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CARBON DIOXIDE EMISSION FROM FOSSIL FUELS; MAJOR COMPONENT OF GREENHOUSE GASES

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Forecasts by 2020, referring to the worldwide energy production, fossil fuel utilization, carbon dioxide emission and averaged global temperature increase are reviewed. By 2020 the CO_2 emission from fossil fuels will show 70% increase compared with the 1990 emission; and 90-fold increase compared with the preindustrial emission. The dioxide is currently responsible for 60% of greenhouse (GH) effect. The percentage would definitely be higher on future increase of anthropogenic CO_2 emission. Even if CO_2 and other GH gases are not exclusively responsible for the already stated climate warming, they significantly contribute to it. Pathways aimed at preventing further warming by suppressing CO_2 emission are described. They include separation of CO_2 from energy producing systems and its sequestration. Underground sequestration seems to be the best option although some barriers resulting from insufficient knowledge still exist. They refer to eventual CO_2 seepage from geological deposits, which would be hard to be monitored and hold back. Ocean sequestration has to be questionable as long as its impact on sea biota is unknown.

Worldwide energy demand and availability of various energy sources

According to International Energy Outlook 2001, world energy consumption by 2020 is expected to increase three times the amount of energy produced in 1970; and to rise by 59% compared with the energy production in 1999 [1]. Thus, the expected 2020 energy consumption will amount app 607 quadrillion Btu (607×10^{24} Btu = 640×10^{24} kJ since 1 Btu = 1.0548 kJ). This is 37 quadrillion Btu less than the amount projected in 1998 [2]. Some uncertainty of the forecast depends on duration and severity of economic crisis in Asia. Another factor that could influence the forecast is whether the Kyoto protocol will finally become effective. As of February 2001, the Protocol had been ratified by only 32 states. They produce less than 55% of the total 1990 carbon dioxide emission, which is the least amount, required under the terms of the treaty to make the treaty effective.

Renewable resources [1]

The expected by 2020 contribution of renewable resources (hydroelectricity, wind, solar, geothermal, biomass) in the production of energy amounts approximately 8% [1]. The relatively low future contribution results from the following circumstances. The present level of energy production from the renewables is low, 9% of the total energy produced. One can hardly expect the fast production increase since energy produced from the resources in question is estimated to be more expensive compared with energy obtained from fossil fuels. It is clear therefore, that this branch of energy production needs to be subsidized. European Union is a good example; the Union is planning to efficiently subsidize the development of energy production from renewable resources and to achieve 12.5% contribution by 2010.

Hydroelectricity is presently assessed as exerting a negative impact, resulting from dams' constructions, on local communities as well as on environment (see the chapter "Environmental Impacts of Hydropower" in [1]). Biomass use for energy production seems to be limited to small local power plants, in order to keep low the ratio of energy used for biomass transportation and energy obtained from the transported biomass.

Nuclear energy [1,3,4,5,6]

In 1999 as well as in 2001 [1], the future role of nuclear energy is expected to amount only 3 to 4% of global 2020 energy production (compared with 6% produced in 1995). The forecast [1,3] is based on the fact that no plans are presently made of constructing new nuclear plants neither in North and South America nor in European Union. Data referring to the USA [4], indicate that investment costs as well as operational costs of nuclear plants are significantly higher compared with the conventional plants using fossil fuels. Moreover, the problem of save and permanent disposal of nuclear wastes has not been solved as yet. The present state of the problem was described in a 2001 report prepared by the US Committee on Waste Disposal [5] and in March 2002 report prepared by the US Department of Energy [3]. The Committee recommended continuing the construction of Yucca nuclear waste disposal site (Nevada). The Yucca Dumpsite is an extremely expensive venture (in total over 50×10^9 USD from Federal budget) aimed at permanent storage of 75 000 t of nuclear wastes [6]. At present, the wastes are temporarily stored in 139 places ("disposition sites"). Such facilities require an ongoing vigilance and expenses to isolate the waste from the society as well as from natural environment. These rather not favorable circumstances for the development of nuclear energy became even much worse after September 11, 2001. The eventual protection of nuclear plants from terrorist attacks would highly raise the costs of energy production. Thus, even the projected 4% contribution to the world energy production seems to be questionable.

Fossil fuels [1,7]

The global increase of energy production (2.3% per year) is expected to take place by means of increasing use of natural gas, crude oil and coal. Among all energy sources, natural gas use will grow most rapidly, by 3.3% annually over the next 20 years [1] and is expected to contribute 28% of the world energy production by 2020. The gas resources are fairly widespread and the gas burns more cleanly and more efficiently than other fossil fuels. The efficiency of electric power production can be increased from the current average coal-fired plant of 34% to over 55% for a modern natural gas-fired turbine combined cycle plant [7]. Most likely, gas use surpasses coal already by 2003 and will continue to dominate the coal in next years.

By 2020 crude oil consumption is expected to reach 41% contribution of the world energy production [1]. In the industrialized countries, oil use continues to grow significantly in the transportation sector where petroleum fuels have limited competition from other energy sources.

Coal use is expected to moderately increase over the projection period (1.5% annual growth). Worldwide coal consumption will reach about 5.8×10^9 t by 2020 (4.2×10^9 in 1999). The largest increases in coal uses are projected for Asia, especially for China and India. Together these two countries account for more than 90% of the projected rise in coal use in the developing world. However, the coal share of total energy production decreases over the projection period from 25% in 1995, and from 22% in 1999 to 19% in 2020. Coal's role in worldwide energy use has shifted substantially over the last 25 years. Now it is primarily used for electricity generation and in a few key sectors such as iron and steel, cement and chemicals industries.

Summing up, the total contribution of gas (28%), oil (41%) and coal (19%) to the world energy production by 2020 is expected to amount app 88% [1]. Thus, the current estimates are several percent higher for gas and oil and 5% lower for coal compared with the contributions projected in 1998.

Carbon dioxide emission [1,8,9]

Carbon dioxide emission resulting from fossil fuel use, is derived from the projections of energy and energy resources consumption. The past, present and future annual world CO_2 emissions from fossil fuels are:

Before 1863	0.4×10^9 t CO_2	(0.11×10^9 t C)
In 1970	14×10^9 t CO_2	(4×10^9 t C)
Current emission	22×10^9 t CO_2	(6×10^9 t C)
By 2010	28.6×10^9 t CO_2	(7.8×10^9 t C)
By 2020	36×10^9 t CO_2	(9.8×10^9 t C)

The 2020 emission would be 70% higher compared to the amount emitted in 1990 [1]. The emission is projected to grow by an average of 3% per year [1]. It is worthwhile to compare the data in question with CO_2 emission before 1863 *i.e.*, before the industrial era [8]. The preindustrial emission was several dozens less than the current and the projected emissions.

A comparison of the emissions resulting from combustion of 1 ton of various fossil fuels is as follows:

Natural gas (100% CH_4)	–	2.7 t CO_2
Crude oils (82 to 87 wt% C)	–	3 to 3.2 t CO_2
Coals (80 to 92 wt% $C_{as\ rec}$)	–	2.9 to 3.4 t CO_2;

and on the basis of energy produced:

Natural gas – 56 kG CO_2/GJ; Crude oil –- 74 kG CO_2/GJ; Coal – 95 kG CO_2/GJ.

Hence, substituting oil and first of all, coal by natural gas is most beneficial from the point of view of carbon dioxide emission.

Carbon dioxide – major component of greenhouse gases (GHG)

The anthropogenic GHG are: CO_2, methane (CH_4), nitrous oxide (N_2O), and halogen-carbons. On a molecular basis, all the three are more potent greenhouse gases than CO_2 since their molecules absorb more infrared radiation emitted by earth surface. However, the concentrations of the two gases are several hundred times lower compared with the CO_2 and of halogen-carbons – even much lower. At present, 60% of greenhouse effect (which is measured in Watt/m^2) is ascribed to CO_2, 20% is due to CH_4, 6% due to N_2O and 14% due to halogen-carbons [9]. More detailed characteristics of the anthropogenic GHG as well as of ozone and water can be found elsewhere [9].

Assessment of recent (1990–1999) partitioning of anthropogenic CO_2 between land and ocean uptake and atmospheric increase is as follows: approximately 27% of the CO_2 total amount emitted by fossil fuel combustion, is absorbed by oceans; 22% of CO_2 is consumed by land vegetation and 51% contributes to an increase of CO_2 concentration in atmosphere [9]. Thus, it is clear that neither oceans nor land vegetation can stop an increase of anthropogenic CO_2 concentrations in atmosphere and in GHG. They can only slow down the increase.

Measurements of CO_2 concentration in air trapped in ice cores indicate that the pre-industrial concentration was approximately 280 ppm. At the beginning of 19 century, the concentration started to increase. Accurate measurements of atmospheric CO_2 began in 1958. The annually averaged concentration of the gas in the atmosphere has risen from 316 ppm (parts per million, molar) in 1958 to 367 ppm in 1999 [8,9].

Climate warming

The global averaged surface (oceans and land) temperature has already increased and is projected to rise significantly by 1.4 to 5.8°C over the period to 2100 [8,9]. The projected rate of warming is much larger than the observed changes during the 20 th century and is very likely to be without precedent during at least the last 10 000 years [9]. There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities [9]. The activities are: changes in land use (mainly deforestation) and energy production from fossil fuels. Land use and its change are out of the scope of the present paper. However, it should be pointed out that current deforestation is estimated to be 10×10^6 to 17×10^6 ha per year [10].

Pathways to stabilization GHG emissions from fossil fuels use are as follows [11]: the first one is to use energy more efficiently (one of the most effective means would be to convert liquid fossil fuel into hydrogen for fuel cells and use them instead of internal combustion engines). The second pathway is to switch as much as possible to wind, solar, geothermal and biomass energy as well as to natural gas and hydrogen. A third way is carbon dioxide removal from energy systems and its permanent storage (sequestration). The latter is discussed in the next sections. It seems, all the three pathways should be simultaneously converted into large scale operations if GHG emissions are to be stabilized. Without the activity of the USA (its current CO_2 emission amounts 25% of the total worldwide emission), and contributions of China and India in a near future, one could hardly say about a success in this field.

Carbon dioxide separation from flue gases

The present and future technologies of the separation are described elsewhere [11–13]. Majority of them seems to be realistic. However, there are key issues involved such as high capital and operation costs as well as energy use which consumes about 20% of the energy produced by a power plant equipped with the CO_2 separation unit. Current cost estimates of carbon dioxide separation from existing coal-fired power plants are 30–50 USD/ t CO_2 [11].

Geological sequestration

Geological formations are likely to be the first large-scale options to be considered for CO_2 storage due to the experience gained from oil, gas and coal exploitation and knowledge of their formations [11].

Injection of CO_2 into oil formations for enhanced oil recovery is a mature technology already used on a large scale. Currently in the USA, a total of about 30×10^6 t CO_2 per year is injected into oil geological deposits for its enhanced recovery [13,14]. In Canada [15] large-scale experiments are carried out (2001–2003); 5 000 t CO_2 per day is pumped into near-depleted oil reservoirs (Weyburn oil field, Saskatchewan). Similar possibilities refer to the carbon sequestration in near-depleted natural gas deposits. Injections of CO_2 into near-depleted oil and gas deposits can enhance the recovery of oil and gas, which in turn would help lowering the costs of sequestration.

Another option is CO_2 sequestration in deep coal seams that are beyond the reach of mining. There is however, lack of criteria for identifying favorable coal formations with respect to their adsorption capacity. In Canada [15], studies are carried out aimed at finding the answer whether injection of CO_2 or unseparated flue gases (they contain large amount of nitrogen) would be more profitable.

Sequestration in saline formations is also considered. Statoil, Norway's state oil company began in 1996 storing CO_2, separated from the natural gas they obtain from Sleipner gas field, into saline sandstone 1000 m beneath the North See. Carbon dioxide is injected at a rate of 20 000 t/week [14], the amount that corresponds to the rate of CO_2 produced from 140 MW coal fired power plant.

All the same, some troublesome issues and barriers are still associated with all the underground sequestration. They are: unknown long-term effects of CO_2 on reservoir impermeability and probability of gas seepage that would be difficult to be monitored and impossible to hold back [11].

Ocean sequestration

Phenomena associated with CO_2 sequestration in oceans depend on an injection depth of the gas [11,16,17]. When the gas is injected at the depth less than approximately 2800 m, its bubbles or hydrates tend to migrate up to the ocean surface but they also simultaneously dissolve in water. Below 2800 m due to high pressure, CO_2 shows higher density than seawater and therefore, tends to drop down to ocean floor. The conclusion is that the deep injection offers the best possibilities of permanent deposition of the gas. However, such deep injection would be very expensive and hard technically. Injection at the depth of several hundred meters is associated with a risk that some upward streams occurring in oceans can bring the gas to water surface. This would end at the desorption of CO_2 into atmosphere. Moreover, no matter what is the injection depth, there is inadequate scientific understanding of the ocean carbon cycle and thus, entirely unknown environmental aspects of increased carbon storage in oceans [11].

Proposed pathways include also an indirect sequestration through the enhancement of the ocean's CO_2 uptake from the atmosphere. Large-scale ocean experiments are already carried out; fertilizers such as iron and phosphorus compounds are supplied to surface water with the aim to stimulate phytoplankton growth [11,18]. This is extremely dangerous venture if one takes into account the following experience. Tropical toxic algae that were grown in Europe and in USA in aquaria had undergone mutagenic changes resulting from fertilization in aquaria. The changes make them resistant to lower temperatures. They found their way (possibly by sewage systems) to Mediterranean Sea coast and San Francisco Bay coast. They grow there at very fast rate since they do not have natural enemies in this new environment, and destroy sea life around. This experience should definitely stop any ocean fertilization experiments.

CONCLUSIONS

- World energy consumption by 2020 is expected to increase app 60% compared with the 1999 energy production.
- The total contribution by 2020 of petroleum, gas and coal to the world energy production is expected to amount app 88%. Renewable resources will contribute about 8% to the world energy production.
- The nuclear energy is estimated to amount by 2020 only 3–4% of the global energy production. The stagnation is a result of unresolved problems of nuclear wastes permanent storage and of high capital costs.

– Carbon dioxide emission by 2020, resulting from the increasing fossil fuel use, is projected to be 58% higher compared with the 1999 emission.
– There is a need to suppress anthropogenic CO_2 emission with the aim to prevent further climate warming.
– Three pathways should be simultaneously followed: (a) more efficient production and use of energy; (b) switching as much as possible to wind, solar, geothermal and biomass energy as well as to natural gas and hydrogen; (c) CO_2 removal from energy producing systems and its sequestration.
– Geological sequestration seems to be a realistic and safe option compared with ocean sequestration.

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