Global Warming – numbers please!

Devabhaktuni Srikrishna
December 27, 2007
contact me at sri at devabhaktuni.us
http://www.devabhaktuni.us/research/GWN.pdf

Global Warming – numbers please!

- Is the globe warming? Yes
- Cause: the greenhouse effect
- IPCC Climate Change Prediction
  - +2-4 °C by 2100 assuming no limit on fossil fuel availability
- Rutledge Climate Change Prediction
  - +1.5 °C by 2100 with producer-limitations on fossil fuels
- The Global Carbon Budget
- Mitigation of greenhouse effect

Conclusions

- Rising levels of Carbon Dioxide (CO_2) in the atmosphere is the most significant contributor to global warming, surpassing all other greenhouse gasses combined.
- It will take near 100% elimination of CO_2 emissions to prevent further global warming. Even then, temperatures will rise for 100 years or more due to the long lifetime of CO_2.
- There is a debate on whether fossil fuel reserves are limited, and whether that will limit global warming to 1.5 degrees Celsius (Rutledge) or otherwise exceed 2-4 Celsius degrees (IPCC) in 100 years.
- No single industry is responsible for the bulk of CO_2 emissions, and a portfolio of solutions to eliminate greenhouse gas emissions are needed for
  - Power generation (26%)
  - Transportation (13%)
  - Industrial (19%)
  - Forestry (17%)
  - Agriculture (14%)
  - Buildings (8%)
- Within transportation, light duty vehicles like cars account for nearly half of all CO_2 emissions, followed by heavy duty trucks, and aviation.

Sources

- ***International Panel on Climate Change***
  - *IPCC, 2007: Climate Change 2007: The Physical Science Basis.*
    - *Frequently Asked Questions*
      http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-faqs.pdf
    - *Technical Summary*
      http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-ts.pdf
  - *IPCC, 2007: Climate Change 2007: Mitigation*
    - *Technical Summary*
      http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-ts.pdf
    - *Transport and its infrastructure*
      http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter5.pdf
    - *Energy Supply*
      http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter4.pdf
- ***David Rutledge, Caltech***
  - *"Hubbert's Peak: The Coal Question, and Climate Change"*
    http://www.its.caltech.edu/~rutledge/Hubbert's%20Peak,%20The%20Coal%20Question,%20and%20Climate%20Change.ppt
  - *"The Coal Question and Climate Change"*
    http://www.theoildrum.com/node/2697
- ***British Petroleum***
  - *BP Statistical Review of World Energy June 2007*
    http://www.bp.com/statisticalreview
    http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2007/STAGING/local_assets/downloads/spreadsheets/statistical_review_full_report_workbook_2007.xls

Global Warming – numbers please!

- Is the globe warming? Yes
- Cause: the greenhouse effect
- IPCC Climate Change Prediction
  - +2-4 °C by 2100 assuming no limit on fossil fuel availability
- Rutledge Climate Change Prediction
  - +1.5 °C by 2100 with producer-limitations on fossil fuels
- The Global Carbon Budget
- Mitigation of greenhouse effect

Is the globe warming? Yes

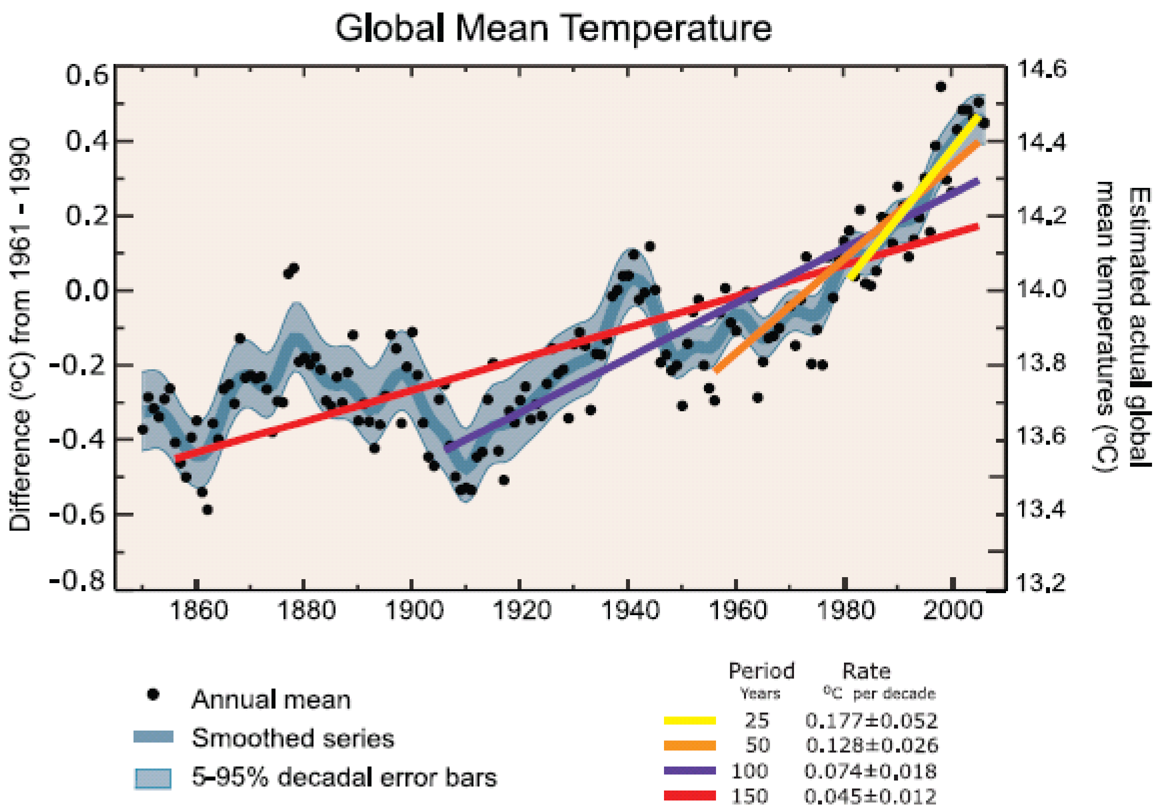
p. 103, FAQ

- Expressed as a global average, surface temperatures have increased by about 0.74°C over the past hundred years (between 1906 and 2005; see Figure 1). However, the warming has been neither steady nor the same in different seasons or in different locations. There was not much overall change from 1850 to about 1915, aside from ups and downs associated with natural variability but which may have also partly arisen from poor sampling. An increase (0.35°C) occurred in the global average temperature from the 1910s to the 1940s, followed by a slight cooling (0.1°C), and then a rapid warming (0.55°C) up to the end of 2006 (Figure 1). The warmest years of the series are 1998 and 2005 (which are statistically indistinguishable), and 11 of the 12 warmest years have occurred in the last 12 years (1995 to 2006).

Global average temperature has been increasing by 0.74°C for the last 100 years

Is the globe warming? Yes

p. 104, FAQ



The rate of global warming (degrees per year) has been rising through the 20th century

Is the globe warming? Yes

p. 114, FAQ

- A different matter is the current rate of warming. Are more rapid global climate changes recorded in proxy data? The largest temperature changes of the past million years are the glacial cycles, during which the global mean temperature changed by 4°C to 7°C between ice ages and warm interglacial periods (local changes were much larger, for example near the continental ice sheets). However, the data indicate that the global warming at the end of an ice age was a gradual process taking about 5,000 years (see Section 6.3). It is thus clear that the current rate of global climate change is much more rapid and very unusual in the context of past changes. The much-discussed abrupt climate shifts during glacial times (see Section 6.3) are not counter-examples, since they were probably due to changes in ocean heat transport, which would be unlikely to affect the global mean temperature.

The rate of global warming (degrees per year) has been faster in the last 100 years than anytime in the last 5000 years

Is the globe warming? Yes

p. 114, FAQ

- *Current global temperatures are warmer than they have ever been during at least the past five centuries, probably even for more than a millennium. If warming continues unabated, the resulting climate change within this century would be extremely unusual in geological terms. Another unusual aspect of recent climate change is its cause: past climate changes were natural in origin (see FAQ 6.1), whereas most of the warming of the past 50 years is attributable to human activities.*

Most of global warming has been attributable to human activities

Is the globe warming? Yes

p. 114, FAQ

- The main reason for the current concern about climate change is the rise in atmospheric carbon dioxide (CO_2) concentration (and some other greenhouse gases), which is very unusual for the Quaternary (about the last two million years). The concentration of CO_2 is now known accurately for the past 650,000 years from antarctic ice cores. During this time, CO_2 concentration varied between a low of 180 ppm during cold glacial times and a high of 300 ppm during warm interglacials. Over the past century, it rapidly increased well out of this range, and is now 379 ppm (see Chapter 2). For comparison, the approximately 80-ppm rise in CO_2 concentration at the end of the past ice ages generally took over 5,000 years. Higher values than at present have only occurred many millions of years ago (see FAQ 6.1).

The rise in atmospheric Carbon Dioxide (CO_2) accounts for most of global warming

Is the globe warming? Yes

p. 114, FAQ

- Further back in time, beyond ice core data, the time resolution of sediment cores and other archives does not resolve changes as rapid as the present warming. Hence, although large climate changes have occurred in the past, there is no evidence that these took place at a faster rate than present warming. If projections of approximately 5°C warming in this century (the upper end of the range) are realised, then the Earth will have experienced about the same amount of global mean warming as it did at the end of the last ice age; there is no evidence that this rate of possible future global change was matched by any comparable global temperature increase of the last 50 million years.

If the most extreme projections of 5 degrees for global warming in the 21st century come true, then this rate will have been unprecedented in the last 50 million years

Global Warming – numbers please!

- Is the globe warming? Yes
- Cause: the greenhouse effect
- IPCC Climate Change Prediction
  - +2-4 °C by 2100 assuming no limit on fossil fuel availability
- Rutledge Climate Change Prediction
  - +1.5 °C by 2100 with producer-limitations on fossil fuels
- The Global Carbon Budget
- Mitigation of greenhouse effect

Cause: the greenhouse effect

p. 94, FAQ

- The amount of energy reaching the top of Earth's atmosphere each second on a surface area of one square metre facing the Sun during daytime is about 1,370 Watts, and the amount of energy per square metre per second averaged over the entire planet is one-quarter of this (see Figure 1).
- About 30% of the sunlight that reaches the top of the atmosphere is reflected back to space.
- Roughly two-thirds of this reflectivity is due to clouds and small particles in the atmosphere known as 'aerosols'.
- Light-coloured areas of Earth's surface – mainly snow, ice and deserts – reflect the remaining one-third of the sunlight.

Sunlight arrives at the edge of the atmosphere at 1370 Watts per square meter

Cause: the greenhouse effect

p. 95, FAQ

- The energy that is not reflected back to space is absorbed by the Earth's surface and atmosphere. This amount is approximately 240 Watts per square metre (W m–2). To balance the incoming energy, the Earth itself must radiate, on average, the same amount of energy back to space.
- The Earth does this by emitting outgoing longwave radiation. Everything on Earth emits longwave radiation continuously. That is the heat energy one feels radiating out from a fire; the warmer an object, the more heat energy it radiates.

Sunlight is absorbed by the earth at the rate of 240 Watts per square meter

Cause: the greenhouse effect

p. 95, FAQ

- To emit 240 W m–2, a surface would have to have a temperature of around –19°C. This is much colder than the conditions that actually exist at the Earth's surface (the global mean surface temperature is about 14°C). Instead, the necessary –19°C is found at an altitude about 5 km above the surface.
- The reason the Earth's surface is this warm is the presence of greenhouse gases, which act as a partial blanket for the longwave radiation coming from the surface. This blanketing is known as the natural greenhouse effect. The most important greenhouse gases are water vapour and carbon dioxide. The two most abundant constituents of the atmosphere – nitrogen and oxygen – have no such effect.
- Clouds, on the other hand, do exert a blanketing effect similar to that of the greenhouse gases; however, this effect is offset by their reflectivity, such that on average, clouds tend to have a cooling effect on climate (although locally one can feel the warming effect: cloudy nights tend to remain warmer than clear nights because the clouds radiate longwave energy back down to the surface).

The earth's atmosphere traps some of the reradiated light/heat and keeps the surface warm. If there were no atmosphere, the earth's surface would re-emit the 240 Watts per square meter and the surface would be -19 degrees Celsius.
This is called the "greenhouse effect."

Cause: the greenhouse effect

p. 98, FAQ

- The two most abundant gases in the atmosphere, nitrogen (comprising 78% of the dry atmosphere) and oxygen (comprising 21%), exert almost no greenhouse effect. Instead, the greenhouse effect comes from molecules that are more complex and much less common. Water vapour is the most important greenhouse gas, and carbon dioxide (CO2) is the second-most important one. Methane, nitrous oxide, ozone and several other gases present in the atmosphere in small amounts also contribute to the greenhouse effect. In the humid equatorial regions, where there is so much water vapour in the air that the greenhouse effect is very large, adding a small additional amount of CO2 or water vapour has only a small direct impact on downward infrared radiation. However, in the cold, dry polar regions, the effect of a small increase in CO2 or water vapour is much greater. The same is true for the cold, dry upper atmosphere where a small increase in water vapour has a greater influence on the greenhouse effect than the same change in water vapour would have near the surface.

Nitrogen, Oxygen, contribute very little to the greenhouse effect.
Carbon dioxide (CO2), Methane, Nitrous Oxide, and others present in small amounts are most significant greenhouse gasses in the earth's atmosphere.

Cause: the greenhouse effect

p. 100, FAQ

- Human activities result in emissions of four principal greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and the halocarbons (a group of gases containing fluorine, chlorine and bromine). These gases accumulate in the atmosphere, causing concentrations to increase with time. Significant increases in all of these gases have occurred in the industrial era (see Figure 1). All of these increases are attributable to human activities.
- • Carbon dioxide has increased from fossil fuel use in transportation, building heating and cooling and the manufacture of cement and other goods. Deforestation releases CO_2 and reduces its uptake by plants. Carbon dioxide is also released in natural processes such as the decay of plant matter.
- • Methane has increased as a result of human activities related to agriculture, natural gas distribution and landfills. Methane is also released from natural processes that occur, for example, in wetlands. Methane concentrations are not currently increasing in the atmosphere because growth rates decreased over the last two decades.
- • Nitrous oxide is also emitted by human activities such as fertilizer use and fossil fuel burning. Natural processes in soils and the oceans also release N_2O.
- • Halocarbon gas concentrations have increased primarily due to human activities. Natural processes are also a small source. Principal halocarbons include the chlorofluorocarbons (e.g., CFC-11 and CFC-12), which were used extensively as refrigeration agents and in other industrial processes before their presence in the atmosphere was found to cause stratospheric ozone depletion. The abundance of chlorofluorocarbon gases is decreasing as a result of international regulations designed to protect the ozone layer.

The greenhouse gasses are CO_2, CH_4, N20, and halocarbons (F, Cl, Br)…

Cause: the greenhouse effect

p. 100, FAQ

- Ozone is a greenhouse gas that is continually produced and destroyed in the atmosphere by chemical reactions. In the troposphere, human activities have increased ozone through the release of gases such as carbon monoxide, hydrocarbons and nitrogen oxide, which chemically react to produce ozone. As mentioned above, halocarbons released by human activities destroy ozone in the stratosphere and have caused the ozone hole over Antarctica.
- • Water vapour is the most abundant and important greenhouse gas in the atmosphere. However, human activities have only a small direct influence on the amount of atmospheric water vapour. Indirectly, humans have the potential to affect water vapour substantially by changing climate. For example, a warmer atmosphere contains more water vapour. Human activities also influence water vapour through CH4 emissions, because CH4 undergoes chemical destruction in the stratosphere, producing a small amount of water vapour.
- • Aerosols are small particles present in the atmosphere with widely varying size, concentration and chemical composition. Some aerosols are emitted directly into the atmosphere while others are formed from emitted compounds. Aerosols contain both naturally occurring compounds and those emitted as a result of human activities. Fossil fuel and biomass burning have increased aerosols containing sulphur compounds, organic compounds and black carbon (soot). Human activities such as surface mining and industrial processes have increased dust in the atmosphere. Natural aerosols include mineral dust released from the surface, sea salt aerosols, biogenic emissions from the land and oceans and sulphate and dust aerosols produced by volcanic eruptions.

…plus Ozone, water vapor (H20), and aerosols

Cause: the greenhouse effect

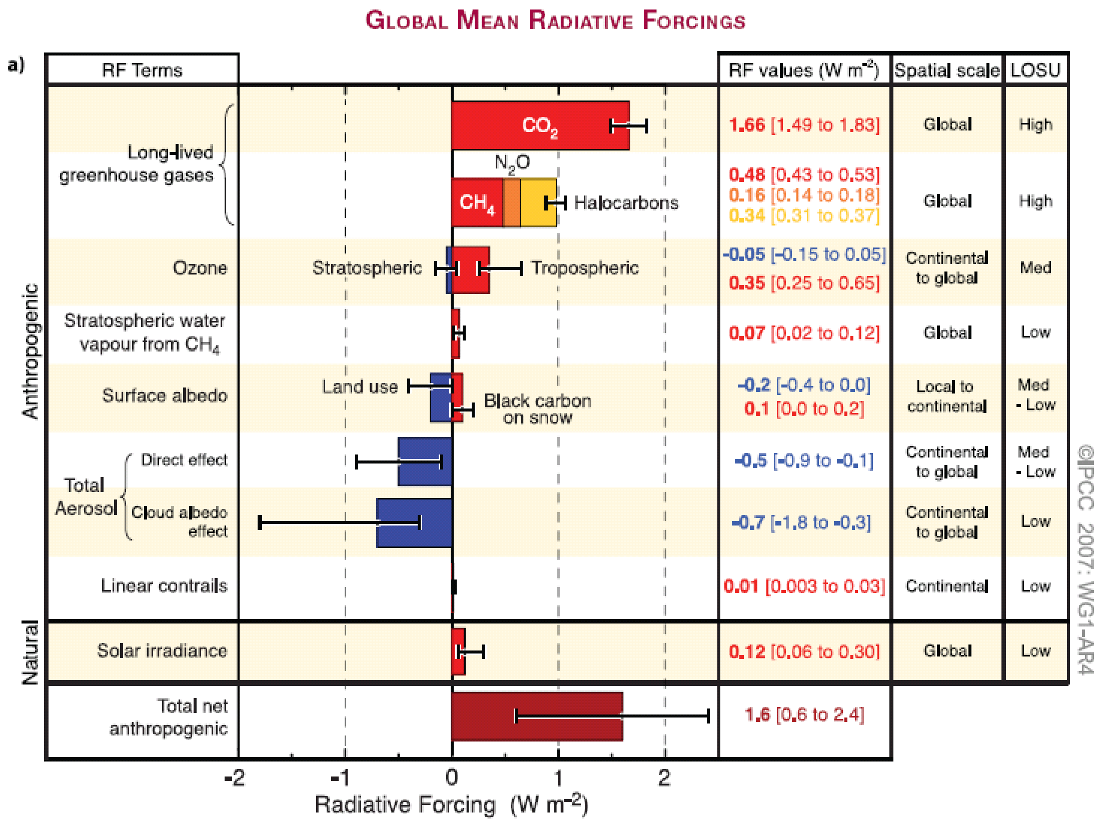
p. 101, FAQ

- What is radiative forcing? The influence of a factor that can cause climate change, such as a greenhouse gas, is often evaluated in terms of its radiative forcing. Radiative forcing is a measure of how the energy balance of the Earth-atmosphere system is influenced when factors that affect climate are altered. The word radiative arises because these factors change the balance between incoming solar radiation and outgoing infrared radiation within the Earth's atmosphere. This radiative balance controls the Earth's surface temperature. The term forcing is used to indicate that Earth's radiative balance is being pushed away from its normal state.
- Radiative forcing is usually quantified as the 'rate of energy change per unit area of the globe as measured at the top of the atmosphere', and is expressed in units of 'Watts per square metre' (see Figure 2). When radiative forcing from a factor or group of factors is evaluated as positive, the energy of the Earth-atmosphere system will ultimately increase, leading to a warming of the system. In contrast, for a negative radiative forcing, the energy will ultimately decrease, leading to a cooling of the system. Important challenges for climate scientists are to identify all the factors that affect climate and the mechanisms by which they exert a forcing, to quantify the radiative forcing of each factor and to evaluate the total radiative forcing from the group of factors

"Radiative Forcing" measures how much of the 240 Watts per square meter arriving at the earth is trapped by the greenhouse effect.
This would be zero with no global warming.

Cause: the greenhouse effect

p. 32, Physical Technical Summary



Out of 240, about 1.6 Watts per square meter remains trapped by the atmosphere today (radiative forcing = 1.6 W/m2).
The C02 present in the atmosphere is the largest cause.

Cause: the greenhouse effect

p. 25, Physical Technical Summary

- Increases in atmospheric CO_2 since pre-industrial times are responsible for a radiative forcing of +1.66 ± 0.17 W m^{-2}; a contribution which dominates all other radiative forcing agents considered in this report.
- Emissions of CO_2 from fossil fuel use and from the effects of land use change on plant and soil carbon are the primary sources of increased atmospheric CO_2.
- Since the 1980s, natural processes of CO_2 uptake by the terrestrial biosphere (i.e., the residual land sink in Table TS.1) and by the oceans have removed about 50% of anthropogenic emissions (i.e., fossil CO_2 emissions and land use change flux in Table TS.1). These removal processes are influenced by the atmospheric CO_2 concentration and by changes in climate.

The radiative forcing due to atmospheric CO_2 alone is 1.6 Watts per square meter, higher than any other greenhouse gas or radiative forcing effect.

Cause: the greenhouse effect

page 27, Physical Technical Summary

- **Increases in atmospheric CH_4 concentrations since pre-industrial times have contributed a radiative forcing of +0.48 ± 0.05 W m^{-2}. Among greenhouse** gases, this forcing remains second only to that of CO_2 in magnitude. {2.3}
- **Current atmospheric CH_4 levels are due to continuing anthropogenic emissions of CH_4, which are greater than natural emissions.**

The radiative forcing due to atmospheric CH_4 is 0.48 Watts per square meter, much lower than for CO_2.

Cause: the greenhouse effect

p. 29, Physical Technical Summary

- **Direct aerosol radiative forcing is now considerably better quantifi ed than previously and represents a major advance in understanding since the time of the TAR, when several components had a very low level of scientifi c understanding. A total direct aerosol radiative forcing combined across all aerosol types can now be given for the fi rst time as –0.5 ± 0.4 W m–2, with a medium-low level of scientific understanding.**

In effect, human made aerosols have a global cooling effect of -0.5 Watts per square meter…

Cause: the greenhouse effect

p. 78, Physical Technical Summary

- **While the warming effect of CO_2 represents a commitment over many centuries, aerosols are removed from the atmosphere over time scales of only a few days, so that the negative radiative forcing due to aerosols could change rapidly in response to any changes in emissions of aerosols or aerosol precursors.** Because sulphate aerosols are *very likely exerting a* substantial negative radiative forcing at present, future net forcing is very sensitive to changes in sulphate emissions. One study suggests that the hypothetical removal from the atmosphere of the entire current burden of anthropogenic sulphate aerosol particles would produce a rapid increase in global mean temperature of about 0.8°C within a decade or two. Changes in aerosols are also likely to infl uence precipitation. **Thus, the effect of environmental strategies aimed at mitigating climate change requires consideration of changes in both greenhouse gas and aerosol emissions. Changes in aerosol emissions may result from measures implemented to improve air quality which may therefore have consequences for climate change.** {Box 7.4, 7.6, 10.7}

… the removal of human made aerosols (like suphate emissions) for improving air quality can contribute to global warming as well by that amount of 0.5 Watts per square meter

Cause: the greenhouse effect

p. 115, FAQ

- *In fact, the observed increase in atmospheric CO2 concentrations does not reveal the full extent of human emissions in that it accounts for only 55% of the CO2 released by human activity since 1959. The rest has been taken up by plants on land and by the oceans. In all cases, atmospheric concentrations of greenhouse gases, and their increases, are determined by the balance between sources (emissions of the gas from human activities and natural systems) and sinks (the removal of the gas from the atmosphere by conversion to a different chemical compound). Fossil fuel combustion (plus a smaller contribution from cement manufacture) is responsible for more than 75% of human-caused CO2 emissions. Land use change (primarily deforestation) is responsible for the remainder.*
- *The concentration of CO2 is now 379 parts per million (ppm) and methane is greater than 1,774 parts per billion (ppb), both very likely much higher than any time in at least 650 kyr (during which CO2 remained between 180 and 300 ppm and methane between 320 and 790 ppb). The recent rate of change is dramatic and unprecedented; increases in CO2 never exceeded 30 ppm in 1 kyr – yet now CO2 has risen by 30 ppm in just the last 17 years.*

Today, atmospheric CO2 exists at 379 parts per million (ppm) and the level of C02 is determined both by emissions from burning fossil fuel and reduced rates of worldwide photosynthesis due to deforestation

Cause: the greenhouse effect

p. 98, FAQ

- Several components of the climate system, notably the oceans and living things, affect atmospheric concentrations of greenhouse gases. A prime example of this is plants taking CO_2 out of the atmosphere and converting it (and water) into carbohydrates via photosynthesis. In the industrial era, human activities have added greenhouse gases to the atmosphere, primarily through the burning of fossil fuels and clearing of forests.
- Adding more of a greenhouse gas, such as CO_2, to the atmosphere intensifies the greenhouse effect, thus warming Earth's climate. The amount of warming depends on various feedback mechanisms. For example, as the atmosphere warms due to rising levels of greenhouse gases, its concentration of water vapour increases, further intensifying the greenhouse effect. This in turn causes more warming, which causes an additional increase in water vapour, in a self-reinforcing cycle. This water vapour feedback may be strong enough to approximately double the increase in the greenhouse effect due to the added CO_2 alone.

Plants take CO_2 out of the atmosphere and convert it to oxygen through photosynthesis. Burning of fossil fuels and clearing of forests counteracts this to produce CO_2.

Cause: the greenhouse effect

p. 95, FAQ

- Human activities intensify the blanketing effect through the release of greenhouse gases. For instance, the amount of carbon dioxide in the atmosphere has increased by about 35% in the industrial era, and this increase is known to be due to human activities, primarily the combustion of fossil fuels and removal of forests. Thus, humankind has dramatically altered the chemical composition of the global atmosphere with substantial implications for climate.

Human activities that increase CO2 through burning of fossil fuels or removal of forests also increase the greenhouse effect and contribute to climate change.

Cause: the greenhouse effect

p. 115, FAQ

- *For methane, another important greenhouse gas, emissions generated by human activities exceeded natural emissions over the last 25 years. For nitrous oxide, emissions generated by human activities are equal to natural emissions to the atmosphere. Most of the long-lived halogen-containing gases (such as chloro-fluorcarbons) are manufactured by humans, and were not present in the atmosphere before the industrial era. On average, present-day tropospheric ozone has increased 38% since pre-industrial times, and the increase results from atmospheric reactions of short-lived pollutants emitted by human activity.*

Human activities that increase CH4, NO2, etc impact the greenhouse effect and contribute to climate change.

Cause: the greenhouse effect

p. 115, FAQ

- The increase in atmospheric CO_2 concentration is known to be caused by human activities because the character of CO_2 in the atmosphere, in particular the ratio of its heavy to light carbon atoms, has changed in a way that can be attributed to addition of fossil fuel carbon. In addition, the ratio of oxygen to nitrogen in the atmosphere has declined as CO_2 has increased; this is as expected because oxygen is depleted when fossil fuels are burned. A heavy form of carbon, the carbon-13 isotope, is less abundant in vegetation and in fossil fuels that were formed from past vegetation, and is more abundant in carbon in the oceans and in volcanic or geothermal emissions. The relative amount of the carbon-13 isotope in the atmosphere has been declining, showing that the added carbon comes from fossil fuels and vegetation. Carbon also has a rare radioactive isotope, carbon-14, which is present in atmospheric CO_2 but absent in fossil fuels. Prior to atmospheric testing of nuclear weapons, decreases in the relative amount of carbon-14 showed that fossil fuel carbon was being added to the atmosphere.

The isotopic composition of Carbon in the atmosphere indicates that the extra CO_2 comes from burning of fossil fuels and vegetation

Cause: the greenhouse effect

p. 120, FAQ

- *It is very unlikely that the 20th-century warming can be explained by natural causes. The late 20th century has been unusually warm. Palaeoclimatic reconstructions show that the second half of the 20th century was likely the warmest 50-year period in the Northern Hemisphere in the last 1300 years. This rapid warming is consistent with the scientific understanding of how the climate should respond to a rapid increase in greenhouse gases like that which has occurred over the past century, and the warming is inconsistent with the scientific understanding of how the climate should respond to natural external factors such as variability in solar output and volcanic activity.*

Global warming is not consistent with variability in solar output or volcanic activity, and very consistent with the increase in greenhouse gasses.

Cause: the greenhouse effect

p. 120, FAQ

- *Climate models provide a suitable tool to study the various influences on the Earth's climate. When the effects of increasing levels of greenhouse gases are included in the models, as well as natural external factors, the models produce good simulations of the warming that has occurred over the past century. The models fail to reproduce the observed warming when run using only natural factors. When human factors are included, the models also simulate a geographic pattern of temperature change around the globe similar to that which has occurred in recent decades. This spatial pattern, which has features such as a greater warming at high northern latitudes, differs from the most important patterns of natural climate variability that are associated with internal climate processes, such as El Niño.*

Climate modelling/simulations have been shown to reproduce historical climate change, and they can be useful in predicting future climate change.

Cause: the greenhouse effect

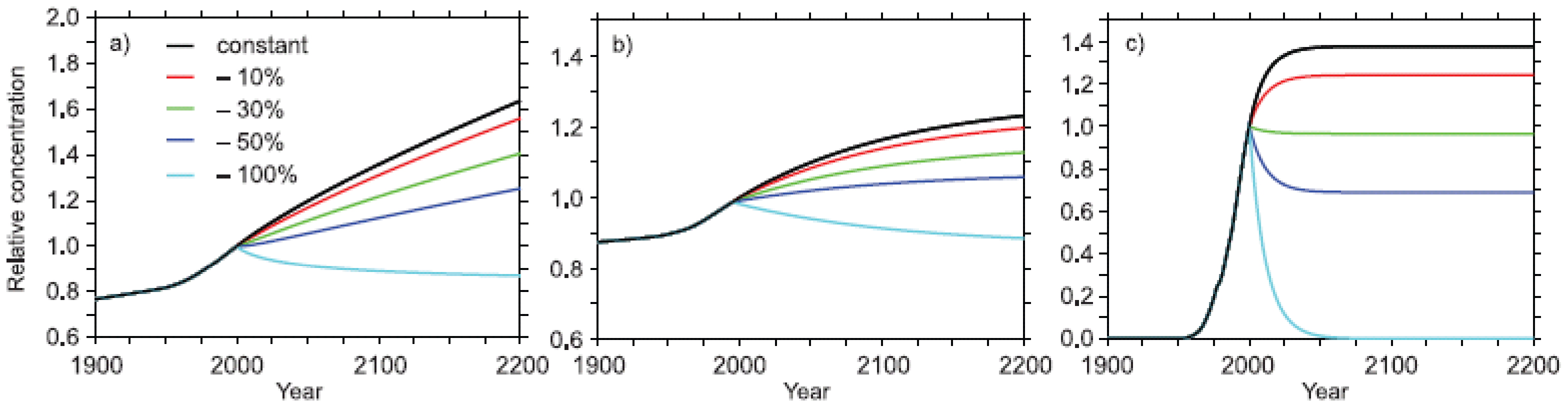
p. 125, FAQ

- The concentration of a greenhouse gas in the atmosphere depends on the competition between the rates of emission of the gas into the atmosphere and the rates of processes that remove it from the atmosphere. For example, carbon dioxide (CO_2) is exchanged between the atmosphere, the ocean and the land through processes such as atmosphere-ocean gas transfer and chemical (e.g., weathering) and biological (e.g., photosynthesis) processes. While more than half of the CO_2 emitted is currently removed from the atmosphere within a century, some fraction (about 20%) of emitted CO_2 remains in the atmosphere for many millennia. Because of slow removal processes, atmospheric CO_2 will continue to increase in the long term even if its emission is substantially reduced from present levels.

While it takes a century for 80% of the CO_2 emitted on to be absorbed, about 20% of the CO_2 emitted remains in the atmosphere for many millennia

Cause: the greenhouse effect

p. 125, FAQ



FAQ 10.3, Figure 1. *(a) Simulated changes in atmospheric CO_2 concentration relative to the present-day for emissions stabilised at the current level (black), or at 10% (red), 30% (green), 50% (dark blue) and 100% (light blue) lower than the current level; (b) as in (a) for a trace gas with a lifetime of 120 years, driven by natural and anthropogenic fluxes; and (c) as in (a) for a trace gas with a lifetime of 12 years, driven by only anthropogenic fluxes.*

Even if 100% of CO2 emissions were to be eliminated by a certain date, the atmospheric CO2 level would remain high for a century. Atmospheric CO2 would grow rapidly even at 50% of today's emission rates.

Cause: the greenhouse effect

p. 126, FAQ

- More specifically, **the rate of emission of CO_2 currently greatly exceeds its rate of removal, and the slow and incomplete removal implies that small to moderate reductions in its emissions would not result in stabilisation of CO_2 concentrations, but rather would only reduce the rate of its growth in coming decades.** A 10% reduction in CO_2 emissions would be expected to reduce the growth rate by 10%, while a 30% reduction in emissions would similarly reduce the growth rate of atmospheric CO_2 concentrations by 30%. A 50% reduction would stabilise atmospheric CO_2, but only for less than a decade. After that, atmospheric CO_2 would be expected to rise again as the land and ocean sinks decline owing to well-known chemical and biological adjustments. Complete elimination of CO_2 emissions is estimated to lead to a slow decrease in atmospheric CO_2 of about 40 ppm over the 21st century.

Since there is a large emission rate of CO_2 today, fractional reductions like 10%, 20%, or 50% will not result in stabilization of atmospheric CO_2.

Cause: the greenhouse effect

p. 125, FAQ

- The behaviour of CO_2 (Figure 1a) is completely different from the trace gases with well-defined lifetimes. Stabilisation of CO_2 emissions at current levels would result in a continuous increase of atmospheric CO_2 over the 21st century and beyond, whereas for a gas with a lifetime on the order of a century (Figure 1b) or a decade (Figure 1c), stabilisation of emissions at current levels would lead to a stabilisation of its concentration at a level higher than today within a couple of centuries, or decades, respectively. **In fact, only in the case of essentially complete elimination of emissions can the atmospheric concentration of CO_2 ultimately be stabilised at a constant level.** All other cases of moderate CO_2 emission reductions show increasing concentrations because of the characteristic exchange processes associated with the cycling of carbon in the climate system.

Unlike other greenhouse gasses such as CH_4, only with near total elimination of CO_2 emissions can the atmospheric concentration of CO_2 be stabilised at a constant level in order to stop further global warming.

Global Warming – numbers please!

- Is the globe warming? Yes
- Cause: the greenhouse effect
- IPCC Climate Change Prediction
  - +2-4 °C by 2100 assuming no limit on fossil fuel availability
- Rutledge Climate Change Prediction
  - +1.5 °C by 2100 with producer-limitations on fossil fuels
- The Global Carbon Budget
- Mitigation of greenhouse effect

IPCC Climate Change Prediction

p 68, Physical Technical Summary

- If the concentrations of greenhouse gases and aerosols were held fi xed after a period of change, the climate system would continue to respond due to the thermal inertia of the oceans and ice sheets and their long time scales for adjustment. **'Committed warming'** is defi ned here as the further change in global mean temperature after atmospheric composition, and hence radiative forcing, is held constant. Committed change also involves other aspects of the climate system, in particular sea level. Note that holding concentrations of radiatively active species constant would imply that ongoing emissions match natural removal rates, which for most species would be equivalent to a large reduction in emissions, although the corresponding model experiments are not intended to be considered as emission scenarios. {FAQ 10.3}

In climate change modeling, the term "Committed warming" means controlling the rate of "global warming" by keeping the level of radiative forcing constant by stabilizing the levels of atmospheric greenhouse gasses.

IPCC Climate Change Prediction

p. 69, Physical Technical Summary

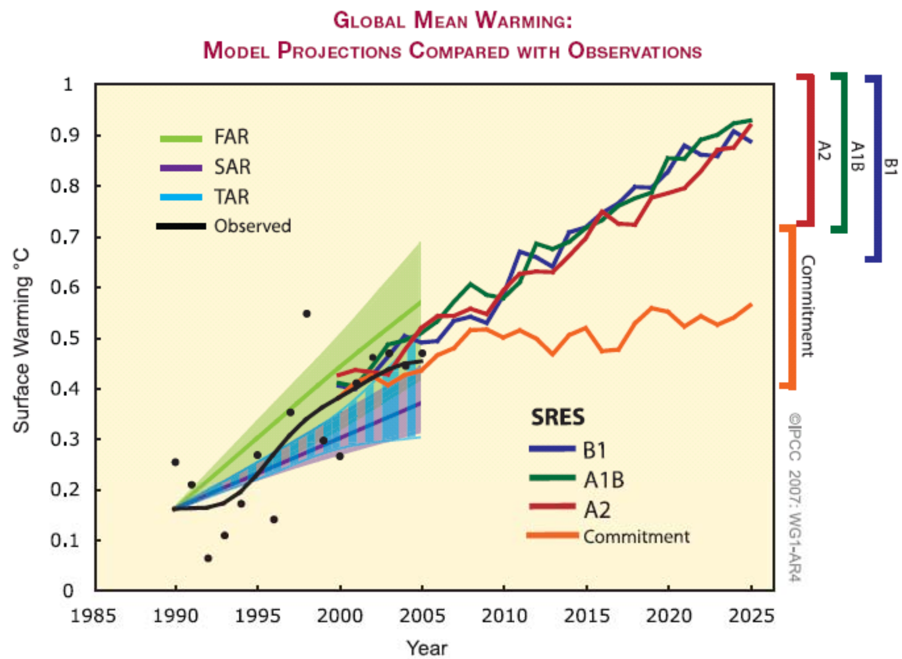


Figure TS.26. *Model projections of global mean warming compared to observed warming. Observed temperature anomalies, as in Figure TS.6, are shown as annual (black dots) and decadal average values (black line). Projected trends and their ranges from the IPCC First (FAR) and Second (SAR) Assessment Reports are shown as green and magenta solid lines and shaded areas, and the projected range from the TAR is shown by vertical blue bars. These projections were adjusted to start at the observed decadal average value in 1990. Multi-model mean projections from this report for the SRES B1, A1B and A2 scenarios, as in Figure TS.32, are shown for the period 2000 to 2025 as blue, green and red curves with uncertainty ranges indicated against the right-hand axis. The orange curve shows model projections of warming if greenhouse gas and aerosol concentrations were held constant from the year 2000 – that is, the committed warming. {Figures 1.1 and 10.4}*

The orange line shows the global warming through 2025 assuming that the greenhouse gasses remained "committed" at year 2000 levels. The red, green, and blue lines show projections for global warming out to 2025 at the current course.

IPCC Climate Change Prediction

p. 79, Physical Technical Summary

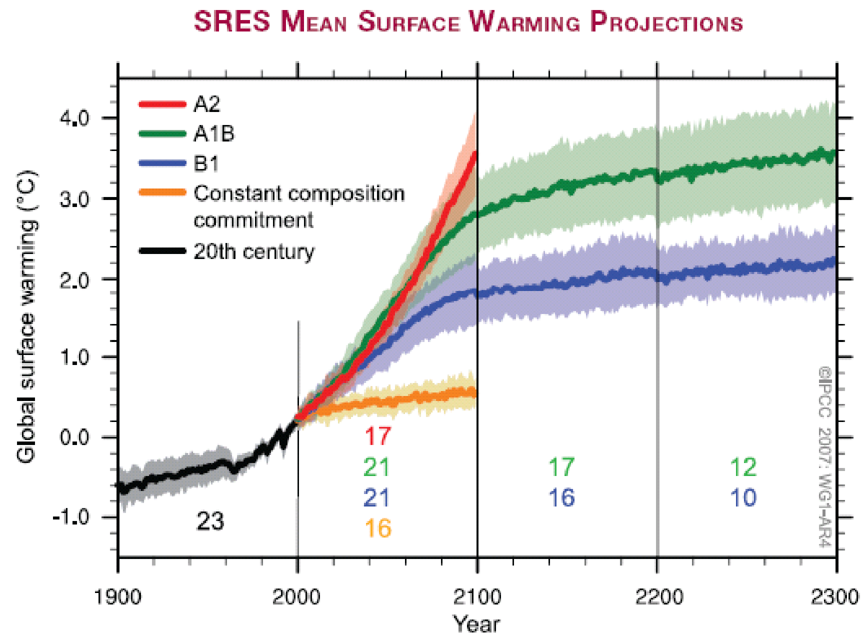


Figure TS.32. *Multi-model means of surface warming (compared to the 1980–1999 base period) for the SRES scenarios A2 (red), A1B (green) and B1 (blue), shown as continuations of the 20th-century simulation. The latter two scenarios are continued beyond the year 2100 with forcing kept constant (committed climate change as it is defined in Box TS.9). An additional experiment, in which the forcing is kept at the year 2000 level is also shown (orange). Linear trends from the corresponding control runs have been removed from these time series. Lines show the multi-model means, shading denotes the ±1 standard deviation range. Discontinuities between different periods have no physical meaning and are caused by the fact that the number of models that have run a given scenario is different for each period and scenario (numbers indicated in figure). For the same reason, uncertainty across scenarios should not be interpreted from this figure (see Section 10.5 for uncertainty estimates). {Figure 10.4}*

Similar graph as previous slide extrapolated out to 2100. At current course of global warming we would expect 2-4 degrees increase by 2100

IPCC Climate Change Prediction

p. 79, Physical Technical Summary

- **The commitments to climate change after stabilisation of radiative forcing are expected to be about 0.5 to 0.6°C, mostly within the following century.** The multi-model average when stabilising concentrations of greenhouse gases and aerosols at year 2000 values after a 20th-century climate simulation, and running an additional 100 years, is about 0.6°C of warming (relative to 1980–1999) at year 2100 (see Figure TS.32). If the B1 or A1B scenarios were to characterise 21st-century emissions followed by stabilisation at those levels, the additional warming after stabilisation is similar, about 0.5°C, mostly in the subsequent hundred years. {10.3, 10.7}

If greenhouse gasses were "committed" in 2100, the earth would experience incrementally similar 0.5 degrees of global warming as after commitment in 2000

IPCC Climate Change Prediction

p. 77, Physical Technical Summary

- Using coupled carbon cycle components, EMICs show that the committed climate change due to past CO_2 emissions persists for more than 1000 years, so that even over these very long time scales, temperature and sea level do not return to pre-industrial values. An indication of the long time scales of committed climate change is obtained by prescribing anthropogenic CO_2 emissions following a path towards **stabilisation at 750 ppm**, but arbitrarily setting emissions to zero at year 2100. In this test case, it takes about 100 to 400 years in the different models for the atmospheric CO_2 concentration to drop from the maximum (ranges between 650 to 700 ppm) to below the level of two times the pre-industrial CO_2 concentration (about 560 ppm), owing to a continuous but slow transfer of carbon from the atmosphere and terrestrial reservoirs to the ocean (see Figure TS.31). {7.3, 10.7}

In a simulation where atmospheric CO_2 levels reached 750ppm by 2100 (up from 379 ppm today), it would still take 1000 years to reduce back to pre-industrial levels even if all CO_2 emissions were stopped in 2100

IPCC Climate Change Prediction

p. 78, Physical Technical Summary

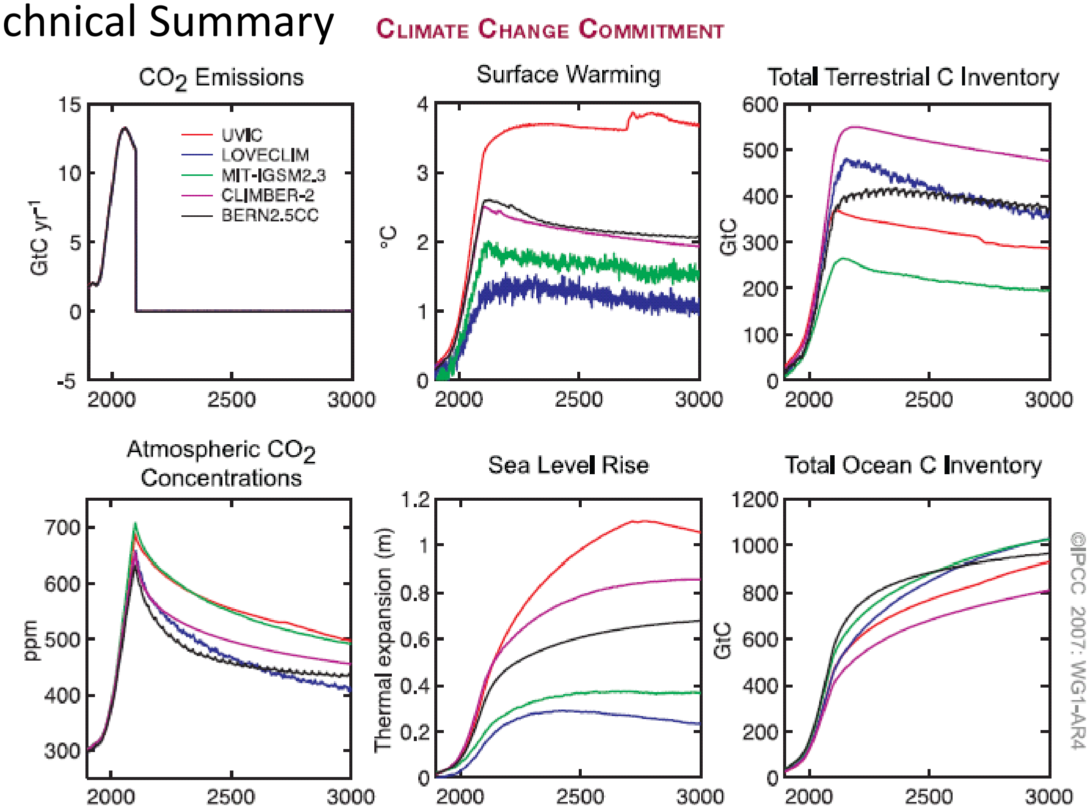


Figure TS.31. *Calculation of climate change commitment due to past emissions for five different EMICs and an idealised scenario where emissions follow a pathway leading to stabilisation of atmospheric CO_2 at 750 ppm, but before reaching this target, emissions are reduced to zero instantly at year 2100. (Left) CO_2 emissions and atmospheric CO_2 concentrations; (centre) surface warming and sea level rise due to thermal expansion; (right) change in total terrestrial and oceanic carbon inventory since the pre-industrial era. {Figure 10.35}*

… during that time the average temperature of the earth's atmosphere would rise by 2-4 degrees Celsius as atmospheric CO2 concentration peaks at 700 ppm

Global Warming – numbers please!

- Is the globe warming? Yes
- Cause: the greenhouse effect
- IPCC Climate Change Prediction
  - +2-4 °C by 2100 assuming no limit on fossil fuel availability
- Rutledge Climate Change Prediction
  - +1.5 °C by 2100 with producer-limitations on fossil fuels
- The Global Carbon Budget
- Mitigation of greenhouse effect

Rutledge Climate Change Prediction

from "The Oil Drum"

- For oil, "The trend line is for **3.2 trillion barrels of oil equivalent (Tboe)** remaining. We will use this number for our simulation of future atmospheric CO2 concentrations and temperature rise. This is 20% larger than the reserves given by the German resources agency BGR, 2.7Tboe. The BGR includes 500Gboe for unconventional sources. In contrast, the IPCC assumes that 11-15Tboe is available for production for its climate-change scenarios."
- For coal, "The world total is 435Gt, **1.6Tboe** if we convert at the current energy density of 3.6boe/t. This is about half the reserves of 963Gt (3.5Tboe). Both are much lower than the amount that is assumed to be available for the IPCC scenarios, which is 18Tboe."

Rutledge (Caltech) makes the case that IPCC estimates the amount of fossil fuels reserves to be 10x more than actually remaining (producer limitation).

Rutledge Climate Change Prediction

p. 44, Mitigation Technical Summary

- Absolute fossil fuel scarcity at the global level is not a significant factor in considering climate change mitigation. Conventional oil production will eventually peak, but it is uncertain exactly when and what the repercussions will be. The energy in conventional natural gas is more abundant than in conventional oil but, like oil, is not distributed evenly around the globe. In the future, lack of security of oil and gas supplies for consuming nations may drive a shift to coal, nuclear power and/or renewable energy. There is also a trend towards more efficient and convenient energy carriers (electricity, and liquid and gaseous fuels) instead of solids (*high agreement, much evidence) [4.3.1].*

Seems like IPCC dismisses fossil fuel scarcity (producer limitations) as possibly being a limiting factor in cumulative greenhouse emissions

Rutledge Climate Change Prediction

Table 4.2, Energy Supply

Table 4.2: *Generalized data for global energy resources (including potential reserves), annual rate of use (490 EJ in 2005), share of primary energy supply and comments on associated environmental impacts.*

Energy class	Specific energy source[a]	Estimated available energy resource[b] (EJ)	Rate of use in 2005 (EJ/yr)[c]	2005 share of total supply (%)	Comments on environmental impacts
Fossil energy	Coal (conventional)	>100,000	120	25	Average 92.0 gCO_2/MJ
	Coal (unconventional)	32,000	0		
	Peat[d]	large	0.2	<0.1	
	Gas (conventional)	13,500	100	21	Average 52.4 gCO_2/MJ
	Gas (unconventional)	18,000	Small		Unknown, likely higher
	Coalbed methane	>8,000?	1.5	0.3	
	Tight sands	8,000	3.3	0.7	
	Hydrates	>60,000	0		
	Oil (conventional)	10,000	160	33	Average 76.3 gCO_2/MJ
	Oil (unconventional)	35,000	3	0.6	Unknown, likely higher
Nuclear	Uranium[e]	7,400	26	5.3	Spent fuel disposition
	Uranium recycle[f]	220,000	Very small		Waste disposal
	Fusion	5 x 109 estimated	0		Tritium handling
Renewables	Hydro (>10 MW)	60 /yr	25	5.1	Land-use impacts
	Hydro (< 10 MW)	2 /yr	0.8	0.2	
	Wind	600 /yr	0.95	0.2	
	Biomass (modern)	250 /yr	9	1.8	Likely land-use for crops
	Biomass (traditional)		37	7.6	Air pollution
	Geothermal	5,000 /yr	2	0.4	Waterway contamination
	Solar PV	1,600 /yr	0.2	<0.1	Toxics in manufacturing
	Concentrating solar	50 /yr[h]	0.03	0.1	Small
	Ocean (all sources)	7/yr (exploitable)	<1	0	Land and coastal issues.

Notes:

[a] See Glossary for definitions of conventional and unconventional.

[b] Various sources contain ranges, some wider than others (e.g., those for conventional oil cluster much more closely than those for biomass). For the purposes of this assessment of mitigation potentials these values, generalized to a first approximation with some very uncertain, are more than adequate.

[c] Hydro and wind are treated as equivalent energy to fossil and biomass since the conversion losses are much less (www.iea.org/textbase/stats/questionaire/faq.asp)

[d] Peat land area under active production is approximately 230,000 ha. This is about 0.05% of the global peat land area of 400 million hectares (WEC, 2004c).

[e] Once-through thermal reactors.

[f] Light-water and fast-spectrum reactors with plutonium recycle

[g] Data from 2005 is at www.ren21.net/globalstatusreport/issuesGroup.asp

[h] Very uncertain. The potential of the Mediterranean area alone has been estimated by one source to be 8000 EJ/yr (http://www.dlr.de/tt/med-csp)

Sources: Data from BP, 2006; WEC, 2004c; IEA, 2006b; IAEA, 2005c; USGS, 2000; Martinot, 2005; Johansson, 2004; Hall, 2003; Encyclopaedia of Energy, 2004.

IPCC and Rutledge agree that proven world coal reserves are 3.6 Tboe, which is same as BP's numbers as well. IPCC says that there are > 16 Tboe of estimated available coal reserves (unproven). Rutledge estimates disagree.

Rutledge Climate Change Prediction

Section 4.3.1 , Energy Supply

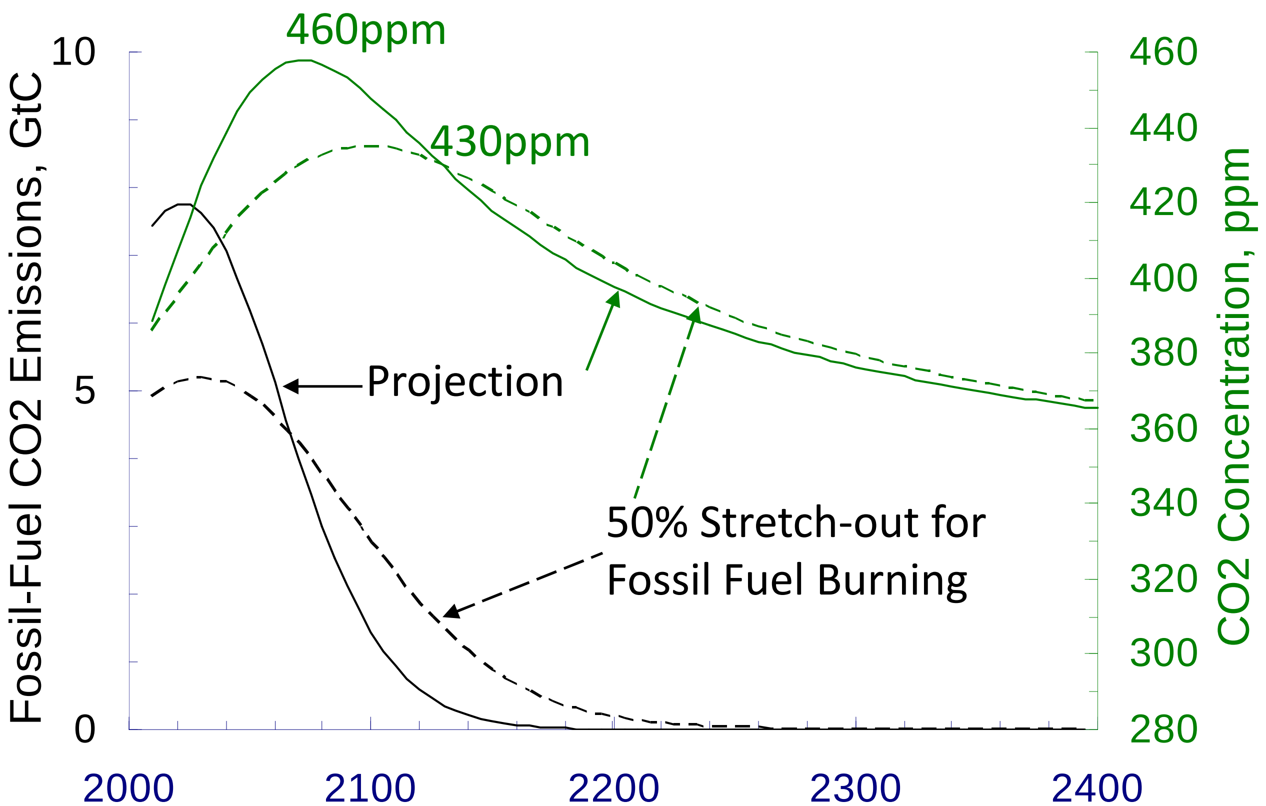
- *"Fossil energy resources remain abundant but contain significant amounts of carbon that are normally released during combustion.* ***The proven and probable reserves of oil and gas are enough to last for decades and in the case of coal, centuries (Table. 4.2).*** *Possible undiscovered resources extend these projections even further."*

- Specifically per the IPCC table 4.2, total estimated coal reserves are > 100,000 EJ = 16 TboE (they say proven coal reserves are 20,000 EJ)
- Rutledge estimates coal reserves at 1.6 TboE
- Conversions:
  - 464 EJ = 11,204 Mtoe or 1 EJ = 24 Mtoe (from IPCC)
  - 1toe = 6.841boe (from wikipedia)
  - 1 ton of coal = 3.6boe (from Rtuledge)

IPCC specifically says coal reserves are the largest when they are talking about total fossil fuel reserves. So IPCC's estimate for coal is 10x more than Rutledge et al, and is the largest compared to natural gas or oil reserves. so both studies are non consistent in this respect. here is what the IPCC is saying in terms of fossil fuel reserves….

Rutledge Climate Change Prediction

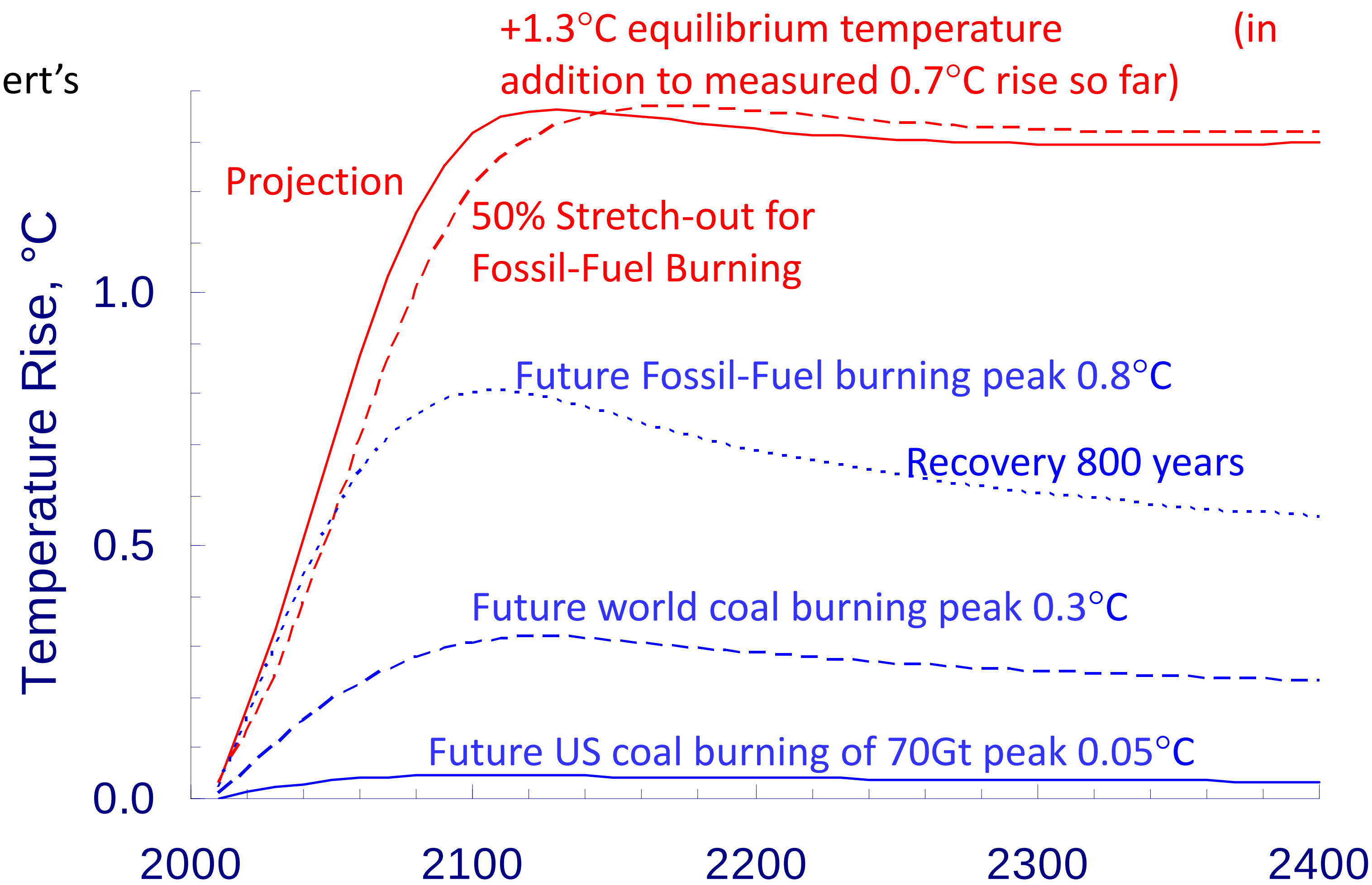
From Hubbert's Peak



Using the producer-limited assumption, Rutledge estimates that atmospheric CO2 concentration will not exceed around 460 ppm.

Rutledge Climate Change Prediction

From Hubbert's Peak



Using the producer-limited assumption, Rutledge estimates that global warming will not exceed 1.5 degrees Celsius.

Global Warming – numbers please!

- Is the globe warming? Yes
- Cause: the greenhouse effect
- IPCC Climate Change Prediction
  - +2-4 °C by 2100 assuming no limit on fossil fuel availability
- Rutledge Climate Change Prediction
  - +1.5 °C by 2100 with producer-limitations on fossil fuels
- The Global Carbon Budget
- Mitigation of greenhouse effect

The Global Carbon Budget

p. 38, Mitigation Technical Summary

- A commonly used target in the literature is stabilization of CO_2 concentrations in the atmosphere. If more than one GHG is studied, a useful alternative is to formulate a GHG-concentration target in terms of CO_2-equivalent concentration or radiative forcing, thereby weighting the concentrations of the different gases by their radiative properties. Another option is to stabilize or target global mean temperature. The advantage of radiativeforcing targets over temperature targets is that the calculation of radiative forcing does not depend on climate sensitivity. The disadvantage is that a wide range of temperature impacts is possible for each radiative-forcing level. Temperature targets, on the other hand, have the important advantage of being more directly linked to climate change impacts. Another approach is to calculate the risks or the probability of exceeding particular values of global annual mean temperature rise since pre-industrial times for specific stabilization or radiative forcing targets

Global warming is directly measured in degrees celsius, but the warming is not completely predictable due to uncertainty in modeling. Therefore, policy targets are discussed in terms carbon emissions which is more easily measurable.

The Global Carbon Budget

p. 39, Mitigation Technical Summary

Table TS.2: *Classification of recent (Post-Third Assessment Report) stabilization scenarios according to different stabilization targets and alternative stabilization metrics [Table 3.5].*

Category	Additional radiative forcing (W/m^2)	CO_2 concentration (ppm)	CO_2-eq concentration (ppm)	Global mean temperature increase above pre-industrial at equilibrium, using "best estimate" climate sensitivity[a], [b] (°C)	Peaking year for CO_2 emissions[c]	Change in global CO_2 emissions in 2050 (% of 2000 emissions)[c]	No. of assessed scenarios
I	2.5-3.0	350-400	445-490	2.0-2.4	2000 - 2015	-85 to -50	6
II	3.0-3.5	400-440	490-535	2.4-2.8	2000 - 2020	-60 to -30	18
III	3.5-4.0	440-485	535-590	2.8-3.2	2010 - 2030	-30 to +5	21
IV	4.0-5.0	485-570	590-710	3.2-4.0	2020 - 2060	+10 to +60	118
V	5.0-6.0	570-660	710-855	4.0-4.9	2050 - 2080	+25 to +85	9
VI	6.0-7.5	660-790	855-1130	4.9-6.1	2060 - 2090	+90 to +140	5
						Total	177

Notes:

a) Note that global mean temperature at equilibrium is different from expected global mean temperatures in 2100 due to the inertia of the climate system.

b) The simple relationships $T_{eq} = T_{2\times CO2} \times \ln([CO_2]/278)/\ln(2)$ and $\Delta Q = 5.35 \times \ln([CO_2]/278)$ are used. Non-linearities in the feedbacks (including e.g., ice cover and carbon cycle) may cause time dependence of the effective climate sensitivity, as well as leading to larger uncertainties for greater warming levels. The best-estimate climate sensitivity (3 °C) refers to the most likely value, that is, the mode of the climate sensitivity PDF consistent with the WGI assessment of climate sensitivity and drawn from additional consideration of Box 10.2, Figure 2, in the WGI AR4.

c) Ranges correspond to the 15th to 85th percentile of the Post-Third Assessment Report (TAR) scenario distribution. CO_2 emissions are shown, so multi-gas scenarios can be compared with CO_2-only scenarios.

Note that the classification needs to be used with care. Each category includes a range of studies going from the upper to the lower boundary. The classification of studies was done on the basis of the reported targets (thus including modelling uncertainties). In addition, the relationship that was used to relate different stabilization metrics is also subject to uncertainty (see Figure 3.16).

The mapping of CO2 concentrations (ppm) to global temperature rise is shown in this table. For example a 3 degree rise corresponds to 450 ppm

The Global Carbon Budget

- p. 26 , Physical Technical Summary

Table TS.1. *Global carbon budget. By convention, positive values are CO_2 fluxes (GtC yr^{-1}) into the atmosphere and negative values represent uptake from the atmosphere (i.e., 'CO_2 sinks'). Fossil CO_2 emissions for 2004 and 2005 are based on interim estimates. Due to the limited number of available studies, for the net land-to-atmosphere flux and its components, uncertainty ranges are given as 65% confidence intervals and do not include interannual variability (see Section 7.3). NA indicates that data are not available.*

	1980s	1990s	2000–2005
Atmospheric increase	3.3 ± 0.1	3.2 ± 0.1	4.1 ± 0.1
Fossil carbon dioxide emissions	5.4 ± 0.3	6.4 ± 0.4	7.2 ± 0.3
Net ocean-to-atmosphere flux	–1.8 ± 0.8	–2.2 ± 0.4	–2.2 ± 0.5
Net land-to-atmosphere flux	–0.3 ± 0.9	–1.0 ± 0.6	–0.9 ± 0.6
Partitioned as follows			
Land use change flux	1.4 (0.4 to 2.3)	1.6 (0.5 to 2.7)	NA
Residual land sink	–1.7 (–3.4 to 0.2)	–2.6 (–4.3 to –0.9)	NA

CO2 emissions are measured in Giga Tons Per Year at 7.2 GtC/yr, and CO2 is absorbed back into the earth by oceans (2.2 GtC/yr) and vegetation (0.9 GtC/yr). Today, the rate of increase in atmospheric CO2 is therefore 4.1 GtC/yr

The Global Carbon Budget

p. 26-27, Physical Technical Summary

- **Carbon uptake and storage in the terrestrial biosphere arise from the net difference between uptake due to vegetation growth, changes in reforestation and sequestration, and emissions due to heterotrophic respiration, harvest, deforestation, fire, damage by pollution and other disturbance factors affecting biomass and soils. Increases and decreases in fire frequency in different regions have affected net carbon uptake, and in boreal regions, emissions due to fi res appear to have increased over recent decades. Estimates of net CO2 surface fl uxes from inverse studies using networks of atmospheric data demonstrate signifi cant land uptake in the mid-latitudes of the Northern Hemisphere (NH) and near-zero land-atmosphere fl uxes in the tropics, implying that tropical deforestation is approximately balanced by regrowth. {7.3}**
- **The direct effects of increasing atmospheric CO2 on large-scale terrestrial carbon uptake cannot be quantified reliably at present. Plant growth can be** stimulated by increased atmospheric CO2 concentrations and by nutrient deposition (fertilization effects). However, most experiments and studies show that such responses appear to be relatively short lived and strongly coupled to other effects such as availability of water and nutrients. Likewise, experiments and studies of the effects of climate (temperature and moisture) on heterotrophic respiration of litter and soils are equivocal. Note that the effect of climate change on carbon uptake is addressed separately in section TS.5.4. {7.3}

One unknown exactly how increased atmospheric CO2 concentrations in the future will be affect terrestrial uptake of CO2, and if so by how much…

The Global Carbon Budget

p. 77, Physical Technical Summary

- **All models that treat the coupling of the carbon cycle to climate change indicate a positive feedback effect with warming acting to suppress land and ocean uptake of CO_2, leading to larger atmospheric CO_2 increases and greater climate change for a given emissions scenario, but the strength of this feedback effect varies markedly among models.**

…but all models considered by the IPCC show that uptake of CO_2 by land and Ocean will decrease with rising atmospheric CO_2, which increases global warming.

The Global Carbon Budget

p. 79, Physical Technical Summary

- The magnitude of the positive feedback between climate change and the carbon cycle is uncertain. This leads to uncertainty in the trajectory of CO_2 emissions required to achieve a particular stabilization level of atmospheric CO_2 concentration. Based upon current understanding of climate-carbon cycle feedback, model studies suggest that, in order to stabilise CO_2 at 450 ppm, cumulative emissions in the 21st century could be reduced from a model average of approximately 670 [630 to 710] GtC to approximately 490 [375 to 600] GtC. Similarly, to stabilise CO_2 at 1000 ppm, the cumulative emissions could be reduced by this feedback from a model average of approximately 1415 [1340 to 1490] GtC to approximately 1100 [980 to 1250] GtC. {7.3, 10.4}

Current models say that cumulative CO_2 emissions in the 21st century should be reduced to approximately 500 GtC to stabilize atmospheric CO_2 levels at 450 ppm and 1200 GtC to stabilize atmospheric CO_2 levels at 1000 ppm.

Global Warming – numbers please!

- Is the globe warming? Yes
- Cause: the greenhouse effect
- IPCC Climate Change Prediction
  - +2-4 °C by 2100 assuming no limit on fossil fuel availability
- Rutledge Climate Change Prediction
  - +1.5 °C by 2100 with producer-limitations on fossil fuels
- The Global Carbon Budget
- Mitigation of greenhouse effect

Mitigation of greenhouse effect

p. 27, Mitigation Technical Summary

In 2004,

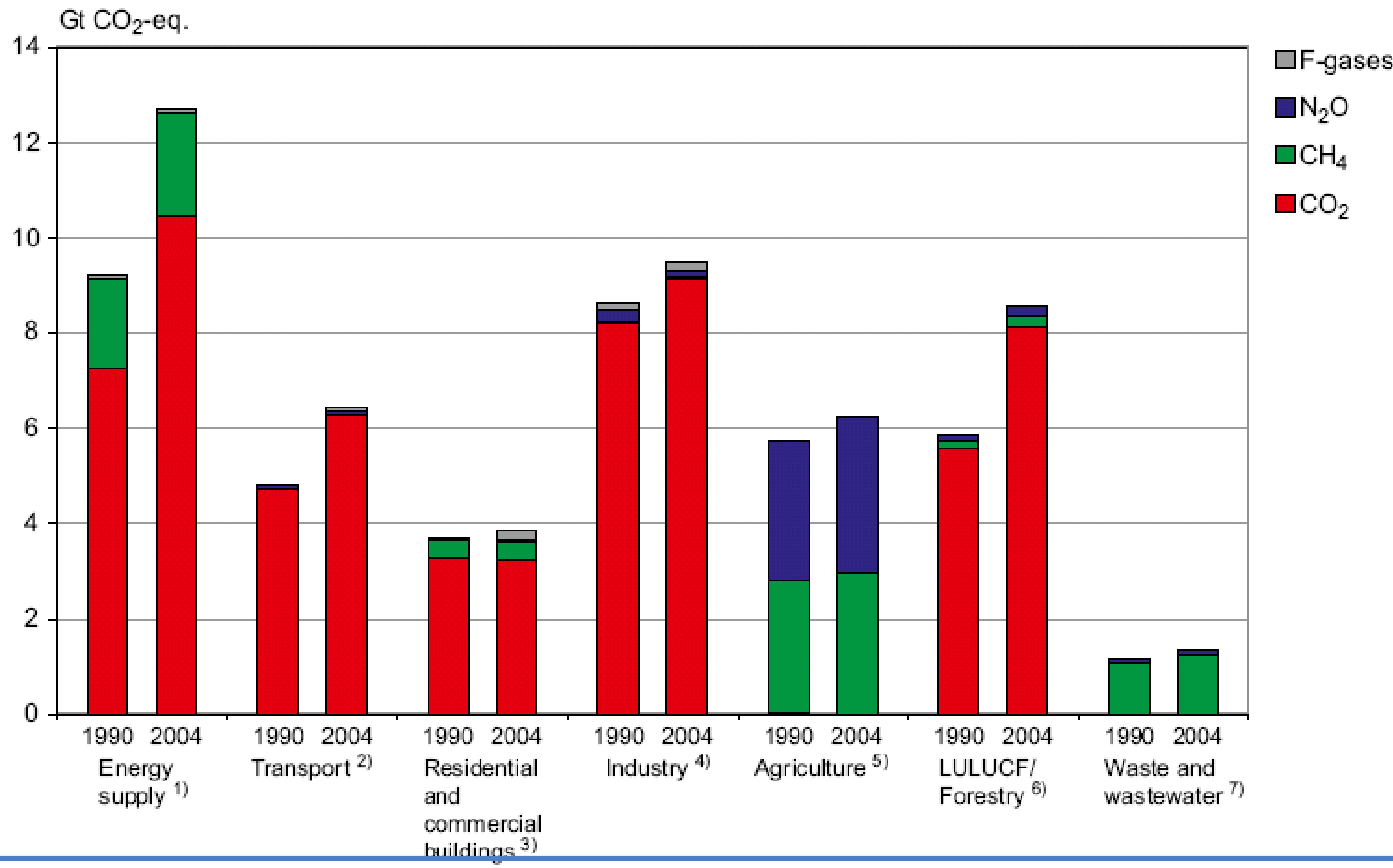
- energy supply accounted for about 26% of GHG emissions,
- industry 19%,
- gases released from land-use change and forestry 17%,
- agriculture 14%,
- transport 13%,
- residential, commercial and service sectors 8%
- and waste 3%

(see Figure TS.2).

In 2004, no one industry accounted for more than a about a quarter of greenhouse gas emissions and energy supply was the largest.

Mitigation of greenhouse effect

p. 29, Mitigation Technical Summary



Energy supply, transportation, buildings, industrial, agriculture, and forestry all contribute significantly to greenhouse emissions

Mitigation of greenhouse effect

p. 29, Mitigation Technical Summary

Figure TS.2a: *GHG emissions by sector in 1990 and 2004 100-year GWPs from IPCC 1996 (Second Assessment Report (SAR)) were used to convert emissions to CO_2-eq. The uncertainty in the graph is quite large for CH_4 and N_2O (in the order of 30–50%) and even larger for CO_2 from agriculture and forestry. For large-scale biomass burning, averaged activity data for 1997–2002 were used from Global Fire Emissions Database based on satellite data. Peat (fire and decay) emissions are based on recent data from WL/Delft Hydraulics. [Figure 1.3a]*

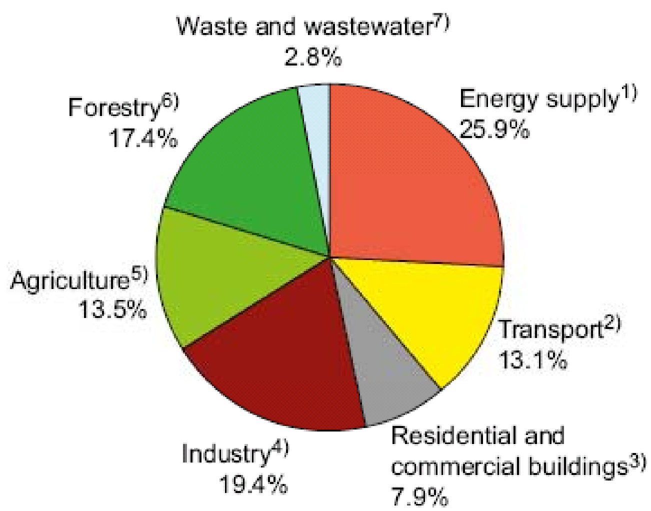


Figure TS.2b: *GHG emissions by sector in 2004 [Figure 1.3b].*

Energy supply, transportation, buildings, industrial, agriculture, and forestry all contribute significantly to greenhouse emissions

Mitigation of greenhouse effect

p. 80, Mitigation Technical Summary

- All approaches indicate that no single sector or technology will be able to address the mitigation challenge successfully on its own, suggesting the need for a diversified portfolio based on a variety of criteria. Top-down assessments agree with the bottom-up results in suggesting that carbon prices around 20-50 S$/tCO2-eq (73-183 US$/tC-eq) are sufficient to drive large-scale fuel-switching and make both CCS and low-carbon power sources economic as technologies mature. Incentives of this order might also play an important role in avoiding deforestation. The various short- and long-term models come up with differing estimates, the variation of which can be explained mainly by approaches and assumptions regarding the use of revenues from carbon taxes or permits, treatment of technological change, degree of substitutability between internationally traded products, and the disaggregation of product and regional markets *(high agreement, much evidence)* [11.4, 11.5, 11.6].

Reducing emissions in any one sector will not suffice, all have to be addressed in a portfolio approach

Mitigation of greenhouse effect

p. 43, Mitigation Technical Summary

- Total fossil fuel consumption has increased steadily during the past three decades. Consumption of nuclear energy has continued to grow, though at a slower rate than in the 1980s. Large hydro and geothermal energy are relatively static. Between 1970 and 2004, the share of fossil fuels dropped from 86% to 81%. Wind and solar are growing most rapidly, but from a very low base (Figure TS.13) *(high agreement, much evidence) [4.2].*

In 2004, fossil fuels account for 80% of global power needs.

Mitigation of greenhouse effect

p. 43, Mitigation Technical Summary

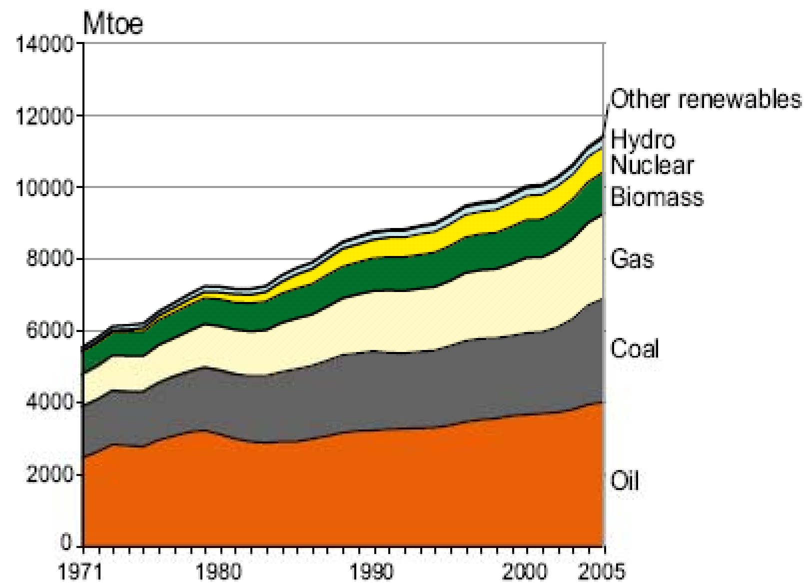


Figure TS.13: *World primary energy consumption by fuel type. [Figure 4.5].*

In 2004, fossil fuels account for 80% of global power needs.

Mitigation of greenhouse effect

p. 48, Mitigation Technical Summary

- Transport activity is expected to grow robustly over the next several decades. Unless there is a major shift away from current patterns of energy use, projections foresee a continued growth in world transportation energy use of 2% per year, with energy use and carbon emissions about 80% above 2002 levels by 2030 [5.2.2]. In developed economies, motor vehicle ownership approaches five to eight cars for every ten inhabitants (Figure TS.14). In the developing world, levels of vehicle ownership are much lower; non-motorized transport plays a significant role, and there is a greater reliance on two- and three-wheeled motorized vehicles and public transport. The motorization of transport in the developing world is, however, expected to grow rapidly in the coming decades**. As incomes grow and the value of** travellers' time increases, travellers are expected to choose faster modes of transport, shifting from non-motorized to automotive, to air and high-speed rail. Increasing speed has generally led to greater energy intensity and higher GHG emissions.

Mitigation of greenhouse effect

p. 49, Mitigation Technical Summary

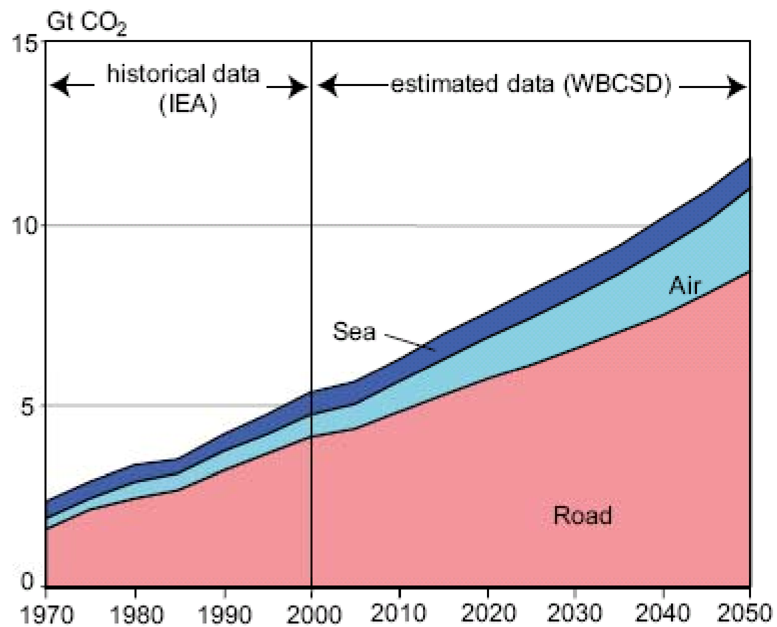


Figure TS.15: *Historical and projected CO_2 emissions from transport [Figure 5.4].*

Most of transportation-related greenhouse emissions are from road transport

Mitigation of greenhouse effect

p. 49, Mitigation Technical Summary

- Estimates of CO_2 emissions from global aviation increased by a factor of about 1.5, from 330 $MtCO_2$/yr in 1990 to 480 $MtCO_2$/yr in 2000, and accounted for about 2% of total anthropogenic CO_2 emissions. Aviation CO_2 emissions are projected to continue to grow strongly. In the absence of additional measures, projected annual improvements in aircraft fuel efficiency of the order of 1–2% will be largely surpassed by traffic growth of around 5% each year, leading to a projected increase in emissions of 3–4% per year (*high agreement, medium evidence). Moreover, the overall climate impact of aviation is* much greater than the impact of CO_2 alone. As well as emitting CO_2, aircraft contribute to climate change through the emission of nitrogen oxides (NO_x), which are particularly effective in forming the GHG ozone when emitted at cruise altitudes. Aircraft also trigger the formation of condensation trails, or contrails, which are suspected of enhancing the formation of cirrus clouds, which add to the overall global warming effect. These effects are estimated to be about two to four times greater than those of aviation's CO_2 alone, even without considering the potential impact of cirrus cloud enhancement. The environmental effectiveness of future mitigation policies for aviation will depend on the extent to which these non-CO_2 effects are also ddressed *(high agreement, medium evidence)* [5.2.1; 5.2.2].

Aviation is likely to play an increasing role in greenhouse emissions,
as the warming effects may be 2-4x those of CO_2 emissions due to water vapor

Mitigation of greenhouse effect

p. 49, Mitigation Technical Summary

- Transport is distinguished from other energy-using sectors by its predominant reliance on a single fossil resource and by the infeasibility of capturing carbon emissions from transport vehicles with any known technologies. It is also important to view GHG-emission reductions in conjunction with air pollution, congestion and energy security (oil import) problems. Solutions therefore have to try to optimize improvement of transportation problems as a whole, not just GHG emissions [5.5.4].

Transportation's dependence on fossil fuels causes other problems besides global warming: air pollution, congestion, and energy security problems.

Mitigation of greenhouse effect

p. 328, Mitigation Transport

Table 5.1: *World transport energy use in 2000, by mode*

Mode	Energy use (EJ)	Share (%)
Light-duty vehicles (LDVs)	34.2	44.5
2-wheelers	1.2	1.6
Heavy freight trucks	12.48	16.2
Medium freight trucks	6.77	8.8
Buses	4.76	6.2
Rail	1.19	1.5
Air	8.95	11.6
Shipping	7.32	9.5
Total	76.87	100

Source: WBCSD, 2004b.

Light duty vehicles make up the largest class of energy use (44.5%), next heavy freight trucks (16.2%) and air transport (11.6%).

Mitigation of greenhouse effect

p. 333, Transport Mitigation

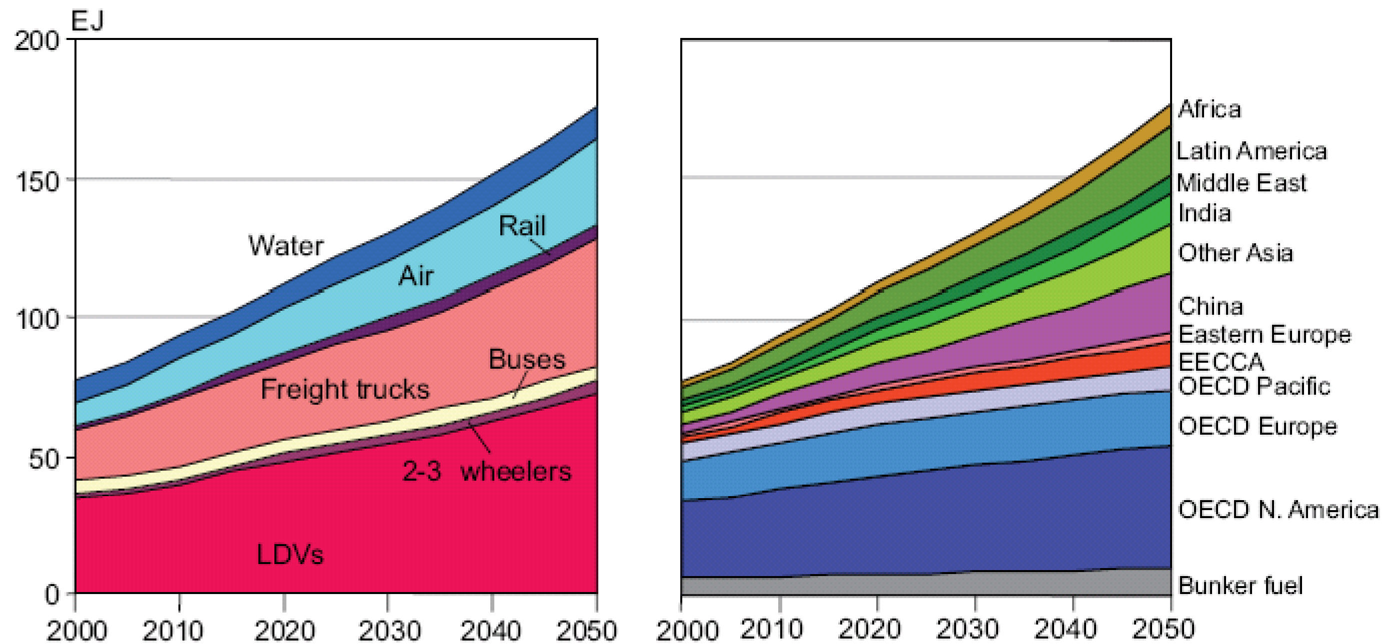


Figure 5.3: *Projection of transport energy consumption by region and mode*

Source: WBCSD, 2004a.

Light duty vehicles make up the largest class of energy use (44.5%), next heavy freight trucks (16.2%) and air transport (11.6%).

Mitigation of greenhouse effect

p. 334, Transport Mitigation

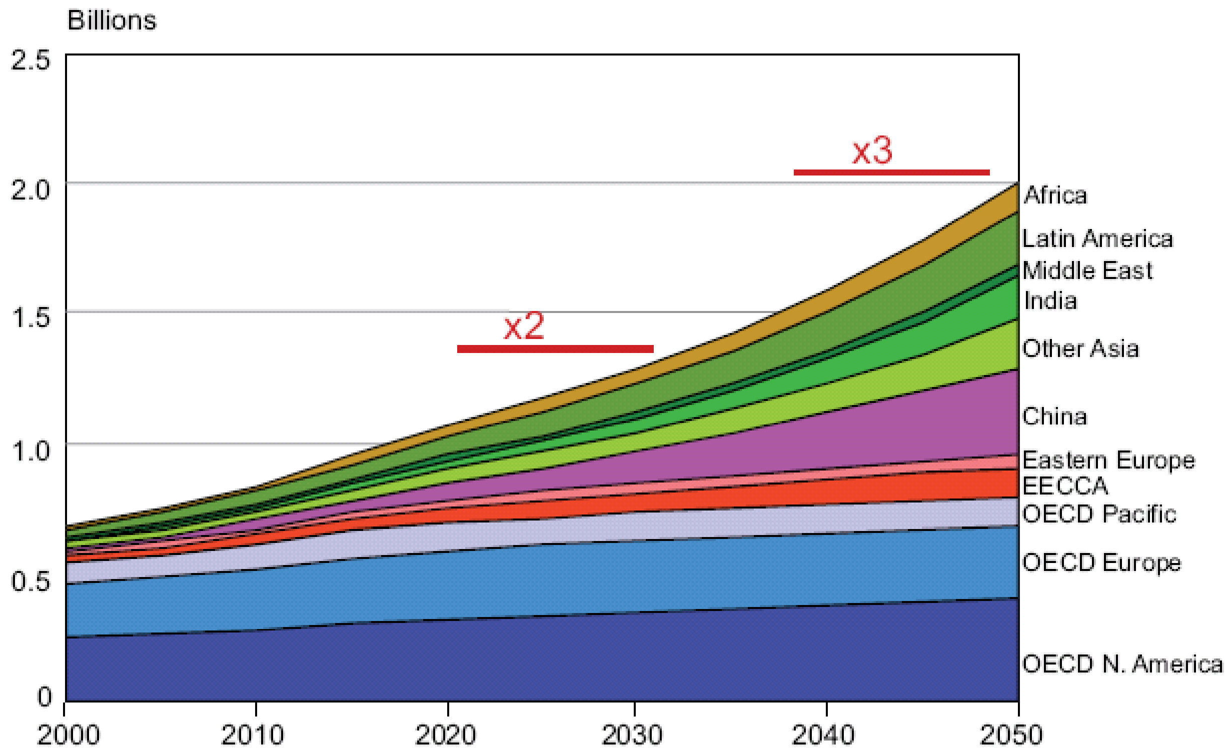


Figure 5.5: *Total stock of light-duty vehicles by region*

Source: WBCSD, 2004a.

Light duty vehicles are expected to double by 2025 and triple by 2050

Conclusions

- Rising levels of Carbon Dioxide (CO_2) in the atmosphere is the most significant contributor to global warming, surpassing all other greenhouse gasses combined.
- It will take near 100% elimination of CO_2 emissions to prevent further global warming. Even then, temperatures will rise for 100 years or more due to the long lifetime of CO_2.
- There is a debate on whether fossil fuel reserves are limited, and whether that will limit global warming to 1.5 degrees Celsius (Rutledge) or otherwise exceed 2-4 Celsius degrees (IPCC) in 100 years.
- No single industry is responsible for the bulk of CO_2 emissions, and a portfolio of solutions to eliminate greenhouse gas emissions are needed for
  - Power generation (26%)
  - Transportation (13%)
  - Industrial (19%)
  - Forestry (17%)
  - Agriculture (14%)
  - Buildings (8%)
- Within transportation, light duty vehicles like cars account for nearly half of all CO_2 emissions, followed by heavy duty trucks, and aviation.