PART V

THE WAY FORWARD

Our Future Dependancy on Fossil Fuels and Possible Approaches to Make the Geological Storage of Carbon Dioxide a Viable Tool to Mitigate Anthropogenic Greenhouse Gas Loading to the Atmosphere

THE ROLE OF FOSSIL FUELS IN THE 21ST CENTURY

Energy Scenario and Climate Aspects

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Abstract: According to a widely accepted forecast the global energy consumption, which is roughly 400 EJ today, will quadruple by the end of the century and the use of fossil fuels will probably increase until the middle of the century. Hence, the energy scenario definitely implies that the emission of greenhouse gases will also increase by a minimum 30%, leveling off at that value for the coming decades. Unfortunately, a simplified idea is that the use of fossil fuels is solely responsible for global warming, and hence climatic changes. Although the anthropogenic impact on climate is represented by only 15% of carbon dioxide emissions, this is the area where science and engineering can focus all efforts to influence its detrimental effects. The small anthropogenic effect on climate, however, clearly proves that the earth is extremely vulnerable to even marginal changes in the atmosphere, hydrosphere and lithosphere.

Key words: energy scenario, fossil fuels, emission of greenhouse gases, global warming, climate, emission trading, sequestration

1. INTRODUCTION

Using fossil fuels for energy produces enormous quantities of CO_2 which is transferred to the atmosphere. The fossil fuels, particularly coal, have been and still are the workhorse of energy production. Replacing coal and oil by natural gas can substantially reduce CO_2 emissions, however unfortunately it cannot eliminate it completely. Although the "clean energy" concept forms a very important strategy for all nations, we must always keep in mind that this effort has serious limitations. The forecasted energy scenario predicts that CO_2 emissions will increase by a minimum of 30%, leveling off at that

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value for two or three decades in the first half of the century. The main question now is how this increased emission will influence the climatic state of the earth? The popular, simplified answer is that the use of fossil energy is alone responsible for the rise of average temperatures, and hence climatic changes. The real scientific fact is that natural factors contribute 96% of climatic changes, while the effect of anthropogenic factors are marginal. As far as the natural factors are concerned, water-induced processes are responsible for 65% of the changes and the influence of CO_2 in the atmosphere is estimated to be less than 30%. In contrast, man-made energy production represents only 15% of the total CO_2 emissions, however it is within this area where science and engineering can and must focus all efforts to decrease CO_2 emissions. For a better understanding of natural and anthropogenic factors this paper analyses various aspects and consequences of energy production based on fossil fuels, its possible effect on climate and the actions that science, society and individuals must take to address this problem.

2. ENERGY SCENARIOS: PAST, PRESENT AND FUTURE

"Energy demand is expected to grow in the 21st century. The energy demand will be met by a global energy mix that is undergoing a transition from the current dominance of fossil fuels to a more balanced distribution of energy sources. Motivation of energy diversification includes population growth, quality of life, clean energy, resources/reserves. An understanding of the energy options available to us in the 21st century requires an understanding of a range of scientific theories. The scientific revolution will be based on fundamental changes of old paradigms" - *John R. Fanchi* in "Energy in the 21st Century", Gulf Professional Publisher, Austin (in print). This quote not only strongly demonstrates the conceivable energy scenario, but also the well-based prediction of the future role of crude oil and natural gas production/consumption. The world energy demand was about 400 EJ (10^{18} J) at the end of the last century (OECD, 2002; US-DOE, 2004) and the share of hydrocarbons was roughly 60% (Fig. 1). A major part of the energy, however, came from utilization of crude oil, which in itself represented about 50%. That fact clearly demonstrates that the western world and the highly developed countries are oil and gas dependent, and it is known that this dependency is steeply increasing today. Thus, Europe and North America are net hydrocarbon importers, with imports representing more than 60% of their oil and gas consumption.

According to various UN reports (UN-ESC, 1996; 2003) the present global energy demand will quadruple assuming that the world population, in an optimistic prediction, will be 8 billion at the end of the century (Fig. 2). Since there is a close correlation between the quality of life index (Fig. 3) and energy consumption (UN-ESC, 1996; 1998; 2003), which will also likely increase from the present average value of 60 to 200 MJ/y per capita, the total global energy demand will probably be 1,600 EJ (10^{18} J) in 2100 (UN-ESC, 1998).

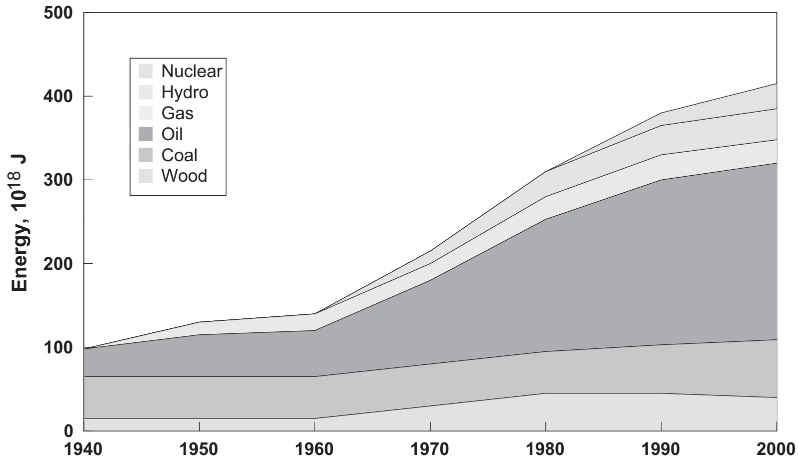

Figure 1. Absolute contribution of different sources to energy production (1940-2000).

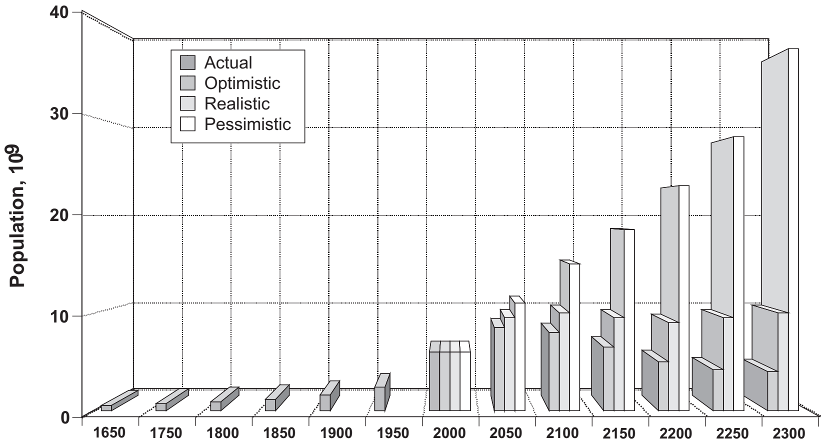

Figure 2. The actual and anticipated growth of world population between 1650 and 2300.

Converging data have been reported by various organizations (OECD, 2002; US-DOE, 2004; BP, 2005; WEC, 1995; Al-Fattah and Starzman, 2000; Skov, 2003; Arscott, 2003; Holditch, 2003; *SPE Review,* 2004; ExxonMobil, 2004; Shell, 2001) detailing the most probable diversification of energy sources in the future (Fig. 4). Although the relative importance of fossil fuels will apparently decrease, the stunning fact is that a total of 250-260 billion t of crude oil (on average 2.5 billion t per year through the whole century) must be produced to meet the world demand.

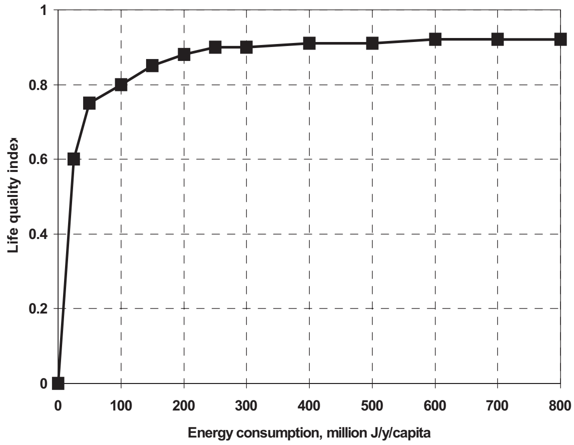

Figure 3. Correlation between the quality of life quality index and the energy consumption.

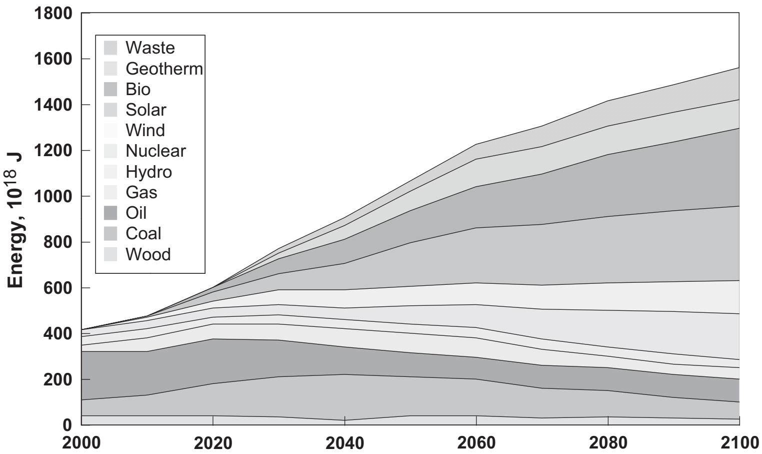

Figure 4. Absolute contribution of different sources to energy production (2000-2100).

This task is enormous if we consider that less than 100 billion t of crude oil has been produced since 1850 and that the average production rate was less than 0.7 billion t/y. As far as the reliable hydrocarbon supply is concerned the real challenge we are faced with is that the available oil reserves (proven and to be explored) amount to only 360-370 billion t. Consequently, the world demand can only be met by the supply if the recovery factor can be increased, on average, from 35% to 67%. Competent professionals and agencies say that the recovery factor can be increased up to 50% by improving existing reservoir engineering technology. Logically, the gap between 50% and 67% can only be surmounted by the extensive use of chemical IOR/EOR methods. The other option is that "dwindling supplies of oil and gas, obsolete power net-works and new environmental regulations threaten the Western world with a new energy crisis. Consequently, mankind is becoming again vulnerable to shortages in hydrocarbons, price shocks, supply interruptions, and in the worst case, political and military blackmail", *Emerson T.*: Newsweek, April 2002. Taking the hydrocarbon reserves and production rates into account, it is also obvious that these countries are dependent on sources from the Middle East which implies a global economic and political dependency which will remain for the coming decades.

3. CONTRIBUTION OF FOSSIL FUELS TO CO_2 EMISSIONS

Based on the energy scenario forecast to the end of the 21st century the probable and necessary demand of fossil fuels can be calculated (BP, 2005; WEC, 1995; Skov, 2003; ExxonMobil, 2004; Shell, 2001; US-DOE, 2005). The absolute and relative contribution of coal, oil and gas to energy production, per decade, are shown in Figs 5 and 6. The data in these diagrams suggest that the global role of fossil fuels, in contrast to various information in the world media, will increase until the middle of the century and then decrease monotonously until 2100.

The stacked columns in Fig. 5, however, indicate that utilization of these energy-bearing materials will represent at least 60-70% of the present amount. Analyzing the structure of the forecasted demand it is predicted that the relative contribution of coal and gas will reach a maximum (and oil a minimum) in the forties and fifties, while their share will stabilize through the last decades at 40-40% (coal and oil) and 20% (gas) (Fig. 6).

Technological improvements in the energy sector had already started well before the Kyoto accord. Significant efforts have been made to increase the efficiency of power stations and to decrease their air pollution. As far as the utilization of fossil fuels is concerned oil, and later natural gas, have replaced enormous amounts of coal. Thus, the extensive use of oil and gas, as a side effect, has also resulted in a substantial reduction in CO_2 emissions, since the average CO_2 emission depends fundamentally on the type of fuel used, be it coal (225 kg/MWh), oil (190 kg/MWh) or gas (128 kg/MWh).

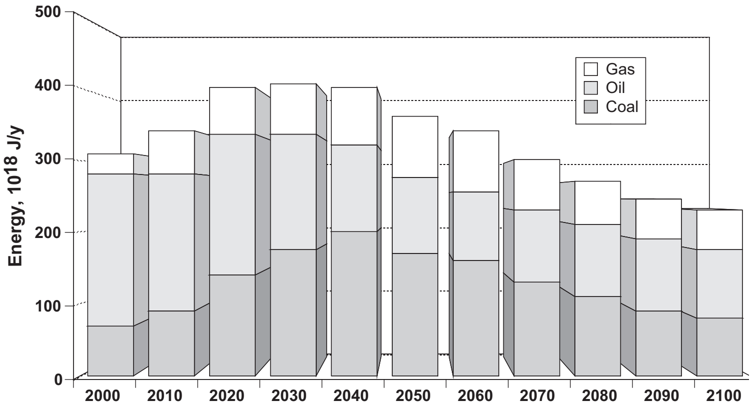

Figure 5. Absolute contribution of fossil fuels to energy production (2000-2100).

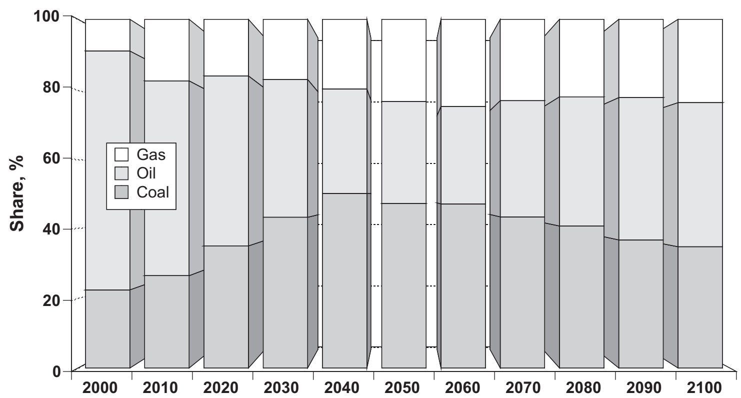

Figure 6. Relative contribution of fossil fuels to energy production (2000-2100).

Thus the hydrocarbons became attractive not only technologically, but also from an environmental point of view. Using these data and the anticipated use of fossil fuels in the future, predicted CO_2 emission rates can be calculated. The breakdown and summarized values of relative emissions are shown in Figs 7 and 8. As shown in Fig. 7 the CO_2 emissions from the use of oil and other liquid hydrocarbons will gradually decrease by about 50% until 2050, after which it will remain constant. A more extensive use of natural gas and coal, however, will unfavourably influence the CO_2 content of the atmosphere. A decreasing trend in CO_2 emissions can be expected only in the second half of the century (Fig. 8). This fact contradicts expectations of many environmental and "green" organizations that are looking forward to a substantial reduction of CO_2 emissions in the near future.

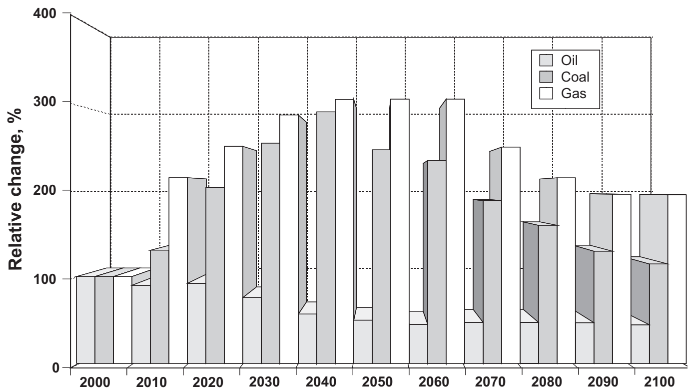

Figure 7. Relative CO_2 emissions of fossil fuels used for energy production (2000-2100).

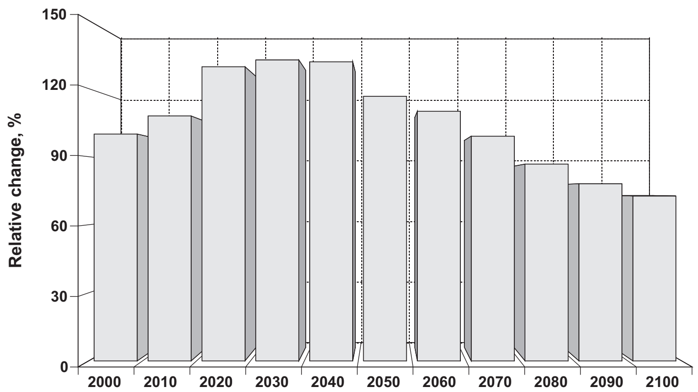

Figure 8. Summarized relative CO_2 emissions from fossil fuels used for energy production (2000-2100).

4. OVERVIEW OF GLOBAL CO_2 EMISSIONS

CO_2 emissions alone increased from 4 Gt/y to more than 10 Gt/y between 1970 and 2003 (ExxonMobil, 2004). The discrepancy in emissions of CO_2 and greenhouse gases can be analysed from different points of view. The Kyoto accord imposes limited or "capped" quotas on each country, taking special circumstances into account. As the natural, economic, industrial and even historical conditions of the nations are significantly different so are the absolute and relative CO_2 emissions. For instance, a surprising conclusion can be drawn from the data in Fig. 9, where specific CO_2 emissions are shown for several regions and countries. According to these data the Gulf countries are the biggest per-capita emitters, while the highly developed countries, like the USA, Germany, etc., rank lower on the list. Obviously, the sequence of countries can be explained by the fact that the energy demand rapidly increases in the OPEC countries and the energy is solely produced from hydrocarbons.

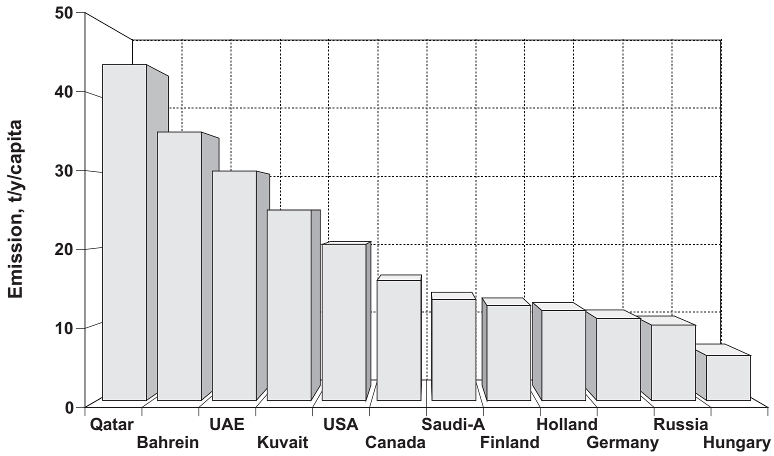

Figure 9. Absolute CO_2 emission per capita in several countries.

In the media we may more frequently observe the data presented in Fig. 10. Since the absolute output of CO_2 is population dependent, the USA is by far the biggest emitter, having a share of roughly 30% of the global CO_2 emissions annually (US-DOE, 2004; 2005). Although the government of the USA defends its decision not to sign the Kyoto accord claiming a similar CO_2 absorption (i.e. zero release), this explanation is not widely accepted yet. Consequently, environmental agencies are supporting efforts to find and use alternative energy sources, instead of fossil fuels. In 2002 a remarkable part of the global energy production already came from alternatives, like hydro, solar, wind and geothermal sources (Fig.11). It is also hopeful that the annual growth rate of renewable energies, particularly of non-polluting solar and wind, has been accelerating recently, while the use of fossil fuels is basically stagnant.

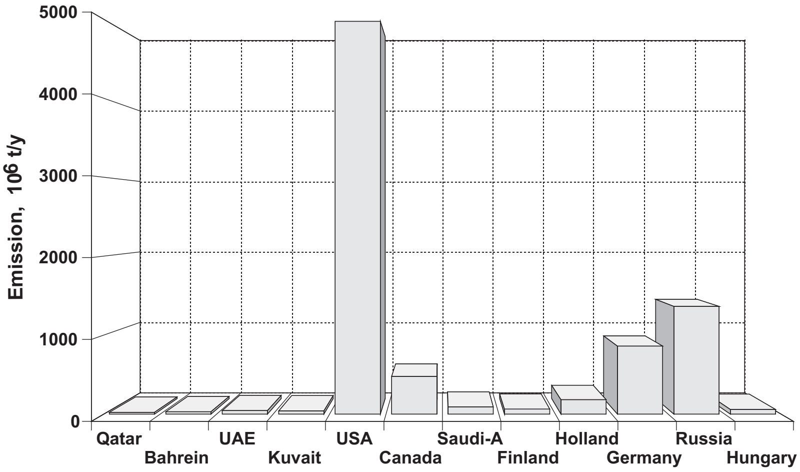

Figure 10. Absolute CO_2 emission in several countries.

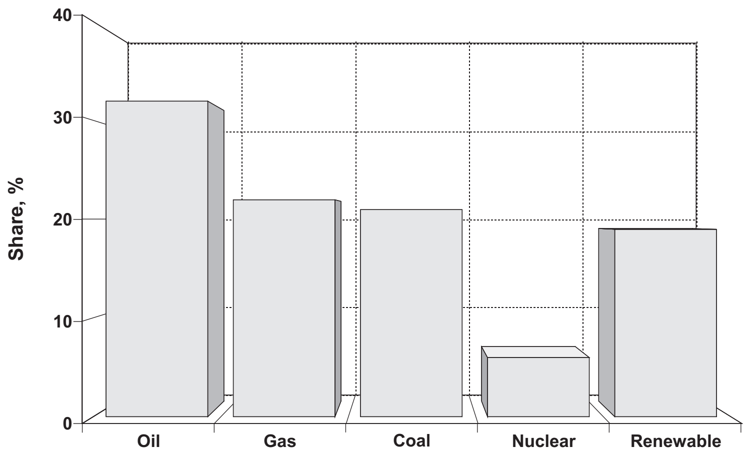

Figure 11. Contribution of different sources to global energy production in 2002.

Recently, a promising decision by the European countries has been to pledge to significantly increase the contribution of renewable energy sources to help meet national energy demand (US-DOE, 2004; Shell, 2001). But the situation, shown in Fig. 12, is not consistent. In some countries, such as Denmark, a radical increase in the use of renewable energy is planned, while in other countries the incremental change will be negligible. The options are partly hindered because the use of renewable energy is already high (Austria and Sweden), or because of unfavourable natural and climatic conditions. For instance, the morphological conditions, number of sunny days and wind conditions are definitely unfavourable for wide scale application of solar and wind renewables in Hungary and thus only geothermal energy offers a realistic possibility to increase the percentage of "clean energy". Unfortunately, extensive agricultural research programs focussed on wood and biofuels (being less harmful than coal and hydrocarbons) will also result in a measurable CO_2 emission.

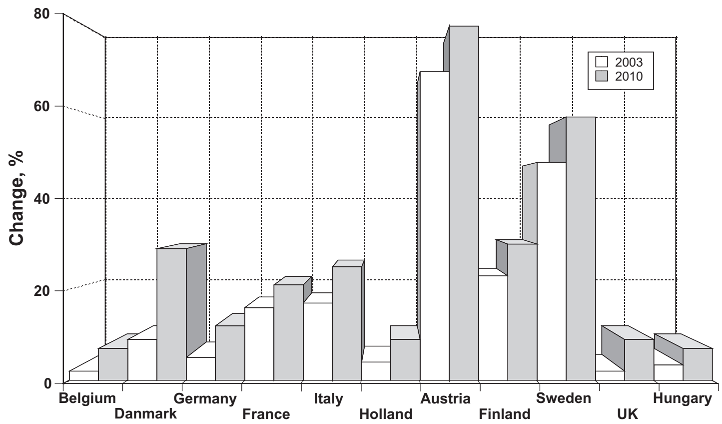

Figure 12. Decision of the European countries to increase the share of renewable energy.

At the present time the annual carbon emission rate is in the range of 5-7 10^9 t/y and great efforts have been made to predict global emission over the coming years. Diverse mathematical models have been developed which address not only technical but also social factors which influence emission rates to anticipate the equivalent carbon emissions. According to the most probable prognosis (Arscott, 2003), carbon emissions will develop as shown in Fig. 13. Although the simulation has a gradually increasing uncertainty with time, the results indicate that the summarized equivalent carbon emission rate can be as high as 30 10^9t/y, approximately six times higher than the present value, by the end of the century. This disturbing forecast puts added urgency on the need to use clean, non-polluting fuels. Parallel with that trend, there is also a need to implement emission trading and apply efficient and innovative CO_2 sequestration methods world-wide.

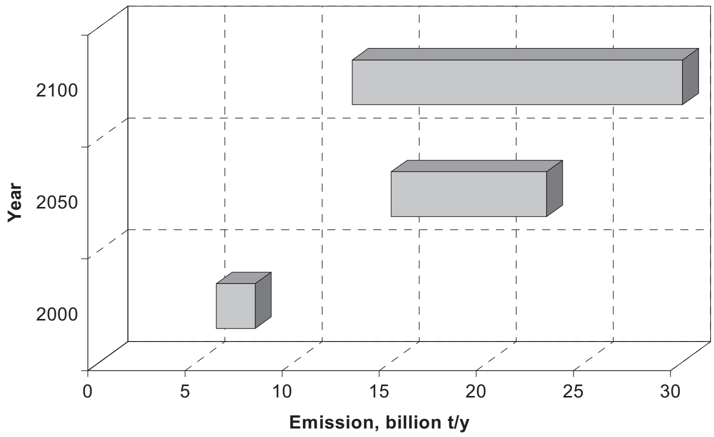

Figure 13. Anticipated global CO_2 emission in 2050 and 2100.

5. THE EFFECT OF CO_2 AND GREENHOUSE GAS EMISSIONS ON CLIMATE AND GLOBAL WARMING

The CO_2 content of the atmosphere has been essentially constant throughout the past centuries (Fig. 14), but measurable change can be detected from 1950 and today the characteristic concentration is about 380-400 ppm (Arscott, 2003; IPCC, 1995; Falkowski, 2002). According to a reliable forecast the CO_2 content in the atmosphere might be as high as 750 ppm by the end of the 21^{st} century. Since CO_2 directly influences the average temperature of the earth its accumulation in the atmosphere results in global warming, as is well demonstrated by the fact that temperatures have been rising since 1970 (Fig. 15).

Responsible organizations (IPCC, 1995; Falkowski, 2002; Glick et al., 2004) have painted global warming in the darkest colour: oceans warm, glaciers melt, sea levels rise, permafrost thaws, lakes shrink, etc. All these unfavourable and accelerating processes may have serious and detrimental impact on flora, fauna and human life. Although the essence of the problem is not questioned, there is no consensus concerning the role of anthropogenic factors. Opponents of the anthropogenic factors usually refer to the distribution of CO_2 on earth. It is a fact that only 2% of the total amount of CO_2 is found in the atmosphere, while the majority (93%) is absorbed in the hydrosphere (particularly in the deep ocean water) (Ónodi, 2003). Hence, the anthropogenic influence may have a negligible effect on CO_2 equilibrium, or in other words, any positive or negative man-made interference in water, CO_2 and other gases might have only limited impact on natural processes and climate.

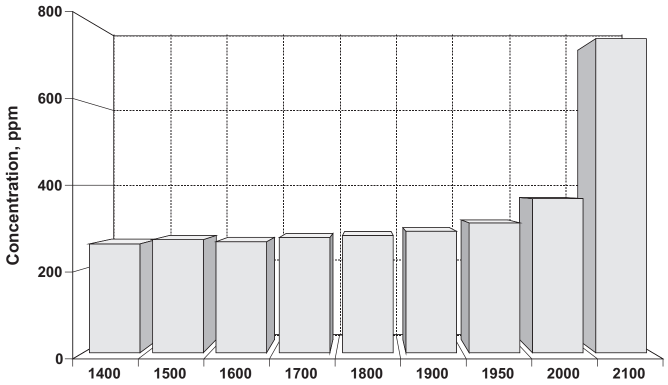

Figure 14. Concentration of carbon dioxide in the atmosphere.

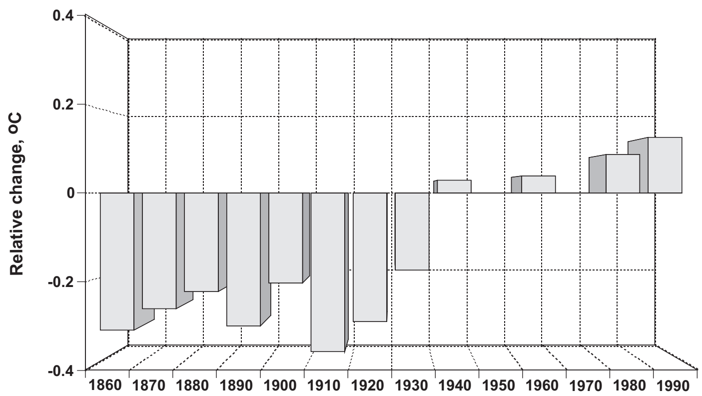

Figure 15. Deviation from average temperature on earth (basis: 1950-1970).

Some sceptic remarks can also be traced back to the cosmic and geological evolution of the earth (Petit, 1999; Gerhard et al., 2001). It is well know that the global climate is fundamentally influenced by long-term factors. In geoscience the following two factors are often mentioned:

1. Extraterrestrial (astronomical) phenomena, like decreasing solar radiation, irregular emission and distribution of cosmic dust and
2. Terrestrial phenomena, like continental drift, polar wandering and changes in the rotation axis of the planet.

These factors may result in a rhythmic fluctuation of glacial (cooling) and interglacial (warming) periods in each cosmic (190-200 million terrestrial) year, which means 15-20 global climate cycles (ice age or global warming) during the past 3 billion years. It is certain that the climate drastically changed in each cycle, but the crucial question today is how fast did these changes proceed in the past. Today it is increasingly apparent that the present rate of global warming is unusual and that the anthropogenic factor is probably decisive in the unfavourable processes.

The net CO_2 production always depends on the rates of emission and absorption. Some countries are net emitters, others absorbers. A detailed study carried out in Hungary (Fig. 16) has definitely shown that the CO_2 balance is negative and that the net CO_2 emission is estimated to be 40 TgC/y. Obviously, all countries must strive for zero CO_2 release or positive absorbance.

Despite different arguments it seems evident that anthropogenic CO_2 emissions are relatively small, but that their decrease may beneficially influence the global warming.

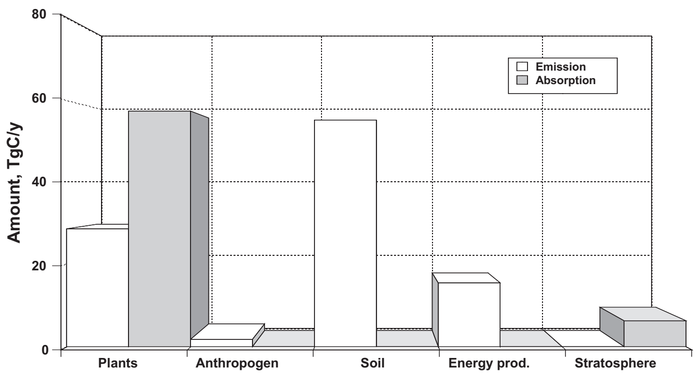

Figure 16. Emission/absorption equilibrium of CO_2 in Hungary.

6. TRADE OF GREENHOUSE GAS EMISSIONS

The Kyoto accord took effect in the last week of January, 2005, with new obligations to reduce the emission of CO_2 and other greenhouse gases (OECD, 2002). The countries signing the accord have a firm commitment to reduce emissions by 5.3%, on average, below those of 1990. Unfortunately, the accord had not been signed by a number of countries, including the USA, Australia and the majority of Middle Eastern and African countries. The principle of the accord is that the total carbon emissions in the ratifying countries are limited (capped) at a fixed level and those nations assign a number of CO_2 and greenhouse gas allowances (1 allowance = 10^6 t equivalent carbon emission) to their major carbon emitting sectors. The participating countries usually offered to reduce emissions by more than 5.3% (8% on average) until 2012. The present situation, however, is a little controversial. In 2002 some countries seem to have significantly exceeded the target, while others have not decreased rates, but rather have produced much higher emissions than in 1990 (Fig. 17). Therefore, the accord makes it possible to trade emissions between countries and companies. In other words, the countries that have unused allowances may sell them, while those that have excess carbon emissions must buy allowances.

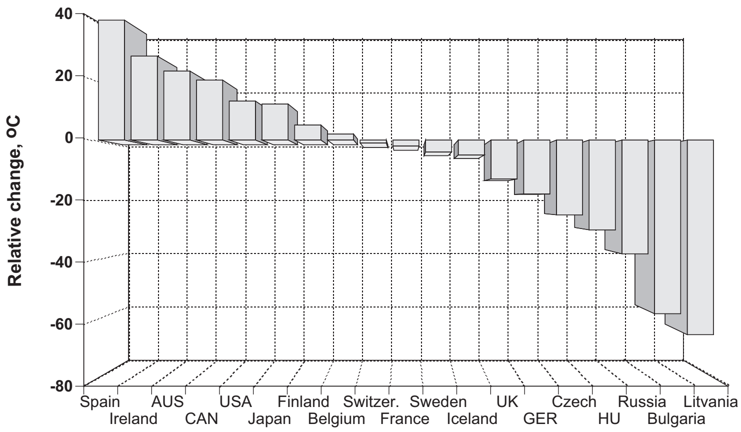

Figure 17. Present greenhouse gas emissions of different countries compared to the level in 1990.

Emission trading is just getting under way and it might be very significant in the future (Bird, 2005). Although only a short time has passed, the financial conditions of emission trading have taken shape and the following average data characterize the present situation:

- Price : ≈ 7 €/ allowance
- Selling unit : 5,000 allowances
- Transaction : 10,000-20,000 allowances
- Weekly volume : 10 million $

The recent trade volumes and the market are still small but they are growing rapidly , and so is the price of an allowance, as the accord took effect. Society has high hopes for emission trading and the Kyoto accord, but some scepticism can also be met. Summarizing the pros and cons, the following arguments can be listed:

Benefits:
1. the accord and emission trading imposes sanctions against the major CO_2 emitting sectors,
2. it encourages the reduction of greenhouse gases emission and
3. it urges the building of clean energy facilities.

Drawbacks:
1. the sanctions do not stop greenhouse emissions,
2. positive discrimination does not encourage technological improvements in those sectors that benefit from emission trading and
3. the new actions do not stop or decrease the concentration of CO_2 and greenhouse gas in the atmosphere.

Thus, parallel with the proposals of the Kyoto accord and emission trading it is fundamental to search for efficient actions and technologies which will provide economic and environmentally-friendly solutions to increase CO_2 and greenhouse-gas absorption and removal from the atmosphere (Orr, 2004). Such options might include:
1. prohibition of clear-cutting and burning of rainforests,
2. planting of more coniferous and deciduous forests world-wide, and
3. sequestration of CO_2 and other greenhouse gases in geological formations, including injection into oil reservoirs, gas-tight underground storage facilities, coal seams and permafrost formations as gas hydrates.

The present decision-makers and stake-holders (scientists, engineers, politicians etc.) cannot shift the responsibility of safeguarding our blue planet and the life of future generations onto somebody else. *The apparent anthropogenic effect on climate clearly proves that the earth is extremely vulnerable to even marginal changes in the atmosphere, hydrosphere and lithosphere. Therefore, all efforts to diminish man-made influence are of* *vital importance for future generations.* The time is short, the task is tremendous, but integrating efforts will allow the main goals to be fulfilled.

7. CONCLUSIONS

1. Fossil fuels will remain important elements of the energy scenario in the 21st century;
2. Emission of CO_2 and other greenhouse gases will increase until the middle of the century;
3. Diversification of energy sources using renewable energy is fundamental;
4. Replace fossil fuels with biomaterials, fusion and hydrogen energy;
5. Geological evidence shows that levels of CO_2 and other greenhouse gases have remained relatively stable on Earth for the past thousand years;
6. The natural and unnatural increase of greenhouse gases may cause global warming on earth;
7. Climate fluctuates naturally between warm and cool periods. Some researchers say that the 21st century has seen the greatest warming in at least a thousand years, and natural forces can't account for it all;
8. Solid evidence for greenhouse warming has not yet been found, but there is an agreement that CO_2 concentration in the atmosphere is increasing. However, there is no real consensus yet that this is responsible alone for global warming;
9. Despite different arguments it seems evident that anthropogenic CO_2 emissions are relatively small, but their decrease may beneficially influence global warming;
10. The apparent anthropogenic effect on climate clearly proves that the earth is extremely vulnerable to even marginal changes in the atmosphere, hydrosphere and lithosphere. Therefore, all efforts to diminish man-made influences are of vital importance for future generations;
11. Emission trading and sequestration of CO_2 and greenhouse gases have priority in the coming decades.
12. International cooperation is necessary to develop efficient, economic and environmentally-friendly methods, technologies and solutions to reduce emissions of CO_2 and other greenhouse gases and to diminish their concentration in the atmosphere.

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