ENERGETICS FOR SECONDARY SCHOOLS

Is energy production accountable for climate change?

Electronic workbook

Prepared by:

István Gärtner

Óbudai Árpád Secondary School – Budapest

ELTE Doctoral School of Physics

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Introduction

This workbook has been written for teachers teaching natural sciences in the first place and for interested secondary school and university student in the second. Most probably the question emerges in many of you: What is the purpose of this whole work, why such a workbook is necessary, since the topic is an organic part of our everyday life. Are you sure, however, you know everything correctly about it?

The goal is clear: to hand down useful information and credible knowledge to teachers and students, respectively. In my mind, several factors substantiate its necessity. One is a survey of mine in 2019 when I tried to assess the level of energy related knowledge of secondary school students before graduation. The outcome of the survey was quite negative, I had to face huge shortcomings and faulty knowledge related to the topic. Another reason – more or less justifying the poor results in the foregoing assessment – was the superficial description of energy related information included in the secondary school curriculum, lacking actual data and offered only as a supplementary material. I would like to lend a stop-gap role to this document as it contains a lot of information and data related to the topic and accessible on the Internet which I think ought to be included in general education in natural sciences.

The background material of this workbook comes from the lectures held by Prof. Dr. Ádám Kiss with the title “Energy production and the environment” at the ELTE Doctoral School of Physics in the past few years. It is accompanied by references supplied with a web address or number, which allow a kind of browsing in the topic for both teachers and students. In this way, everyone can further deepen their knowledge individually, but it must also be taken into account that due to the importance and politicization of the topic, it is also possible to come across information that is inaccurate or possibly untrue.

However, reality must be a little bit more than only the goal of the answer given to the first question! According to my opinion the current and the emerging secondary school generations will need the knowledge included in this workbook in order to have a clear view on the energy production potentials of his or her own life, and the relationship of this with the energy use in place from time to time. I think these factors taken together will construct a key issue in future society and in eventual decision situations citizens holding true information in the given topic will be able to take informed positions. This would be the ultimate goal!

Piliscsaba, September 2019

István Gärtner
secondary school teacher

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1. The relationship of energy and human societies

Energy of energetics? Are the same, or are they substantially different? The answer is not easy, because there are similarities just as well as differences. Energy is an actual concept in physics meaning the ability to work, while energetics is the term to express the energy production of society, emerging as an independent field of social and economic life. Although it is not a scientific term *per se*, but related to physics, standing the closest to physics because of the topics covered in it. It is because both energy and energetics are closed associated with the single most fundamental law of physics, the law of conservation of energy. Most probably physics teachers are best prepared in education to teach it, which will be heavily needed both these days and in the near future. You have to acknowledge that energetics has become a fundamental matter of vital importance determining the future of humankind, and its seems to be advisable to ensure that the growing new generations of society acquired their knowledge concerning the issue from people who can be seen as credible in this respect. Unfortunately, this theme is covered only marginally in current physics teaching in secondary schools in Hungary, and since students hardly encounter the related physical explanations, the physical background of the phenomena and concepts in the curriculum, their competence in this field is considerably weak.

1.1. *Known units of measurement and fields of use of energy*

The unit of measurement generally used for energy is joule (J), but primarily in heat technology calorie (1 cal ≈ 4.2 J) may also occur, and as a unit related to electricity, kilowatt hours (1 kWh = 3600 kJ), while in Anglo-Saxon territories BTU (British Thermal Unit) is still in use. The latter corresponds to the amount of heat necessary to increase the temperature of 1 pound of water from 59°F to 60°F. (Its meaning in the European Union: the quantity of energy needed to raise the temperature of 0.4536 kg water from 15°C to 15.6°C. According to this, 1 BTU ≈ 1056 J, and 1 kWh ≈ 3400 BTU.) Since energetics means the production of energy, is naturally closely associated with the unit of measurement for energy, therefore it is best to provide all energy values in joule which are related to this concept. [Table 1.1]

1 cal	$\approx 4{,}2$ J
1 Cal (kcal)	$\approx 4{,}2*10^{3}$ J
1 BTU	≈ 1056 J
1 kWh	$= 3{,}6*10^{6}$ J
1 Quad	$\approx 10^{18}$ J

Table 1.1: Comparison of energy units

The size of the quantities mentioned justifies the introduction of prefixes corresponding to the higher powers [exa (10^{18}) = E, peta (10^{15}) = P, tera (10^{12}) = T, giga (10^{9}) = G]. These can not only be associated with the joule as the basic unit, but with BTU, the unit used in Anglos-

Saxon area just as well. In these areas, in fact, yet another unit with a different name appears, which is actually used in energetics, that is in energy use, and is called Quad. (1 Quad = 10^{15} BTU, and hence, with an accuracy of 5% 1 Quad ≈1 EJ.)

Energy content of the carriers needed for energy production varies widely, may depend on the location, fuel composition and in the case of natural gas from factors such as pressure or temperature. All in all, 1 EJ ≈ 1 Quad of energy shall equal ≈ the amount of energy derived from 36 million TCE (tonne of coal equivalent), or 190 million barrels of oil, or 25 billion m^3 (bcm) natural gas in the normal state. For these data the average calorific values specific for the energy carrier in question was used, which says that the energy contents are ≈ 30 GJ for 1 TCE, ≈ 44 GJ for 1 t (≈ 7.9 barrel) oil, and ≈ 40 MJ for 1 m^3 natural gas in the normal state, respectively. These figures are naturally only approximate values, and the energy data in this lecture notes will also contain some 5-10 % uncertainty. [Table 1.2]

1 tonne TCE coal	≈ 30 GJ
1 tonne crude oil	≈ 44 GJ
1 m^3 natural gas in normal state	≈ 40 MJ

Table 1.2: Energy content of energy carriers

Why do we need energy? What would happen, if energy supply stopped overnight? In which areas would it cause problems and what the consequences would be?

Without a supply of energy, human society would most probably undergo a radical transformation or may even be eliminated within a very short period of time. The reason for this is that in lack of energy supply no human community is able to function, all in all you can state with confidence that energy plays a role in all human activities.

Let us thus have a look on the key areas where the energy needs of society are most apparent! Such needs are, of course the provision and maintenance of an appropriate amount of food, clear drinking water and habitation. Second, the needs of industry are very significant, since all product manufactured by man has an energy content. Additional substantial energy needs include those of transportation and traffic, not to forget such significant areas like waste management, or the provision of various services. The list is naturally far from being comprehensive.

The level of the overall energy needs of various human groups is evidently different, which depends on the development level and structure of the respective societies, manifesting in such considerations as from which strata of society the energy consumers come from. However, you definitely cannot tell any area or class where energy would not be needed at all. The question emerges why humanity does not produce the necessary energy using human power that is at the cost of mechanic work? The answer is clear: Humans are simply not able to do so, since total energy needs are greater by orders of magnitude than that which can be produced by mechanic work of people! This statement can be justified by a simple calculation.

A man of average physique is able to exert an output of about 100 W [1] daily on the longer run. Meaning, that in 8 hours a day 0.8 kWh = 2.88 MJ energy can be “produced”, provided that the rate of efficiency is 100%. The population of the world is currently 7.7

billion [2]. If everybody, from the infant to the ancient produced the 2.88 MJ of energy referred to above each day, the result would be ≈ 8.1 EJ in a year. However, the annual energy consumption of the world was 601 EJ [3] in 2018, in other words the difference is still nearly two orders of magnitude when assuming an efficiently rate of 100 %!

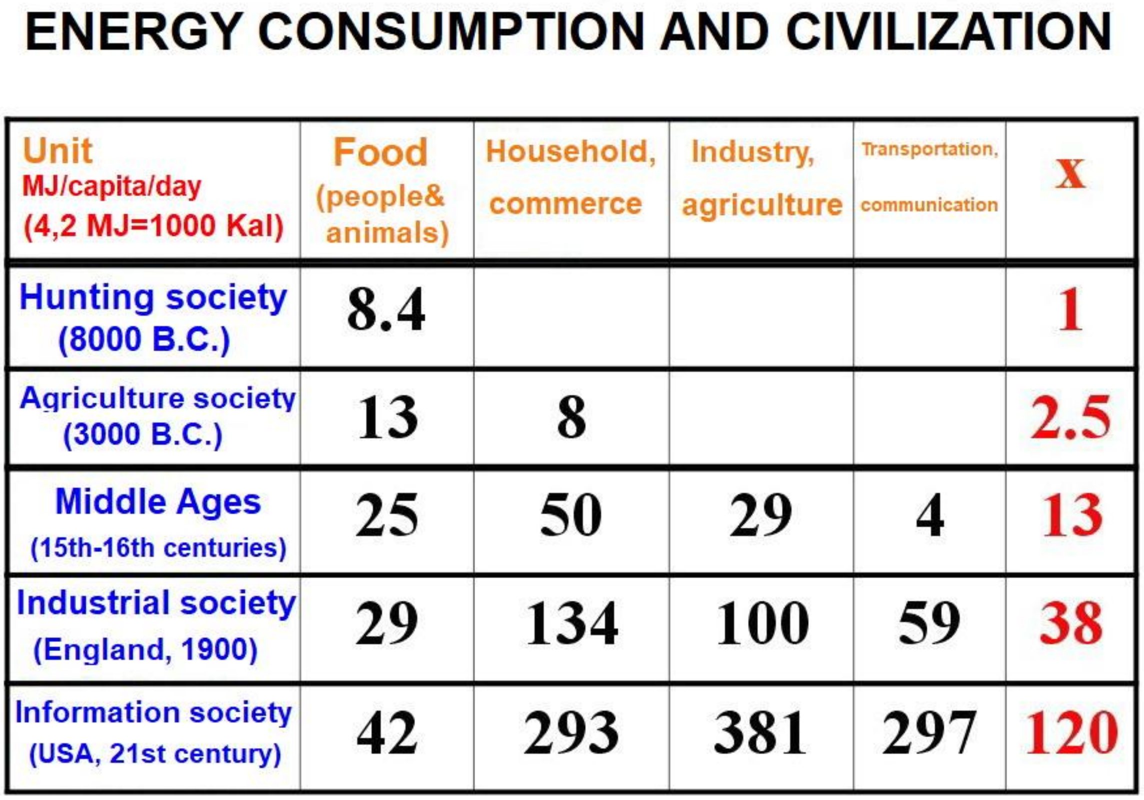
What are the fields where energy is used? Energy use can be grouped by sectors, and four sectors can be distinguished this way: industry, transportation, household and community. The share of energy use per sector is naturally far from being equal, and the difference can be attributed to a number of factors, including the economic development, population, geographic conditions of a country (climate, territory, terrain). No major variations exist, however, all percentage figures are two digit numbers. In the case of Hungary, these values are as follows: industry 27%, transportation 20%, household 34% and services 19%.

1.2 Energy used by human societies throughout history

What is the role energy played in the history of evolution of human societies over time? Which were per capita energy use trends in various communities? Is it worth to analyse this using actual figures, since changes in civilisations and energy figures per person have always been in strong correlation with each other. A number of estimated and several other data which are already available, that is seen as actual figures can be used for comparing the energy use of historical periods. Line one and two on the table of Figure 1.1, concerning the society of ancient man and Mesopotamia in antiquity, contain estimated figures only, as no exact values are known from these periods. However, line three, four and five, presenting energy use values in Batavia, England in the Victorian age and our contemporary society, respectively, are already derived from existing knowledge, determined on the basis of the records and research of each of the periods. Lines of the table encompass some 10000 years of time, covering 400-500 generations. During this time no directed selection would be possible, the human species (Homo sapiens) could not have changed substantially, meaning that people are more or less the same as thousands of years ago. Thus, the figures in the tables refer to the societies in question and people living in them can be seen as consuming the same amount of energy.

How this table can be interpreted and which conclusions can be drawn from it? The basic unit of energy, that is the figure marked as 1 in column six of the table is considered to be the daily energy needs of a human, which was formerly taken as 2000 calories. Since this unit of measurement must not be used any more officially, the currently valid equivalent, 8.4 MJ was put in line 1 of column 1.

You can see that energy consumption is in close correlation with the transformation of society over time. Palaeolithic man needed only as much energy as to cover nutritional needs. Evolution of society entailed the emergence of ever newer areas with additional energy needs, first commerce, later agriculture, industry, transportation and finally communication. It can be noted that – although the initial amount of energy has grown 120 fold in the past 10000 years, the growth rate was far from being constant. Increase of energy consumption by one order of magnitude took place only during millennia in the Palaeolithic, the Antiquity and the Medieval periods, but the same extent of change happened throughout centuries in Modern times, and in hardly more than a hundred years in the most Modern times.



ENERGY CONSUMPTION AND CIVILIZATION

Unit MJ/capita/day (4,2 MJ=1000 Kal)	Food (people& animals)	Household, commerce	Industry, agriculture	Transportation, communication	x
Hunting society (8000 B.C.)	8.4				1
Agriculture society (3000 B.C.)	13	8			2.5
Middle Ages (15th-16th centuries)	25	50	29	4	13
Industrial society (England, 1900)	29	134	100	59	38
Information society (USA, 21st century)	42	293	381	297	120

Figure 1.1: Energy use of societies

2. The system and future of current energy supply

In order to allow forward thinking for the future in this topic, it is expedient to get acquainted with the trends in energy use over the past decades and the key parameters of current energy supply.

2.1 Trends in energy use in the past decades

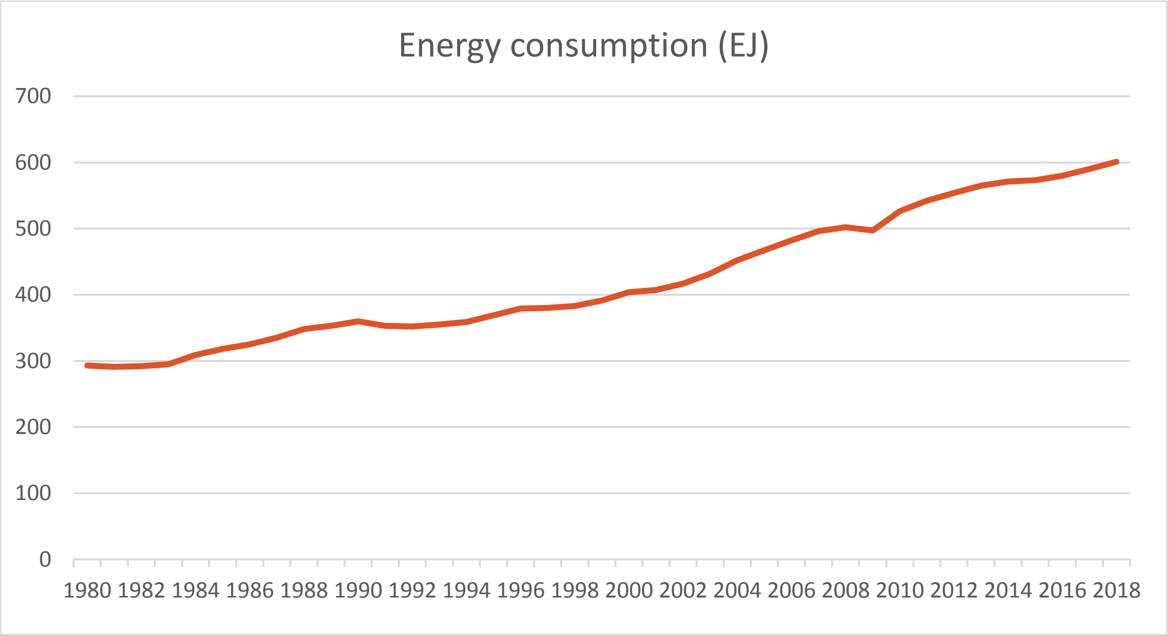


Figure 2.1: Annual energy consumption of the societies of the world

It might be worth to study trends of energy consumption both in total and in a per capita breakdown. The graph on Figure 2.1 shows that energy use in the past 40 years was steadily growing, and the energy used by the world's population doubled during this time.

The graph of Figure 2.2 provides annual energy consumption in per capita figures. In the year of 2018 this was 78.3 GJ. The population of the Earth in 1980 was 4.498 billion, in 2018 7.674 billion, [2] that is in nearly four decades the population growth was 70%. It is remarkable, however, that energy use per person was increased only by 20%, in other words the change in this indicator is a lot less striking than population growth itself. Such a change can mostly attributed to the evolution of societies, and is manifested in the fact that consumption habits have undergone a substantial transformation in the past nearly 40 years. In this way, however, the trend also means that energy consumption of the world is clearly correlated with the growth of the population, and taking into account an annual increase of approximately 80 million, it is expected to grow further. Based on the ratios alone, the extent should be at around 1%, but in fact it is higher and exceeds 2% for years [5].

It is worth to calculate the per capita energy figures for the three largest energy consumer countries. The single largest energy consumer on Earth in 2018 was China with a level of ≈ 133 EJ [5], and considering the 1396 million [6] people living in this country, it provides ≈ 95

GJ/person, which is 20% higher than the world average in 2018. As to the US, the total energy used was ≈ 95 EJ [5] for a population of 330 million [6], thus the per capita consumption equals ≈ 287 GJ, representing a multiplier of more than three and a half. Finally India, the third with the 39 EJ [5] value, and a population of 1366 million [6], which gives a per capita energy use of 29 GJ, hardly more than a third of the world average and a tenth of that of the USA. For comparison, let's see the figures in Hungary in addition to the three largest energy consumers! According to the Central Statistical Office (CSO) the annual energy consumption of the country was 1126.5 PJ [10] in 2018, with a population of 9.773 million [11], thus the per capita consumption is ≈ 115 GJ, also very high, one and a half of the world average.

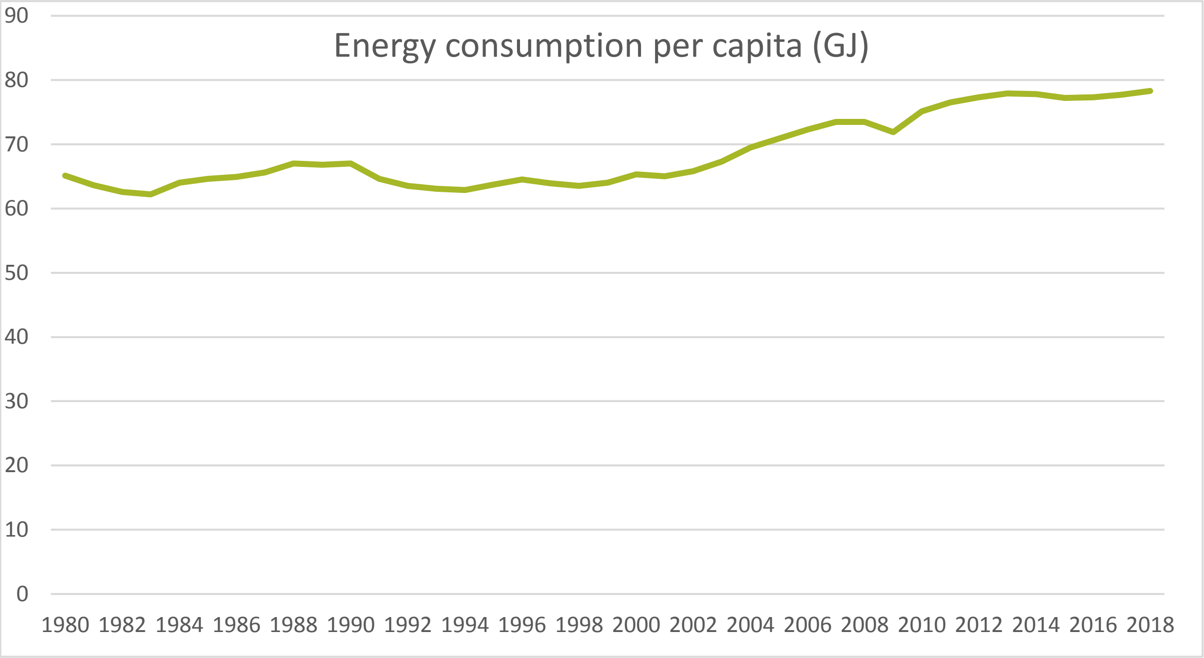


Figure 2.2: Per capita energy consumption

The growth in the consumption of electric power must be highlighted within the overall energy mix, which has always been more intensive in the past four decades than the growth of the overall total, and the gap is constantly widening. Electric power consumption and total energy consumption in 2018 have grown by 4% and 2.3%, respectively, than the 2017 figure. The growth, thanks to a society which needs more and more electricity, is bound to continue in the coming years!

Seeing such differences, the question may emerge in many, whether or not the current energy supply system of the world can be sustained on the long term and for each of the countries? Before you give the answer, first the energy household of the Earth must be explained clearly and a quantitative analysis of the parameters ensuring the energy supply of the world must be quantified.

2.2 Energy household of the Earth

Based on the figure above (Figure 2.3) [4] it can be seen that energy on Earth can be derived from three different sources, solar radiation, geothermal energy and the gravitational interaction between the Earth and the Moon. Of the three sources energy transferred by the

Sun in any unit of time is dominant, representing 99.98 % of the total value. Albeit it varies a little, quantitatively it corresponds to an average output of 178 PW. In comparison, the other two outputs, 32-40 TW and 3 TW originating from geothermal energy and the gravitational interaction between the Earth and the Moon can be seen as negligible quantities.

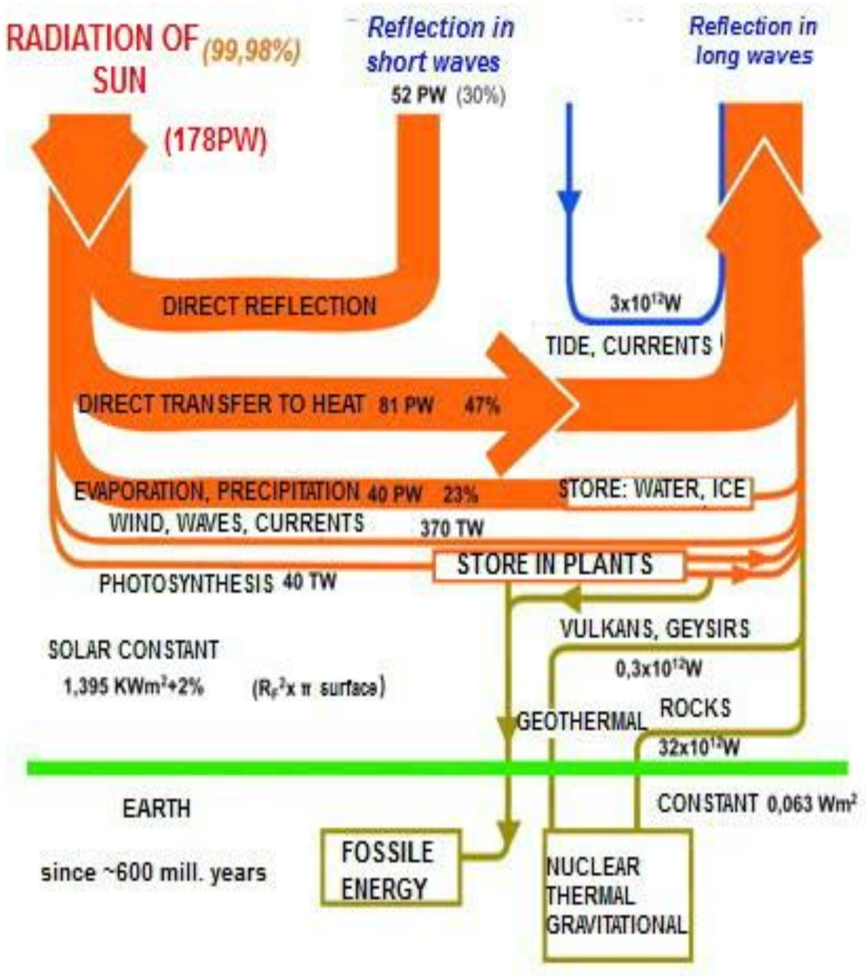


Figure 2.3: Energy household of the Earth

What is the size of these performance values when you want to relate them to the annual energy consumption of the world? The energy consumption level of the year 2018 mentioned in the first chapter, 601 EJ energy would get to the boundary of the Earth’s atmosphere within 56 minutes, if you take only the solar radiation into account, and considering a 10% efficiency rate, in somewhat more than 9 hours down to the Earth’s surface. Unfortunately, however, humankind currently is able to exploit only a minute part of this energy in power generation, as it will be explained at a later point in the chapter on renewable energy sources, thus, although the radiation power originating from the Sun would cover the annual energy requirement of the world’s population within less than half a day, now this path cannot be negotiated.

What can be used to produce the annual energy requirement, what are the energy sources of the societies of the Earth? The first thing you need to deal with at this point is the fossil energy resources, since they were predominant in the energy mix of the Earth both in the last century and up to date. Their relative proportion varies in the 80-85 % range for years, and, albeit all political and economic powers stress a radical reduction thereof loudly as opposed to the substantial increase of the role of the renewables, probably no material changes can be expected in this respect in the forthcoming years. This has several reasons, in my mind. One of them is definitely of economic nature, as the discharge of fossil fuels with renewables, for instance, requires large investments, and their return is doubtful on one hand and takes surely a long time. The other reason is of political nature, the countries and interest groups within countries holding the sources, have power also and do not intend to share it with others.

2.3 Current fossil energy resources on the Earth

In order to ensure a better understanding, it might be worth to analyse each of the energy carriers one by one, assessing their energy content, and their distribution across the Earth, as well as the problems which may render energy production using them more difficult.

a) Oil

Oil is a mineral resource of organic origin, derived from living beings alive several hundred million years ago. The complete oil resources of the planet are not known exactly, proven reserves range up to about 140 billion tons, with an energy content of somewhat more than 6000 EJ. Only estimates are available for the exact quantity of the reserves, it is assumed to be two or three times the proven resources, some countries, such as Venezuela, have significant but untapped quantities.

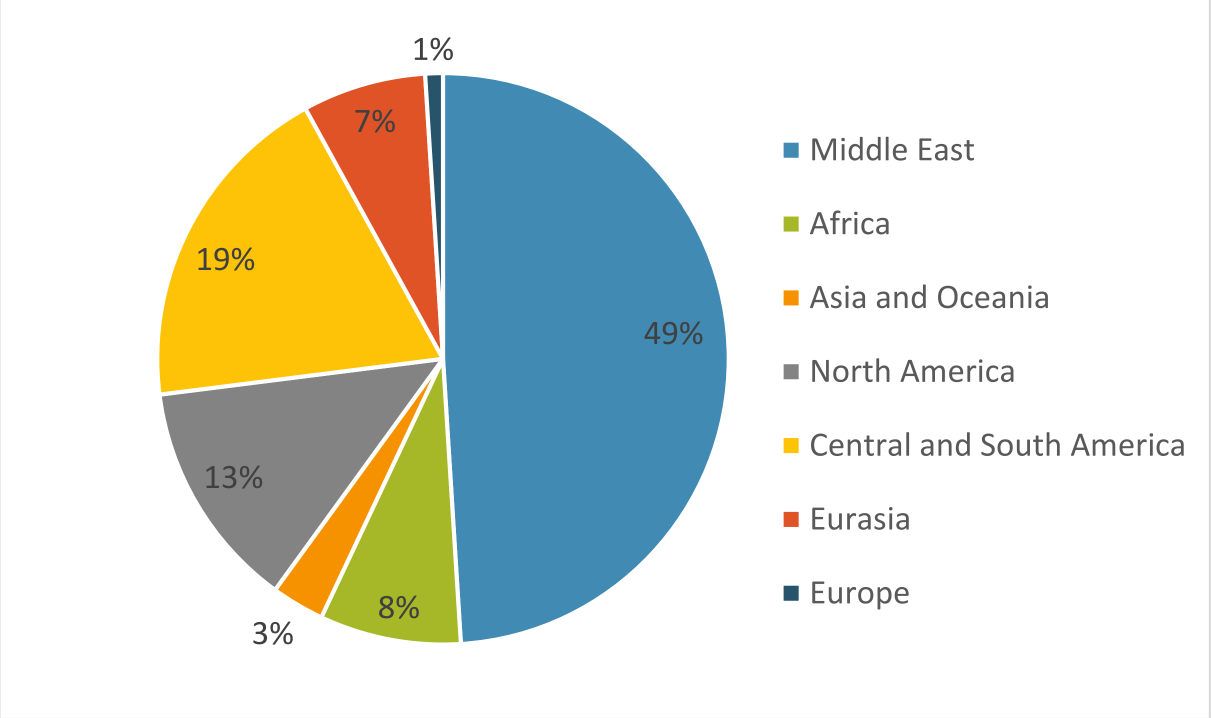


Figure 2.4: Oil reserves of the Earth – US Energy Information Administration 2013

Oil reserves can be found in all the continents (Figure 2.4), but a substantial amount of the oil reserves – nearly half of it – is found in the countries of the Middle East. Practically only 5 countries share this oil treasure among themselves, Saudi Arabia, Iraq, Kuwait, United Arab

Emirates and Iran (Figure 2.5) [4]. The countries mentioned before and 10 other oil producing countries are members of the OPEC (Organization of Petroleum Exporting Countries), which accounts for nearly half the oil production on Earth, thus it has a dominant role in determining spot prices for oil and hence, indirectly, the energy prices.

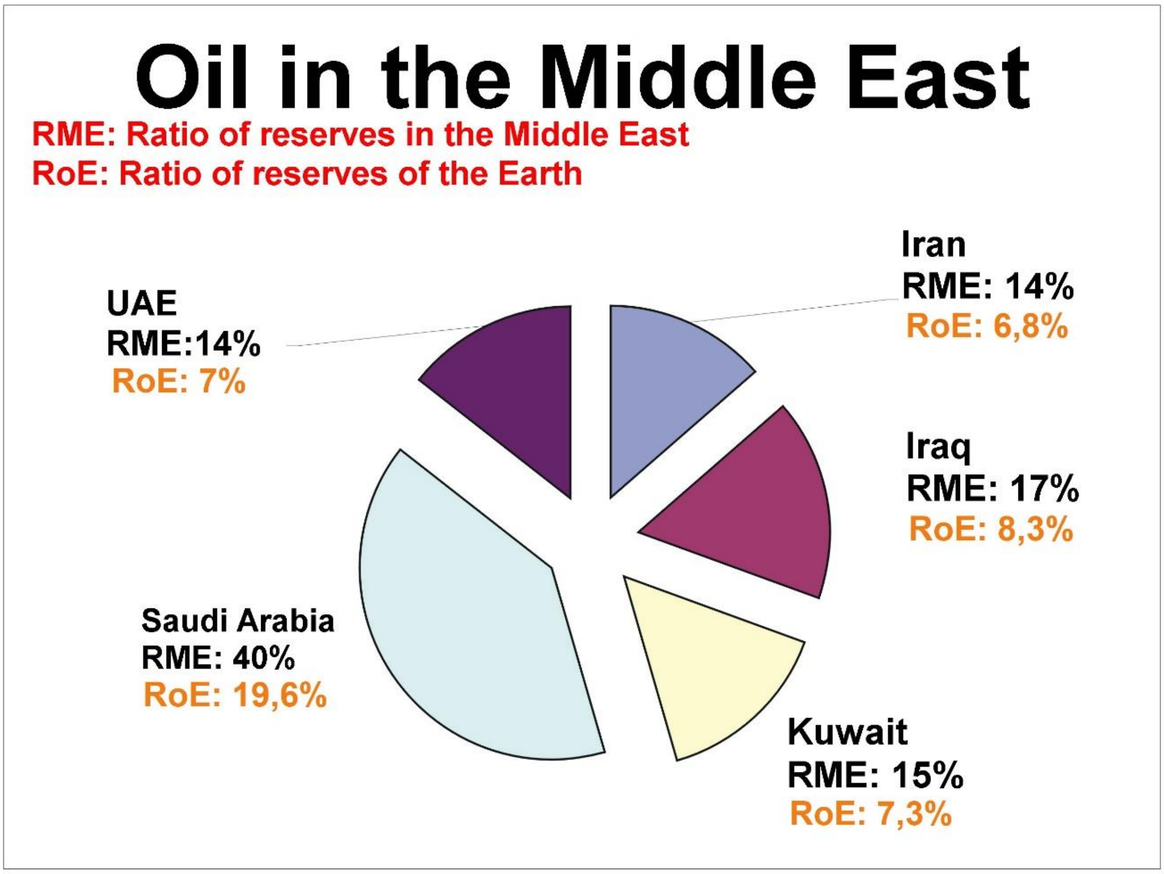


Figure 2.5: Oil reserves of the Middle East, proportions for individual states and the Earth as a whole.

b) Natural gas

According to the assumptions of the geologists the natural gas reserves of the planet are also organic in their origin, although no clear evidence exists that they could have been produced together with crude oil everywhere, even though both of them can be found frequently together in places of small extent, in the so called synclines.

The distribution of natural gas is also uneven on each continent, with more than 70% found in the former Soviet Union and the Middle East (Figure 2.6) [4]. The estimated total value of natural gas is about $160*10^{12}$ m^3, its energy content is ~ 5700 EJ, which is approximately equal to the energy content of crude oil.

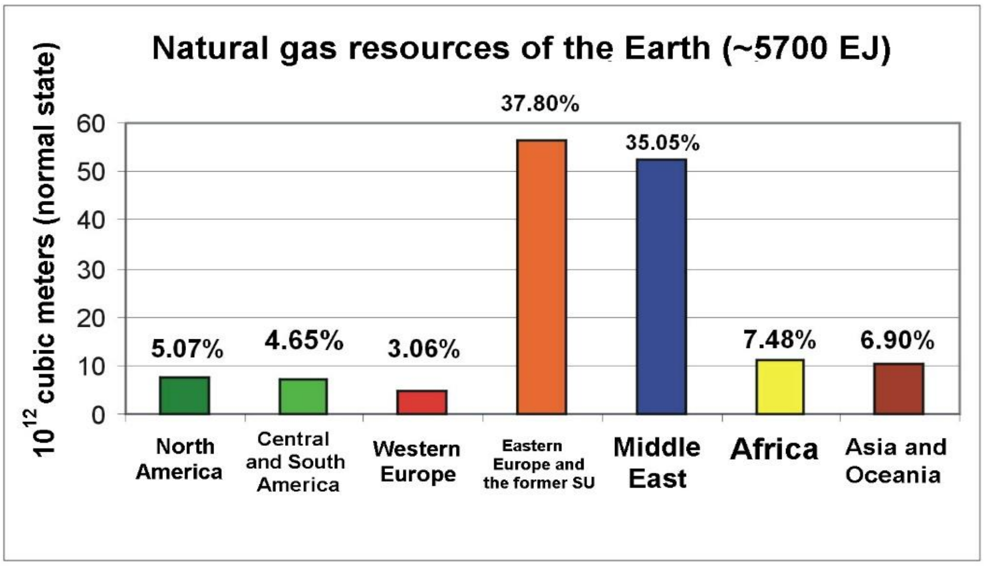


Figure 2.6: Natural gas reserves on the planet

Beside natural gas, the so called ‘shale gas’ need to be mentioned which evokes more and more media coverage lately (or, to put it more precisely, non conventional natural gas). In fact, it is just the same natural gas, as the type of hydrocarbon known to everybody, used for instance as a fuel for firing, but this type of gas is situated differently in the geological formations than classical natural gas. After formation, classical natural gas migrates into traps under geological strata with low permeability, where it is captured and can be extracted relatively easily by traversing the formations. Shale gas, on the other hand, is captured in the cracks of shale formations after its generation, thus production can not be accomplished using the conventional methods, special technology is needed for its extraction. (Figure 2.7) [7]

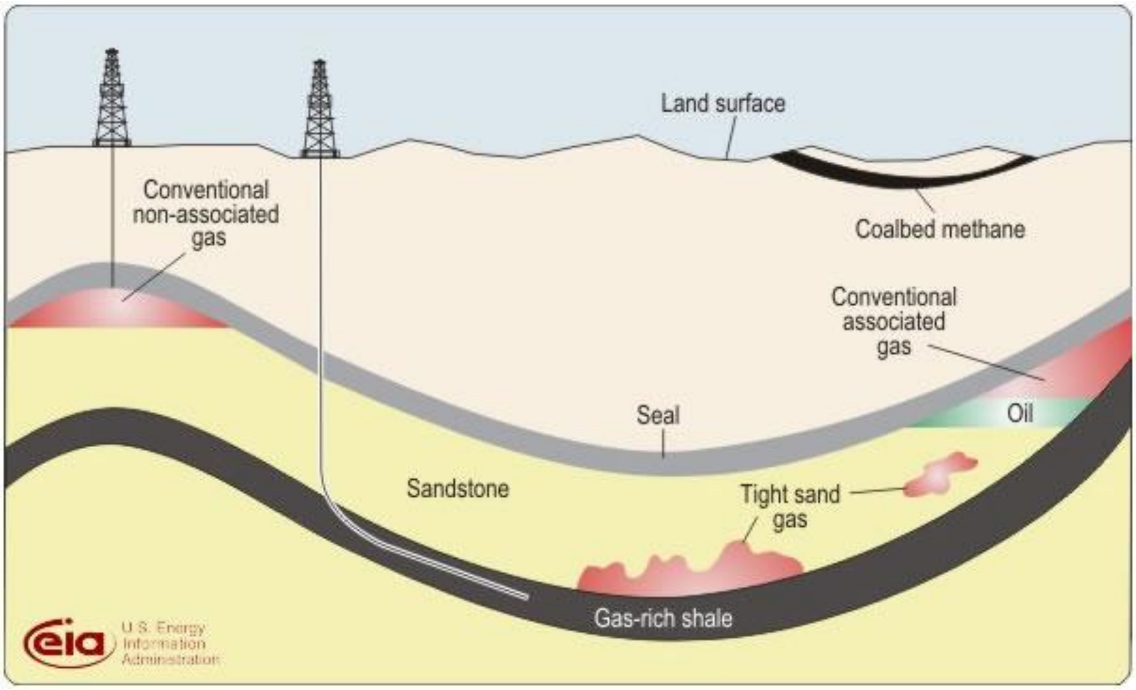


Figure 2.7: Conventional and non conventional natural gas sites

This process is called hydraulic fracturing, where the point is to transfer a mixture of high pressure water and sand and various chemicals into the several thousand metres deep formation, having penetrated into the gas containing layer first by vertical, than by horizontal drilling. This high pressure mixture breaks the rock in the depth (shale, marl), and thus, the number of cracks in the layer increases significantly and the voids containing the gas will get in contact with each other. If you reduce the pressure of the introduced liquid and pump is back, the gas found in the gaps can be led to the surface. The procedure is used for 70 years, in the USA and Canada, mainly. No such projects have been made in Europe so far, because the European Union did not approve it due to environmental aspects, since the high pressure, chemical laden water injected in the rock formations in a great depth may easily cause severe pollution. Lately, however, recognising the future role of non-conventional hydrocarbons in energy supply, the position taken by the EU has been changed to such extent that now recommendations are formulated for commercial exploitation.

The shale gas reserves of the Earth – according to the report of the U.S. Energy Information Administration (EIA) issued in September 2015, containing 2013 figures except a few data – range up to $7576.6*10^{12}$ cf (cubic feet) [8], which corresponds to $\approx 215*10^{12}$ m^3 normal state volume when converted. This amount of gas, calculated with 40 MJ/m^3, represents approximately 8600 EJ energy, which accounts for about one and a half of the energy extracted from conventional national gas. The report mentioned listed 46 countries on five continents, where the reserves are proved, with the largest quantities in China, Argentina, Algeria, US and Canada. Poland and France are the European countries with the most significant resources, but production was commenced in Poland only. According to the geological surveys Hungary has a major amount of shale gas as well, but the exploitation of this can not be expected in the coming decades. This is because the reserves are in an extremely deep layer at around 6-7000 metres, and currently no such technology is available which would make mining economically feasible from this depth.

c) Coal

The coal reserves in our Earth can be estimated relatively accurately, since the deposits are found in large formations, which can be surveyed geologically with great accuracy. The estimated quantity is $3*10^{13}$ TCE with an energy contents of about 100000 EJ. This is nearly five times as much as the total energy which could be derived from oil, conventional and non-conventional oil jointly.

In all continents of the planet there is coal, but in fact only three of them have significant reserves, North America, Eastern Europe, and Asia, accounting for more than 85 % of the Earth's coal reserves. (Figure 2.8) [4]

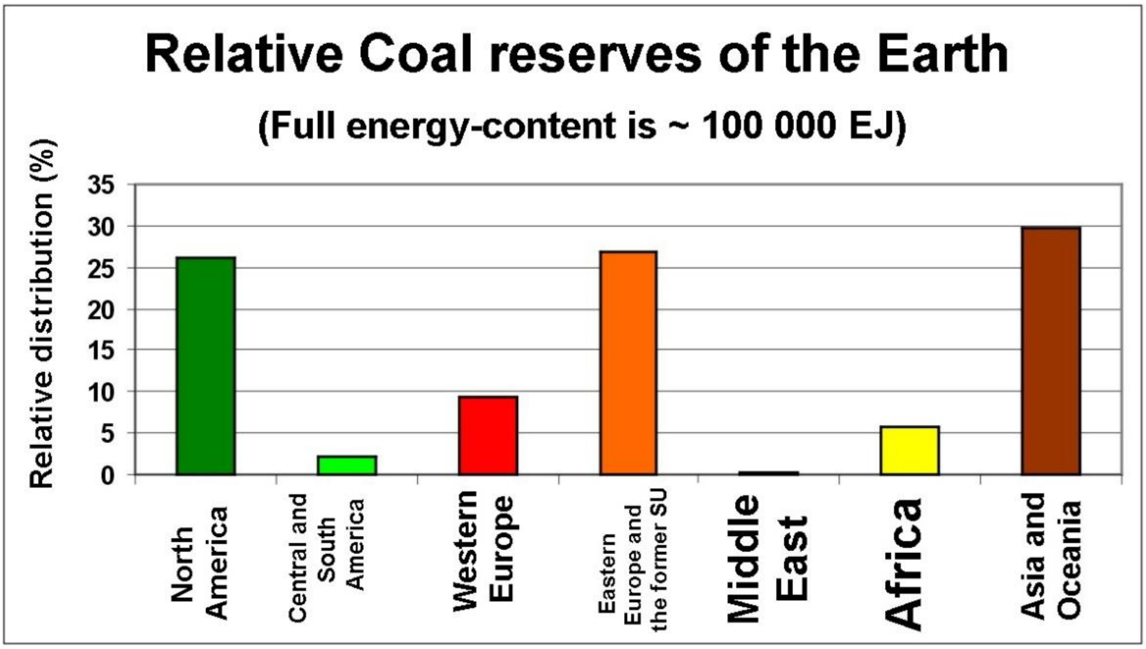


Figure 2.8: Coal reserves of the Earth

Since these three energy carriers account for more than four fifth of the total energy production, thus the problems associated with their utilisation must also be mentioned.

2.4 Problems of energy production emerging from fossil resources and experimental evidence thereto

The first and maybe most important problem is to be faced in the course of the energy production is the environmental pollution generated by the use of fossil fuels. This is manifested in the substantial amount of carbon-dioxide discharge on one hand and the appearance of other contaminants (sulphur-dioxide, nitrogen dioxide, heavy metals and radioactive elements) on the other. Of the fossil fuels, a unit of brown coal emits the most carbon-dioxide into the atmosphere when burnt, the same value for natural gas is less than half.

The proportion of carbon dioxide in the atmosphere accounts for approximately 0.04% at the time being, beside 78% of nitrogen and 21% oxygen. However this level is constantly on the rise, attributed clearly to human activities. Growth is confirmed by actual measurements, such as the Mauna Loa observatories data in Hawaii, containing carbon dioxide concentration levels collected from the second part of the last century over a 50 years period. [Figure 2. 9] [4]

The larger figure illustrates the entire process across half a century, the lesser graph reflects the periodicity within a year. In winter, concentration keeps on rising up to about May, while in the second half of the year carbon-dioxide is incorporated into photosynthesising plants, reducing atmospheric levels up to October continuously. Red curve and blue line on the figure provide measured and annual average values, respectively.

All in all it is striking that the 315 ppmv (parts per million by volume) concentration level measured in the second part of the 1950s grew up to 380 ppmv by 2006, which is already a 20% change, but in the somewhat more than one decade passed since further growth occurred, and the current carbon dioxide concentration is about 409 ppmv. Why does this cause any problem and what could, and what will be the consequence?

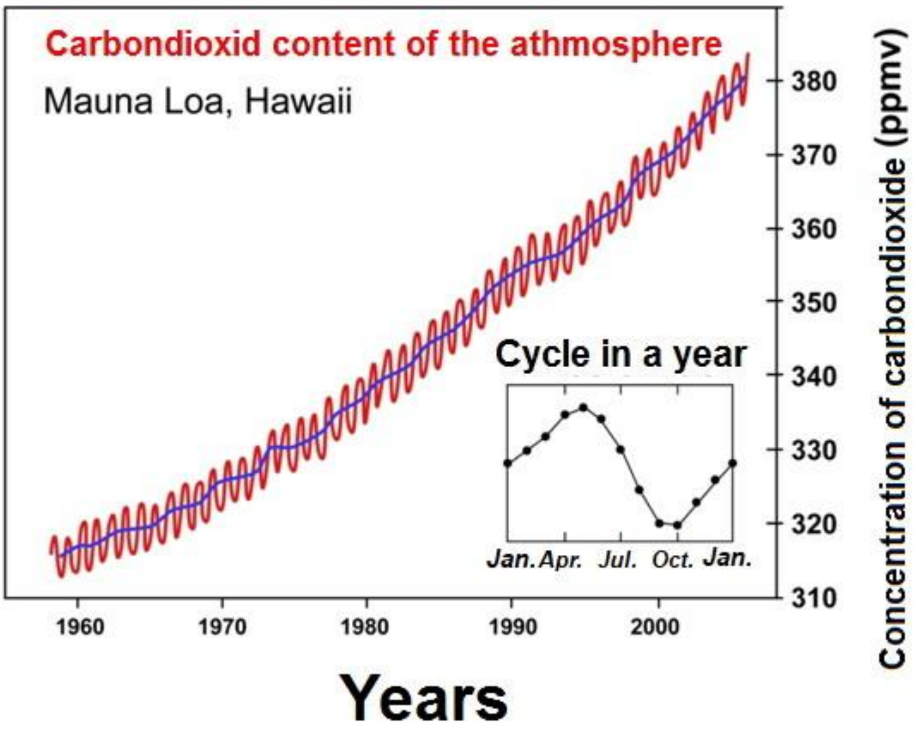


Figure 2.9: CO_2 concentration increase 1956-2006

Researchers maintain that the growth of carbon-dioxide concentration is one of the factors responsible for the greenhouse effect. Greenhouse gases (carbon-dioxide, methane, water vapour) impact the Earth climate by increasing temperature, the underlying cause of which is the frequency transformation taking place on the surface of the Earth. Energy originating from the radiation of the Sun hits the Earth in the form of short wave radiation [Figure 2.10] and the atmosphere is penetrable for waves of this kind, therefore they are able to get to the surface of the Earth and warm it up.

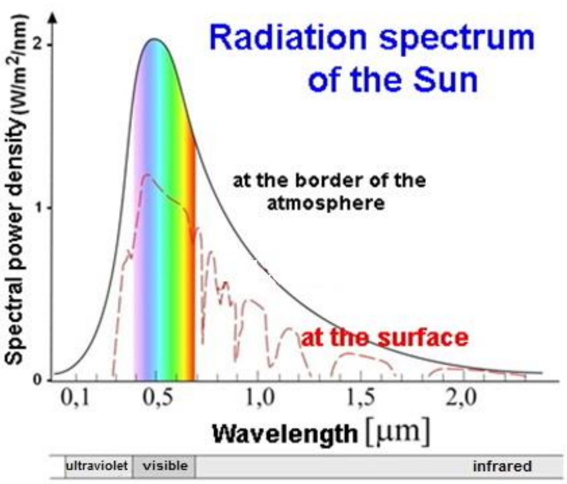


Figure 2.10: Solar radiation spectrum

Radiation absorbed by the Earth is returned to the atmosphere in the form of radiation with a wave length one order of magnitude longer [Figure 2.11] but them neither carbon-dioxide, not methane are transparent, causing indirectly the increase of the temperature, playing an important role in an eventual climate change.

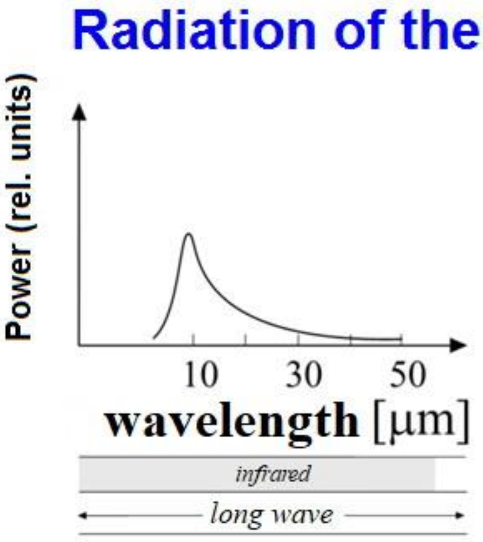


Figure 2.11: Radiation spectrum of the Earth

Whether or not climate change can be averted, can not be actually confirmed by scientists as of yet. It may be influenced by multiple factors, and nature extends a helping hand by having completed an “experiment”. This was the experiment of the Vostok-ice core sample, containing the results of the measurement carried out by the Vostok station on the Antarctic [Figure 2.12] [9].

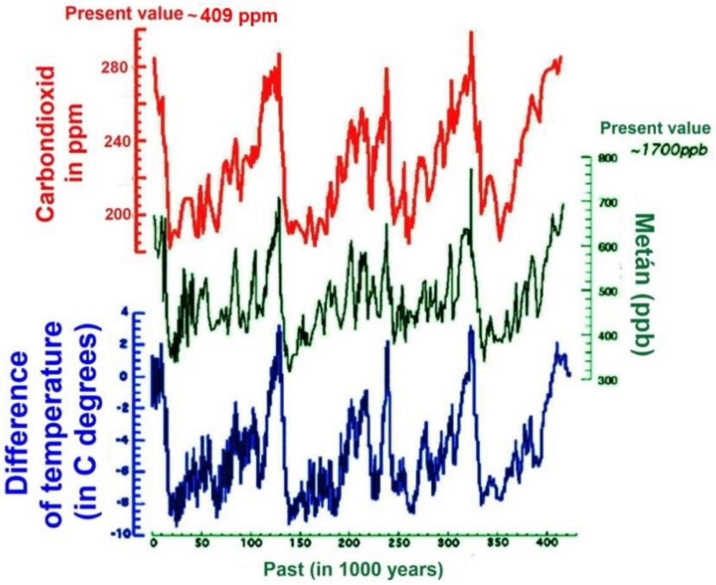


Figure 2.12: Vostok-ice core sample

The point in the experiment is that the carbon-dioxide and methane content of the atmosphere would appear in the ice retrospectively for a couple of hundred thousand years at the time of precipitation. This is reflected by the examination of the ice drilling core on the Pole, and the data on the figure show these results. The age of the ice core can be derived from the annual snow deposit, while carbon-dioxide and methane contents can be determined by direct measurement. The temperature change is referred to by the ratio of the isotope oxygen 16 and 18, a higher temperature assumes more isotope oxygen 18. It can be seen on the figure graph that greenhouse gas concentrations and temperature change values have been running in parallel over the past millennia. This also means that probably the same tendency can be expected to continue in the future, in other words an increasing amount of carbon-dioxide and methane emission into the atmosphere will definitely lead to a rise in temperature, the potential consequences of which can already be seen [Figure 2.13].

Beside the pollution issue, other questions, mainly of economic nature may also emerge. Mineral reserves are limited and their exploitation, the related transportation activities are in many cases cumbersome and naturally extremely expensive, thus the analysis of these activities requires constant analysis. This relates to the question raised by many, whether chemical industry gets an appropriate role in the use of the mineral resources, since to spend energy only to produce heat is probably not too economic.

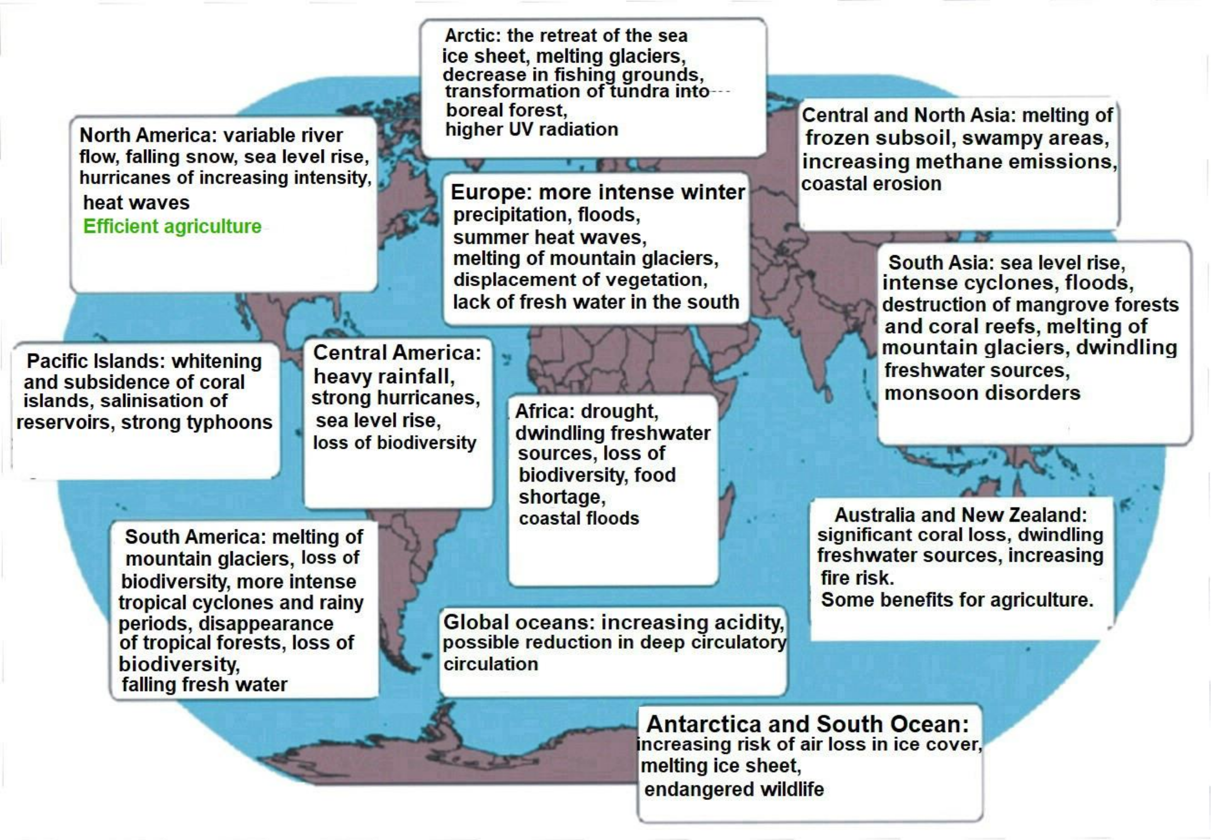


Figure 2.13: Harbingers of climate change

Last, but not least, you need to face the fact that uneven distribution of mineral occurrence on the planet Earth triggers a complex system of political and economic interdependence, leading to serious frictions between certain countries. History of the past decades provides a number of proof to substantiate the statement, and due to the finite amount of the mineral reserves the possibility will be still there in the future.

3. The energy saving issue with the eyes of a physics teacher

The potential consequences of a stalling, or even completely stopped supply of energy were mentioned in chapter one. Though historical experiences show that individuals may fare well using relatively little energy, contemporary man would not put up with a declining energy use, and the annually growing energy indicators, as well as the trend in use suggest that societies do not intend to step back and renounce of energy. At the same time it must be seen that this growing trend of energy use definitely can not be maintained and a more serious efforts must be made in the future to save energy. In our case this will most probably mean that services meeting current and future needs in society will be performed at a better efficiency rate. In order to do so first it should be clarified what factors the energy requirement of a society depends!

Energy needs are determined by three factors: number of people living in the society, the social state of the society, and its economic, technological development level. The amount of energy used will apparently decline when the factors themselves are diminished. Obviously, not all of them will decline, it is widely known that the population of the Earth is increased by 80 million people in a year, thus the positive tendency of this factor must be compensated by the other two.

Social state means the needs for per capita services in society, while economic, technological development accounts for the amount of energy associated with the services needed. Of the two, the latter has a larger reduction potential, the former can only be diminished when members of society recognise the services they absolutely need. Energy needs of people, however, is subject to a number of factors, such as actual physical needs, consumption habits, the desired standard of living, and the moral values, yet it has to be clear that energy saving must apply to society as a whole.

In order to reduce the quantities of energy referred to above it is not sufficient to produce technology development only, energy efficient development projects need investments with the associated political will and capital requirement. Economic benefit derived from such investments will appear only after a lag phase, thus the market frequently dismisses energy efficient solutions, in other words the prospects of such a trend in the future are not favourable. All in all it can be assumed that not more than the per capita energy consumption can be reduced to some extent, even this only in the case when members of society understand the importance of energy saving for the sake of their future.

Which are the areas with a potential to save energy? Increasing efficiency rates is the goal in all fields. This can be achieved by either increasing effectiveness or by the broadening of the scope of efficient production. Let us first see how you can increase effectiveness! There are a number of such fields, let’s try to focus on the most important ones!

Heating of spaces can be our first area of investigation. At the time being, one fifth of all energy used accounts for heating spaces. The figure can be reduced by better insulation of spaces and increasing the efficiency of boilers, thus pushing it down below even 10%. The second field is the network losses of the electric grids. Since these can also achieve two digit numbers (about 15% in Hungary), thus a slight improvement may entail significant saving. The third area is transportation of people and goods, including for instance the issue of community traffic, the rationalisation of which and hence, improving its effectiveness may contribute to energy saving as well.

How can you broaden the scope of effective production? One parameter of this is the technical and engineering development work, providing new solution in product manufacture, thus reducing the energy needed for production. A second potential parameter may be economising on materials, which can be achieved by reasonable organisation, and the reuse, or reutilisation of materials. The latter depends strongly on the environmental sensitivity of the society as such, economic incentives, but it may also provide a few percentage in itself.

Where is the task of a physics teacher in relation to these? The first and maybe most important aspect is to train in an environmentally conscious use. This means that the attention of the students need to be called to the saving potential in day to day life. These can be possibilities connected to lighting or heating, such as efficient light sources, or the issue of ventilation and overheating. The second task for a teacher is to convey knowledge and information. To teach students the physical background of equipment functioning, and make them learn the efficiency rate of the activities related to energy use. Finally, an important role is to present the real physical content of the ideas appearing on the Internet, or the various forums for saving energy.

4. Renewable energy sources

What does this concept mean, which energy sources are called renewable and what are their characteristics? Renewable energy resources are sources of energy which are able to replenish themselves within the time scale of human history (10 000 years). Their key features include low energy density, meaning a large area required for their utilisation, or large masses of material must be moved, or change must be made over a large area in order to produce appropriate and significant amount of energy. Additional problems also occur. One of them is whether the investment required for energy production is feasible economically and technically. Another problem may be derived from the capacity of society to absorb technology that is whether people accept the change. Finally, do not forget that energy production using renewable sources raises serious environmental problems, due to intervention in wildlife and aesthetic transformation of the environment. Based on realistic assessment it can be concluded that renewables are unable to solve the energy shortage of humankind in the short term, according to the calculations about 25 to 35 per cent can be covered using this source.

4.1. Direct use of solar energy

It was mentioned already in Chapter 2.2 that humanity can utilise only a very small fraction of the Sun’s energy, but it is expected to be increased in the future. This will be needed indeed on the basis of the known data which show a growth course, since less than merely 2% of the entire energy consumption on the Earth was covered by direct solar energy in the year of 2018 [3].

What are the possibilities by which solar radiation energy can be used directly? One of the three options is to produce electricity directly using photovoltaic equipment. The equipment is operated on the principle of semiconductors, voltage is generated when light hits the semiconductor diodes. (This paper can not assume the detailed description of the physical basics these pieces of equipment operate on, but a website dedicated to secondary school students, prepared by a practicing secondary school teacher is linked in here where detailed descriptions on this topic can be found: www.felvezetok.hu).

Photovoltaic systems are one of the most rapidly developing electric power generation methods, at the time being (in 2019) the single largest solar power plant called Bhadla Solar Park can be found in India [Figure 4.1][12], the nominal capacity of which is 2250 MW, and covers an area of 40 km^2. (For comparison, note that figures of the largest Hungarian solar plant. The facility, found in Bükkábrány, Heves county, was inaugurated in 2019 and has a nominal capacity of 22.6 MW, covering an area of 0.32 km^2.)

Figure 4.1: Bhadla Solar Park – Rajasthan-India

The effectiveness of the photovoltaic cells found in solar plants depends on the materials incorporated, temperature and eventually special solutions, their value varying between 20-40%. Beside this, the number of sunny hours is also an important parameter, all in all the actual electric output of these plants is significantly lower than their rated capacity, about a sixth or eighth.

Additional problems also emerge with respect to operation. Due to the large area demand the high capital need follows right away, but beside it two other adverse consequences are also encountered. One of them is desertification under the panels, where wildlife is practically eliminated, and the other is the meteorological impacts, such as the occurrence of windstorms. With respect to operation, two tasks to be tackled must be solved, the permanent need for maintenance and the environmental concerns due to the materials incorporated. Beside the worries, however, a serious advantage is also to be noted. Photovoltaics are used in a decentralised pattern, can work independently of the national grid, which may be of paramount importance in Africa, for instance.

Another possibility is to use solar radiation as a source of heat. In this case the heat impact of the Sun is exploited with the help of the so-called solar thermal power plants. Figure 4.2 [Figure 4] shows that the operating principle is similar to other power plants using fossil fuels, except that the high thermal capacity liquid (synthetic oil or salt melt) circulated in pipelines is heated by sunshine.

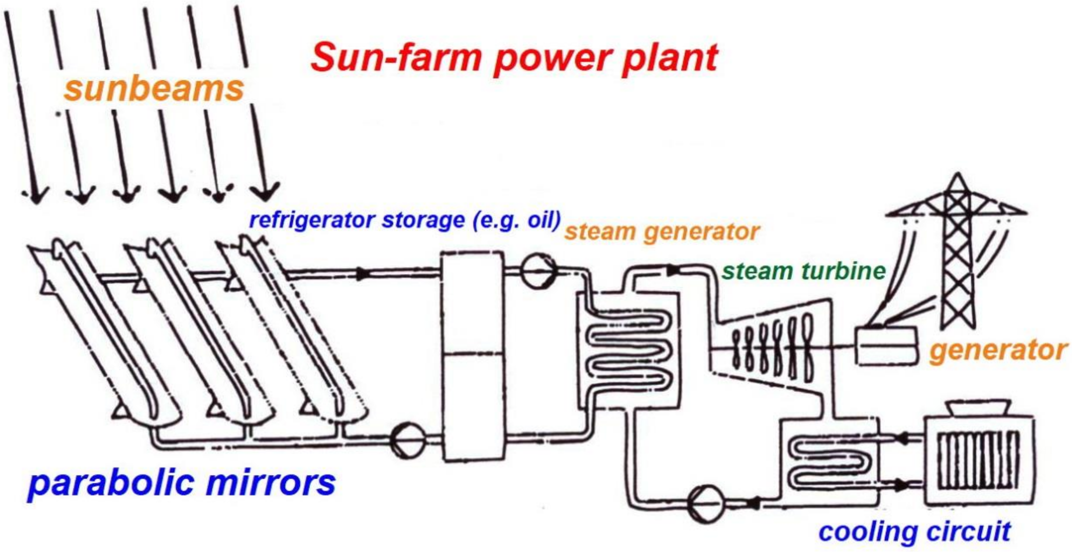


Figure 4.2: Sun-farm power plant

Figure 4.3: Odeillo solar oven – France

Heating may happen directly by solar collectors or by using mirrors focusing sunbeams to a single location where liquid in a tank is heated up to high temperature. The latter example is the Odeillo solar oven in the Pyrenees [Figure 4.3][13]. The temperature here rises up to 3800 K due to solar radiation and the electric output generated is 1 MW.

A most recent implementation possibility is the solar chimney situated in Manzanares, Spain [Figure 4.4] [15]. It was used for one of the test exercises in the medium level GSCE exams in physics during Spring 2019 [14]. The "chimney", in fact, is a tower standing in the middle of a site covered by clear glass. Air under the glass roof is heated up by the sunshine, and flows towards the chimney turning turbine blades on its way. The rotating turbine blades produce electricity in a generator and the air rises through the chimney. Constant air flow and hence, continuous power generation is ensured by water filled pipes laid on the ground, which are warmed up during the day and release the absorbed heat during the night [14].

Figure 4.4: Solar chimney – Manzanares – Spain

When the thermal impact of the Sun is utilised this way, several concerns emerge. The substantial size of the area required applies to all of the aforementioned solutions and makes the otherwise inevitable maintenance more difficult. Electricity production capability is relatively low relative to the high investment costs, questioning profitability. Last, but not least, eventual adverse environmental impacts may affect both the landscape and vegetation or wildlife.

Figure 4.5: Photovoltaic cells (middle), and thermal collectors (right side) on the roof of a home

A third option for direct utilisation of sunshine is direct use on ‘small scale’. This means ‘trapping’ of the Sun’s energy using thermal collectors to produce domestic hot water for residential houses and other institutions and to contribute to heating [Figure 4.5].

In temperate climates maximum 50% of the heating requirements can be replaced this way because of the low number of sunny hours in the winter period, therefore some other kind of conventional heating system is necessary anyway. This means additional costs for the installation and maintenance of thermal collectors, with definitely more than 10 years pay-off periods at the current energy prices. On the other hand, in Hungarian farms where greenhouses or stables for livestock are heated by hot water, this application could have a significant role and a substantial amount of fossil energy carriers could be spared.

Hungary’s situation, current and future possibilities are worth a discussion of the topic! Hungary made serious efforts to develop solar energy systems lately. Substantial government subsidies go to private or public investments with energy production facility using solar energy. The process goes on, but it must remembered that the number of sunny hours is satisfactory for this purpose only in part of the country (the Great Plain), and between May and October. Other parts and the rest of the year are significantly less favourable. Hardly more than one per cent is produced currently this way in our country. Even if growing steadily in the upcoming years, whereas Hungary is scheduled to build 110 solar power plants in the next 2 years, but this value will fall short of 10% after a decade. Based on this it is clear that energy problems of Hungary can be diminished by solar energy only to a minimum extent.

4.2. *Indirect use of solar energy*

Solar energy can be used indirectly, that is, by converting energy forms created indirectly by the Sun. Let’s them one by one, including their energy generation potentials! The first of this, hydropower, is used by humans for the longest time, more than 4000 years!

4.2.1 Hydropower

Water is circulated by the Sun, a really renewable energy. Water is used today almost exclusively to produce power, 16% of all electricity worldwide is generated in hydropower plants [16] and this figure did not change in the last decade. The largest hydropower plant on Earth is Three Gorges Dam on the river Yangtze, China, commissioned in 2008 with an electric output of 22.5 GW [19]. The largest European plant is beside Volgograd, Russia with an output of 2.5 GW [19]. Hydropower utilisation in Europe is maximised, no significant changes can be expected in the near future. On the other continents, especially in Asia, Africa and South America, there are still many opportunities to construct new hydropower plants.

Energy production from hydropower plants can be achieved by taking the advantage of the geographical level difference or operating pumps. The former solution can be done by impoundment using higher dams [Figure 4.6] [17] [18], or by diversion and lower dams, or even without them. In both cases the kinetic and potential energy of the river are converted into electricity with the help of a turbine and a generator.

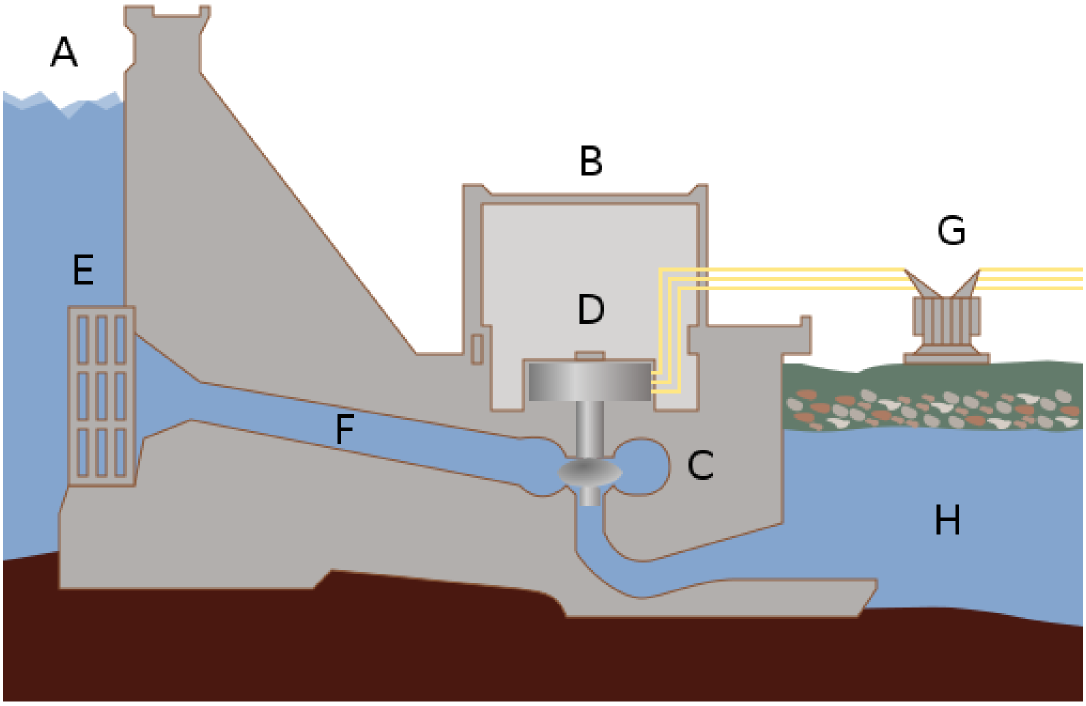


Figure 4.6: Hydropower plant with impoundment

Components: A - reservoir, B – power house, C – turbine, D – generator,
E – sluice, F – by-pass canal, G – power transmission line, H – river

Pumped storage power plants [Figure 4.7] [18] play controlling role in electricity supply, providing ‘fine tuning’ to power generation systems. That is, when electricity produced by base load plants is not sufficient, pumped storage plants are switched on and additional electricity produced by letting down water from the reservoirs upstream/uphill.

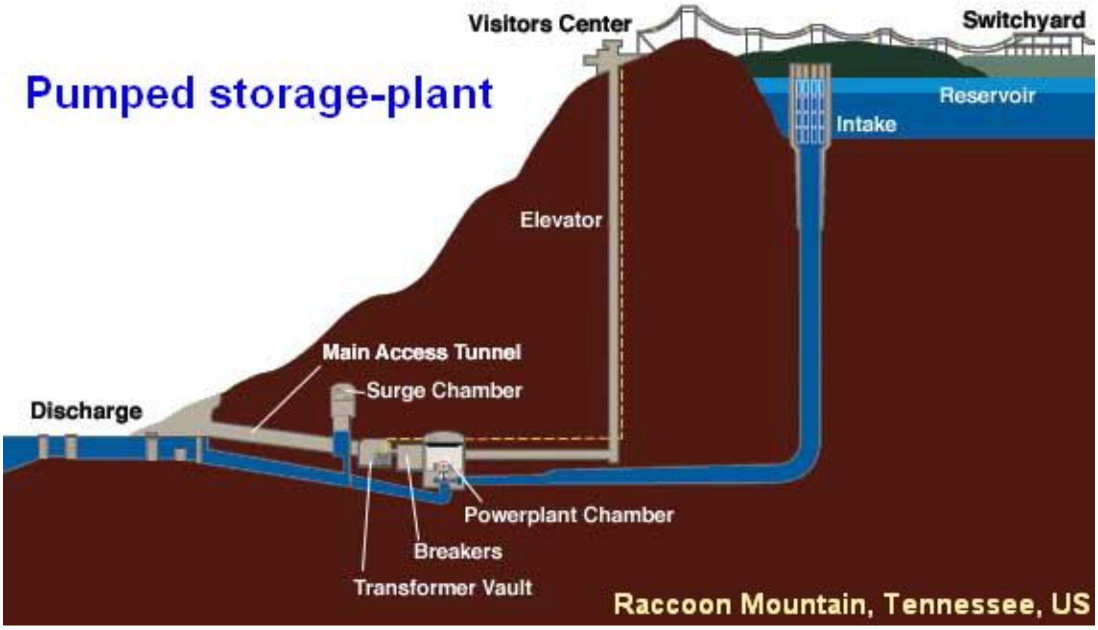


Figure 4.7: Pumped-storage hydropower plant

What are the benefits and disadvantages of water power? Benefits include by all means the millennial experience of mankind in water treatment despite the fact that the largest electricity-producing hydropower plants are less than 100 years old. An additional advantage is that the completed power plant runs on low cost budget, with a handful of people as operators. A hydro-electric plant is environmentally friendly, it has no harmful emissions, and is expected to operate throughout a useful lifetime of more than hundred years, which is several times the lifetime of other power plant types. Beside optimising the power generation system, hydropower renews water management and has a role in flood control and inland navigation.

Adverse impacts must be mentioned, naturally, as well! Construction is very costly and lengthy. Establishment entails flooding of hundreds, in some cases thousands of km^2, involving the resettlement of their population. The area submerged by Three Gorges Dam ranged up to 632 km^2 (larger than Lake Balaton) and 1.3 million people had to be ousted! Environmental impacts are disadvantageous just as well as beneficial, since it ruins the landscape and has a number of other adverse impacts. Let’s see a few examples from these too! Groundwater table levels, water quality and river flows are changed, fish migration restricted with inevitable changes to the aquatic and wetland habitats, i.e. many different ecological harms occur.

Finally let us see the possibilities of Hungary from the perspective of hydropower utilisation! Geographic conditions are not too favourable since the two major rivers with the largest water flows have only a very slight fall within the country’s territory. The two largest Hungarian plants are found on the Tisza at Kisköre and Tiszalök, with a capacity of 28 MW, and 12 MW, respectively, while no power plant was built on the Hungarian section of the Danube! The total hydropower capacity installed in Hungary was only 57 MW in 2018, power originating from them accounted for less than one per cent of electric power generation and no material developments can be expected in this field in the future.

Beside unfavourable geographic conditions the underlying cause for this is that our country can be assumed to have given up any utilisation of water power for a long period of time. The process started in the last decades of the last century by cancelling the intergovernmental agreement on the establishment of the Gabcikovo (Bős)-Nagymaros large barrage project. As a result, Hungary lost a source of as much electricity as is produced by one unit in the Paks Nuclear Power Plant. Since electricity is still needed, the electricity produced by the power plant built up nevertheless on the Slovak side is purchased by the Hungarian party. No further hydropower plants are envisaged or planned, this kind of renewable source will not be instrumental in solving domestic energy problems.

4.2.2 Wind power

Wind power is also renewable and derived from the Sun, used by man for centuries. First in navigation using sails, later, from about the 12th century, performing work with the application of windmills, wind wheels. Wind energy is used today only for generating power when the blowing wind turns a rotor which induces a generator to rotate and produce electricity. What factors does the work carried out by wind depend and how much energy can be produced this way? Let's make a rough estimate!

It can be proved by simple calculations that the performance of the wind per surface unit (P/A) is directly proportional with the third power of wind speed, and the proportional-action coefficient is half the air density. Based on this the unit surface output at a wind speed of 10 m/s in normal state air will be 600 W/m^2. This accounts for a pretty low level in terms of capacity, therefore, is you want to reach large capacities, you have to use large surface blades. Wind generator used today have blades about 50 m long and the total rotor surface pending on the number of blades is about a thousand metre square. Such a large surface generates strong force impacts, being several hundred thousand newtons pending on the speed of the wind. The force must be compensated by the tower of the wind mill, which is the reason why these generators are stopped at higher wind speeds (>20 m/s).

The physics of the wind turbines related to Bernoulli's theorem. The blade profiles are designed to raise pressure differences on the two sides of the blade, generating a force perpendicular to the profile of the blade. Mathematical calculations suggest that the maximum effectiveness of wind turbines is 59 % (Bentz-limit). It can be demonstrated that such a rate can be reached when the speed of the wind drops to one third of its original having left the rotor. Such a value can be best approached by three blades rotors, this is why they are used most frequently.

Several factors influence the installation possibilities of wind turbines at a geographic location. Continuous operation requires steady and strong wind. Mainly sea coasts provide such conditions on the Earth, wind speeds are considerably less and uneven inland, leading to fluctuation of the output, causing concerns when hooking on the grid. Experiences so far suggest that wind power generators are best installed on locations with an availability exceeding 20%. Availability shows the ratio between the power actually produced and power theoretically available in a year for an equipment with a given rated capacity. In extremely windy areas such as the Danish or Northern German coast this figure ranges up to about 45-50%, but in Hungary it reaches 25% only at selected locations and stays below 20% for a large part of the country.

Wind speed also depends on the height above ground, the higher the elevations, the faster the wind. This explains the sometime 150 metres height of wind turbines including the blades, which of course increase investment costs. Substantial costs are associated with other problems when wind power generators are installed in large numbers. One is the oscillating output caused by varying wind speed as mentioned earlier. Additional issues need to be tackled in terms of frequency and voltage when connecting the transmission network. Another problem relates to nature conservation. Windmills are claimed to be an eyesore in the landscape, and ugly blemish in the environment. As a consequence, permit is not granted in many locations, not only in built-up areas, but nature conservation areas, national parks just as well, due to touristic considerations.

What is the case in Hungary with the utilisation of wind power, what are the possibilities and implementation? Since we are a land-locked country, the geographic situation determines the possibilities. The most important windy region is the Little Plain where availability exceeds 25%, and wind power plants are found in greatest number here [Figure 4.8].

Figure 4.8: Wind power farm near Mosonszolnok

Except a few locations, the situation is a lot worse, Figure 4. 9 [20] shows all the wind turbines installed up to September 2010 in the country. It can be seen on the figure that such type of investment project were worth implementing only in a few sites nationwide.

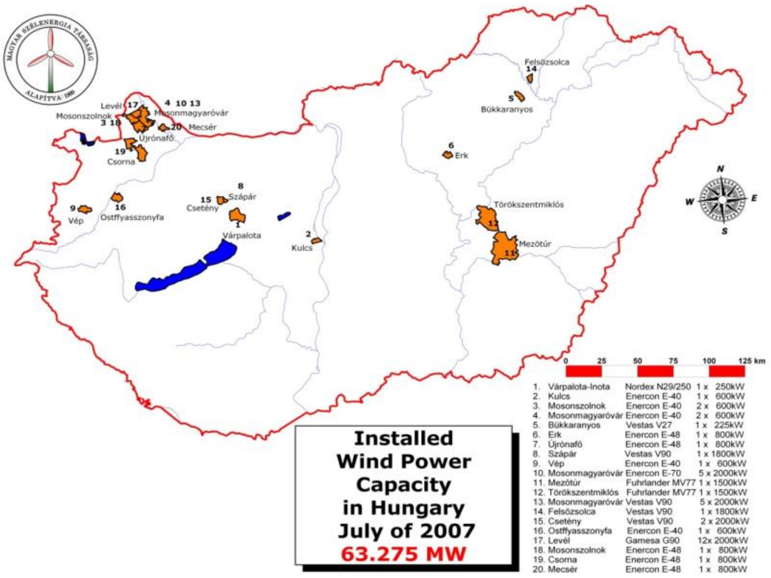


Figure 4.9: Wind power plants in Hungary

The total installed capacity of 295 MW – featured on the map – hardly changed over a whole decade, currently runs up to 329 MW. At the time being, wind power is somewhat more than a mere 1% in the total electric power produced and is not expected to rise in the forthcoming decades. The underlying cause is that the current legislation adopted in 2016 makes the establishment of new wind power plants practically impossible. It mandates such minimum safety zones which can not be met anywhere in the country and determines technical conditions which are currently deemed to be obsolete and outdated. The average lifetime of existing wind turbines is about 15 years, their expected lifetime is 20-25 years, which means, that it will be necessary to rethink in a couple of years, whether or not it will be profitable to generate electric power in Hungary at all, given the current regulatory framework and the known environmental, and meteorological conditions.

4.2.3 Biomass

Biomass per definition is the total of organic matter present in a life space, used by humans for energy production throughout history. In terrestrial areas it is produced on the fertile land, is derived from photosynthesis that is the direct exploitation of the Sun's energy. However, merely 40-100 TW of the total solar input of 178 PW mentioned in chapter 2.2 is spent on this process, which is practically negligible. It is considered to be a renewable source, because it is replenished by photosynthesis again and again, yet opinions differ on its use in several aspects. What are these considerations?

Biomass, like most renewable sources, are characterised by low energy density, large areas are needed for any substantial amount of power to be generated. Make a short calculation to demonstrate this, using data from Figure 4.10 [4], showing the energy content of selected plants in air dried state (maximum 20 % moisture content)!

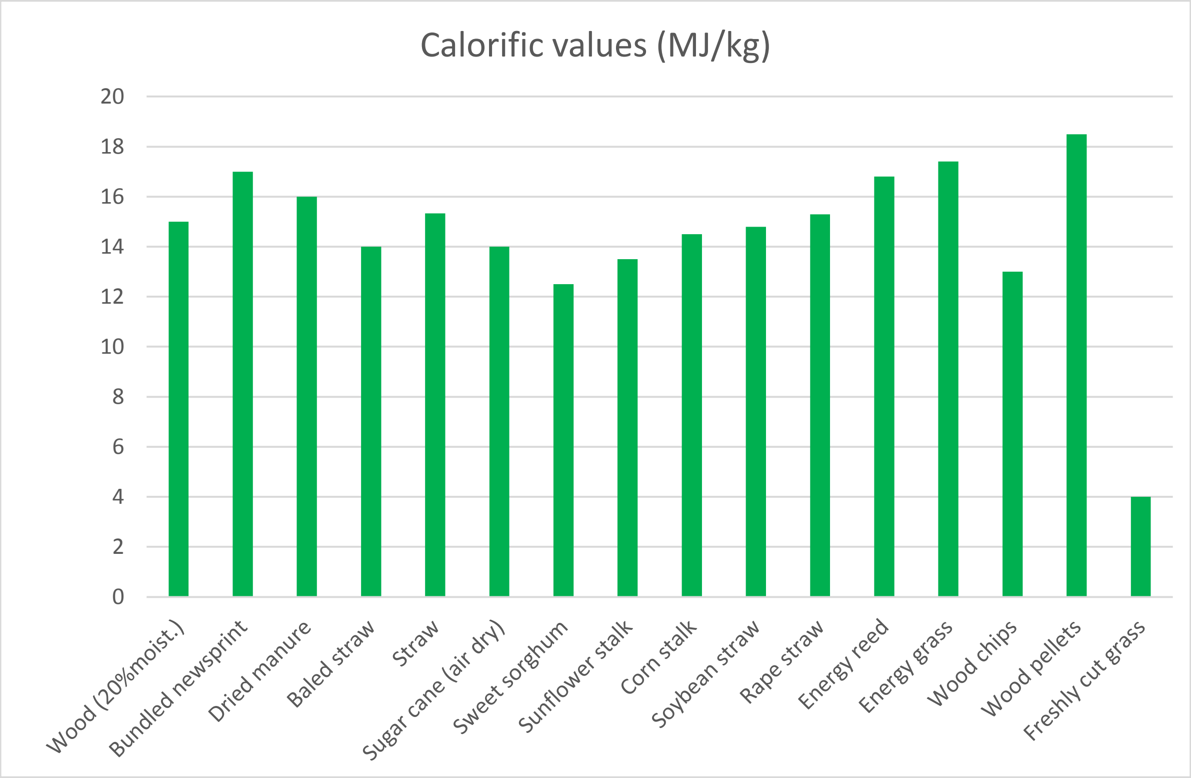


Figure 4.10: Calorific value of selected plants

Except one, calorific values of the plants featured on the figure are in the 12-18 MJ/kg range. If you take an average 15 MJ/kg, this is half of that of coal! Yields per hectare vary between 3 and 9 tonnes, subject to the produce, which is diminished to 90 per cent after drying. Therefore, a total of ≈ 40-120 GJ energy can be produced on one hectare using energy crops, resulting in 18-54 GJ (5-15 MWh) electricity annually, taking into account a conversion factor of 45 %, representing a capacity of ≈ 0.6-1.8 kW assuming continuous operation. Certainly, transportation and energy demands related to production, harvesting and processing must not be forgotten, which all reduce the energy gain.

Additionally, a serious problem emerges in terms of sustainability. In power plants fired by biomass with a useful lifetime of 30 years, continuous fuel supply is important for the entire period to ensure permanent production. Fuel supply might be uncertain for two reasons. Conditions may occur which lead to a kind of overexploitation such as clear-cutting of forests. In order to secure operation of these plants with their maximum capacity, the procurement of large volumes of biomass is inevitable, which must be provided even at the cost of buying up from other regions. Another reason is the ownership of land which might be subject to a change, allowing no guarantee that continuous supply can be maintained over the 30 years mentioned above. It can be seen from the foregoing that large power plants are not worth constructing, and more accurate calculations suggest that the optimal size of a power generator unit is maximum 30 MW. The size of the land required for this would be 167-500 km^2 according to the calculations made before, corresponding to the area of a circle with a radius of ≈ 7-13 km. (Two actual figures from Hungary for comparison and further thinking: Budapest lies on 525 km^2, and the output of Paks Nuclear Power Plant, providing approximately half of the country’s electric power production is 2000 MW!)

Beside used for energy production, biomass is, of course, also fit for food production and industrial use. This raises further issues, and an ethical approach. What is more important for humankind? To provide sufficient amount of food to everybody or should we produce energy from biomass, at the cost of causing famine?

Carbon-neutrality, misinterpreted by many, and the environmental harms, encountered in reality, must also be mentioned! The use of biomass of for energy production can only be considered carbon neutral, when you only see production and use, but is far from being true when you consider transportation, harvesting and processing as well! Environmental exposure is derived from the airborne solid and aeriform pollutants emitted during combustion and burning. Let us examine the purposes for which biomass can be used with a view to energy production!

Utilisation might take place by direct firing, producing heat directly and electricity indirectly. Environmental pollution of this procedure results from the airborne aerosols and the large amount of potassium derived from wood fired facilities. Another possibility is to produce fuel for machines as bioethanol, biodiesel, and biogas. The latter is suitable also to produce heat and/or electricity. All three requires a lot of energy to produce, entailing external costs. Note, that power produced from biomass is far the most expensive of all renewable sources. Additionally, liquid fuels (e.g. biodiesel) derived from biomass have substantially worse effectiveness than conventional fuels, and their application requires conversion of the engines, questioning profitability of the approach.

Finally let us summarise the benefits and disadvantages of energy production from biomass! Most benefits emerge in the conversion of agriculture, with several factors to substantiate it. What are these? Agricultural waste is used, forests are rejuvenated, no land is left fallow, creates jobs, liquid fuel produces can be best used for agricultural implements. On the other hand, adverse effects emerge not only in agriculture. A part of the energy production processes pollute the environment and require energy themselves, thus their profitability is questionable. Energy crop production impairs soil quality, reduces biodiversity, leads to monocultures, can help invasive species to settle, some of them promote genetic contamination, the introduction of diseases and pests.

Hungary undertook a 13% ratio of all energy consumption to be covered by production using renewable energy sources by 2020. This can be achieved but most of it is produced in conventional power plants converted to be run on biomass. Several such plants operate in the country to produce heat and power with a capacity varying between 2 and 50 MW. The largest is Pécs Thermal Power Plant [21], with two purely biomass fired boilers producing heat and power, one using wood chips, the other baled agriculture by-products of herbaceous crops.

4.2.4 Wave energy

Waves on ocean and sea surfaces are caused by the wind, and hence, indirectly from the radiation of the Sun. In certain parts of the Earth they may exceed a height of 10 metres, so man is puzzled with the idea how to utilise them for a long time. The goal is to create rotational movement in turbines directly or indirectly by the force of the waves, which in turn can be used to produce electricity in a generator. Several examples exist worldwide using multiple technologies in Portugal [22], or Australia [23] but the amount of electricity produced by them is insignificant compared to the total.

4.3. Tidal energy

The rise and fall of the sea is part of the Earth’s energy household, even though the power involved is less 2 hundred thousandth of the solar power [2.3]. The phenomenon itself is derived from the gravitational interaction of the Earth and Moon, with the gravitation of the Sun contributing as a strengthening and weakening force, respectively. All in all, Figure 4. 11 shows the water level increase caused by the gravitational interaction of the Earth and Moon and the rotation of the Earth in a somewhat more than 12 hours period on both sides of the Earth, along the line connecting the Earth with the Moon. The sea rise is about one metre in average, but due to resonance water moving in a given geographic environment may tide and ebb several times more than this. Certain places on the Earth, in Newfoundland, Canada, for instance, where the difference between tide and ebb is more than 21 metres, but similar tidal phenomenon is seen in Europe as well, at the Bretagne coasts with a height of 13,5 metres.

How can this be used to produce energy? The physical possibility is derived from the fact that rising water level changes its potential energy and hence, in a bay closed off by a dam water might flow according to the level differences in place from time to time, that is the bay is filled up during tide and is emptied when there is a low tide. If led through turbines in both directions, flowing water can be exploited to produce electricity in a tidal plant. Of course, appropriate placement of the dams is very important, as dams are costly anyway and a poorly placed facility can reduce the tidal difference caused by resonance with several metres. Environmental damages add up to the high costs of dam construction, such plants disturb the ecosystem and the bay of the sea is silted up.

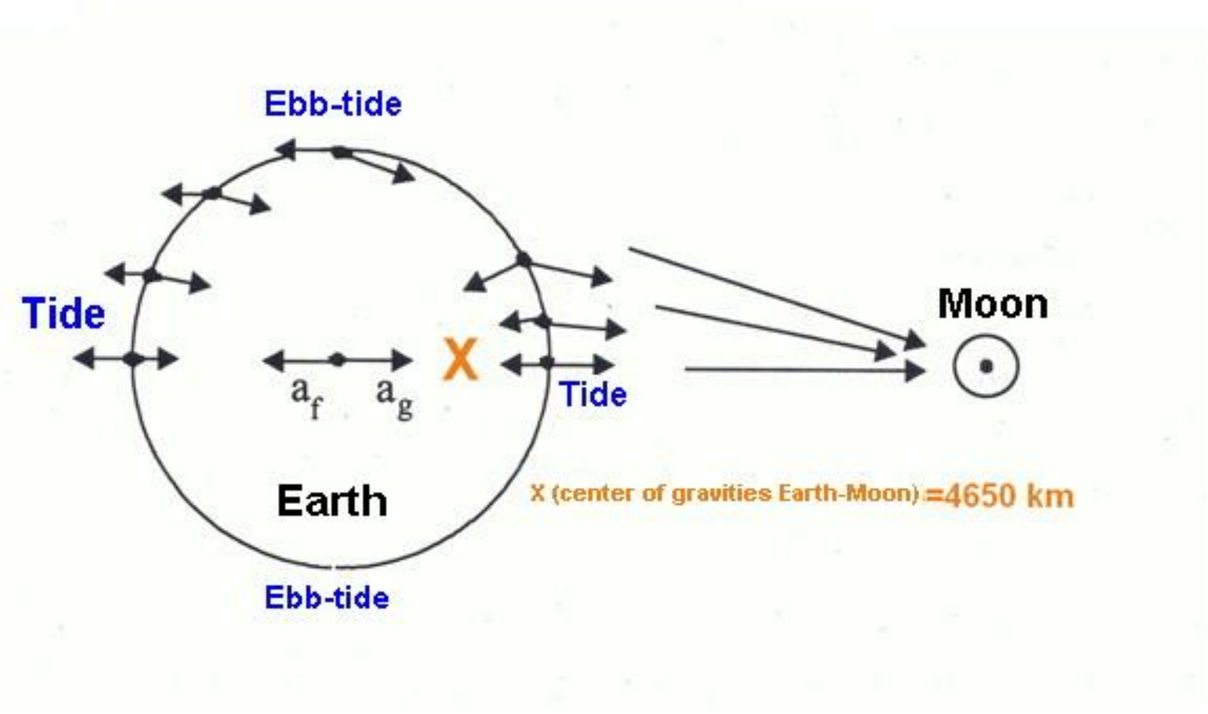


Figure 4.11: Tidal phenomenon on Earth

Currently the largest tidal power plant on Earth is the Sihwa Tidal Power Plant, inaugurated in 2011 in South-Korea [24]. Ten turbines operate in it with a total rated capacity of 254 MW. The largest and also the oldest operating tidal plant in the world, in service since 1966 is in France, La Rance at the Bretagne coast [24]. It has a nominal capacity of 240 MW and produces electricity using 24 turbines and generators.

4.4. Geothermal energy

Geothermal energy (Earth's heat) is also part of the energy household of the planet [Figure 2.3] like tidal energy, but its power is one order of magnitude larger than the latter. No exact value is known, and according to the present knowledge the energy is originated from the natural decay of radioactive isotopes with a long half time, mainly isotope ^{40}K, and ^{232}Th, as well as ^{238}U. They are all found in the Earth's crust, and is probable that a considerable part of the heat flow provided by such elements.

Geothermal heat is not distributed evenly across the Earth's surface, the power flow constant of 63 mW/m^2 on Figure 2.3 can only be seen as an average. Geothermally the most active zones are found at the meeting points of tectonic plates, along fault lines and in the surrounding of volcanos. Differences exist, however within continents, in the Pannonian-basin in Europe, for instance, thermal output per unit surface area is nearly twice as much as the average mentioned above, with a value of 80-110 mW/m^2. In general, the older the rock, the lower is the heat flux.

Geothermal energy can be used in two different ways, to produce electricity or to use the heat. Electricity can be produced in two ways. One is using thermal water found in the geothermal storage formations, filling the pore voids of rocks and found at sufficiently high temperature (>150°C), at high pressure using heat exchangers, steam generation [Figure 4.12]

[25] and for environmental reasons as well as to maintain formation pressure, by injecting spent water back into the formation. Several examples can be cited for using the application seen on the figure, such as in the „geothermal powers” Iceland and New Zealand, but even in Hungary such a small scale power plant is operated on Tura since 2017 [25].

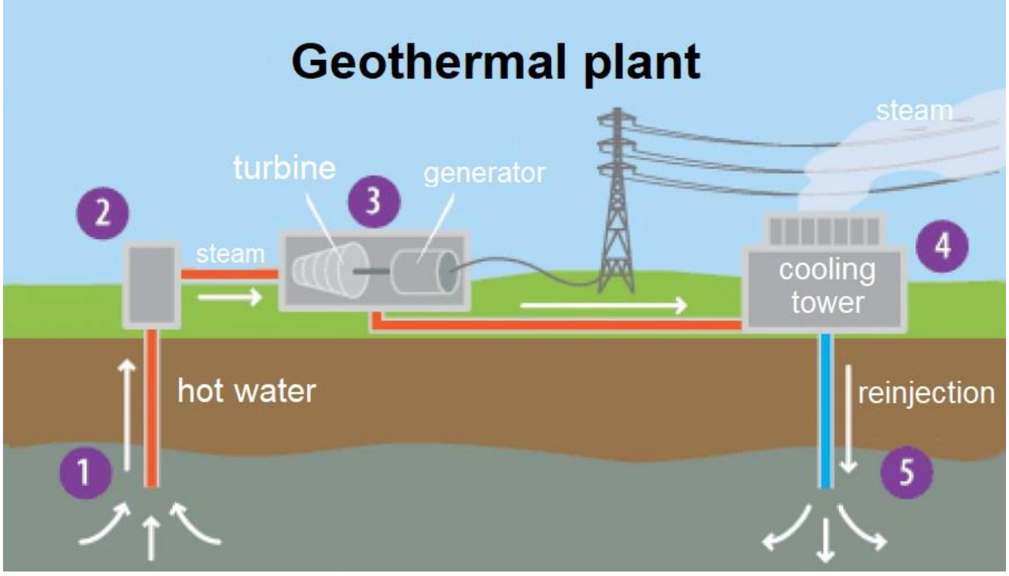


Figure 4.12: Operation of a geothermal plant

Another possibility is called EGS (Enhanced Geothermal System). The application was initially piloted at the end of the 1970s in the USA under the name HDR (Hot Dry Rock) at the time. The procedure exploits the fact that the energy content of low porosity, waterless deep rocks is a lot more considerable than that of water in geothermal reservoirs. Thus, if a liquid is injected, circulated and extracted into and from these deep layers, the energy gain will be considerable, because the amount of energy surfaced with the liquid is several times higher than the energy input needed for pumping [Figure 4.13] [4].

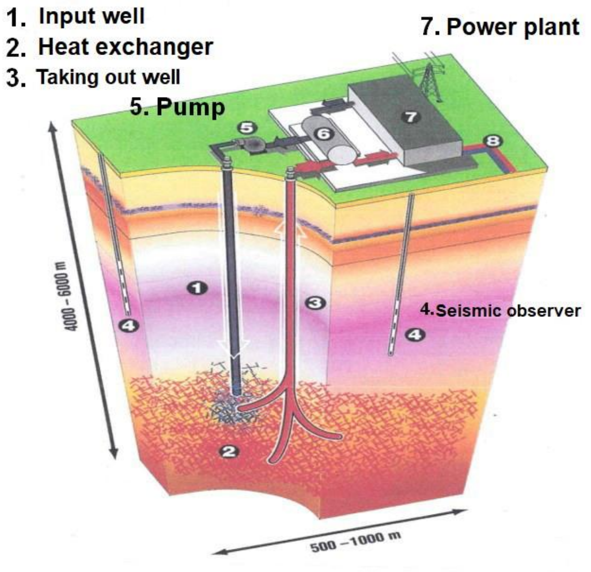


Figure 4.13: Geothermal power plant with EGS technology
6 – Heat exchanger, 8 – Water treatment

At the time being 7 such kind of projects are in progress in Europe, two in France and Germany each, and one in Sweden, United Kingdom and Switzerland each. In each case the greatest problem is that the rock cools down quickly when the procedure is applied, but replenishment of heat is a lengthy process, as the thermal conductivity of abyssal rock (granite) is extremely low. Besides, an additional problem emerges, namely drilling is difficult and extremely costly due to the hard rock, requiring new technology for implementation.

Another way of utilising the geothermal energy is direct use of heat, which is mainly feasible with waters not hotter than 100-120 °C. More and more examples exist for instance in agriculture, such as greenhouse heating, produce drying, but in many places spatial heating of residential buildings of public institutions is also secured using geothermal energy. Please note that the simplest solution is when hot water itself is used in thermal spas.

Small scale use is worth mentioning specifically, this is the application of heat pumps. (Point of interest for additional information and deeper understanding:) http://csodafizika.hu/fiztan/kutcsop/munkacsoportok/kornyezet/heatpumps.pdf

This equipment is nothing else but a reverse refrigerator, which pumps heat from a lower temperature tank into a higher temperature tank by carrying out work. The operation of a heat pump can be seen on Figure 4.14 [4] beside the website referred to above. Heat pumps are used for heating, hot water generation in residential houses and lesser industrial buildings.

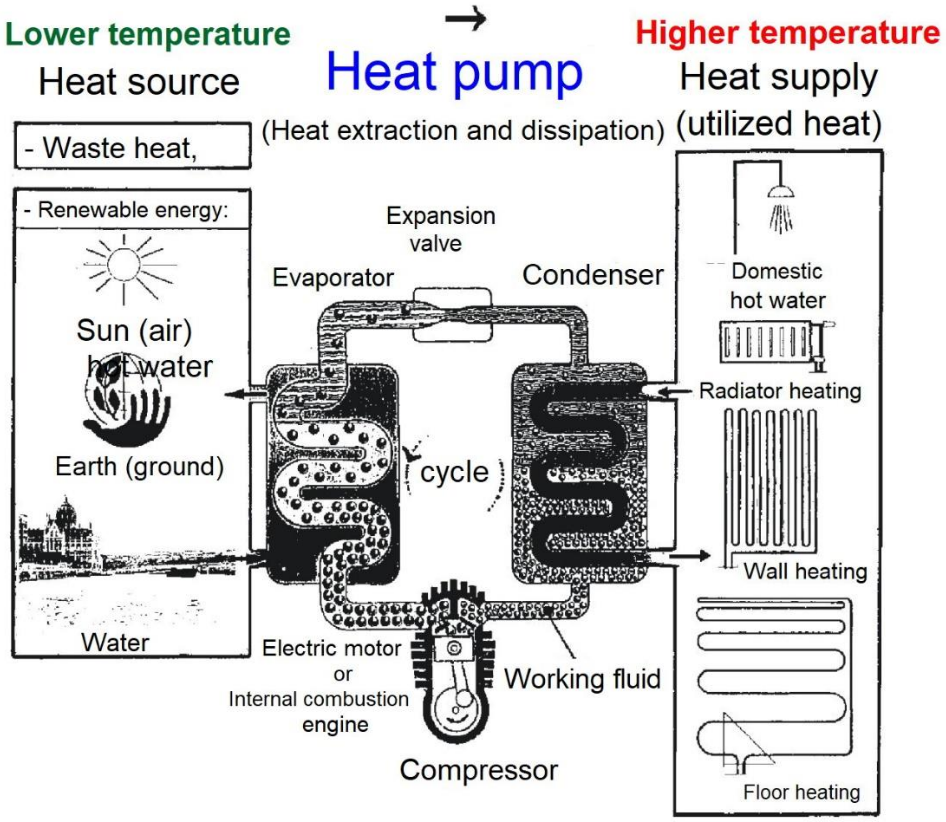


Figure 4.14: Operation of the heat pump

The metrics for efficiency is COP (Coefficient of Performance), the ratio of useful heat and work input. Operation at current energy prices can be economical if the COP value is in the range of 3-5.

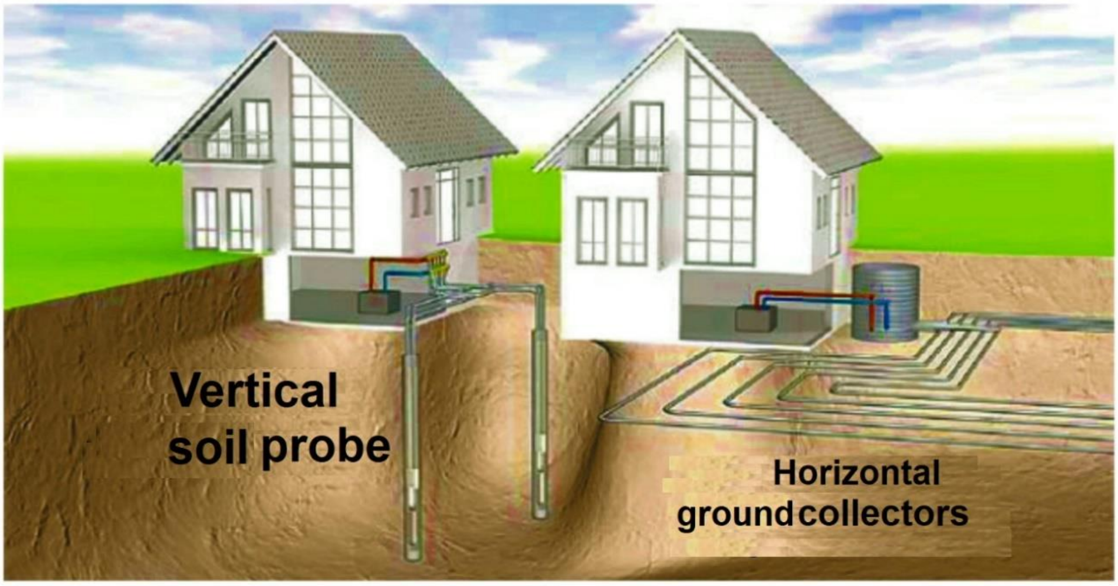


Figure 4.15: Practical application of heat pumps

Today three types of heat pumps are applied in practical uses, here I would just like to mention the two higher COP values [Figure 4. 15]. One works with geothermal soil probes, when drilling is stripped perpendicular to the surface up to 50-200 metres and the bore hole is filled with a 15 cm U shaped tube supplemented with a heat exchanger. The other system uses ground collectors, where pipes are laid horizontally underground in a depth of one or two metres. The area needed for the pipes is twice or three times the size of the area to be heated.

Which are the environmental impacts which may emerge using geothermal systems? Not all of them are negative, some may be considered even beneficial.

Harmful gas emissions are negligible in these systems compared to other types of power plants, only the hydrothermal power plants emit minimal amounts of carbon-dioxide and sulphur-dioxide. As opposed to this, water contamination may be substantial, water may contain more dissolved matter at higher temperature and the boron and arsenic content of surfaced water may represent a risk to wildlife, and an eventually occurring pipe burst even the drinking water supply reserves. On the other hand, water extraction brings up dissolved solids which can be used as raw materials. They can be various minerals, or heavy metals such as zinc or lead.

An operating geothermal system discharges 75-80 dB noise loads to its surrounding, corresponding to a busy city street. During drilling it might be higher, reaching 80-100 dB. (Connection point to interpret noise exposures: www.karinthy.hu/home/grofandrea/)

The land use requirement of geothermal systems is low, hardly more than 1000 m^2, which can be seen as negligible compared to a fossil or even photovoltaic power plant. Costs involved in the implementation of the investment project are substantial (accomplishment of drilling, significant need for water) but operation of a commissioned system can be regarded cheap. For hydrothermal power plants, however, injection of water, a mandatory requirement, also needs some funding.

Drilling might entail adverse effects just as well. On one hand, it may disturb natural hydrothermal systems, on the other, might influence the eco-system, and third, may be the source of accidents due to its hazardousness. Several such examples can be mentioned from Hungary in the past decades, drillings influenced the water level and temperature of the Héviz Lake adversely, and the well blow-out in 1985 at Fábiánsebestyén, where the solution needed for suppression was found only one and a half month later.

Currently, some 1% of all energy production in Hungary comes from the use of geothermal energy, with a slight increase seen lately. Thanks to the developments, this level is expected to increase two or three hold in the coming years.

5. Nuclear power

The term nuclear relates to the atomic nucleus, nuclear energy postulating a kind of energy derived from the transformation of the atomic nuclei. It has two forms, nuclear fission and nuclear fusion. Fission and fusion means the disintegration of one nucleus into more, and merger of multiple nuclei into one, respectively. The underlying physical events can be better understood in both cases from Figure 5.1 [4], showing the specific binding energy (that is, what one nucleon gets).

The figure shows that the highest specific binding energy is attributed to iron, the graph increases from the light nuclei up to iron and from there a slight decline towards heavier nuclei. Energy can be released under two conditions: if lighter nuclei merge, or heavy nuclei decay. As it can be derived from the graph, new nuclei get into a state with higher specific energy in both cases, compared to the original nuclei. This provides the physical explanation of the energy gain originating from either process, described below.

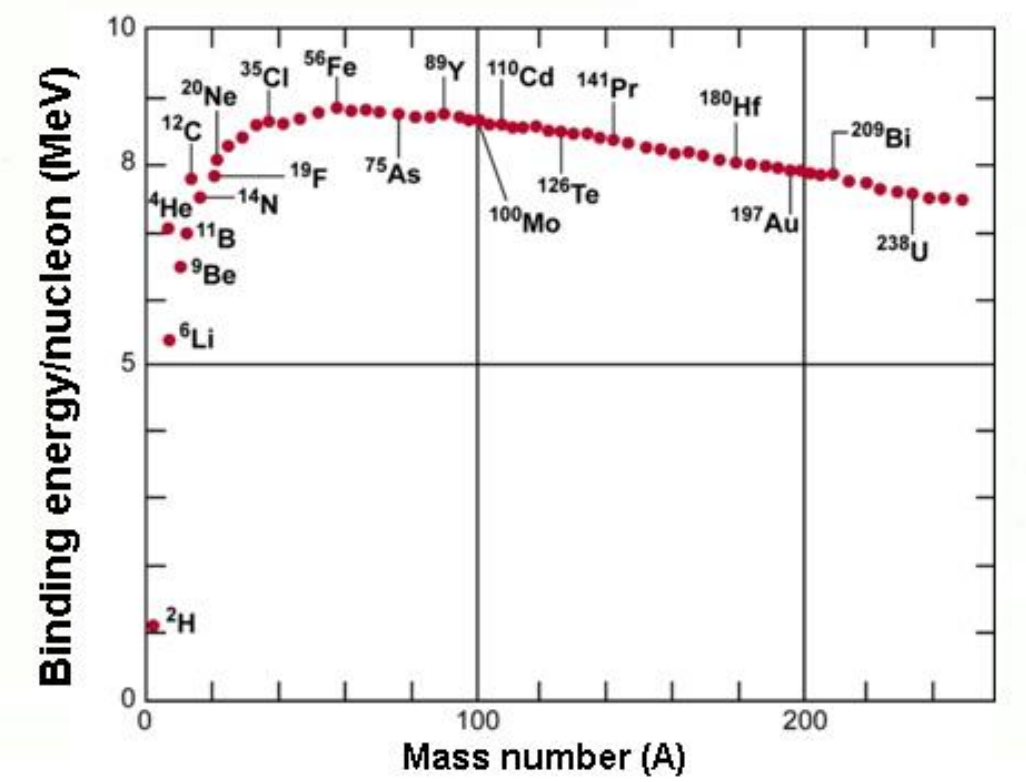


Figure 5.1: Specific binding energy

5.1 Nuclear fission

Nuclear fission was recognised by German physicists Otto Hahn and Friedrich Strassman in 1939. Following its discovery, most efforts were limited to its use in nuclear weapons, any peaceful use of nuclear energy to produce power was started only after the end of World War II. Currently, even though its initial positive acceptance was impaired in the last decade, about 5% of the total energy production on Earth is derived from nuclear fission.

5.1.1 Description of the process

Upon the decay of heavy nuclei two new arise with lesser mass numbers, with higher specific binding energy each than that of the originating nucleus. Decay may happen by spontaneous and induced fission. Spontaneous fission is very improbable, for the purposes of power generation induced fission is applied.

Induction takes place when a heavy nucleus is bombarded using atomic particles. This might be protons, neutrons, or even α-particles or γ-quantums, it is true in general that the energy input is a lot less than the amount of energy released upon fission. The nucleus maintains a potential barrier before fission, formed by nuclear forces and the Coulomb-interaction, but the energy of the particle input may overcome this potential barrier (activating energy). In such cases the nucleus stars to oscillate as an impact of the energy transmitted, its shape will be altered and disintegrate into decay nuclei, which are pushed apart from each other by the Coulomb-repulsion.

The probability of the fission is expressed by the fission section. Figure 5.2 [4] shows that two isotopes of the same element (^{235}U and ^{238}U) decay with quite different probabilities. The uranium nucleus with the lesser mass number, in particular with lower energy neutrons, will disintegrate a lot better than that with the higher mass number, and the latter also has an energy ‘threshold’ (1.2 MeV) under which the probability of fission is very low.

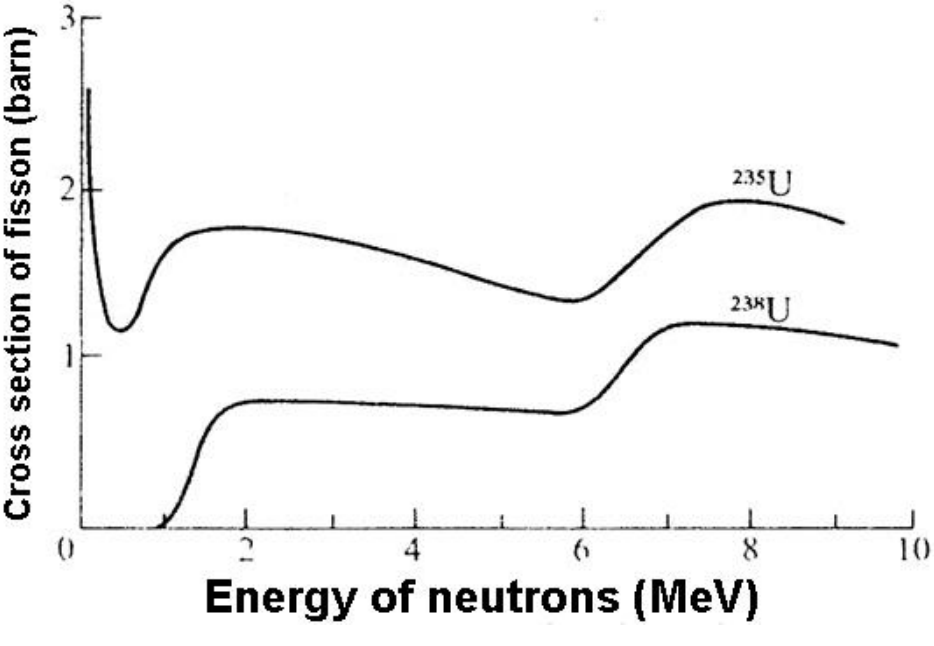


Figure 5.2: Comparison of fission probability in uranium nuclei

It is true in general that isotopes with odd mass numbers decay better than those with even mass numbers. It is because nucleons within nuclei arrange in pairs, to be bound stronger, and this enhances the binding energy of the nucleus itself. If the neutron hits a nucleus with odd number of neutrons, the nucleus will get excited more with the energy of the pair and hence, decay more easily.

When ^{235}U decays, most of the decay products will have mass numbers around 90 and 140, which correspond most frequently to elements such as strontium 90, and caesium 140. In each case of fission, neutrons also exit, meaning 2 to 4, in general 2.5 neutron. This is because too many neutrons would be left in the freshly generated nuclei compared to the original nucleus, and the new nucleus reduces its energy level by releasing neutrons.

Not all the neutrons leave the nucleus simultaneously, approximately 0.6% represent the so called late neutrons, which can be regarded as the ‘miracle of nature’. These exit after fission with a delay of several seconds during the time when the new nucleus formed during fission continues to decay with long half time β-decay into a nucleus, in which one of the neutrons is not bound, thus emitting a neutron. They play in important role in warranting safe operation of nuclear power plant units, the fission processes triggered by these late neutrons can be used to make energy production self-sustaining in controlled chain reactions.

5.1.2 Chain reaction, power production using reactors

Two uranium isotopes occur in nature, in quite different ratios. One with a mass number of 238 and the other with a mass number of 235 can be found in 99.3% and merely 0.7%, respectively. Upon fission high energy level (≈ 2 MeV) fast electrons are generated, triggering two kinds of processes, yet another fission, or neutron capture with radiation. Calculations made on the basis of the relative proportions of the two isotopes and their respective properties suggest that the average number of 2.5 fast neutrons is not enough to implement the chain reaction spontaneously, the probability of fission to occur is too low, ^{238}U simply absorbs neutrons. Fast neutron does not split, it must be slowed down. In order for the chain reaction to start another condition must be met, the appropriate amount of fissile material, the so-called critical mass, existence. What are the solutions, how can uranium be used for energy production nevertheless?

There are two possibilities for this, thermalisation and enrichment. Thermalisation means the slowing down of high-speed neutrons, when the neutron energy drops several orders of magnitude (25 meV), and as shown on Figure 5.2 will be able to split isotope ^{235}U only, not ^{238}U. he probability of fission for these slow neutrons will be orders of magnitude higher. Enrichment means increasing the ratio of isotope ^{235}U in the given block of uranium, where the probability of fission also seen on Figure 5.2, will increase significantly.

Implementation of the possibilities outlined above is effectuated using two different kinds of reactors [Figure 5.3] [4]. Both types are structured similarly, differences include the moderators slowing down the neutrons and the breeder zones.

The figure on the left hand side illustrates the so called thermal-neutron reactor in which moderated (slowed down) neutrons ensure fission while uranium used as a fuel for the reactor is enriched slightly (3-5 %). Most reactors in the world are of this type at the time being. This technology is namely a lot safer, the neutrons cause the same number of fissions per second, and hence, energy production is constant and chain reaction controlled.

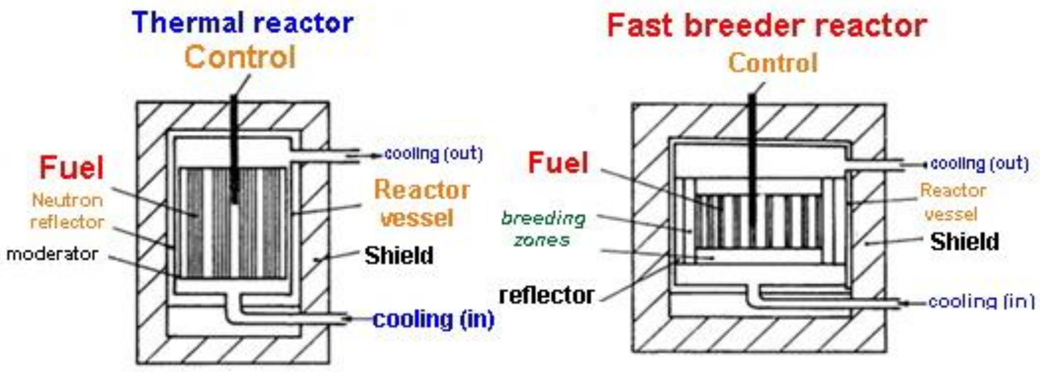


Figure 5.3: Thermal and breeder reactors

The other type is the fast, or breeder (production) reactor, with a fuel composed entirely of ^{235}U, where no neutron thermalisation is made and no moderator media are used. The reactor core for this type is surrounded by ^{238}U breeding zone. Here, from the ^{239}U formed after neutron absorption, after two beta decays, the odd ^{239}Pu is formed, which is a fissile material with a half-time of 24,000 years. Thus, in addition to energy production, we also produce fissile material, the amount of which in the case of a well-designed reactor is larger than that used by the reactor. The primary goal of these reactors to produce artificially bred radioactive materials, i.e. isotopes with odd mass numbers, which easily decay. Currently, only one type of reactor is in operation on Earth due to the significantly more complex and unsafe solutions.

The energy production process in nuclear reactors is presented on Figure 5.4 [4]. In the case of each reactor the fundamental regulatory principle is that the number of neutrons must be constant. Moderators and absorption (neutron control) rods are found in thermal-neutron reactors, while breeder reactors only have control rods. Moderators include water, heavy water or graphite, absorbers boron or cadmium. Control rods also play a critical role in shutting down the reactor.

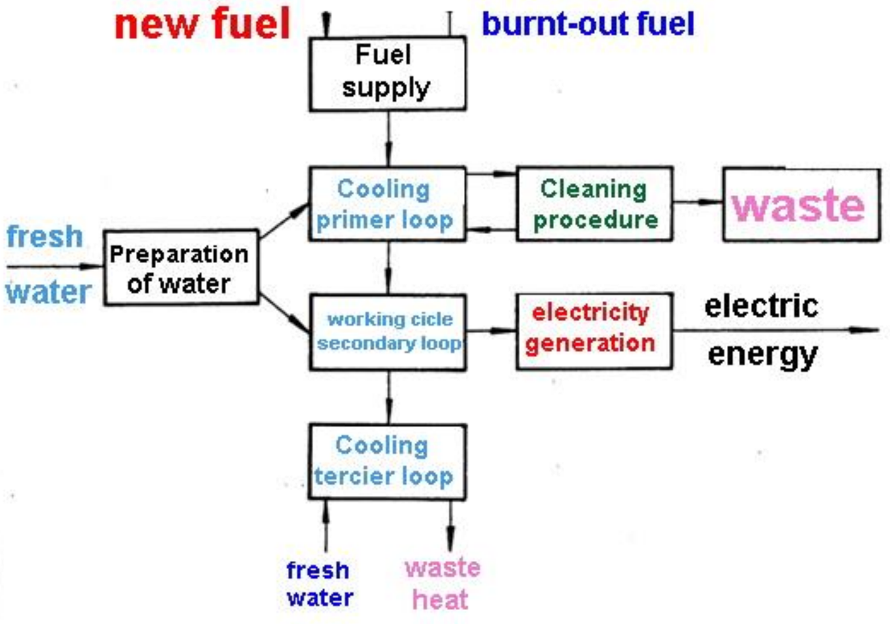


Figure 5.4: Process of energy production

Fuel rods are bundled, they become hot during operation of the unit and the heat generated can be used to develop steam, which, in turn, is let onto turbines to generate electric power. The system is cooled by liquid (water), or gas (helium), or eventually solid (lead) applications.

5.1.3 The nuclear fuel cycle

Correct comparison of energy from different sources and benefits against disadvantages analysed when the entire fuel cycle, all the steps related to energy production, is assessed for the same amount of energy. Nuclear energy was the first to have undergone a detailed analysis of this kind. Figure 5. 5 [4] followed the nuclear fuel cycle from mining of the ore up to processing of the waste. Activities seen in the rectangles of the figure bordered by a double line indicate areas subject to social debates. These are enrichment, potential operating troubles of plants, reprocessing and waste disposal [Table 5.1].

Subject of the debate	***Reason***
Enrichment	Can be used to produce nuclear weapons
Power plant operation	Due to high density, constant cooling is critically important
Reprocessing	Chemical procedure with high activity, obtaining plutonium is cause of concern
Disposal of radioactive waste	Final disposal of high activity waste is not settled

Table 5.1: Key problems of nuclear energy production

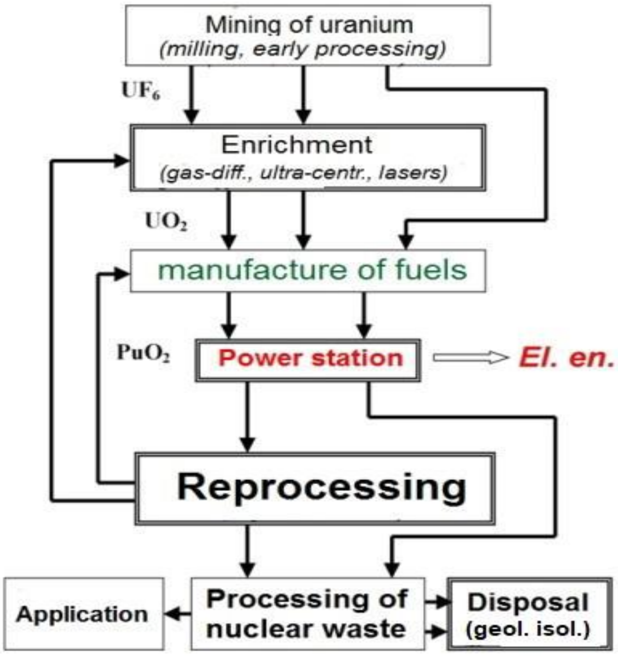


Figure 5.4: Nuclear fuel cycle

The first phase, mining of the ore is not specifically problematic, it is roughly the same as any other mining procedure. Only radon concentration increase may cause concern to be eliminated. Mining is best where the parent rock is rich in uranium (at a concentration of at least ~5 parts per thousand). This was one of the reasons to abandon uranium mining in the Mecsek mountain, Hungary in 1997, because the rock there was very low on uranium. The known uranium reserves of the Earth economically feasible for exploitation is estimated to be 5.6 million tonnes, with the most significant sites in the territory of the former Soviet Union and Australia, but lesser and/or greater quantities are found on each of the continents [Figure 5.6][4]. The energy content of these reserves depends on the type of the reactor it is used. When burnt in light water thermal-neutron reactors, it would account for about 6000 EJ, equivalent with oil that is to be depleted within a couple of decades.

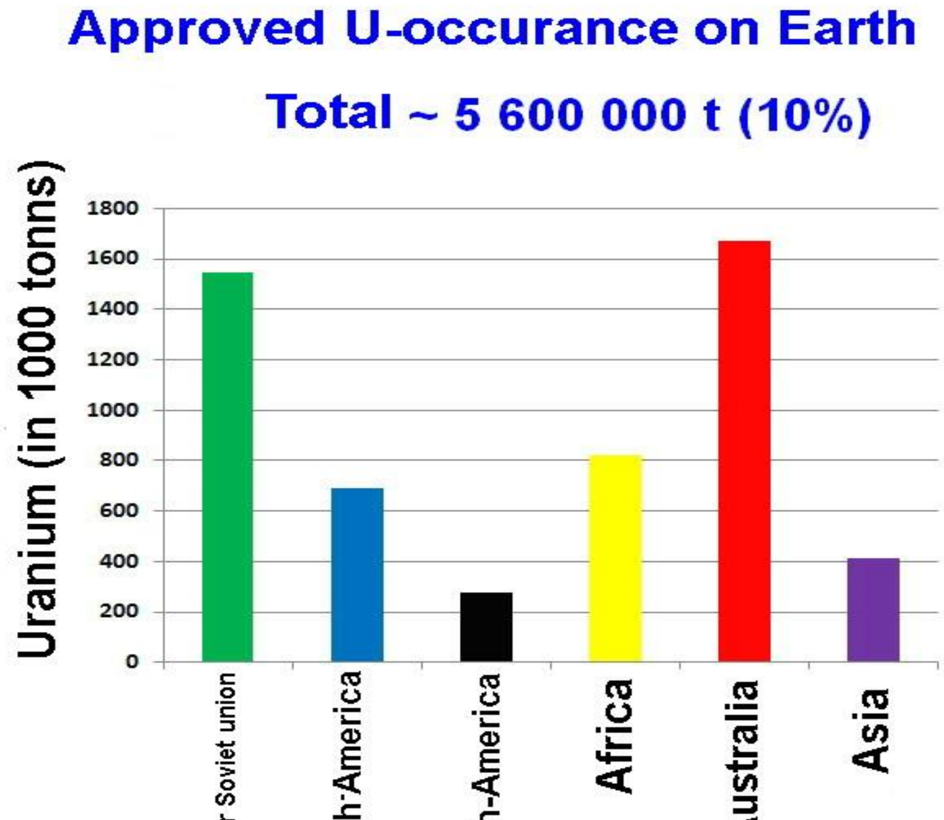


Figure 5.5: Geographic distribution of uranium reserves on Earth

The second step is enrichment, as mentioned, means increasing the ratio of isotope ^{235}U, and is challenged because of its potential to produce nuclear weapons. All procedures used for the process are based on the three neutrons mass difference, which can be used to separate isotope 238 and isotope 235 safely.

The next phase is the production fuel elements, which is a standard chemical procedure, during which the fuel is brought to a shape to be used in the reactor unit. Most frequently, this form is uranium-dioxide. In the active zone of the power plant [Figure 5.3], where fuel elements are placed, radioactivity is very high beside the extremely high thermal performance, the escape of which into the biosphere must be absolutely prevented. Therefore, constant cooling must be maintained even then the chain reaction was already shut down, otherwise the reactor core may melt down and large amount of radioactive substances can get into the environment (Fukusima 2011).

The fourth step is reprocessing, where uranium and transurane elements of the spent fuel rods are separated from decay products. Anti-nuclear activists may worry for obtaining plutonium which is seen on Figure 5.5, considering the chance to get it into illicit hands.

Finally, the last stage of the nuclear cycle is waste processing, the final disposal of radioactive waste to places where they do not represent any risk to the environment any more. Waste generated in nuclear plants is divided into two parts, low and medium activity, as well as high activity wastes, respectively. Disposal of the first one is a national affair in each of the countries and is in principal and in practical settled. High activity waste, however, is not disposed of reassuringly anywhere in the world, it is even today deposited in provisional storage sites. From this perspective society's concern against nuclear energy is well founded.

5.1.4 Reactors of the future

All in all, 453 reactors operated on the Earth in 2018, with a total electric output of 395 GW, with 3.46 PWh of electricity produced, approximately 15% of the total electrical energy use of the world [3]. This is a substantial proportion and this quantity will be required by humankind in the future just as well. Lately, nuclear power is the target of serious criticism for several reasons. One is the fear from accidents, the production of nuclear weapons, concerns related to the disposal of nuclear waste, and to the depleting uranium reserves, plus the economic risks associated with the erection and dismantling of nuclear power plants. What is, then, the function of reactor units in the future?

Maybe the most important task is to ensure sustainability meaning the most efficient utilisation of uranium and thorium, and to solve the problem of final disposal of nuclear waste in a way which is reassuring for humankind. Beside sustainability, it must be clear to everybody that nuclear power might have advantages over other energy generation methods, but the problem must be solved, how it can be rendered suitable to produce other types of energy, such as process heat, in addition to electric power. A very important additional consideration is the safety issue, with a view to already occurred nuclear catastrophes (Chernobyl 1986, Fukusima 2011). This must be manifested in regulating the inner safety of reactors by physical laws reducing the risk of damaging the reactor core to a minimum. Finally, a considerably important aspect is lately to render the facility protected and less vulnerable against terrorist attack.

5.1.5 History, presence and future of the Paks Nuclear Power Plant

Hungary has a single nuclear power plant producing significant amount of energy. The amount of electricity produced by the four units covers approximately half of the national power needs. Let's talk a few words on the power plant itself, past, present and future!

The story goes back to the 1960s. The decision to erect a nuclear power plant in Hungary was made in 1966. The construction works started in 1974, and the legal predecessor of the current company was created in 1976. The first and fourth unit of the plant started production in December 1982 and August 1987, respectively, with all four units granted operating permits for a period of 30 years. Lifetime extensions were obtained for the first unit in 2012 and for the other three gradually for additional 20 years each. Thus the nuclear power plant units can generate electricity up to the years 2032 to 2037, with a total capacity of 2000 MW [Figure 5.7] [26].

Under the Hungarian-Russian agreement announced in 2014 the Paks Nuclear Power Plant will be expanded and according to the present state of affairs two additional units will go live by the second half of the 2020s with substantially larger outputs than the current ones (2*1200 MW).

The concerns referred to in the previous chapter, challenging the utilisation of nuclear energy and incited by media just as well are present in the Hungarian society also, several interest groups make attempts to forge political capital to achieve their goals. However, how much a secondary school student knows about the topic of nuclear energy production, to which extent he or she comprehends the physics behind, and how can he or she formulate a realistic picture, not influenced by the media? To promote this in society would be the function of competent sources with reliable professional background (Connection point: www.mavir.hu, www.atomeromu.hu), but in the secondary school context such information must be disseminated primarily by a physics teacher.

Figure 5.6: Paks Nuclear Power Plant

Some help is represented by the operation of the nuclear reactors and the physics of nuclear fission which are included in the curriculum, even though only in grammar schools and only in the 11th grade, the last when physics as a subject is taught. On the other hand, most students show genuine interest in this theme and if they are given appropriate information, they will be able to understand the underlying physics. Such pieces of information, assumed to come from credible and authentic sources, may make clear for them why the prospective Paks extension will be safe, economic and, from the perspective of energy stability, inevitable. Let us review shortly these pieces of information built on the secondary school curriculum!

When talking about the issue of safety, it is expedient to clarify – based on what was learnt with respect to the penetrability of the various radiations and how can you control various radiations, as well as how this is implemented in Paks. When analysing profitability, you have to provide the factors adding up the costs necessary for the production of electricity in the case of the various power plant types. Even though the data for exact units of energy are not available, it might be worth noting that in the case of Paks nuclear energy this figure is ~12 HUF/kWh (i.e. less than 4 eurocents/kWh), uniquely low even on the European level. The amount contains those costs which emerge in relation to disposal of radioactive waste in storage sites and the final decommissioning of the plant.

Energy stability as a problem must be discussed third. This means the availability of various power plant types and energy generating equipment, how steadily are they able to produce electricity. You should note which of them can be regarded as stable and which are to be operated only when the functional conditions of plants driven by renewable sources are not fulfilled (such as a no wind condition or overcast weather) How much extra costs are involved? The opposite may also happen, when overproduction is encountered in the energy supply system! Is it possible in such cases to store energy somehow? What are the indirect costs?

All in all, it is expedient to investigate what the short term and long term advantages of extension will be. The first one includes the assumption that nuclear plants are environmentally friendly and do not discharge carbon-dioxide, dust or greenhouse gases. It’s application is safe, transportation and stockpiling of fuel is easy, and due to its high level of reliability it is able to provide power continuously, while the increased capacity contributes to the energy import dependence of the country. Long term advantages include economic profitability, job creation and the contribution to the development of the region.

However, the problems emerging must also be mentioned beside benefits. One of these relates to the waste produced. Even though the absolute quantity is incomparably smaller than that created by any coal fired plant, this waste is radioactive, deserving special attention. Storage must be accomplished at a location which is able to exclude radiation exposures completely and serves on a long time. Such a place for the disposal of the low and medium activity waste is already available in Hungary. Such substances are received in Bátaapáti since 2012, but the issue of final disposal of high activity waste is still an open issue in this country just as much as anywhere else. A second problem is the provision of manpower to operate an extended power plant. At the time being this can not be seen as overcome, there is too few professionals available, but certainly, practicing physics teachers in secondary schools will have a dominant role in meeting this challenge.

5.2 Nuclear fusion

We saw that another possibility to produce energy by the conversion of the nuclei is nuclear fusion, where merger of nuclei with lower mass number a higher mass number nucleus comes into existence, releasing energy in the process. This phenomenon provides energy for the Sun and other stars just as well and it would be an immense opportunity for man to use it successfully for a peaceful purpose under terrestrial conditions. It was already used for armament and war (hydrogen bomb, pilot explosions), that is the nuclear physical background is completely known to science, only a clear solution for producing energy can not be seen yet.

A condition precedent to create nuclear fusion is that nuclei overcome the Coulomb-repulsion, otherwise they can not interact with their respective nuclear forces. This can be implemented at a temperature in the order of magnitude of 100 million K, when matter is in plasma state. In order to realise energy production, this plasma must be kept together at the extremely hot temperature. There are two possible solutions, for a short time or a somewhat longer time with relatively high plasma density or lower density, respectively. The first option could be implemented using high performance lasers, which are not available at the time being, although there are remarkable results in the USA. Another prospective solution could be to keep lesser density plasma together with strong magnetic fields. An attempt to implement this is made in the ITER (International Thermonuclear Experimental Reactor), which is being constructed since 2007 in South-France in international cooperation [Figure 5.8] [27].

Figure 5.7: Fusion power plant under construction in South-France (Chadarache)

The construction is currently in progress, the first plasma operations are expected for the middle of the 2020s, but according to the plans ITER would only be followed by a thermonuclear plant producing significant quantity of energy only after 10 years of experimental operation. Although power generation by fusion would represent a lot less environmental risk than the fission reactors, the commercial energy production is not expected to take off in the upcoming 30 years.

6. The future of energy policies

Safe and continuous energy supply to humankind in the future is a critical issue for the functional health of society. In order to implement it, however, society must also recognise the facts of the present and the actions to be taken which may ensure such a scenario. Which facts are these?

Fossil energy carriers are finite resources, they will last for a few more decades only, while renewables can replace not more than 20-30 % of current use, they are unable to full substitution. Conversion of the power structure is a lengthy process entailing environmental harms and adverse economic, social consequences. Continued population growth triggers an ever increasing energy demand with the accompanying economic, social and political tensions. The usually short term thinking of political systems does not favour the solution of the energy supply problem, an issue requiring long term planning. What are the actions which may be of help after all?

We need organisational forms able to arrive at long term decisions in energy issues. Energy supply in the decades to come can only be ensured with the use of the advancement of the technical sciences, and in this the support to energetics research must be given priority. In addition, it is of paramount importance for society to recognise the significance of energetics. Beside centrally controlled, but realistic scientific information disseminated to all the teachers in secondary school delivering natural science curricula play an important role. Their responsibility will be to hand down credible, yet easy to understand knowledge to the generation who will face this on a day to day basis throughout their lives. Not an easy task, but very uplifting!

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