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World energy demands and coal reserves

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Spotreba svetovej energie a zásoby uhlia

On the basis of the expected increase in the world's population and taking the estimated improvement in both technology and living standards into account, the paper forecasts energy demands. In 2000, actual energy consumption was 380-400 EJ.year^{-1}, the forecast for the year 2050 is 600-1,050 EJ.year^{-1}, while for the year 2100 it is 900-3,600 EJ.year^{-1}. On the basis of the expected shares of the different fuels (coal, mineral oil, natural gas, nuclear energy, renewable energies), it can be assumed that in 2050 coal demand will be between 122-200 EJ.year^{-1} while the total coal demand for the 45 years ahead is estimated to be 5,500-6,900 EJ.year^{-1}. This rate of demand basically involves an approximately 2 % increase every year.

On the basis of data in relevant literature, the world's coal reserves are: the industrial coal reserve is 800-1,000 · 10^9 tons, the geological stock is 5-15 10^{12} tons and the expected stock is 8-35 10^{12} tons. The world's industrial coal reserve (which is economically exploitable at the present technological level) guarantees supply for 200 years while the detected geological stock guarantees supply for a round 1,000 years.

Key words: *coal reserves, world energy demands*

Introduction

The material affluence, living standards and indirectly the culture of a society are usually characterised by the specific value of gross domestic product (GDP). As it has been proved by many, the economic and living standards of a country are also characterised by the extent of energy use [GJ.person^{-1} year^{-1}].

Its natural endowments, i.e. the quality of soil and the amount of mineral resources, influence the economy and the living standards of a country, too.

There are, however, other factors that exert an influence, e.g. intellectual work and technical standards are also determining factors. An example is provided by Switzerland, where high living standards are ensured despite the modest raw material resources and the unfavourable conditions of agriculture.

The level of development and the living standards of the population are commonly characterised by specific energy use. While, for example, in North America the use of primary fuels was 325 GJ.person^{-1}.year^{-1}, it was 205 GJ.person^{-1}.year^{-1} in Australia and Oceania, 136 GJ.person^{-1}.year^{-1} in Western Europe, the same factor being 35 GJ.person.$^{-1}$.year^{-1} in Central and South America, 24 GJ.person^{-1}.year^{-1} in Asia and 13 GJ.person^{-1}.year^{-1} in Africa. The relative values of the final energy use per person per year in proportion to the unit of world average (1.00) are: United States 4.10; Western Europe 2.20; Hungary 1.50; China 0.33; India 0.11 and Black Africa 0.01 [1].

Recently, in the political, social, technical and economic scenes and primarily in the debates initiated by the "green" organisations, the question is raised again in what proportion it is possible and necessary (suitable) to fulfil the energy demands of the present and the future by using fossil fuels (coal, mineral oil, natural gas) and in what proportion it is necessary (possible) to utilise renewable energy sources (solar, wind, water, geothermic and bioenergy). With good intentions but in many cases non-professionally, the loud supporters of the utilisation of renewable, and, as they are often called, "clean" primary energy sources, only and exclusively emphasise the environmental impacts when arguing against the use of fossil and nuclear fuels, ignoring the technical and economic limitations and problems of the utilisation of renewable energies.

According to expert opinion, the amount of renewable energies that can realistically be exploited is not as limitlessly large as it is supposed by many. Therefore it is an illusion to expect that mineral fuels and nuclear energy may exclusively be replaced or substituted by relying on renewable energies. Renewable energies represent an important opportunity but may only contribute to the energy supply of the world instead of offering a radical solution. Due to the relatively high investment costs involved, it cannot be expected that they will soon become widespread [2].

Energy Demands in the 21st Century

The long-term (30-50-100 years) energy demands of the population of the Earth are basically determined by the number of people and specific energy consumption, the level of supply. Therefore, it is not

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an easy task to specify the total energy demand of the future. On the one hand, the increase in population in the different continents will be different due to the different cultural levels, and on the other hand, as we have seen, the increase in specific needs greatly depends on the present supply level, too.

Figure 1 shows the increase in the Earth's population according to different forecasts. They state that the population (inner relation) of the industrialised countries (Western Europe, North America) will show only a minimal increase while the world's total population will increase considerably. Due to the great uncertainty involved, there is a significant difference between the low-pessimistic, medium-realistic and high-optimistic estimations. Prognoses for 2050 show a deviation between 8-11 billion whereas those for 2100 show one between 8-14 billion [1,4,5].

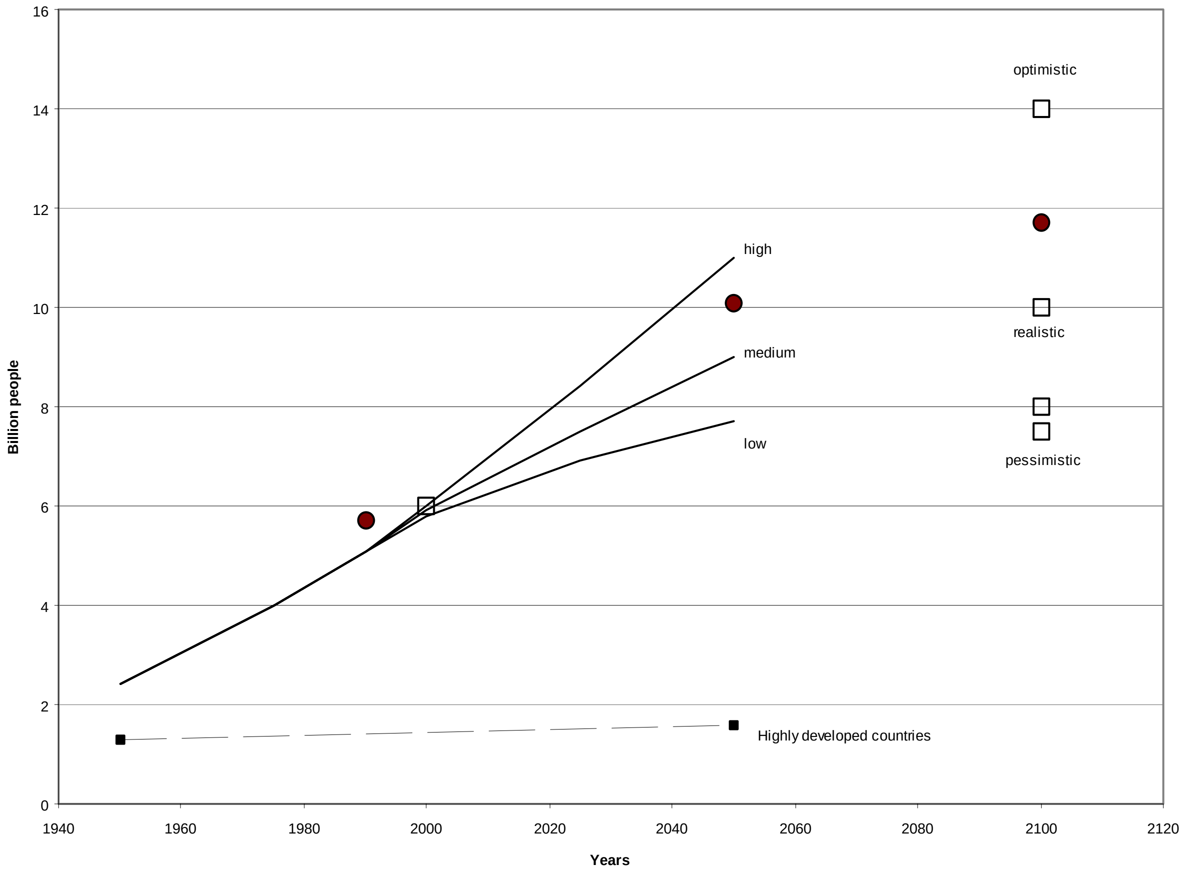


Fig. 1. *Prognoses for world population, Vajda Gy.* ———— ‐‐‐‐‐‐‐‐, *Lakatos I.* □, *S. Kumár* ●.

Prognoses of energy demand are based on the forecasts of population increase and the estimations of specific energy demand. Figure 2 shows the estimations of total primary energy demands by different authors. The actual use in 2000 was 380-400 EJ.year^{-1}, prognoses for 2050 predict 600-1,050 EJ.year^{-1} while those for 2010 estimate it to be between 900-3,600 EJ.year^{-1}. There is a significant difference between the data of the limited, medium and high rates of increase [1,2,3,4,5]. The dotted line in the figure indicates the lowest demand, which is adopted from Fig. 4, publication [12] referring to I. Yantovska after the data of Geothermal Explorers Ltd.

On the basis of Fig. 2, we can assume that taking the present use of primary fuels (fossil, nuclear, renewable energies) into account, a total energy demand of 700-1,000 EJ.year^{-1} may be expected for the 2050s. Perhaps the data of the 2100 prognosis, showing considerable deviation, are not worth investigating in greater detail with regard to the fact that it is not realistic (considering time and efficiency) to take into account basically new fuels or technologies (fusion energy, production of hydrocarbons from CO_2).

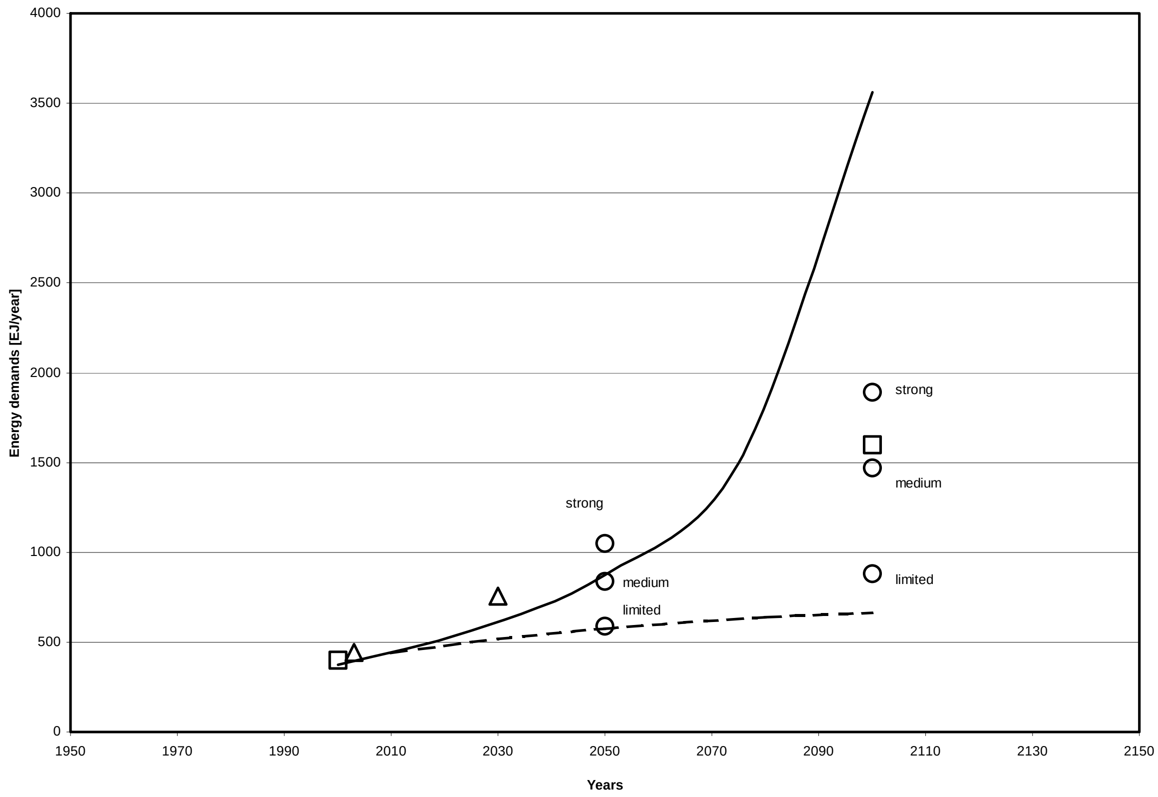


Fig. 2. Prognoses for world energy demands, Vajda Gy. ——, *Lakatos I.* □, *Büki G. Δ, S. Kumár* ○, *I. Yantovska* ---.

Energy Types, Expected Rates of Use

It is convenient to rely on the present data in the prognostications of the expected rates and demands. According to György Vajda [1,2], in the years 2000-2005 the world's primary energy use was: mineral oil 34 %, natural gas 22 %, coal 31 %, altogether 87 %, nuclear energy 6 % and renewable energies 7 %.

According to Gergely Büki's data [3]: mineral oil 37.5 %, natural gas 23.1 %, coal 25.6 %, altogether 86.2 %, nuclear energy 6 %, renewable energies 7.5 %.

Similar data are published by József Pápay with reference to Exxon Mobil [6]: mineral oil 37 %, natural gas 26 %, coal 21 %, altogether 84 %, nuclear energy 5 %, water-biomass-solar energy- wind 11 % altogether.

Shaski Kumar gives the following data for the year 1990: mineral oil 34 %, natural gas 19 %, coal 24 %, altogether 77 %, nuclear energy 5 % and all the renewables including water: 18 %.

According to the actual data presented, at the turn of the millennium (2000) 77-87 % of the world's primary energy demands were covered by fossil fuels while nuclear energy accounted for 5-6 % and renewable energies for 7 % or 8 % together with water.

Naturally, there are greater differences in the prognoses in the analysis of long-term (30-50 years) possibilities of future supply.

Gergely Büki forecasts a 84 % rate of fossil fuels for 2030 with a 10-11 % rate of renewables [3].

Taking a total energy demand of 700-1,000 $EJ.year^{-1}$ into account, Shaski Kumar gives the following rates for the different rates of growth: mineral oil 18-32 %, natural gas 19-32 %, coal 10-32 %. He sets the rate of nuclear energy at 4-12 % and that of all the renewable energies between 22-39 % [4].

In his forecast until 2100, György Vajda assumes a realistic rate of 13-16 % for renewable energies as the maximum potential of these energies is a round 30 % [1, 2].

József Pápay assumes a 11 % rate of renewable energies until 2030 [6]. The prognosis of the International Energy Agency (Paris) gives a 30-40 % rate of renewable energies for 2060.

Besides the rates, the amount of the particular energy types is naturally a basic indicator, too. On the basis of the exactly 400 EJ. $year^{-1}$ use in the year 2000, the 85 % rate of the fossil fuels equals an amount of 340 EJ.year, within which the average 36 % rate (34-37.5-37-34) of mineral, oil equals

144 EJ. year^{-1}, the average 23 % rate (22-23.1-26-19) of natural, gas equals 92 EJ. year^{-1} and the average 26 % rate (31-25.6-21-24) of coal equals 104 EJ.year^{-1}.

According to the aforementioned and the data in Fig. 2, total primary energy demand may be expected to be between 700-1,000 EJ.year^{-1} in 2050.

For 2030, G. Büki and J. Pápay forecasts a 84-94 % rate of fossil fuels while S. Kumar gives the figure 51-73 % for 2050. The expected average value of the latter prognosis is 62 %, within which the average rates of the individual fuels under the different (strong, medium and limited) ecological conditions of growth are the following:

- mineral oil 21 %,
- natural gas 24 %,
- coal 16 %.

Taking the average value of the estimated data given by G. Büki, J. Pápay and S. Kumar, the rate of fossil fuels in the year 2050 is estimated to be a round 70 %, within which the rate of mineral oil is 27 %, that of natural gas is 23 % and that of coal is 20 %.

Assuming a lower limit of 700 EJ.year^{-1} in the estimation of demands, the demand for mineral oil is 189 EJ.year^{-1}, that of natural gas is 161 EJ.year^{-1} and the value for coal is 140 EJ.year^{-1}. In comparison with the 340 EJ.year^{-1} use in 2000, there is a 44 % increase with an annual 0.9 % average increase. The average of the actual use in 2000 and the prognosis value for 2050 for the individual fuels is:

- mineral oil 165 EJ.year^{-1},
- natural gas 127 EJ.year^{-1},
- coal 122 EJ.year^{-1},

and the total demand for the 45 years between 2006 and 2050 is:

- o mineral oil 7,425 EJ.year^{-1},
- o natural gas 5,115 EJ.year^{-1},
- o coal 5,490 EJ.

If we calculate with the upper limit of 1,000 EJ/year estimated for 2050, then the demands for 2050 (again with an inner rate division of 27, 23 and 20 %) are the following:

- mineral oil 270 EJ.year^{-1},
- natural gas 230 EJ.year^{-1},
- coal 200 EJ.year^{-1}, which shows a 106 % increase compared to the use in 2000 with a round annual increase of 2 %.

The 'average' of the actual use in 2000 and the prognosis value for 2050 for the individual fuels is the following:

- mineral oil 207 EJ.year^{-1},
- natural gas 161 EJ.year^{-1},
- coal 152 EJ.year^{-1},

and the total demand for the 45 years between 2006 and 2050 is:

- o mineral oil 9,315 EJ.year^{-1},
- o natural gas 7,245 EJ.year^{-1},
- o coal 6,840 EJ.

Therefore, the expected limit values for the fossil energy demands of the coming 45 years based on the estimations of experts is:

- mineral oil 7,500-9,400 EJ,
- natural gas 5,700-7,300 EJ,
- coal 5,500-6,900 EJ.

Thus it is the question of the future to what extent and for what period the so far (at present) explored industrial (verified) reserves of fuels will fulfil these demands, and what newer resources will be provided by the detected geological resources, the resources to be found in the future and the production increasing effect of the technologies under the economic-market conditions of the given period.

On the basis of the energy (EJ) and production (109 t, 1012 m3) data, the specific heat content and average heating value of fossils fuels are (world average):

mineral oil 40 GJ.t^{-1} natural gas 40 GJ.10^{-3} m^3 coal 25 GJ.t^{-1}.

Coal Resources and the Level of Supply

It presents a factor of uncertainty in the comparison of coal resource data on the world level that the extent of exploration and the reliability of the estimations of coal reserves may differ both from country to country and in the different sources. Different interpretations may be involved in the consideration of industrial and verified reserves, and workable, exploitable, geological, estimated and expected stocks. As it is with the majority of mineral resources, it may be the case with coal, too, that in the different areas exploration has been done with methods of different levels (different reliability) so the limits of exploration depth may vary. It can also be assumed that the exploration levels of the different continents are not identical (either horizontally or in depth).

The qualification 'workable' or 'explorable' may be assigned according to different technical-economic criteria in the different countries, and may also differ for anthracite, black and brown coals and lignite.

The present publication uses these terms with the following definitions.

Industrial reserve: given the present technological level, the reserve that can be exploited economically and is well explored [7].

The definition of verified reserve as adopted from a source: 'under the given market conditions, it is the stock that can be economically exploited with the available technology ... Neither of the conditions is constant.' [8].

At a given level of probability, the part of our estimated geological resources changing in time can be regarded as reserve. Geological resource: the resources possessing the parameters (thickness, quality) characteristic of mineral resources, which is verified by research data. It is the resources calculated without any technical or economic limits.

Expected resource: the amount of mineral resources estimated on the basis of geological assumptions.

Before presenting the data in current publications, it can be stated that the questions of energy supply no longer arise only as scientific but as philosophical or poetic issues, as well. At the end of the 19-th century, the authors of study [13] wrote the following: 'There is no other question in natural sciences with which scientists and laymen would be concerned so much as the problem of what will provide fuel if coal runs out on the Earth.' Later they write: '... and coal is actually running out'. In the same paragraph the following data can be found:

- the coal reserve of Great Britain amounts to about 100 billion tons ... it will run out in 435 years.
- Belgium, Prussian Silesia and Russia possess the highest amount of coal but not even this will be able to meet the rising demands for longer than 500 years.
- According to Hall, North America would be able to cover the present demands of the world for 10,000 years.

In contrast to this (these worries), the same authors write the following:

'Let us not be desperate, however, about the fuel of the future. As human genius is conquering newer and newer territories, it may find such resources that nobody can even dream about today ... and it seems that the energy necessary for the machines will be provided all the time.'

(Note: It is especially unnecessary to supply coal for 200, 500, 1,000 or 10,000 years if coal-based power plants will be closed down for environmental reasons, anyway.)

Let us see more detailed coal reserve and prognosis data from the same, more remote period of the past (1944). Kálmán Sztrókay covers the issue in his book entitled Föld, víz, tűz, levegő ('Earth, water, fire and air') [14]. (Note: he wrote this in 1944.)

The brown coal resources (in the present terminology: geological resource) of the Earth is 3,000 billion tons, of which 400 billion tons can be safely calculated with (in the present terminology this is the industrial reserve). Black coal resources amount to 4,400 billion tons, of which the industrial reserve is 300 million tons. Converting resource data into a 7,000 calorie black coal equivalent, the author gives the following reserve, production (for the year 1929) and supply data:

	Coal reserve 10^6 tons	**Annual production** 10^6 tons.year^{-1}	**Level of supply** [year]
Europe	790,650	605	1,300
America	3,449,700	533	6,500
Asia	1,216,000	69	17,400
Africa	57,230	11	4,800
Australia	148,900	19	7,800
	5,662,480		

As we will see later, the reserve equivalent to $5.7 \cdot 10^{12}$ tons (7,000 kcal/kg) is within the range of the geological resource for black and brown coals estimated to be $5\text{-}15 \cdot 10^{12}$ tons nowadays.

Kálmán Sztrókay gives production prognoses, too – taking into account an annual 5 % increase in black coal and 10 % increase in brown coal production in 1944, he comes to the conclusion that the coal resources explored at that time 'will run out in exactly two hundred years'.

The book, which is among the first publications to touch upon the issue of sustainable development in the analysis of energy demands and resources, writes the following on the topic of the production and supply of fossil fuels (coal, mineral oil, natural gas) in relation to the new dominance of mineral oil and natural gas over coal: 'It is the solution on the world level to the coal problem – and this problem, as it has been mentioned, is that of surplus and not that of want - ...' [15].

Here, the resource data given in the different publications are put in the abovementioned three categories. It reveals the uncertainty of the data, the exploration rate of the expected Russian reserves is 5.4 % while in the other countries of the world – and the author surely had the countries with the traditional rate in mind – this value varies between 11-87 %. (It is doubtful, however, what % refers to here.)

After the United States of America, Russia possesses the second largest coal resources in the world according to present research. The Russian geological resources amount to 5,335.3 .·10^9 tons, which accounts for 35.9 % of the geological resources of the world. Calculated from these data, the geological resources of the world amount to a round 15,000·. 10^9 tons.

According to data supplied by the Hungarian Geological Service [7], the world's industrial reserve of black coal is 519,062 10^6 tons, which will be enough for 150 years at an annual production rate of 3,460·10^6 tons, while the 465,391·10^6 ton brown coal reserve ensures supply for 545 years at an annual production rate of 853·10^6 tons. The total reserve of 984,453·. 10^6 tons ensure supply for an average 228 years at an annual production rate of 4,313·10^6 tons.

According to György Vajda's data [1], the world's industrial black coal reserve is 510 10^9 tons, the brown coal reserve is 475·. 10^9 tons, altogether 985 . 10^9 tons, which will ensure supply for an average 219 years at an annual production rate of 3.6 + 0.9 = 4,5 .·10^9 tons.year^{-1}. The industrial black and brown coal reserves of the eight most important countries (Russia, USA, China, Australia, Germany, India, Poland and South Africa) amount to altogether 817 . 10^9 tons. The author estimates the geological resources of the world to be 4,000·. 10^9 tons and the expected resources of seven countries (Russia, USA, China, Australia, Germany, India and Poland) to be 8,800·. 10^9 tons.

The study published by EUROCOAL [9] gives industrial coal resource data in two dimensions 670 10^9 tons of industrial reserve – 4.5 . 10^9 tons/year production – supply for 149 years 624 . 10^9 toe (mineral oil equivalent) – 3.875 . 10^9 toe/year production – supply for 161 years.

Klaus Brendow is another author who deals with the question of the world's coal resources and the expected prospects of coal production [10]. The world's industrial reserve is 510 . 10^9 tce (coal equivalent) of black coal, 200 . 10^9 tce of brown coal, altogether 710 . 10^9 tce, which ensures supply for 160 and 460 years respectively, and for 196 years on the average. Geological resources are: 6,000 . 10^9 tce black coal and 2,700 . 10^9 tce brown coal, altogether 8.700 . 10^9 tce.

In addition to the resource data, Klaus Brendow also publishes production prognosis data adopted from various sources (EU-WETO, WEC/II, ASAB, IEA(2004)). Given the base value of 3.4 . 10^9 tce for 2000, he forecasts the 2020 production as 3.7 . 10^9 tce and the 2030 production as 3.9-6.8 . 10^9 tce while after the data given by the World Energy Council (London), he predicts the coal production of the year 2100 to be 11 . 10^9 tce. Adding up the coal demand values of the different regions (countries), Klaus Brendow himself calculates coal production to be 7 . 10^9 tons in the year 2030.

According to a study by István Lakatos [5], the industrial reserve is 1,083 . 10^9 tons, of which a round 40 % is black coal.

According to the data given by Shaski Kumar [4], the world's industrial coal reserve (2002) is 519,062 . 10^9 tons black coal, 465,391 . 10^9 tons brown coal, annual production is 2,379.4 . 10^6 toe (oil equivalent) and the average supply level is 204 years. (The publication also gives the 4.7 . 10^9 tons production data, which ensures supply for 209 years.)

According to study [9], the world's geological resources in coal amount to 4,773· 10^9 tons and mankind has so far exploited 3% of the workable amount.

Referring to the data supplied by Bundesastalt für Geowissenschaften und Rohstoffe (BGT), the authors of study [11] speak about supply for longer than 200 years on the basis of the world's industrial coal reserve data and mention a supply of 1,500 years on the basis of the expected (assumed) resources, which presupposes resources of 6,750 . 10^9 tons with an annual production rate of 4,5 . 10^9 tons.

According to the data presented, the world's industrial coal resources can be estimated to be 800-1,000 . 10^9 tons. According to the publications, geological resources amount to 5-15 . 10^{12} tons and expected resources to 8-35 . 10^{12} tons.

On the basis of the industrial reserve data, the level of supply exceeds 200 years, on the basis of geological resource data it is in the range of 1,000 years.

According to the prognosis for energy demand presented in the first part of this publication, a total coal demand of 5,500-6,900 EJ can be taken into account for the period up to 2050, which amounts to 22-30 %, i.e. one third or quarter of the (800-1,000) . 10^9 t x 25 GJ/t = 20,000-25,000 EJ energy content of the 800-1,000 . 10^9 industrial coal reserve. This means that in the next 45-50 years, there will only be demand for the exploitation of the third or quarter of the industrial coal reserve.

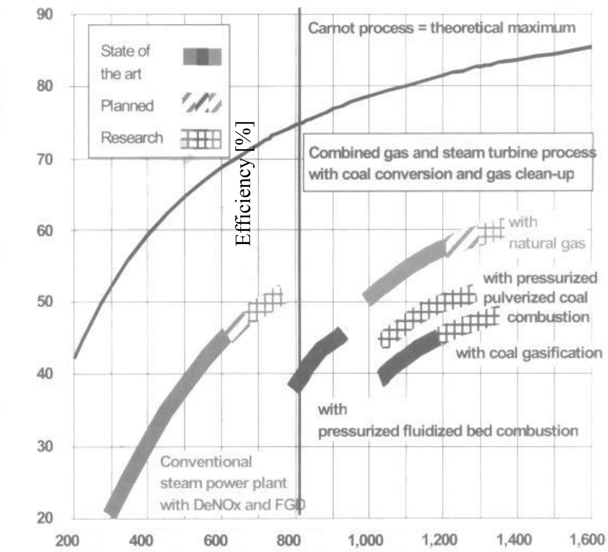
Foreseeably, the coal demands of the world will certainly be covered by the industrial coal reserves for 50-150-200 years. The safety of supply is also ensured by the fact that the production technologies matched to the natural (geological and mining) characteristics that became known during the exploration of industrial reserves are still available (both surface mining and deep working) and the cost (economic) factors of production are controllable and predictable.

During the use of coal in the power industry (for electrical energy production), the present average efficiency rate of 32-35 % (the thermal efficiency of power plants) has already risen to 40-42 % in the industrialised countries, and within 5-10 years even the rate of 55-60 % may be attained. This, of course, means that in the future 20-30-40 % less coal will be needed to produce the same amount of electrical energy. This will, then, increase coal supply to the same extent.

It is favourable for coal supply that there is a ‘relatively’ even regional distribution of coal reserves (among continents), or at least, it is more favourable than that of the known mineral oil and natural gas reserves. Europe possesses significant brown coal reserves and Poland, Russia, China, India, Indonesia, Australia, South America, the USA, Canada, Brasil and Colombia all possess considerable coal reserves. The conditions of Black Africa may be problematic. Lignite can only be utilised locally, but the black coal with high heating value may be economically transported by sea even to long distances (8-10,000 km). Naturally, it is not all the same if coal has to be transported to Marseille, Rotterdam, Hamburg or Berente.

In the utilisation of coal as a fuel, brown coal and lignite are almost exclusively used for electrical energy production while a part of black coal is used in metallurgy and other areas. Technological development is increasing power plant efficiency practically continuously. As a result, the production of the same amount of electrical energy requires less and less coal on the one hand, and parallel with the improvement of efficiency, the amount of combustion products, especially that of sulphur and carbon dioxide, is gradually decreasing.

Figure 3. shows the variation in the efficiency of coal-fired power plants. It shows the variations of thermal efficiency related to the technological level of the power plant as the function of steam temperature. The maximum theoretical efficiency of the Carnot process shows a variation of 40-80 % between temperatures 200 and 1,400 ºC. The figure shows actual and planned efficiency values and those that can be expected according to research results, in relation to the different technological solutions. The present approximately 40 % efficiency can be expected to be raised to 45-60 % thus reducing both specific fuel demand and noxious emissions.



Temperature [ºC]

Fig. 3. *Efficiency of electrical energy produced from coal.*

In addition to its utilisation as such, coal may ‘serve’ energy supply in other ways, as well. The methane content of certain coal types may be tapped without mining production, too. Under certain geological conditions, underground gassing is also feasible. Naturally, these forms of utilisation require special technical and economic conditions.

Likewise, the production of liquid hydrocarbons from coal is a technical and economic issue. With the known technology that has already been applied in emergency situations (embargo), one ton of liquid fuel (petrol, diesel or solar oil) may be produced from 3 tons of black or 5 tons of brown coal (after mining production). Coal may replace natural gas in the chemical industry.

All these forms of utilisation are made feasible by the present coal reserves.

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