 1700 PWh

Fossil energy
Natural gas projections

- 2006: 2977Gm^3, estimated for 2030: 5800 Gm^3
- Present increase 2.5%/year

- Estimated reserves 155-175 Tm^3 but could be larger by a factor of two.

- Reserves may last 10-15 years longer than for oil

- Total energy content: > 1250 PWh

Fossil energy
Coal projections

- 2006: **5370** Mton estimated for 2030: **7000** Mton but probably underestimated as previous projections were much lower
- Recent increase very rapid and has gone up by **33%** during the last 4 years
- Proven reserves of anthracite and lignite are estimated to 1000 Gton but additional fossil residuals exist as oil shale and bitumen.

- Total energy content: > 7100 PWh

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Fossil fuel contribution to CO_2 emission in 2005. Total emission 27.1 Gton

As coal again is increasing the CO2 will go up faster

	Contribution to TPES In %	CO2 emission In %
Oil	35	39.5 (1.13)
Gas	20.7	19.7 (0.95)
Coal	25.3	40.5 (1,60)

Annual CO_2 emission in Mton

Country	2002	2005	Increase	Est 2007
China	3271	5060	+54.7%	6250
US	5652	5817	+2.9%	5930
Sweden	50.12	50.95	+1.7%	51.5
Norway	33.06	37.00	+11.9%	38.7

Table 1. Expressions for Calculating Radiative Forcing*

Trace Gas	Simplified Expression Radiative Forcing, ΔF (Wm^{-2})	Constant
CO_2	$\Delta F = \alpha \ln(C/C_o)$	$\alpha = 5.35$
CH_4	$\Delta F = \beta(M^{½} - M_o^{½}) - [f(M,N_o) - f(M_o,N_o)]$	$\beta = 0.036$
N_2O	$\Delta F = \varepsilon(N^{½} - N_o^{½}) - [f(M_o,N) - f(M_o,N_o)]$	$\varepsilon = 0.12$
CFC-11	$\Delta F = \lambda(X - X_o)$	$\lambda = 0.25$
CFC-12	$\Delta F = \omega(X - X_o)$	$\omega = 0.32$

*IPCC (2001)

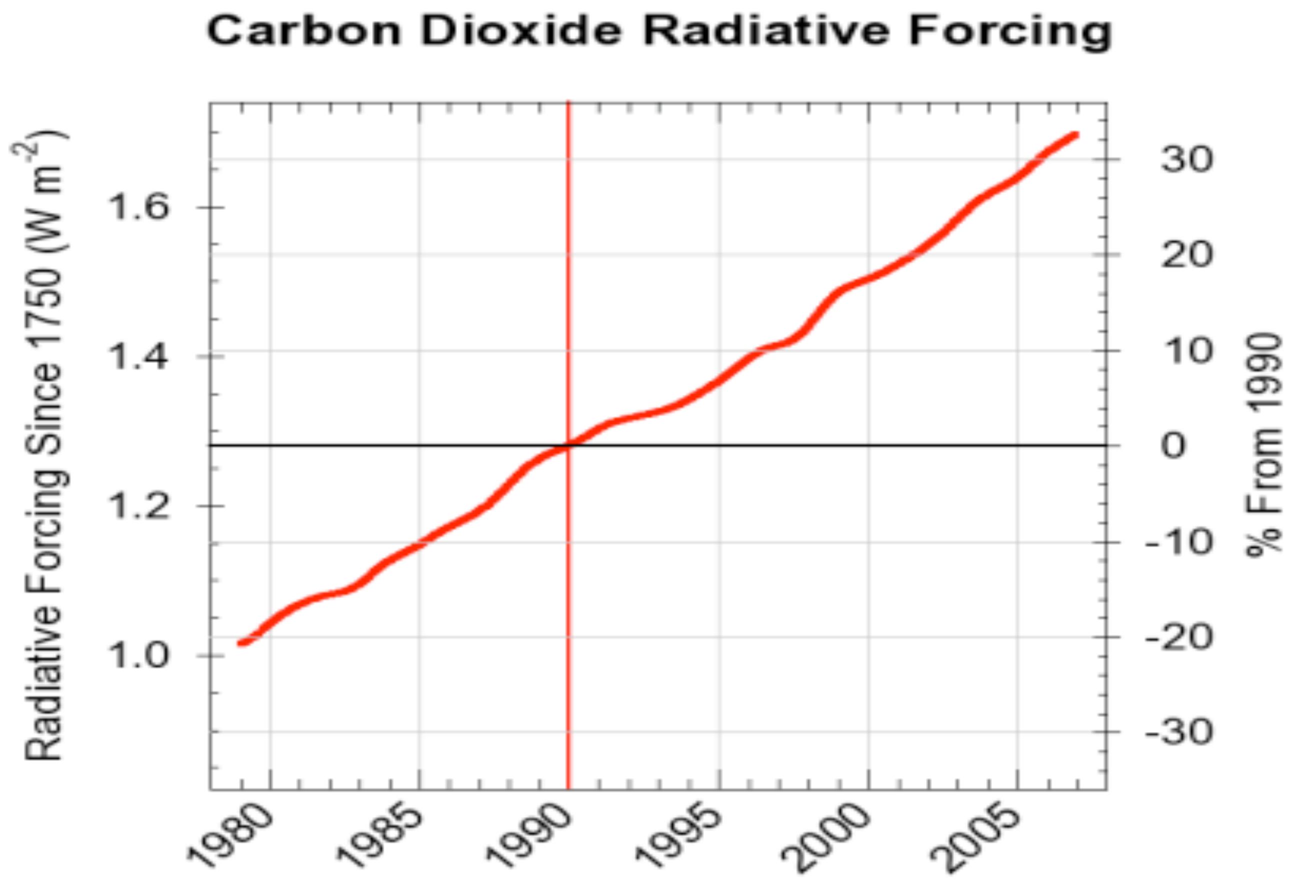
The subscript "o" denotes the unperturbed (1750) concentration

$f(M,N) = 0.47\ln[1 + 2.01\times10^{-5} (MN)^{0.75} + 5.31\times10^{-15}M(MN)^{1.52}]$

C is CO_2 in ppm, M is CH_4 in ppb

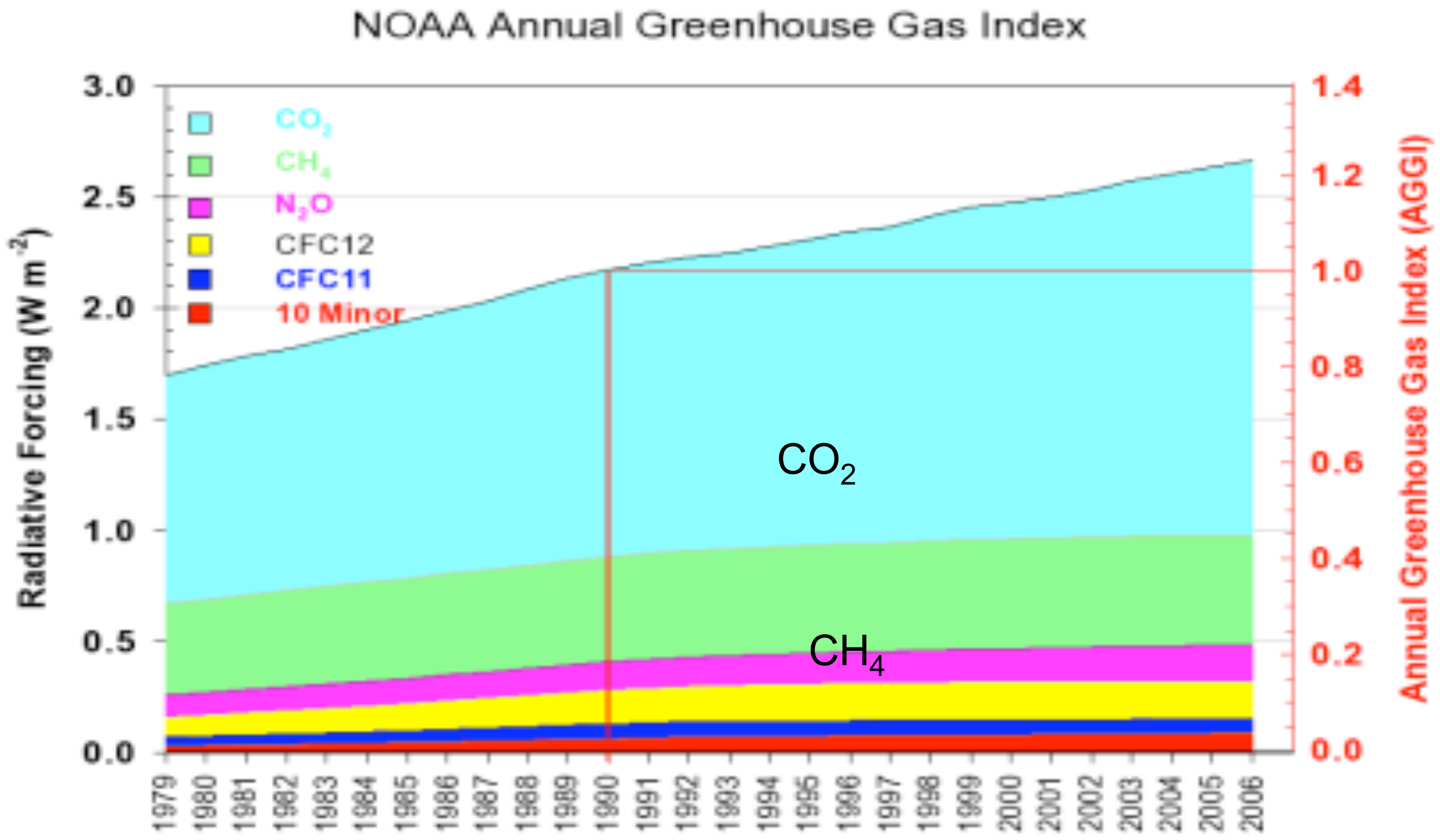
N is N_2O in ppb, X is CFC in ppb

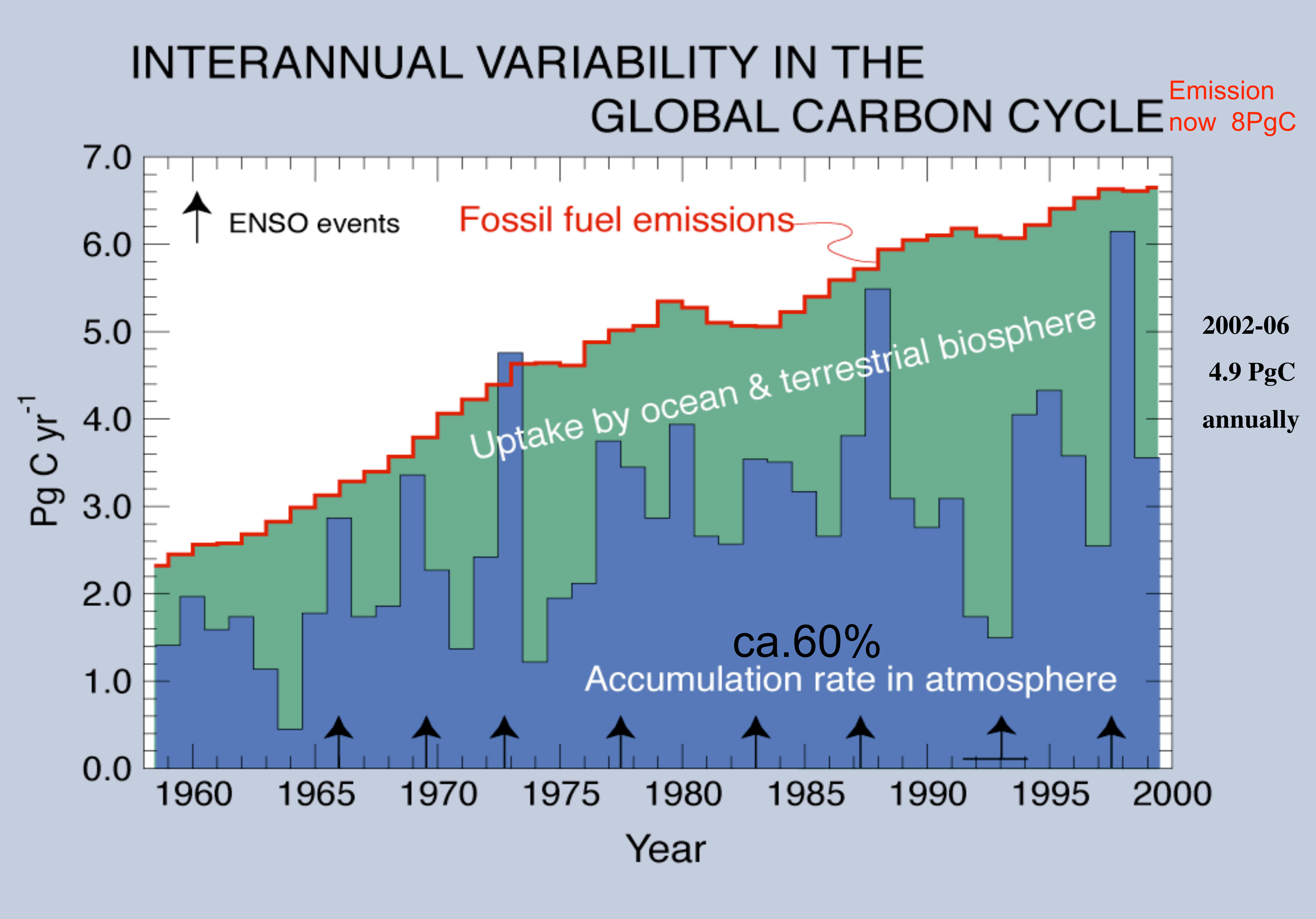
$C_o = 278$ ppm, $M_o = 700$ ppb, $N_o = 270$ ppb, $X_o = 0$



Carbon Dioxide Radiative Forcing
Radiative Forcing Since 1750 (W m-2)
1.6
1.4
1.2
1.0
30
20
10
0
-10
-20
-30
% From 1990
1980
1985
1990
1995
2000
2005

Change in radiative forcing in W/m^2
(Reduced outgoing radiation)
1979 to 2006




INTERANNUAL VARIABILITY IN THE
GLOBAL CARBON CYCLE
Emission
now 8PgC
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Pg C yr-1
ENSO events
Fossil fuel emissions
Uptake by ocean & terrestrial biosphere
ca.60%
Accumulation rate in atmosphere
1960
1965
1970
1975
1980
1985
1990
1995
2000
Year
2002-06
4.9 PgC
annually

Emission of CO_2

- Using the IEA's energy projections the the total CO_2 emission for the period 2005 to 2030 will amount to 800-1000 Gton.
- Assuming that some 60% will remain in the atmosphere we may expect that the total concentration of CO_2 will reach a value between 450 and 500 ppm at 2030.
- Because of the inertia in the global energy system and the lack of realistic and politically acceptable alternatives this is probably unavoidable.

Conclusions 1

- Energy production and consumption has over the last 32 years broadly followed the population growth.
- Over the last years there is indication of a trend change as it is now increasing faster than the population growth. (10% increase between 2002 and 2005). This is presumably the effect of globalization.
- In recent years there has also been a very rapid increase in the use of coal leading to a more rapid emission of CO_2
- A global warming including the thermal inertia of the oceans of some 2C around 2050 is probably unavoidable.
- The proportion of fossil fuel is still over 80%. The slight proportional decrease is due to increase in nuclear energy.
- Contribution from regenerative sources is insignificant except biomass and waste (only partly regenerative).

Conclusions 2

- Regenerative or so called sustainable energy resources are fully insufficient to solve the energy problem of the Earth.
- The political establishment in many western countries appear incapable to realize the magnitude of the problem.
- One example: a 10% reduction in CO_2 emission in Sweden, which could be feasible following major efforts and considerable investments would be nullified by 3 days of present increasing emission in China!

Conclusion 3

- **Where are the limits?**
- To provide decent living conditions as we now have in the industrial world would probably require say 50 MWh/year/person.
- All functioning societies are expected to give priority to this
- In 2050 with 9 Gpeople this would mean an annual energy production of **450 PWh** or more than 3 times the present.

- **How can this be produced?**
- **What will be the consequences if we fail to deliver?**
- **What will be the environmental consequences?**

Conclusion 4

- **What will happen if we fail?**

- Fossil fuel is likely to be insufficient or prohibitively expensive around 2050.
- This is likely to generate severe political and military tensions
- Lack of energy will probably be considered as more severe than the environmental consequences (more affluent societies may here have a different view)
- The inherent global limitation of regenerative energies is a serious problem. To believe that they should satisfy the energy needs is to follow a dangerous blind alley

Conclusion 5

- What needs to be done

- I believe serious efforts must be invested to explore the development of nuclear energy for energy production.
- This must include a major effort to inform and educate the public and to increase scientific knowledge on all levels in society.
- To enhance research on fusion energy.
- Here we need a Manhattan type project.

END

Thanks for your attention

I invite you for Questions