2. Carbon Cycle

One of the main reasons for an assumed future CO_2 disaster has been IPCC's assumption that this greenhouse gas is accumulating in the atmosphere – leading to the frequently repeated 60% Toronto reduction demand.

But it is known that the oceans contain about 50 times more carbon than the atmosphere, but may dynamically take up only about 6 times more CO_2 at equilibrium. The photosynthesis of land biota may increase by up to 18 Gt C/yr for a concentration doubling, i.e. three times today's fossil emission. At present, the oceans are still mostly on a pre-industrial level.

The IPCC's accumulation hypothesis needs to be firmly contradicted. Supposed we pour water into a bucket that has a hole. Nobody will state from observation that "about half accumulates in the bucket". This fully depends on the hole, the water level and how much water we are pouring.

The problem is easily solved when the global carbon cycle is understood as a dynamic system in the manner of control engineering. The atmosphere has a CO_2 decay function with a half-life time of about 38 years as will be shown in the following. If the input function is doubling within the same time span the system response would simply be a linear concentration increase. The increase was misunderstood by IPCC as a nearly irreversible accumulation – one reason that led to hasty conclusions for negotiating an unnecessary global reduction treaty.

A simple waterbox model can be used to explain the atmospheric CO_2 excess lifetime and to find a plausible value (Fig. 2.1). The atmosphere is represented by a waterbox, filled up to a level of 350 ppm (in 1988) with 743 Gt carbon (2724 Gt CO_2). This box is placed in a larger waterbox, representing the ocean.

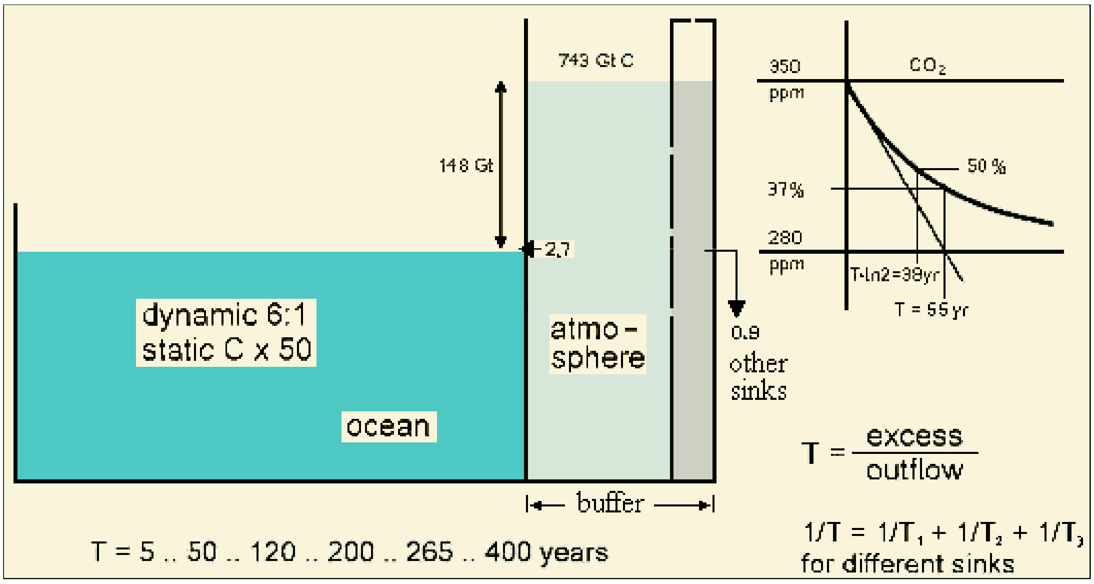


Fig. 2.1: Waterbox model for the excess CO_2 lifetime

The atmosphere box has an outlet, releasing about 2.7 GtC/yr into the ocean. The level decreases according to an e-function if we postulate the transition flow is roughly proportional to the water level difference or pressure. The lifetime T can be defined as the time lapse until the level goes down to 1/e (37%) against the equilibrium. The value for T can be calculated dividing the amount of present excess by the present outflow, yielding 55 years:

$$T = (148\ \mathrm{Gt} + 33\%) / (2.7\ \mathrm{Gt/yr} + 33\%) = 55\ \mathrm{yr}$$

The 33% stands approximately for extra-atmospheric buffers (fast rotting biomass, surface water and soil moisture) and extra-oceanic sinks (e.g. trees, polar ice) respectively. For the time interval considered, the small ocean response and the long time for distribution can be neglected.

Multiplication of T by ln(2) yields a **half-life time of about 38 years**. So any CO_2 impulse injected into the atmosphere will take about 38 years to be reduced to half the original value – the contribution to the increment in atmospheric CO_2 concentration being considered. If we consider the individual CO_2 molecules of the injected fossil impulse, half of them would already disappear within 3 years as the turnover time (the time natural fluxes take to exchange the atmospheric CO_2 content) is about 6 years. Btw the latter is clearly proved by the fact that carbon isotope measurements show that the present atmospheric fraction of fossil CO_2 is not 30 % but only 4-5 %. This fact, yet not being admitted by IPCC **[isotopes discussed in SAR p. 78f]**, indicates that the atmospheric CO_2 has been mixing during the last century with reservoirs that are about 5-6 times larger and thus the content of fossil CO_2 has been thinned out.

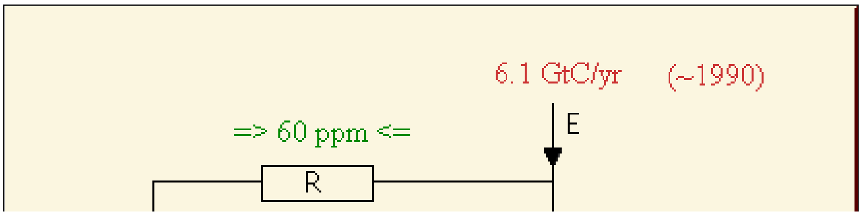
Lacking a proper carbon model and ignoring the fact that the CO_2 lifetime is closely related to sink flows, greenhouse scientists have arbitrarily manipulated this key parameter in the past, stating that no definite value exists or can be defined. The IPCC SAR said it is "variable" and IPCC used a nonlinear CO_2 impulse response function **[figure in SAR on p. 86]** for the convolution integral, which is not permissible. In Fig. 2.1, some of the CO_2 lifetime values are shown that have been used. In 1987 the e-fold time was assumed to be 400 years in Germany *(e.g. H. Grassl, E. Maier-Reimer, W. Bach)*. In 1989 *Grassl* published 100 years and by 1995 it was 50 to 200 years. Though the IPCC mentioned 100 and 120 years, their scenarios mostly used about 360 years for stabilization. At the very low end of reported CO_2 lifetimes we sometimes find a value of about 5 years, which is not the lifetime, but the turnover time.

H. Grassl stated, a single lifetime value cannot be defined because of different sinks. This doesn't hold up. Suppose, the atmosphere box in Fig. 2.1 has three different outlets representing small, medium and large lifetimes. The resulting value is equal to the sum of stored carbon excess, divided by the sum of sink flows. So the resulting lifetime for parallel sinks is

$$T = 1 / (1/T_1 + 1/T_2 + 1/T_3)$$

IPCC's 120 years had been erroneously derived from an arithmetic mean of different sinks of the Bern model. But the smallest T (largest sink) is leading and a small additional sink flow (large T) which would considerably increase the mean value of T, is indeed decreasing the resulting lifetime.

IPCC's eddy diffusion ocean model (*H. Oeschger, U. Siegenthaler, F. Joos, J. Sarmiento*) is illogical in assuming that a part of a CO_2 impulse will be absorbed straight away, another part fast at the beginning and then slowing considerably (at the end e.g. to 360 years) and the rest, about 16%, to remain forever in the air. CO_2 impulses are continuously injected into the atmosphere and nature should treat them all equally as it cannot distinguish between 'old' CO_2 to be absorbed slowly and 'new' CO_2 to be absorbed fast. Thus the half-life time of 38 years has to be considered as an operational overall value from observed sink flows at present conditions, assuming the reservoirs are big enough and the system behaves in a roughly linear/proportional manner within the operating regime.



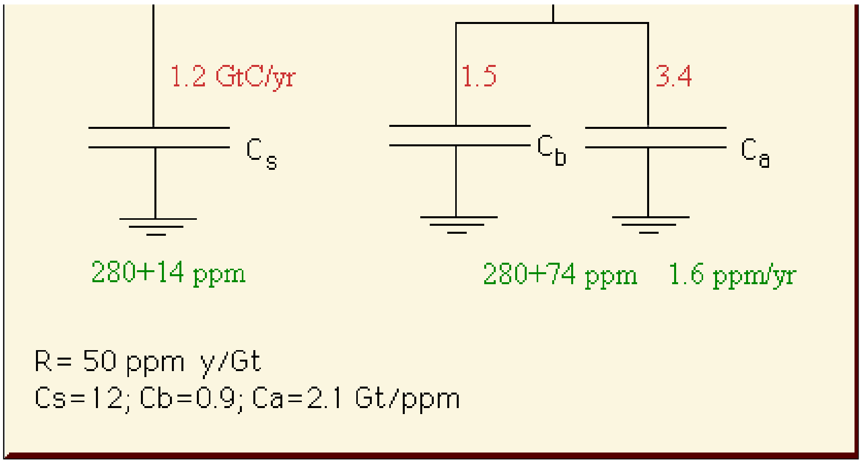


Fig. 2.2: Electrical dynamic CO_2 model scheme (*J. Goudriaan* 1999 at daly/co2debat.htm) explaining a 150 yr lifetime. Capacitors are C_s: sinks, C_a: atmosphere and C_b: buffer

A simplified linear carbon model scheme has been presented by *J. Goudriaan* as an electrical circuit (Fig. 2.2). It helps to explain essential flaws in IPCC's carbon model parameters, e.g. a CO_2 lifetime of 150 yr and unduely coping with the fossil emissions part only. If we consider C_s rather as infinite and add up the buffer C_b and atmosphere C_a as C, we get the CO_2 lifetime as **T = R*C = 50 ppm/Gt * yr * (2.1+0.9) Gt/ppm = 150 yr**. One reason for this high value: the buffer is quite large (43% of the atmosphere). So 30% of the (fossil only) emission, i.e. 1.5 GtC/yr, disappears straight away into the buffer, erroneously considered as to be a sink. So the remaining sink flow becomes 1.2 GtC/yr only instead of the 3.6 what it really should be (see Fig. 2.1). 1.2 GtC/yr is indeed far too small for the ocean and biomass together. This is why the modelled CO_2 lifetime T is nearly trebled.

To develop a realistic dynamic global Carbon Cycle Model, the waterbox model was extended, Fig. 2.3 showing the transient state in 1988 containing no missing sinks. Net photosynthesis of land biota amounts to about 60 Gt C/yr, marine photosynthesis is roughly 20 Gt C/yr. The three upper boxes represent the land biota (650 Gt C), the atmosphere (743 Gt C) and the mixed ocean layer (800 Gt C) which is closely coupled with the atmosphere by precipitation and gas diffusion and exchanging about 100 Gt C/yr with the atmosphere. In high latitudes the icy cold salt water absorbs large amounts of CO_2 . This makes the essential part of the net uptake (eddy diffusion as with IPCC is indeed a minor part), the CO_2 being taken into the deep sea and mixing via the conveyor belt into all oceans. The central link is the Antarctic Circumpolar Current. In warm upwelling regions, especially where off-land trade winds are pulling up cold deep sea water, we observe an outgassing of uptaken CO_2 – the time delay being about 400 to 1000 years.

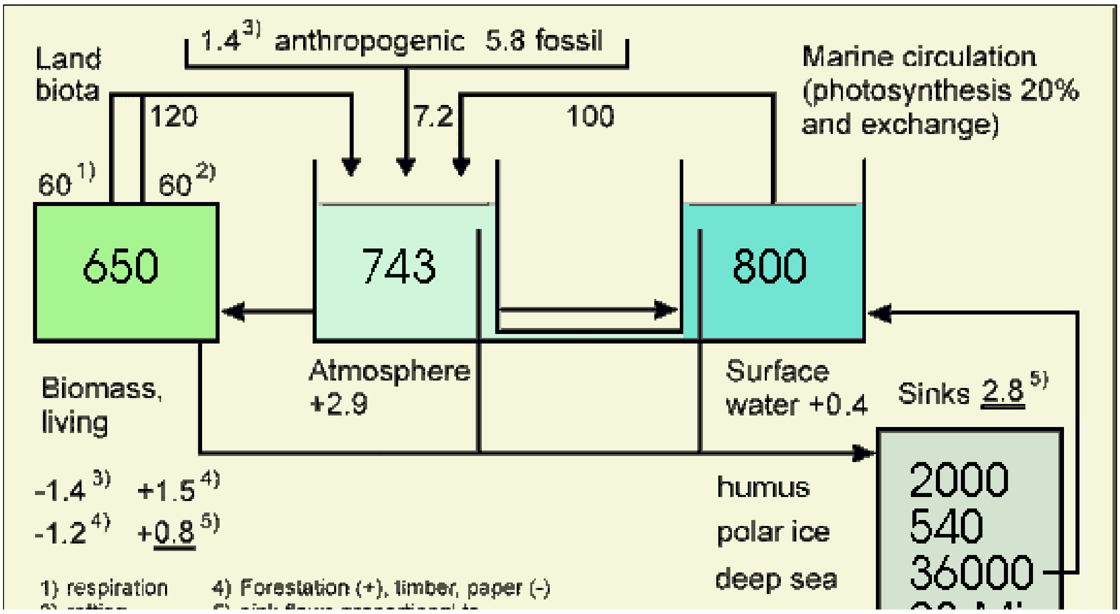


Fig. 2.3: Extended waterbox model with proportional sink flows (numbers in GtC and GtC/yr for 1988)

Our sink flow approach does not use IPCC's unrealistic eddy diffusion model which leads to extremely small future uptake but we use the basic diffusional mass transfer theory that can easily be quantified by numerical-statistical treatment of well-known recent data (compare the carbon model of Jarl Ahlbeck). Given a high exchange rate with big reservoirs, 95 % of the sink flows from anthropogenic perturbation (so *Ahlbeck*) tend to be proportional to the concentration increment against the equilibrium state. For the system's differential equation (box), being linearized around the present operating regime, the concentration increment in ppm can be calculated with a convolution integral for the system being subjected to an arbitrary total emission E(t) given in GtC/yr.

$$\boxed{dC/dt = E - C/T} \qquad \Delta p = 0.354 \int_0^t E(\tau)\, G(t-\tau)\, d\tau \qquad G = e^{-t/T}$$

Here 0.354 = 1/(2.123*1.33) is the conversion factor from GtC to ppm. For each 100 ppm the total buffer excess C is 100/0.354 = 282 GtC, 212 GtC hereof being buffered in the atmosphere and 70 GtC in surface water, soil moisture and fast-rotting biomass. We will first consider a constant emission scenario to demonstrate the model characteristics. For this case we get **Dp = 0.354 E*T*(1-e$^{-t/T}$) ppm**. Setting the total emission to be E=7 Gt/yr and T=55 yr, the concentration will increase by 136 ppm for large t (Fig. 2.4).

The emission and concentration start with the preindustrial equilibrium to perform a clean cold-start. To match the actual concentration of 350 ppm in 1988 (with a sink flow of 3.6 Gt), the constant emission of 7 GtC/yr is started here in 1948. The concentration increases according to curve (a) as an e-function with a T value of 55 years. The right hand vertical axis shows the model's proportional sink flow reaching 7 Gt at a maximum concentration of no more than 416 ppm.

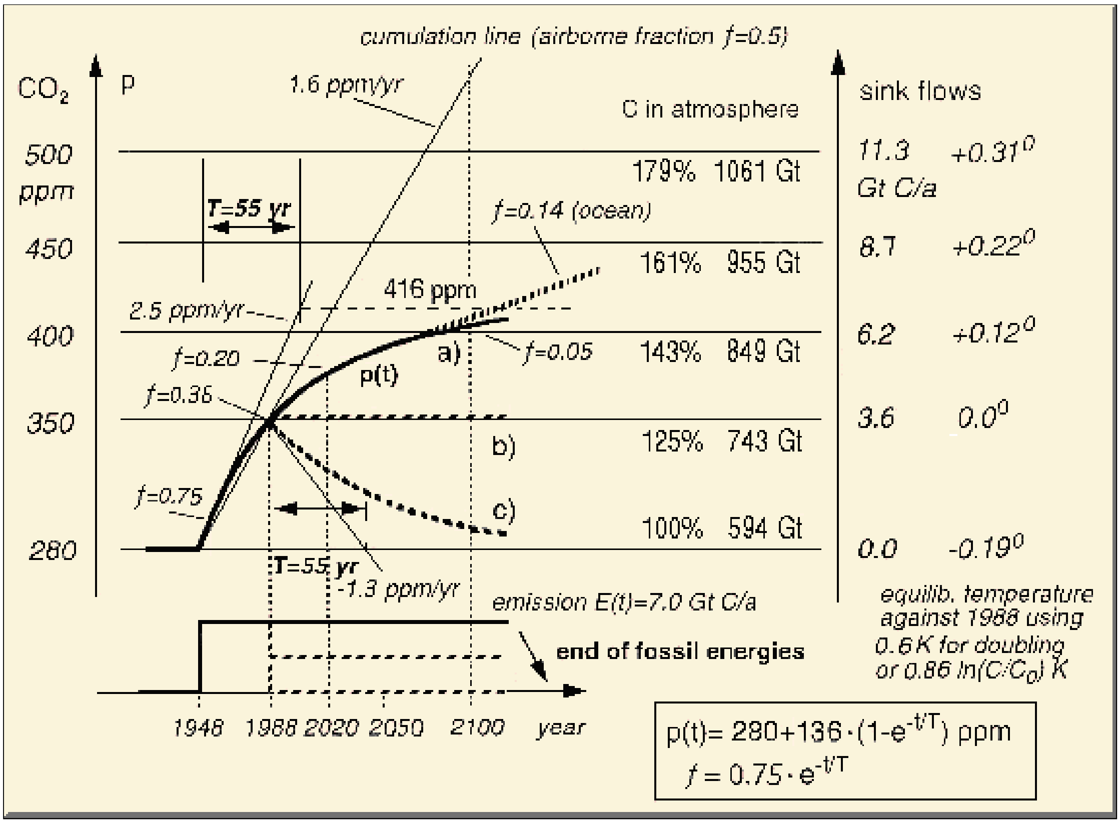


Fig. 2.4: Concentration response and equilibrium temperature for

a) constant emission, b) after reduction to 50% in 1988 and c) after stopping emission

At the start the airborne fraction is 75%, which soon reduces to 36% in 1988 and to 20% in 2020. The temperature scale shows an equilibrium increment of only 0.32 K till yr 2100. After 1988 it is merely 0.15 °C which shows that reduction claims are indeed unnecessary. Here the equilibrium temperature increment is based on a (logarithmic) doubling sensitivity of 0.6 K, i.e. a quarter of IPCC's.

The dashed line at the upper part of curve (a) is a hypothetical ocean equilibrium reaction for ideal mixing after taking up nearly six times more CO_2 than the atmosphere, caused by the Revelle buffer factor (50/9 = 5.6). But in fact this ocean response can be neglected as it will be mostly delayed by several hundred years. The straight cumulation line shows how the IPCC airborne fraction of about 50% would yield an increase up to 530 ppm – an 80 % higher increment than in reality. IPCC actually assumes about 500 ppm for this case.

Fig. 2.4 presents two further scenarios. Curve (b) shows the response after reduction to 50 % emission beyond 1988. As this amount equals the actual sink flows, concentration and temperature remain quite constant. The increment from start is then only 0.2 K and not 2 K (!) as has been assumed in early IPCC scenarios even claiming a reduction by 60% until 2050, and as formerly documented in the Greenpeace Report **[*J. Legget* (edt.), Oxford Univ. Press NY (1990)]**. Curve (c) shows a hypothetical stop of emissions in 1988. The concentration decays according to the e-fold lifetime of 55 years, the oceans and biomass absorbing most of the CO_2 excess within 120 years.

Discussing the effect of a carbon and energy tax in Europe, an emission reduction of 4 to 5% has been estimated – this means 0.7% worldwide. The EU contribution for temperature reduction would be **0.7% of 0.32 = 0.002 °C only**. But the projected taxation would be about US$ 660 billion within 12 years. This seems absurd as the effect is absolutely unnoticible.

According to a suggestion of *J. Goudriaan* a numerical model test for total emissions during the industrialization era till 1995 was carried out, using CDIAC data after 1970. In Fig. 2.5 the convolution integral was sequentially solved by Excel in 5 yr interval steps and a good replication of the Mauna Loa curve was obtained – i.e. a concentration of 368 ppm for the interval around yr 2000.

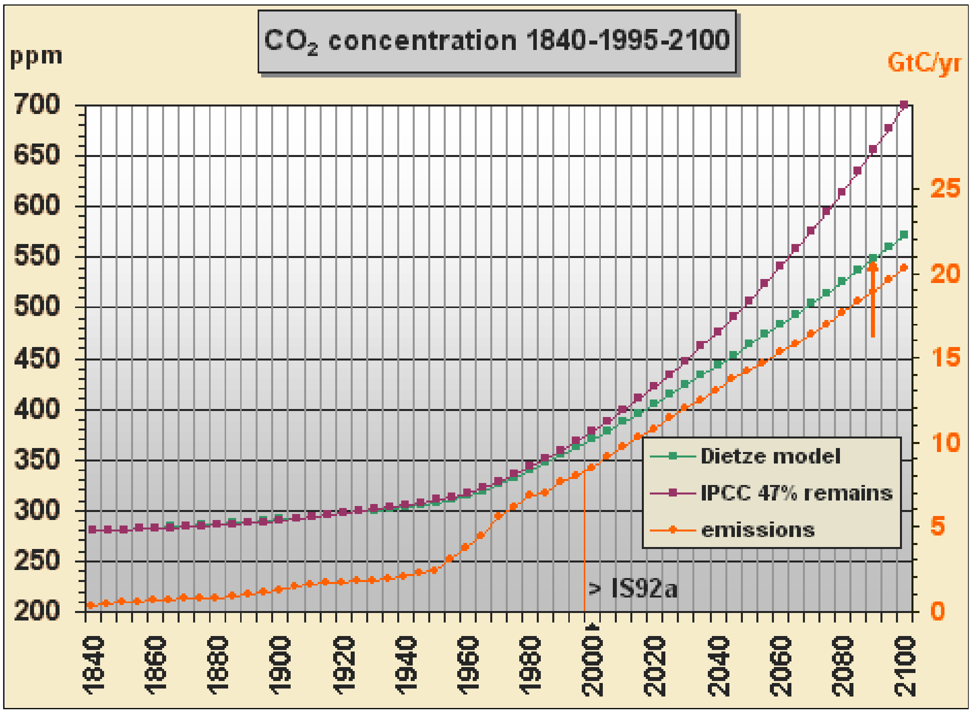


Fig. 2.5: Model test with total emissions until 1995 and further acc. to IS92a

After 1995 emissions were applied according to the *business as usual* scenario IS92a with piecewise linear increments up to 20.3 GtC/yr in 2100. The concentration increases rather linear to only 571 ppm whereas IPCC's climbs to 700 ppm in yr 2100. The IPCC curve (being parabolic) has been approximated here by simply using a 47% airborne fraction.

Our model properly reproduces the observed rather linear CO_2 increment in spite of a linear increase of emission – which (according to IPCC's flawed accumulation hypothesis) should result in a quadratic or exponential increment. Most interesting is the behaviour of the airborne fraction f, here being defined as the ratio of the atmospheric increment and the total emission (i.e. not only fossil). At the beginning f is 1/1.33 = 75 % (see Fig. 2.1). For 1995 f is reduced to 35.3 % and in 2100 f becomes 19.8 %. IPCC models mostly yield an airborne fraction of roughly 50 % that results in a far too high future CO_2 concentration – for yr 2100 the increment is 50 % too high with IS92a.

IPCC mostly uses an exponential increment of 1 %/yr for modelling i.e. doubling of forcing occurs within 70 yr, though the TAR Technical summary (on p. 12) says that the presently observed rate of CO_2 increment is 0.4 %. For IS92a IPCC's CO_2 increment is 0.62 %/yr. How unrealistic a 1 %/yr CO_2 increment is, can be demonstrated as follows: With our model airborne fraction being 35 % in 1998, a total emission of 22 GtC/yr would be required for a 1 % increment, whereas it was actually only about 8.3 GtC. Debating the 1 %/yr assumption with *David Schimel* per email, he emphasized that IPCC only carries out case studies, mostly to test their models. The consequence is that **IPCC results cannot be interpreted as to be realistic future projections and thus should not be (mis)used for political decisions**.

The *usable* fossil fuels (secured coal reserves, 4-fold gas and 3-fold oil being assumed because of exploration and improved extraction) are estimated to be about 1300 GtC. With IS92a, this amount will be depleted until 2090. The CO_2 concentration at that time **only reaches 548 ppm which is even less than doubling**. IPCC's CO_2 increment to 700 ppm is by a factor 1.6 higher. Then, taking about four times the realistic temperature sensitivity, **IPCC has boosted the yr 2100 climate impact by about a factor of 6**.

The 650, 750 and 1000 ppm WRE stabilization scenarios shown in Fig. 26 and 27 of the 2nd TAR draft, **are definitely infeasible**. Until yr 2300 WRE 1000 would require about 3300 GtC, i.e. 2.5 times more than available. IPCC obviously has only created new scenarios but neither changed their carbon modelling nor coped with limited fuel reserves. Their stabilization emission for 550 ppm remains 2 GtC/yr only (equal to the sink flow). As in our model the total CO_2 excess for atmosphere and buffer is 784 GtC, the sink flow acc. to the 1/e lifetime should be 784/55 = 14 (!) GtC/yr – **IPCC's is by a factor 7 smaller**.

See as well the papers Little Warming with new Global Carbon Cycle Model and discussion and the German paper Der Klima-Flop des IPCC.