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Sustainable energy development

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Abstract

The paper presents an overview of sustainable energy development and is aimed to emphasize the important aspects relevant to this activity. A short introduction, related to the present energy outlook with a survey of available data, is presented. This gives the possibility to assess the motivation for a sustainable energy development.

Special attention is devoted to the definition of sustainability and its generic meaning. In this respect, particular attention is devoted to the discussion of different aspects of sustainability in the present world. In order to present an engineering approach to the sustainable development, attention is devoted to the review of sustainability criterions as they have to be introduced in the future products.

The main emphasis is given to review a potential development in the energy engineering science which may lead to a sustainable energy development. Seven major areas are listed with specific problems and their relevance to the sustainable energy development. This includes the following areas: energy resources and development; efficiency assessment; clean air technologies; information technologies; new and renewable energy resources; environment capacity; mitigation of nuclear power threat to the environment.

The education system is the milestone for any economic development. In this respect, sustainable energy development will require special attention to be devoted to the new development of the education system. The distance learning education system is envisaged as the potential option for the knowledge dissemination of the new energy technologies.

1. Introduction

Energy resources have always played an important role in the development of the human society [1]. Since the industrial revolution, energy has been a driving force for

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modern civilization development. Technological development and consumption of energy, along with the increase in the world population, are interdependent. The industrial revolution, especially to the momentum created by the change from reciprocal engines to the great horsepower of steam engines in the late nineteenth century, which brought about a revolution in dynamics—began a drastic increase both in consumption and population of the world [2].

The history of life on the Earth is based on the history of photosynthesis and energy availability [3]. The history of such a planet lies in the capture of solar energy and its conversion by photosynthesis in plants and phytoplankton as organic molecules of high energy content. The plants convert this energy into other organic compounds and work by biochemical processes. Photosynthesis counteracts entropy increase and degradation since it tends to put disordered material in order. By capturing the solar energy and decreasing the planetary entropy, photosynthesis paves the way for biological evolution.

Boltzman [4], one of the Fathers of modern physical chemistry, wrote, in 1886, that the struggle for life is not a struggle for basic elements or energy, but a struggle for the availability of negative entropy in energy transfer from the hot Sun to the cold Earth. In fact, life on the Earth requires a continuous flux of negative entropy as the result of the solar energy captured by photosynthesis. The Sun is an enormous machine that produces energy by nuclear fusion and offers planet Earth the possibility of receiving large quantities of negative entropy. Every year the Sun sends 5.6×10^{24} joules of energy to the Earth and produces 2×10^{11} tons of organic material by photosynthesis. This is equivalent to 3×10^{21} joules/year. Through the billions of years since the creation of the planet Earth this process has led to the accumulation of an enormous energy in the form of different hydrocarbons. Most of the fossil fuels belong to the type of material where molecular binding is due to Van der Waal's potential between every two molecules of the same material. Mankind's energy resources rely heavily on the chemical energy stored in the fossil fuel. Table 1 shows assessed energy resources [5].

Energy and matter constitute the earth's natural capital that is essential for human activities such as industry, amenities and services in our natural capital as the inhabitants of the planet Earth may be classified as:

Table 1
World non-renewable energy resources in 1995

	Total 10^9toe	CPE %	North America a %	Latin America a %	West Europe %	Africa %	Asia Pacific %	Middle East %
Oil	95	11.5	4.9	13.5	3.2	7.9	2.7	56.3
Gas	85	41.5	8.3	3.7	3.5	6.1	6.2	26.7
Coal	530	46.6	26.6	0.6	9.8	7.5	89	0.00

- Solar capital (provides 99% of the energy used on the Earth)
- Earth capital (life support resources and processes including human resources)

These, and other, natural resources and processes comprise what has become known as 'natural capital' and it is this natural capital that many suggest is being rapidly degraded at this time. Many also suggest that contemporary economic theory does not appreciate the significance of natural capital in techno-economic production.

All natural resources are, in theory, renewable but over widely different time scales. If the time period for renewal is small, they are said to be renewable. if the renewal takes place over a somewhat longer period of time that falls within the time frame of our lives, they are said to be potentially renewable. Since renewal of certain natural resources is only possible due to geological processes which take place on such a long time scale that for all our practical purposes, we should regard them as non-renewable. Our use of natural material resources is associated with no loss of matter as such. Basically, all earth matter remains with the Earth but in a form in which it can not be used easily. The quality or useful part of a given amount of energy is degraded invariably due to use and we say that entropy is increased.

The abundant energy resources in the early days of the industrial development of modern society have imposed the development strategy of our civilization to be based on the anticipated thinking that energy resources are unlimited and there is no other limitations which might affect human welfare development. It has been recognized that the pattern of the energy resource use has been strongly dependent on the technology development. In this respect it is instructive to observe [6, 7] the change in the consumption of different resources through the history of energy consumption. Worldwide use of primary energy source since 1850 is shown in Fig. 1 [6]. *F* is the fraction of the market taken by each primary-energy source at a given time. It could

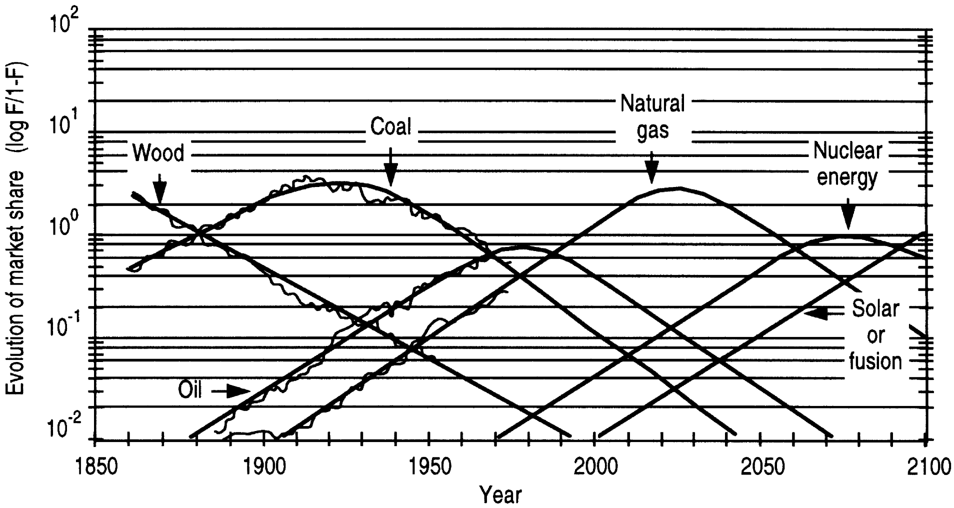

Fig. 1. Market penetration of primary energy sources.

be noticed that two factors are affecting the energy pattern in the history. The first is related to the technology development and, the second, to the availability of the respective energy resources. Obviously, this pattern of energy source use is developed under constraint imminent to the total level of energy resources consumption and reflects the existing social structure both in numbers and diversity [8, 9, 10]. The world energy consumption is shown in Fig. 2 [11].

Looking at the present energy consumption pattern, it can be noticed that oil is a major contender, supplying about 40% of energy. Next, coal supply is around 30%, natural gas 20% and nuclear energy 6.5%. This means that the current fossil fuel supply is 90% of the present energy use. In the last several decades, our civilization has witnessed changes which are questioning our long-term prospects. Fossil fuel, non-recyclable is an exhaustible natural resource that will be no more available one day. In this respect it is of common interest to learn how long fossil fuel resources will be available, as they are the main source of energy for our civilization. This question has attracted the attention of a number of distinguished authorities, trying to forecast the energy future of our planet. The Report of the Club of Rome "Limits to Growth", published in 1972 [12], was among the first ones which pointed to the finite nature of fossil fuel. After the first and second energy crisis, the community at large has become aware of the possible physical exhaustion of fossil fuels. The amount of fuel available is dependent on the cost involved. For oil, it was estimated that the proven amount of reserves has, over the past twenty years, leveled off at 2.2 trillion barrels produced under \$20 per barrel. Over the last 150 years we have already used up one-third of that amount, or about 700 billion barrels which leaves only a remaining 1.5 trillion barrels. If compared with the present consumption, it means that oil is

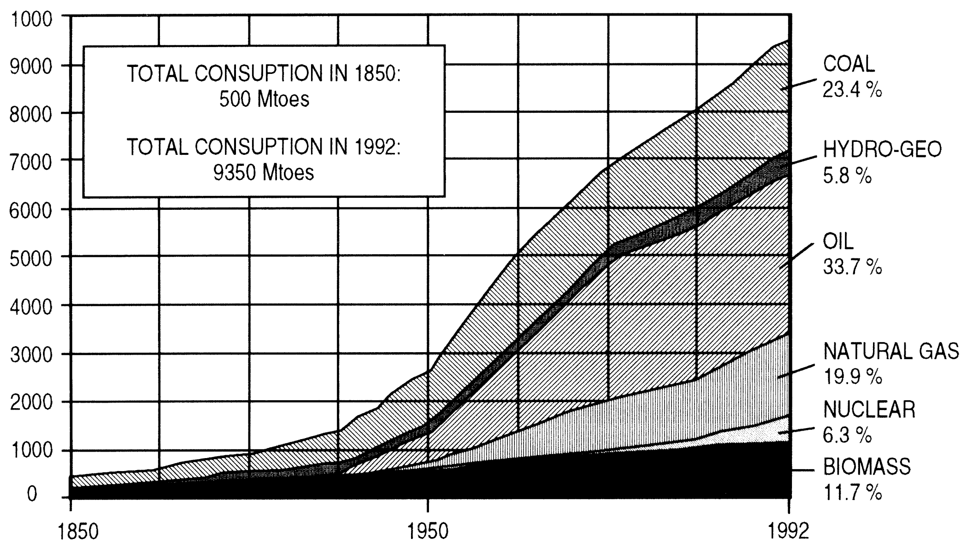

Fig. 2. World energy consumption.

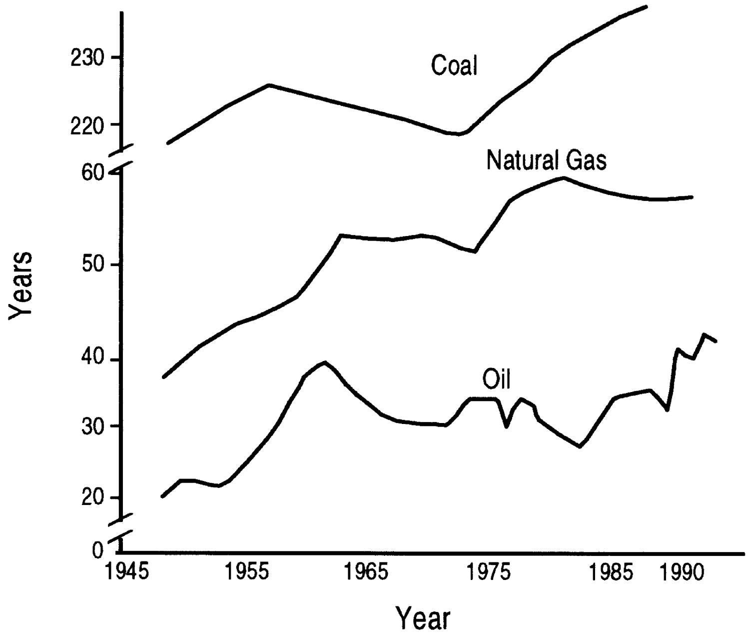

Fig. 3. Residual life forecast of energy resources.

available only for the next 40 years. Figure 3 shows the ratio of the discovered resources to the yearly consumption for the fossil fuels [11].

From this figure it can be noticed that coal is available for the next 250 years and gas for the next 50 years. Also, it is evident that as much as the fuel consumption is increasing, new technologies aimed at the discovery of new resources are becoming available, leading to a slow increase of the time period for the exhausting of the available energy resources.

It is known that the energy consumption is dependent on two main parameters, the amount of energy consumed per capita and the growth of population. It has been proved that there is a strong correlation between the Gross Domestic Product and Energy consumption per capita. Figure 4 shows the economic growth and energy consumption for a number of countries, in 1990 [12].

There are a number of scenarios which are used for the forecast of the world economic development. With the assumption that the recent trend in the economic development will be conserved in the next 50 years and considering the demographic forecast in the increase of human population, as shown in Fig. 5 [13].

Future energy consumption could be calculated, as shown in Fig. 6 [14].

Compared with the available resources it is easily foreseen that the depletion of the energy resources is an imminent process which our civilization will face in the near future. Nevertheless, whatever is the accuracy of our prediction methods and models, it is obvious that any inaccuracy in our calculation may affect only the time scale but

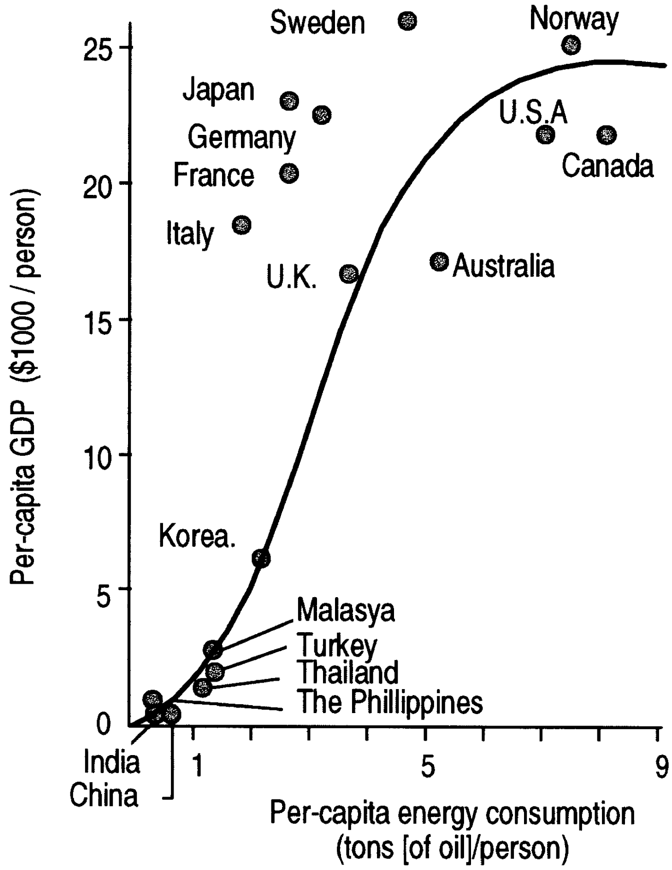

Fig. 4. Economic growth and energy consumption.

not the essential understanding that the energy resources depletion process has begun and requires human action before adverse effects may irreversibly enforce.

Natural resources scarcity and economic growth are in fundamental opposition to each other. The study of the contemporary and historical beliefs showed [15], that: (1) natural resources are economically scare, and become increasingly so with the passage of time; (2) the scarcity of resources opposes economic growth. There are two basic versions of this doctrine. The first, the Malthusian, rests on the assumption that there are absolute limits; once these limits are reached the continuing population growth requires an increasing intensity of cultivation and, consequently, brings about diminishing returns per capita. The second, or Ricardian version, views the diminishing returns as current phenomena reflecting the decline in the quality of resources brought within the margin of a profitable cultivation. Besides these two models, there is also the so called 'Utopian case' where there is no resources scarcity There have been several attempts to apply these models to the energy resources in order to

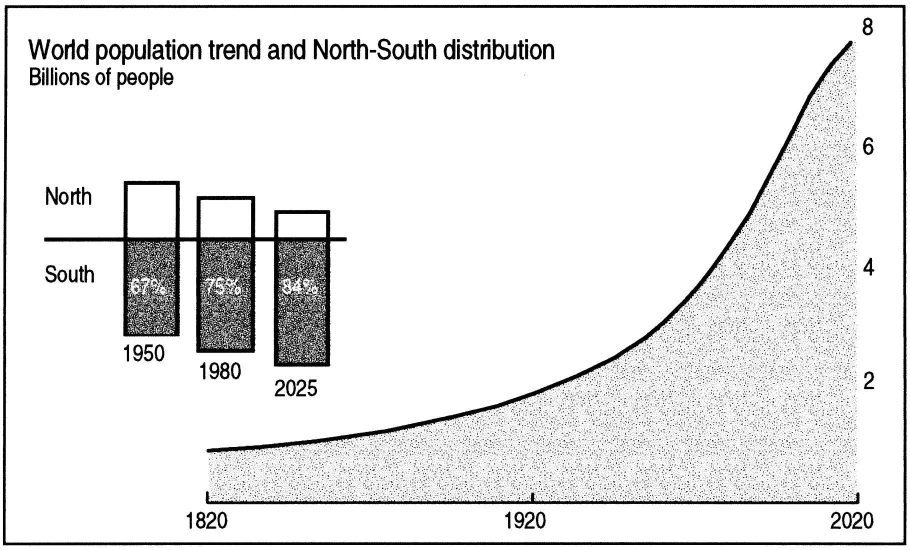

Fig. 5. Demographic forecast of human population.

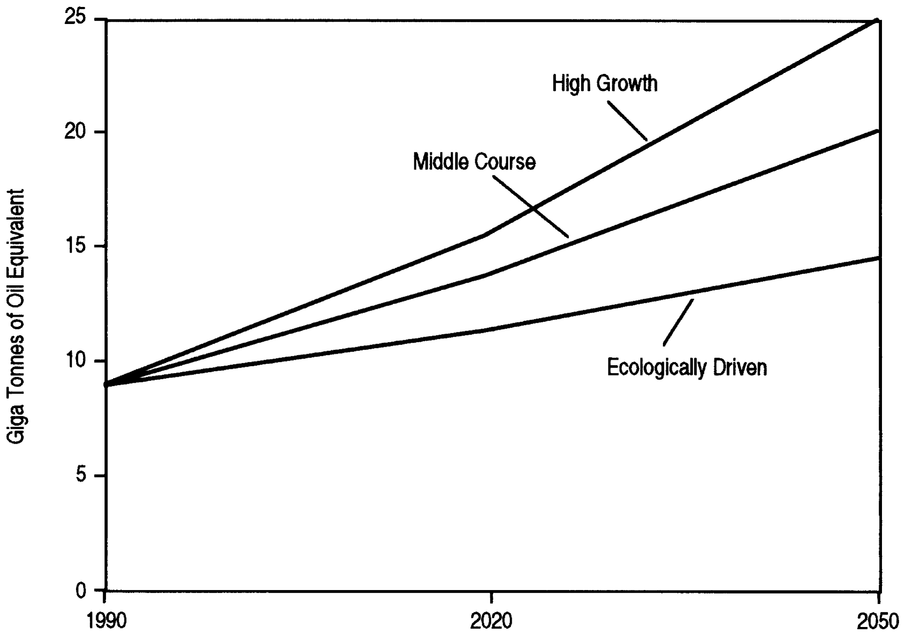

Fig. 6. Future energy consumption forecast.

define the correlation between specific energy resources and economic growth. The substantial questions related to the scarcity, its measurement and growth are: (1) whether the scarcity of energy resources has been and/or will continue to be mitigated and (2) whether the scarcity has 'de facto' impacted the economic growth. An analysis based on the relative energy prices and unit costs has been applied to natural gas, bitumen coal, anthracite coal and crude oil. The U.S.A. analysis in this respect can serve as the indication for the future trend in a world scale. Using two measures of scarcity—unit cost and relative resource price change in the trend of resource scarcity for natural gas, bitumen coal, anthracite coal and crude oil, over three decades are shown in Fig. 7 [6].

It can be noticed that each of the energy resources has become significantly scarcer during the decade of the 1970s. The situation reversed itself during the 1980s. The change that took place, has implications for future economic growth the extent that resources scarcity and economic growth are interrelated, even if it was not proven that short-term energy resources scarcity fluctuation has substantial implications on long term economic growth. The need for an active involvement in allocating scare, non-renewable energy resources has become obvious, considering its potential effect on economic growth.

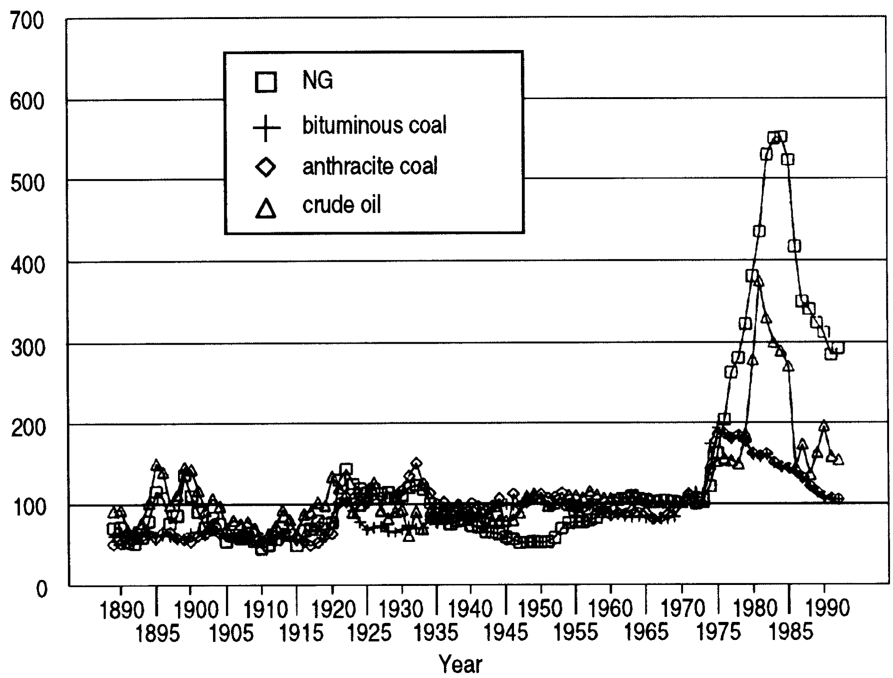

Fig. 7. Scarcity factor for fossil fuels.

2. Environment

Primary energy resources use is a major source of emissions [17, 18, 19, 20]. Since fossil fuels have demonstrated their economic superiority, more than 88% of primary energy in the world in recent years has been generated from fossil fuels. However, exhaust gases from combusted fuels have accumulated to an extent where serious damage is being done to the world global environment. The accumulated amount of CO_2 in atmosphere is estimated at about 2.75×10^{12}t. The global warming trend from 1900–1990 is shown in Fig. 8 [21].

The future trend of the carbon dioxide concentration in the atmosphere can be seen in Fig. 9 [21].

It is obvious that the further increase of CO_2 will lead to disastrous effects on the environment. Also, the emission of SO_2, NOx and suspended particulate matters will substantially contribute to exasperate the effect on the environment.

On a world scale, coal will continue to be a major source of fuel for electric power generation. Many developing countries, such as China and India, will continue to use inexpensive, abundant, indigenous coal to meet growing domestic needs [22, 23, 24]. This trend greatly increases the use of coal worldwide as economies in the other developing countries, continue to expand. In this respect the major long-term environmental concern about coal use has changed from acid rain to greenhouse gas emissions—primarily carbon dioxide from combustion. It is expected that coal will continue to dominate China's energy picture in the future. The share of coal, in primary energy consumption is forecast to be no less than 70% during the period 1995–2010. In 1993, China produced a total of 1.114 billion tons of coal; in 2000 it is planned 1.5 trillion and 2010 it will be 2.0 trillion. Since China is the third largest energy producer in the world, after the U.S.A. and Russia, its contribution to the global accumulation of CO_2 will be substantial if the respective mitigation strategies are not adopted. The example of China is instructive in the assessment of the future

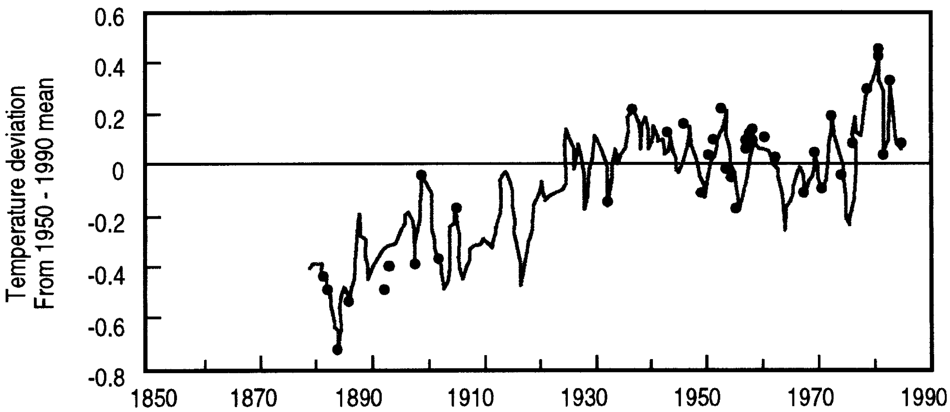

Fig. 8. Global warming trend—1900–1990.

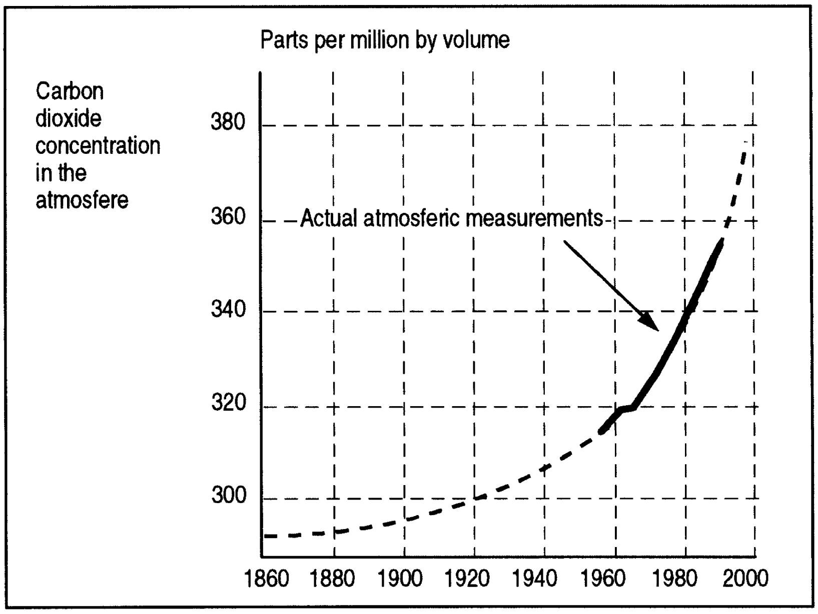

Fig. 9. Carbon dioxide concentration change forecast.

development of developing countries and their need for accelerated economic development.

3. Sustainability

It has been shown that energy resources are the bricks for building our civilization [25]. Their polyvalent use has offered a service to human society, leading to the welfare commodity for a decent level of human life. Sadly, however, production and consumption of energy are going hand in hand with less than welcome side-effects. This is the reason why society has recognized the importance of intelligent energy use with a sensibility that the required energy services be provided as clean and efficient as possible. Crucial importance is added due to the rapid growing world population and the need for accelerated economic development of developing countries. This is the reason why energy takes a centre stage in the debate surrounding one of today's main dilemmas: how to combine economic development with a habitable environment in a world that is undergoing rapid changes as a result of population growth and economic development of the developing part of the world.

Lately, in a few years, 'sustainability' has become a popular buzzword in the discussion of the resources use and environment policy. The word sustainability has a Latin root—sustinere—meaning "to hold up" by world inhabitants, present and future ones. Before any further discussion of the subject, it is necessary to define and properly assess the term we are going to use. It should be emphasized that the definition is needed in order to clarify the concepts. So what is sustainability? Among the terms most often adopted there are the following:

(a) for the World Commission on Environment and Development (Brundtland Commission) [26]: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".
(b) for Agenda 21, Chapter 35 [27]: "the development requires taking long-term perspectives, integrating local and regional effects of global change into the development process, and using the best scientific and traditional knowledge available".
(c) for the Council of Academies of Engineering and Technological Sciences [28]: "it means the balancing of economic, social environmental and technological considerations, as well as the incorporation of a set of ethical values".
(d) for the Earth Chapter [29]: "The protection of the environment is essential for human well-being and the enjoyment of fundamental rights, and as such requires the exercise of corresponding fundamental duties".
(e) Thomas Jefferson, Sept. 6 1889 [30]: "Then I say the Earth belongs to each generation during its course, fully and in its right no generation can contract debts greater than may be paid during the course of its existence".

All five definitions stand for the emphasis of a specific aspect of sustainability. Definitions (a) and (e) imply that each generation must bequeath enough natural capital to permit future generations to satisfy their needs. Even if there is some ambiguity in these definitions, it is meant that we should leave our descendants the ability to survive well and meet their own needs. Also, there is no specification in which form resources are to be left and how much is needed for the future generations, because it is difficult to anticipate the future scenarios.

Definitions (b) and (c) are more political pleas for the actions to be taken at global, regional and local levels in order to stimulate the United Nations Organization, Governments and Local Authorities to plan development programs in accordance with the scientific and technological knowledge. In particular, it should be noticed in definition (c) the ethical aspect of the future development actions to be taken to meet sustainable development.

Definition (d) is based on religious beliefs, paying responsibility and duty towards nature and the Earth. In this respect it is of interest to enlighten that the Old Testament, in which the story of creation is told is a fundamental basis for Hebrew and Christian doctrines of the environment. In the world of Islam, nature is the basis for human consciousness. According to the Koran, while humankind is God's vice-regent on Earth, God is the Creator and Owner of nature. But human beings are his trusted administrators, they ought to follow God's instructions, that is, acquiesce to the authority of the Prophet and to the Koran regarding nature and natural resources.

4. Sustainable development

Since the Brundtland Commission, in its 1987 report, Our Common Future, warned of the growing threat to the Earth from pervasive world poverty, environmental degradation, disease and pollution, it has become indispensable for the scientific community to pay increasing attention to the subjects related to these problems. Five years later the United Nations Organization Conference on Environment and Development was held in Rio de Janeiro. An unprecedented number of world leaders met to discuss and map the road to sustainable development. Among the Documents adopted at the Rio Conference is the 'Agenda 21', a blueprint of how to make development socially, economically and environmentally sustainable. Agenda 21 calls on governments to adopt national strategies for sustainable development.

Sustainable development focuses on the role and the use of science in supporting the prudent management of the environment and for the survival and future development of humanity [31, 32, 33, 34]. It is recognized that scientific knowledge should be applied to articulate and support the goals of sustainable development, through scientific assessment of current conditions and future prospects for the Earth system. The program areas which are in harmony with conclusions and recommendations of this International Conference on an Agenda of Science for Environment and Development into the 21st century are:

(a) Strengthening the scientific bases for sustainable management;
(b) Enhancing scientific understanding;
(c) Improving long-term scientific assessment;
(d) Building up scientific capacity and capability.

It is essential for the implementation of this program that it be focused on the long-term perspectives and the global changes of life support systems. In particular, there is a need for a constant interaction with governmental, industrial, political, educational, cultural and spiritual authorities participating in the realization of the program. It is of crucial importance that, in the realization of the program, an active role be given to scientists from developing countries. Since the major part of the population increase is expected in the developing part of the world, the participation of scientists from developing countries will bridge deficiencies in dealing with the problems which are imminent to their environment by an academic approach.

Sustainability development has even become a political movement with a strong connotation related to the existing differences among continents, regions and countries; its strength should be seen in the promotion for the salvage of the planet, the only place for our human civilization. In this respect, the determination of the interested parties, including the United Nations Organizations, government organizations, non-government organizations and religious organizations, to recognize sustainable development as the path for the creation of the future of new generations, is a guarantee for the economic prospectives and social development.

There are several ways in which the ideas of sustainable development are presented and interpreted. Ecocentric interpretations indicate a conspicuous degree of reference to ecosystems. Anthropocentric interpretation tends to put humans at the centre of the issues. Others such as biocentric interpretation focus on the protection of the elements of the biosphere. Our main concern in this general setting is energy, and whatever we do for and with energy may be reflected in any of the above mentioned perspectives and interpretations. While this concern for sustainability in the energy sphere should include considerations at the global level, more importantly, there is the need to look at it as a regional issue in the overall global scenario. There are several perspectives on this. Figures 10 and 11 attempt to distinguish sustainable and unsustainable development.

5. Energy sustainability criterions

There has been a number of attempts to define the criterions for the assessment of the sustainability of the market products. In this respect the Working Group of the UNEP on Sustainable Development has come out with qualitative criterions for the assessment of the product design [35, 36].

Having these criterions as bases, we would like to introduce them as a specific application in the energy system design. In this consideration, energy system is taken as the entity which should comply with sustainability criterions.

Energy System design is defined as:

5.1. Strategic design

Strategic design will require holistic planning that meets and considers all interrelated impacts e.g., logistic, space planning and resource planning. As regards the energy system, it may be interpreted as: mixed energy concept with optimization of

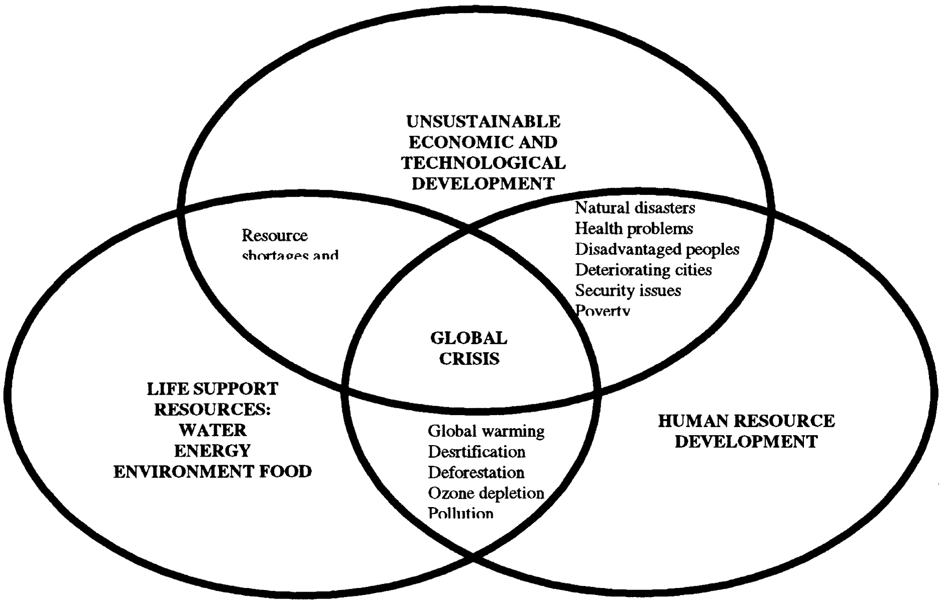

Fig. 10. The consequences of unsustainable development.

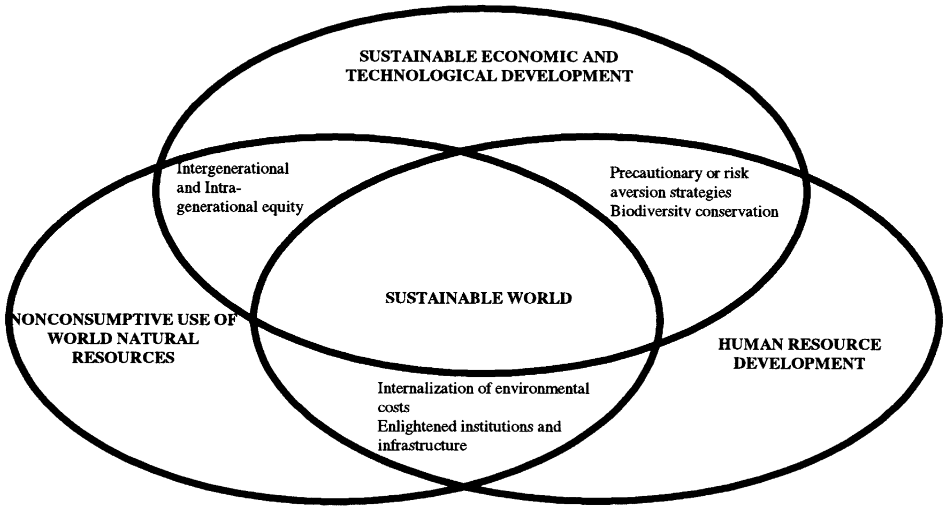

Fig. 11. Sustainable development.

local resources, urban and industrial planning with transport optimization, use of renewable energy sources.

5.2. Optimized design

The design optimization of the energy system means the selection of the structure and design parameters of a system to minimize the energy cost under conditions associated with available materials, financial resources, protection of the environment and government regulations, together with safety, reliability, availability and maintainability of the system.

5.3. Design of dematerialization

This will imply that the energy system, plant and equipment are designed with optimal use of information technology in order to prevent duplications, prevent operational malfunction, and assure rational maintenance scheduling. Dematerialization in the design may be seen as the introduction of knowledge based systems, use of virtual library, digitized video, use of on-line diagnostic systems, development of new sensor elements and development of new combustion technologies.

5.4. Design of longevity

A complex energy system is commonly composed of different subsystems and individual equipment elements. It has been recognized that the life time of the elements and subsystems is not equal. In this respect, optimal selection of the life cycle for elements and subsystems may lead to the retrofitting procedure which will reflect the need for the sustainable criterion application. Examples for this criterion can be seen as: modular design of subsystems, standardization of elements, lifetime monitoring and assessment, co-ordination of suppliers and buyers.

5.5. Life cycle design

This will mean that the energy system and its subsystems have to be designed to meet sustainability through every stage of the life cycle. It is known that the energy system is designed to work under different conditions in order to meet load changes, environment change, social changes, etc. It is obvious that there will be different cycles for each of the mentioned time scale processes. In this respect the system has to fulfil its function without failing to meet sustainability requirements. As an example, we can see: water cooling temperature change, social change may lead to the requirement to decrease the load to meet sustainability criteria, building pumping power stations for energy saving at night, period of thermal power plant technical minimum etc.

6. Energy sustainable development

In order to reach the goals indicated by the sustainable energy development the efficiency conversion use has to meet several criteria [37]. The potential for efficiency improvement is generally underestimated. Most of the energy conversion systems consider efficiency improvement as a separate process and their analysis reflects only the potential improvement of the process but not the potential for the efficiency improvement obtained by an exergy analysis of the energy system. Fossil fuel energy resources use is mostly conversion to heat by the combustion processes. Since the combustion process is taking place at temperatures between 900–1300°C and over 40% of heat is used at low temperature, it is vital to take into consideration the thermodynamic assessment of the efficiency in order to bring in line energy conversion processes and energy demand to obtain the optimum fuel utilization.

In the definition of sustainability, it is of substantial importance to envisage its broad aspect which composes versatility of the components to be taken into consideration [38, 39, 40]. In this respect, wholeness of sustainability has to include definitions of those components which are linked to specific parameters to be taken into consideration of the assessment of sustainability of specific situations in global, regional and local environments. There are a number of characteristic entities which will be used to define the wholeness of sustainability: life diversity, natural resources, environment capacity, population increase, social disturbances and ethic changes.

It is out of the scope of this writing to dwell on all characteristic entities for sustainability definition. Energy is one of the essential commodities required for human life and is affecting the sustainable wholeness in its total change [41]. For this consideration we will focus our attention only on those characteristic entities which are in direct correlation with energy sustainability measurement. In this group are included: (i) natural resources; (ii) environment capacity; (iii) population increase.

Each of these entities has to be defined with specific parameters which can be used to determine characteristic indictors for global assessment. The possible use of indicators is characterizing the changes which are determined by the maximum values technically feasible. It is reflecting the difference between the state of the entity with the maximum availability and respective current state of the entity. If applied to the individual energy resources there is a difference between known maximum exploitable resources with known technologies and current resources to be obtained with present technological capacity. Possible changes are functions of the technological development in the resource discovery. This implies that there are two means for the increase of the resources, i.e., by additional capital investment for the discovery and by new technology for the resource discovery.

In the assessment of sustainability, the current consumption change has to be taken into consideration which is reflecting the current consumption change in the reference time period. In order to form some kind of resource indicator for sustainability measurement a ratio between the current change and the maximum potential change has to be established. Its trend will give the measuring parameter for the resource depletion in time. It is known that the current consumption of energy resources strongly depends on the efficiency of their use, which may be classified in two groups. The first one is the possible efficiency increase due to the change in the efficiency of primary energy source conversion and the second one is due to the change in the efficiency of the final energy use.

A number of authoritative studies have presented forecasts for the energy supply in the 21st century. Conclusions drawn from this analysis have become a driving force for the development of the plan for the sustainable energy supply system. Even if a number of options are taken into consideration, common issues are the following:

6.1. Prevention of the energy resources depletion with scarcity index control

Whichever scarcity model is used, the energy resource scarcity is in direct relation to the social production output. In this respect, the efficiency of resources use and technology development are of fundamental importance. It is obvious that the efficiency of the energy resource use is a short-term approach, which may give a return benefit in the near future [42]. As regards the technology development, long term research and development is needed. In some cases it will require respective social adjustments, in order to meet requirements of the new energy sources.

The availability of energy resources is limited by two factors: capital to be invested in prospecting of new resources and prospecting technologies for energy resources.

From recent experience it was learned that there is a direct correlation between capital invested in prospecting and the amount of the available reserves. It was proved that a fixed amount of 18 \$/t is needed for new energy reserves. In many developing countries this is a limiting factor for the availability of energy resources.

The prospecting technology is composed of three phases. The geological subway based on the real prospecting and respective diagnostic techniques for electromagnetic waves detection. The resolution of the instrument employed is one of the limitations, and is under consideration for further development.

The second phase of prospecting technology is related to software for the design of the resource body based on the ultrasonic scattering or earthquakes generated by local explosions. The main limitation in the development of new software is the speed and memory size of computers. It can be expected that with the further development of computer technology this problem will be overcome. Also, new numeric schemes will substantially contribute to the accuracy and time expectation for the prediction of the size of resources body.

From the beginning of energy resources exploration, drilling technology was the limitation to the achievement of new resources. The development of drilling technology has marked a direction for the discovery of new resources. A recent example with new drilling technology has led to a gas resource in the Mexican bay. Also, North Sea gas resources are the result of a new off shore drilling technology. The same has been proved in the discovery of new gas resources in Algeria. Deep sea drilling has become one of the global issues which may remove the scarcity problems of energy resources for the next few centuries. It should be mentioned that two thirds of the earth surface is covered by deep sea so that the breakthrough in deep-sea technology may lead to a substantial change in the energy resource picture in the world.

6.2. Efficiency assessment

The potential improvement of the energy conversion process is a driving force for its development [43]. In the assessment of the conversion process a promising tool is the exergy analysis of the energy system. The exergy analysis is based on the maximum potential availability and its use for the assessment of the conversion process. By definition, the exergy is parameter for the validation of the efficiency of the energy conversion process and system. Taking into account the law of thermodynamics, the technology improvement appears as a significant factor responsible for an entropy change in the energy system. The application of the principle of Carnot therefore allows to determine an absolute limit to any transformation of the deposit of free energy [44, 45].

Following the first energy crisis, many countries have organized an energy efficiency assessment campaign with the aim of improving efficiency and gain-saving which has contracted the increase of energy price. It was proved that this approach has resulted in the increase of efficiency of energy use between 10–20% in a number of European countries. The main emphasis has been given to the evaluation efficiency of different technologies and utilizations of energy.

The effort directed to the evaluation of the technological processes for energy saving is of great importance [46, 47]. A new development of products is also under consideration for the minimum use of energy. In accordance with one of the criteria for sustainable development, products have to meet the requirement related to the minimum use of energy. A favourable example for this achievement is the development of a new lighting system with fluorescent lamps and which, in comparison with traditional bulbs, have a saving of about 40%.

Cogeneration of heat and electricity is one of the potential means to improve the efficiency of the energy resource utilization. Cogeneration plants in conjunction with the desalination in regions where water and energy are needed are an example. Figure 12 shows a schematic representation of cogeneration in desalination plants [48].

Recent projects with gas fired cogeneration plants have demonstrated extremely high efficiency [49]. The increased gas resources may lead to further development of highly efficient power plants for electricity production. The cogeneration will play a special role in the development of new energy systems.

6.3. Clean air technology development

The combustion process is an irreversible thermodynamic process with a high degree of availability losses in the energy conversion cycle. In this respect there is a potential opportunity to increase the energy conversion efficiency by improving the combustion process. There are a number of potential combustion technologies which might lead to an efficiency increase of the combustion process. Among those there are:

6.3.1. Catalytic combustion

The low temperature catalytic combustion of lean natural gas mixtures represents an effective method for heat generation [50]. Coexistence with reactant catalysts enhances the chemical reaction but is stechiometrically independent of the reactant. Among the processes of catalysis there is the absorption into the catalysis reaction at the catalyst surface and the liberation of the chemical products. Zeolite is a catalyst widely used in the chemical industry. Detailed behaviour of the catalyst has not been fully understood. In particular it is expected that the catalytic combustion may lead to an

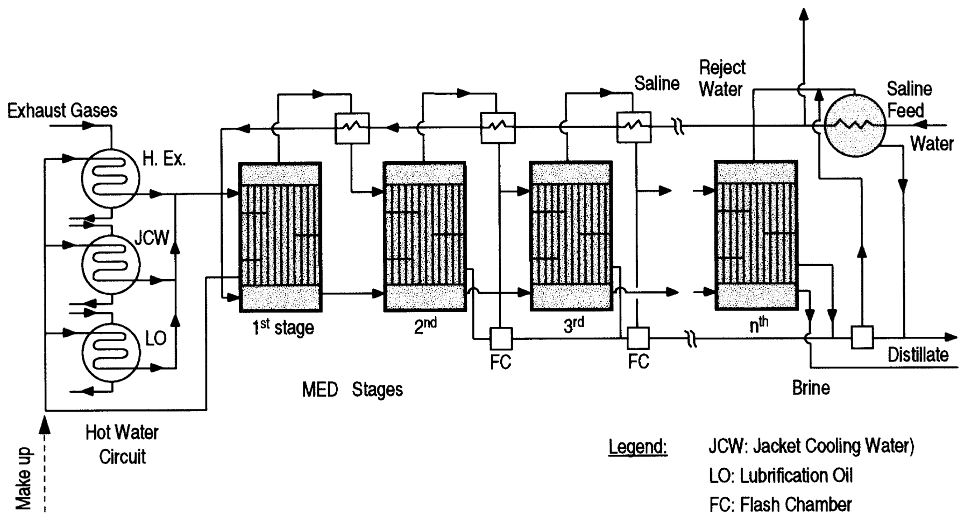

Fig. 12. Schematic representation of desalination plant.

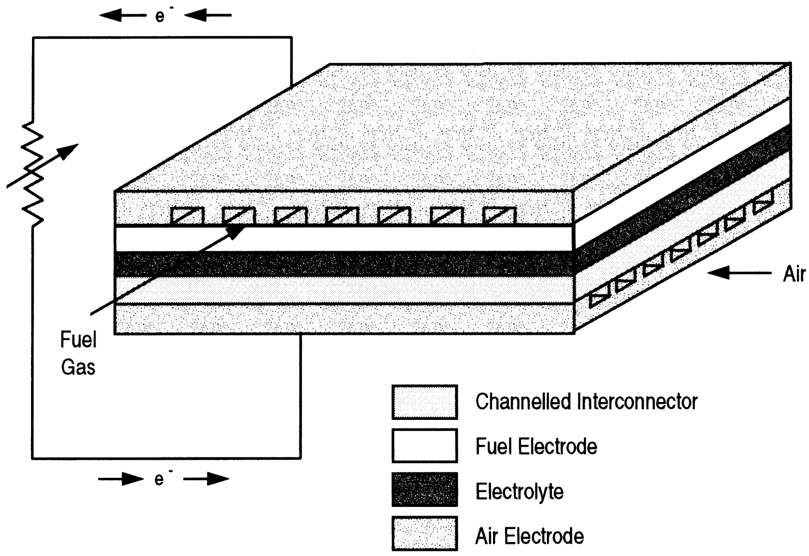

Fig. 13. Schematic representation of fuel cell.

efficient use of the fuel cell. Figure 13 shows a schematic representation of the catalysis of platinum in a fuel cell.

The catalysis mechanism at the interface between electrode and electrolyte ensures the electron transfer from the input hydrogen molecule to the electron metal. The search for low cost alternatives has not been very successful but lately the good performance of some of active composition of La, Ni, Co, O (LSNC powder) leads to promising expectations.

6.3.2. Fluidized bed combustion

A recent progress in the fluidized bed combustion has led to substantial developments of this new energy system [51]. In the combustion in fluidized beds the coal is depressed in a mass of its ashes and absorbent lime and the process is developed at a temperature of 850°C. There are two types of boilers: bubbling and circulating (Fig. 14).

The bubbling alternative offers a good thermal design. In principle, this is a clean option for electricity generation with medium and good quality coal. The energy efficiency of a bubbling boiler in the Rankine cycle with steam turbines, is similar to that of the conventional pulverized coal power plant.

A 350 Mwe bubbling atmospheric fluidized bed power plant is an option with a very good performance with medium and high quality coal.

The second alternative of the fluidized bed combustion power plant is the circulating fluid design, offering a high degree of operating flexibility in coal quality use. It is a complex design, which includes fuel chambers, large cyclone, recovery boiler and, in some cases, outer ash cooler. This option reduces the energy efficiency compared to present pulverized coal plant. A factor contributing to these problems significantly is

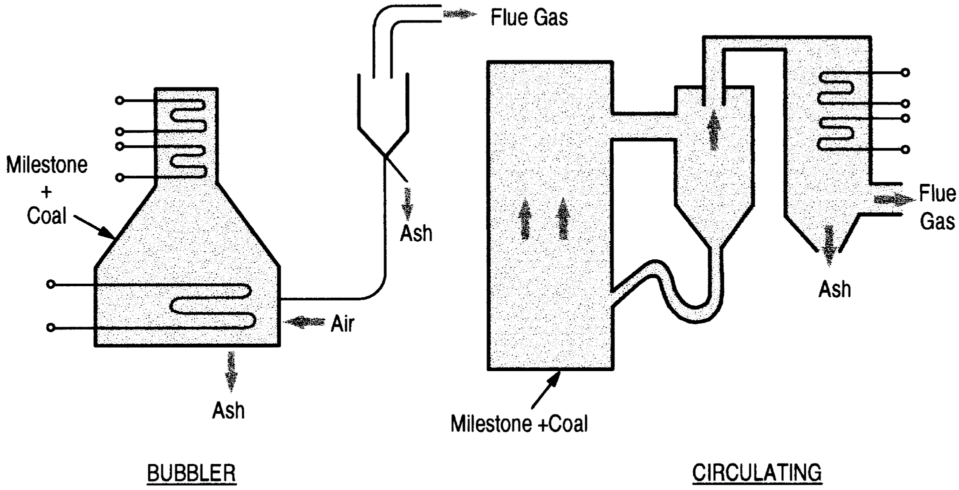

Fig. 14. Fluidized bed boiler types.

the high electric energy consumption in auxiliary services, particularly for the ventilator for recirculation. The efficiency of the existing circulating fluidized bed plants is about 30%. A 250 Mwe plant is in operation with low quality coal. The use of circulating fluidized bed boiler technology is rapidly increasing due to the ability to burn low grade coal, while meeting the required NOx, SOx and particulate emission requirements.

The pressurized fluidized bed combustion boiler is an option offering a 10% increase in efficiency over conventional pulverized coal fired plants. It is a compact plant with moderate specific investment using high quality material and it is conceived for medium and good quality coal.

6.3.3. Low NOx burners

The present, advanced energy technology is focused to reach further improvements in the emission control [52]. In principle there are two approaches: the first one, by reorganization of combustion processes in the burners and the second one, by post-combustion processes in the furnace.

In order to minimize SOx, NOx and particulate emissions a new burner design is envisaged to meet the requirements for minimization of initial NOx formation. It is expected that the new burners will reach 370–490 mg/Nm^3 in properly designed new furnaces [53], which is the limit for present emission control.

Further NOx reduction can be achieved through furnace staging. Here the boiler combustion zone is opened close to the stechiometric chemistry condition and the balance of air is added in the upper furnace through an overfire airport. NOx emission can be lowered through post-combustion technologies such as selective catalytic reduction. NOx is reduced with molecular nitrogen and water and by reduction with ammonia in presence of a catalyst.

Numerical modeling of the processes in combustion chambers has become important in design and analysis of tools [54, 55] for improving air distribution in power plant burners. Numerical modeling allows the analysis of designs for optimal modifications of turning vanes, flow splitters, perforated plates and burner shrouding. Also, numerical models of boiler furnaces [56] are available as computational fluid dynamic software which allows practical analysis of power plant furnace behaviour with minimum emissions of SOx, NOx and particulate. Retrofitting of existing power plants with advanced combustion technologies will lead to substantial increases of efficiency and minimize emission, to the environment [57, 58]. Figure 15 shows a typical low NOx burner.

6.3.4. New boiler designs

Coal fired boiler power plants will continue to be one of the major contributors in the future. Modern pulverized coal-fired systems presently installed generate power at net thermal efficiency ranging from 34–37%, while removing up to 97% of uncontrolled air pollution emissions. A new generation of pulverized coal-fired boiler technologies currently under development, which will permit a generating efficiency in excess of 42%. In this respect, further development is needed for improvements in reducing emissions and expanding operability. To achieve a high thermal, special attention has to be devoted to the load cycling operation. In this respect a low-emission boiler system in development is based on the diagnostic monitoring of process parameters and expert systems.

The development of high performance power systems is an ultimate goal for upgrading pollution control with corresponding combustion system improvements and the

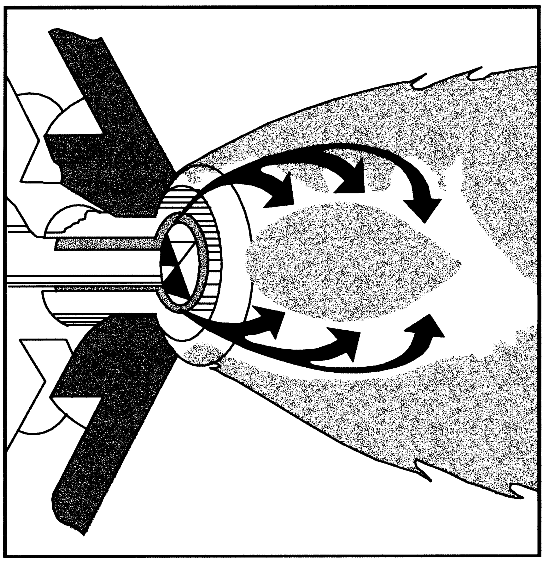

Fig. 15. Low NOx burner.

control of SOx, NOx through the implementation of new burner design and post combustion emission control. Also, the implementation of the boiler numerical codes for the determination of process parameters will be used as a tool for the efficiency control and early diagnostic function monitoring. This improvement in heat and mass transfer research [59, 60, 61, 62] has substantially contributed to new boiler designs and will lead to the increase of availability of modern power plant systems [63]. Figure 16 shows a schematic representation of new boiler design.

6.4. Development of intelligent energy systems

The recent development of artificial intelligence has opened the possibility to utilize those achievements in the energy sustainable development. There are three major paths, namely: expert system development in energy engineering; new control based on fuzzy logic and respective reasoning; intelligent thermal system design.

6.4.1. Expert system in energy engineering

The expert system development in energy engineering is focused in two directions: expert system for energy system design and knowledge-based for on-line diagnostic [64, 65, 66, 67]. It has been shown that the expert systems for energy system design can be efficient tools in the selection, optimisation and assessment of power plant design. Also, expert system logic can be used in energy system planning, including optimization of the energy system, reflecting the potential use of renewable energy sources. An example of expert system use in the design of thermal equipments is demonstrated by the heat exchanger design [68]. Further developments of knowledge-

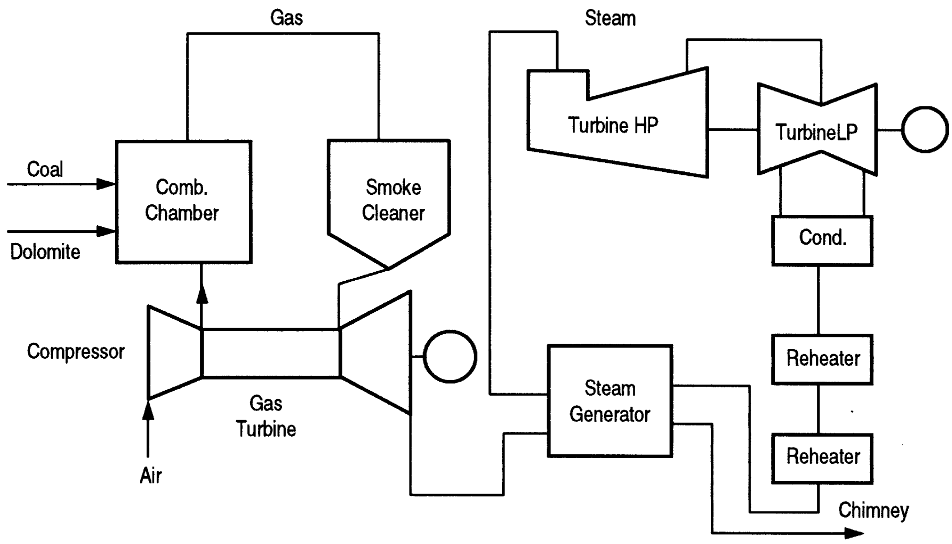

Fig. 16. New boiler design.

based systems for the design of energy systems will promote an increase of efficiency and reliability.

The knowledge-based system for the fault diagnostic in energy systems has proved to be a powerful tool for the evaluation of system parameters in order to forecast a potential malfunction of system elements. Figure 17 shows a schematic representation of an expert system for fouling assessment.

There are several attempts which have proved the possibility of knowledge-based systems in the diagnostic of thermal power plants. The efficiency monitoring and respective logistic evaluation of diagnostic parameters has been demonstrated to be a good and reliable tool for the advanced diagnostic of operational deficiency. The boiler fouling and tube leakage knowledge-based system prototypes demonstrated the possibility of the detection of processes leading to the degradation of power plant efficiency [66]. The diagnostic systems are based on on-line monitoring of diagnostic variables and their fuzzification for the reasoning retrieval of the cases representing diagnostic results.

6.4.2. Fuzzy logic control

The new fuzzy logic control system is demonstrated to be a qualitatively efficient system for the on-line control of energy systems [69]. While similar model-based control systems designs are trial and error, the knowledge-based controller is 'ad hoc' at the present time. A gap exists between solid theoretical results such as stability, controllability etc. A real-time implementation of intelligent control systems uses fuzzy logic, neural networks, general algorithms, expert systems etc. A common definition of fuzzy control system is that it emulates a human expert. Under this situation, the knowledge of a human operator would put in form of a set of fuzzy

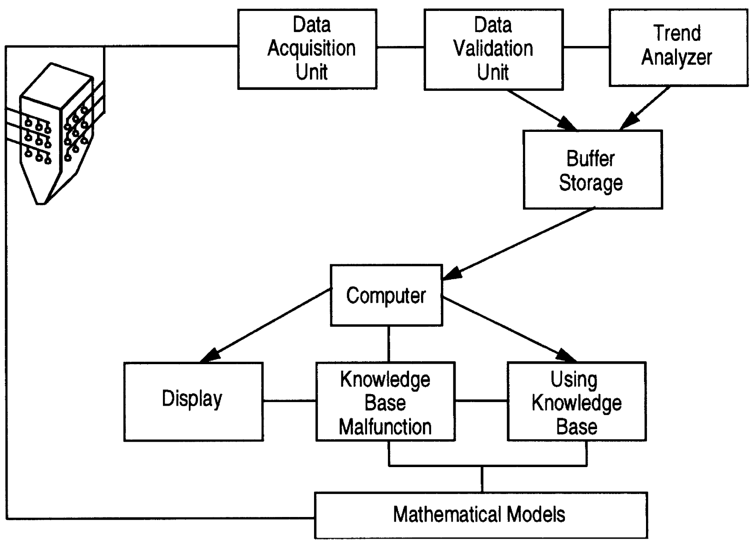

Fig. 17. Knowledge-based system for power plants.

linguistic rules. These rules would produce an approximate decision, like a human would. Figure 18 shows a block diagram of fuzzy control systems.

6.4.3. Intelligent energy systems

The present world has learned that some basic assumptions are not valued and so requires a new approach for adjustment to its future development. There have been world scale meetings emphasising the need for the economic order to meet contemporary development within the limits recognised by irreversible changes in energy resources and environment capacity.

New measurements called 'indicators of sustainability' are designed to provide information for understanding and enhancing the relationships between the economic energy use, and environmental, and social elements inherent in long-term sustainability.

There are different terms used in the consideration of the product design. The 'clean' design is used in the widest sense of all management as well as technical decisions related to specification, planning and development of products not just technical processes designed by engineering. The 'eco'-design refers to the processes of systematic incorporation of environmental life cycle consideration into product design.

'Intelligent product' design comprises the specifications reflecting resource life cycle, environmental cycle, product-life cycle, end of life and clean design. The generic design procedure to be adopted for the intelligent product design of the thermal equipments require the definition of indicators for the assessment and optimization of the specific design.

In order to provide the design criteria reflecting complex requirements imposed by the intelligent design, it is necessary to define the respective indicators to be used in the evaluation of the specific design of thermal equipment [70, 71]. These indicators should be based on the optimization of the efficiency of respective thermal equipment, resource use assessment and validation, environment capacity use and degradation,

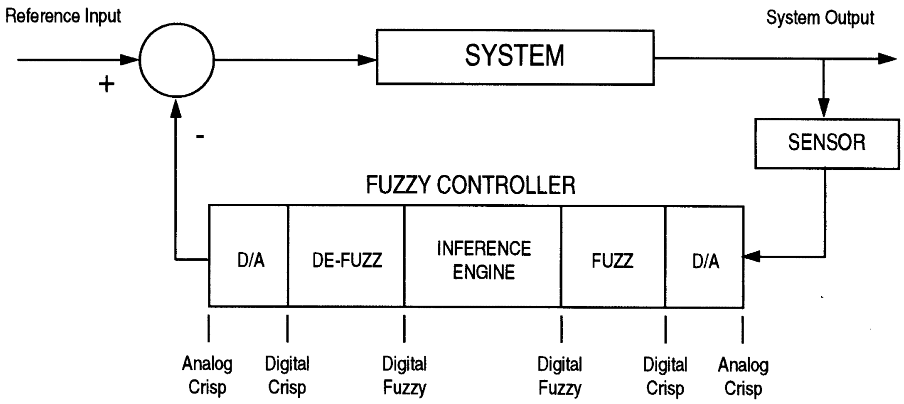

Fig. 18. Block diagram of fuzzy control system.

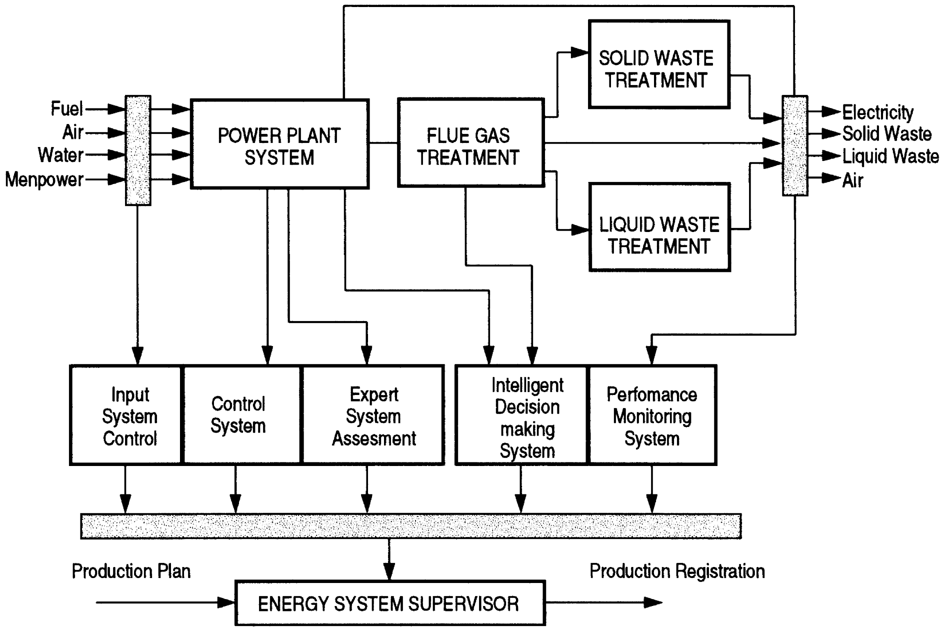

Fig. 19. Scheme of intelligent energy system.

modular structure with multipurpose elements, end of life assessment and economic justification of specific designs. Figure 19 shows a schematic presentation of an intelligent energy system.

In order to evaluate the validation of the indicators the thermal equipment will be used. In this respect, the criteria will be adapted for the specific thermal equipment. It is aimed to develop the algorithm with the indicators to be used for the assessment of design. The assessment will be made for a number of selected products presently on the market to be evaluated within the frame of the criteria for intelligent design.

6.5. New and renewable energy sources (NRES)

Besides the possibility offered by the efficiency improvement of processes in power generating units, there is a great challenge to increase the efficiency of energy systems by introducing energy mixed systems. The energy system includes power or heat generating units, energy transport systems, energy storage systems and energy end-use systems. From the energy resources point of view, there are a number of options which might be taken into consideration for the optimization of the energy system. In this respect, high interest is shown in the potential use of the renewable energy resources as power or heat-generating unit in the energy system. The imminent advantages of the renewable energy resources due to their availability and low cost impact, are promoting the renewable energy source to be included in the energy system.

Renewable energy sources, by definition, meet the requirements of sustainability. It is therefore expected that the long-term energy strategy will rely on renewable energy resources. The total availability of renewable energy resources is very large. This picture reflects the presently available technologies in the field of renewable energy resource use and exploitation [71, 72]. Very promising alternatives are envisaged with the promotion of new technologies under development.

6.5.1. Solar energy resources

Solar energy can be exploited in three main modes:

- by enhanced absorption of solar energy in collectors, which provide low-grade heat;
- by using reflecting devices to concentrate the solar energy in a heat carrier, which is then used to generate electricity;
- by converting sunlight directly into electricity.

Solar energy resources do not have clear limits. The annual influx on the Earth surface is 10,000 times as large as the current human energy consumption; the fraction reaching the land surface is 3000 times as large and even 35% of this would make 1000 times more energy than we demand today. As we can see, the resource of solar energy is huge but diluted. In the literature, it is assessed that the feasible tool use of solar energy from the technical standpoint is about [74]:

Thermal solar for	170 Mtoe/year
Decentralized electric solar for	450 TWh/year
Network electric solar for	230 TWh/year

In the local resources evaluation for these three solar systems one could take into consideration their minimum and maximum capacity to be installed. From the present status of the development the following capacity can be taken into consideration

	Minimum:	Maximum:
Thermal solar	150 kW	80 MW
Decentralized electric solar	30 kW	5700 kW

If the mean insulation for the specific location is taken into consideration then the respective values for the land to be used will be obtained. For this purpose, it will be used $q_R = 5.4$ kWh/m^2/day so that the following extension of land is required for the specific use of the solar energy:

	Minimum land [m^2/kW$_e$]
Thermal solar	20–35
Decentralized electric solar	36–80

It should be mentioned that for insulation lower than $q_R = 4$ kWh/m^2/day, it might be difficult to adopt the same method of validation.

Solar energy use is presently demonstrated in three options: solar thermal, solar photovoltaic and solar power plant. Solar thermal energy production plant has reached an industrial level and is available on the market in many countries [75, 76, 77]. There are a number of designs differentiated with respective efficiency and sophistication of the material used. Solar thermal option is mostly available for the hot water production units. It is also demonstrated for air heater and climatization units. Since it has reached maturity, it is not expected major breakthrough in this field, which might affect its potential use. Water heater units are available in the market with the following ranges:

	Temperature range [°C]
Unglazed flat plate collectors	< 40
Glazed flat plate collectors	40–100
Vacuum tube collectors	150–200

The solar thermal is anticipated to cost 8-9 U.S. cents/GJ in the medium term. In the long term this could come down to 4–6 U.S. cents/GJ.

The solar photovoltaic system is also in its demonstration stage, with a number of various applications. It has been demonstrated in three levels, i.e.,

	Power
Ubiquitous solar cell	not fixed
Solar unit for electronic application	50 W–1 kW
Solar units for irrigation	5–60 kW

The first level is not an energy intensive application and has no significance for its consideration for the energy source strategy point of view. The second option is being used as the only energy source in remote areas and has been demonstrated as a reliable energy source. It ranges in power production from 50 W–1 kW and is commercially available at competitive prices. Figure 20 shows schematic representation of Solar power plant.

For the third option, there have been a number of demonstration projects which have proved its feasibility for rural areas. Even, the energy available from the grid for many countries is lower than the energy produced by a photovoltaic unit, and the difference in energy may be compensated by the additional capital investment needed for a new grid construction for remote areas.

Solar power plants are in the stage of development. They are available as photovoltaic cell modular units and can be installed when the power demand requires a system augmentation. As demonstrated, the modular power ranges between 50 kW and 1 MW. Solar power plants with concentrators are still in the development stage and will not be considered in the technical assessment of the solar energy utilization [77, 78].

Solar plant power	50 kW–1 MW

Present estimate of photovoltaic solar plant electricity ranges from a cost of 23–33 U.S. cents/kWh. It is expected that in the medium term this cost will be as low as 2.2–2.4 U.S. cents/kWh [79].

6.5.2. Geothermal energy resources

Resources exploitable at current energy prices correspond to aquifers in narrowly localized volcanic zones [80, 81]. Presently installed and in construction plants reach

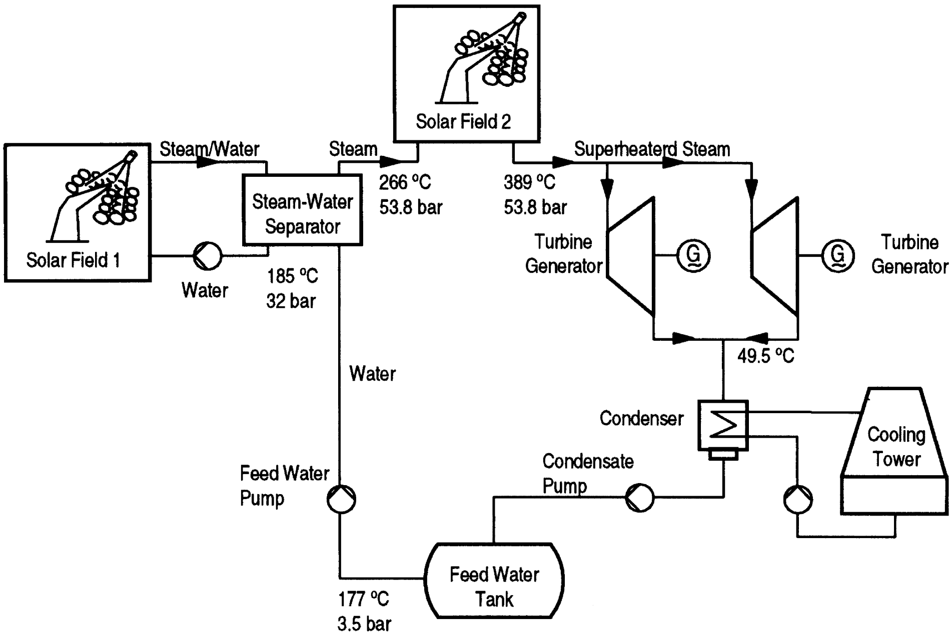

Fig. 20. Solar power plant.

a total electrical capacity of 7100 MW (high enthalpy energy). Low enthalpy hot water to be used directly for heating is estimated to about 13 Mtoe/year. These two groups of geothermal energy systems are specified by the temperature and flow capacity of the individual well. From experience, the following limits are adopted:

	Min. temperature [°C]	Min. capacity [m^3/h]
High enthalpy geothermal	90	2900
Low enthalpy geothermal	35	1000

Particular resources evaluations will require a specific assessment of the respective aquifer volume in order to estimate uncertainty in the lifetime of the geothermal energy system to be built. It is expected that the volume of the aquifer should exceed several times the capacity needed for the respective system lifetime. In the local resource evaluation for the geothermal system it should be included also the land required for the brine to be deposited during the lifetime of the plant.

Geothermal utilization is commonly divided into two categories: electric production and direct application. Figure 21 shows the minimum production temperature in a geothermal field that is required for different utilizations.

Conventional electric power production is limited to fluid temperatures above 140°C but a considerably lower temperature may be used with the application of binary fluids. Geothermal electric energy plants have reached their maturity and have

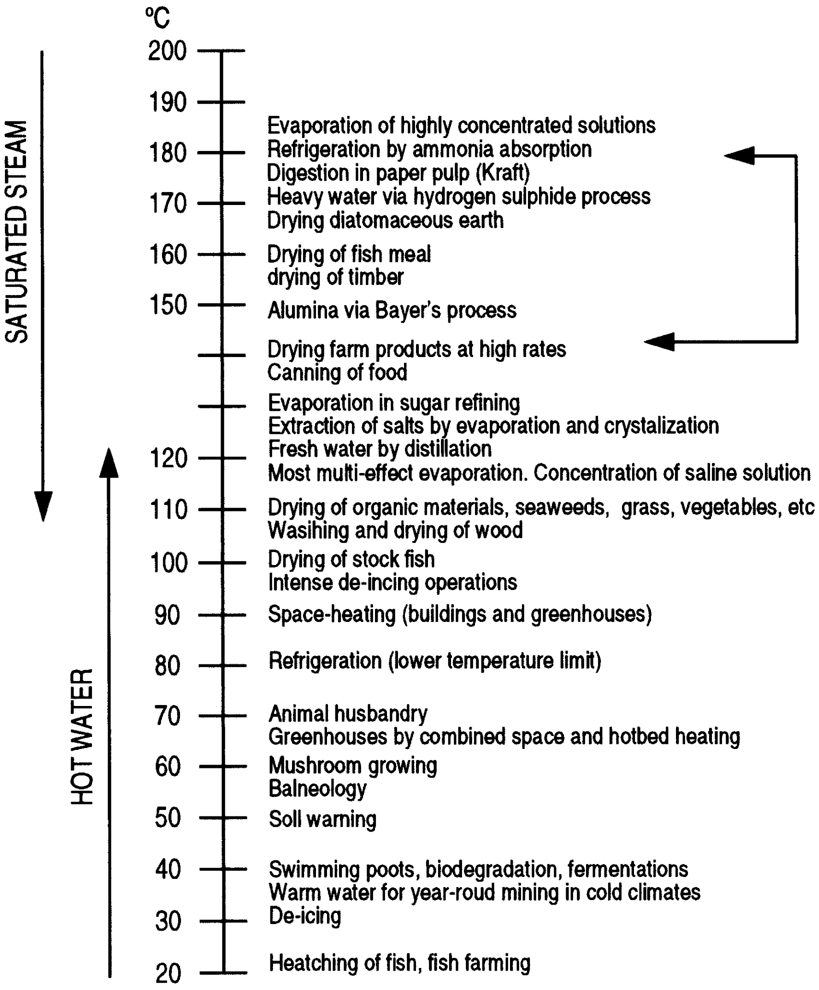

Fig. 21. Minimum production temperature in geothermal field.

proved to be very reliable sources of energy. They are used in 21 countries, with a total world installed capacity of 6017 MW distributed over 330 individual turbine generator units. The geothermal power plants are built in four versions, i.e., direct steam plants, flash steam plants, binary plants and hybrid plants.

Direct steam plants are used with vapour dominated resources. Steam from production wells is gathered and transmitted via pipelines directly to a steam turbine. In most direct steam plants the capacity of the turbine is greater than 5 MW. Typical schematic representation of direct steam plant is shown in Fig. 22.

Flash steam production is used when the fluid, in the geothermal reservoir is pressurized hot water or a mixture of liquid and vapour at the well head. It is designed

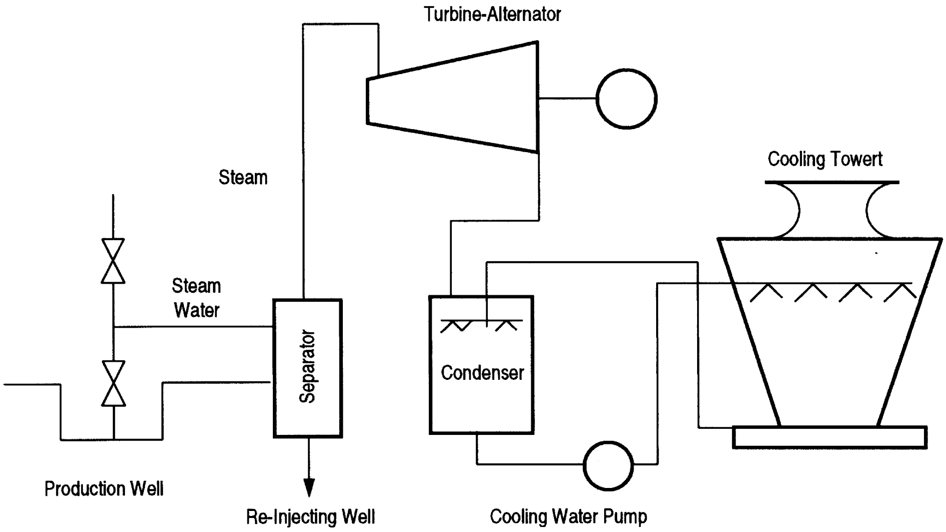

Fig. 22. Direct application of geothermal energy.

in two modifications, i.e., with single flash steam unit and dual flash units. A single flash plant is a simple flash unit. The flashing process takes place between the reservoir condition and the power plant. The flash usually occurs in the well at the point where the geofluid pressure falls to the saturation pressure corresponding to the temperature and composition of the geofluid. A significant improvement in resource utilization can be achieved by adding a secondary flash process. Instead of being discharged, the liquid that is removed from the separator is subjected to another pressure drop in which additional steam is released. The lower pressure steam is admitted to the turbine at an appropriate stage and generates additional power.

Binary plants are used when it is not advisable to allow the geofluid to come in contact with the power production equipment, i.e., the turbine, for danger of scaling, corrosion or effects of large quantities of non-condensable gases. In basic turbine system, the hot liquid enters a vapour generator where it transfers heat to a secondary fluid. The working fluid is chosen to provide good thermodynamic matches to geofluid and obtain a high utilization efficiency, safety and economy.

Besides the basic binary cycle there are two cycles, which exhibit a higher efficiency: a dual pressure system and a dual-fluid system. In dual pressure binary plants the turbine receives the working fluid at two pressure levels. Either two separate turbines or a dual admission turbine may be used. Optimized dual-pressure binary plant can have 15–25% higher brine utilization compared to the basic binary plant geofluid temperature of 95–150°C. The dual fluid binary plant is a system with two binary loops, each of them with a particular fluid. The key for producing a high efficiency cycle, is to couple the two loops by means of a recuperator in which the heat otherwise wasted, from the upper loop is transferred to the lower loop in sufficient quantity to provide the evaporation for the lower cycle working fluid.

Hybrid plants are described so far and combined in various ways to achieve a higher efficiency or to overcome the potential problems related to geofluid characteristics. The following are examples of hybrid plants: direct steam/binary units and flash steam/binary units.

There are three classes of turbine power units used in geothermal plants:

(a) 30–40 MWe
(b) 5–10 MWe
(c) 0.2–0.5 MWe

The power rating for the respective geothermal power cycles are:

Direct steam plant	5–40 MWe
Flash steam plant	1–35 MWe
Binary plant	0.02–0.5 MWe
Hybrid plant	Not yet available

The ideal inlet temperature for house heating is about 80°C, but with the application of large radiators with heat pumps or auxiliary boiler, the thermal water with a temperature of only a few degrees above the ambient temperature can be used beneficially.

It uses mostly known technology and straightforward engineering. It is estimated that the installed thermal power, that uses geothermal fluids for direct non-electric application, is over 11,385 MWt, with a total energy production of 31.10^{12} Kcal. This was achieved with a flow rate of about 84,000 kg/s at an average load factor of 36%. These data do not include all uses where the inlet temperature is below 35°C. This also excludes fish farms using warm water at the scale of tens of MWt. This further more ignores most of the heat pump installations, which have a growing market for space heating and cooling and will become the largest application of geothermal energy systems. Such application of heat pumps reduces the energy consumption by 30% when compared with air source heat pumps and more than 60% when compared with electric or fossil fuel heating and cooling. There are two parameters, which are relevant for the assessment of the geothermal energy for non-electric applications, namely: fluid temperature and fluid flow rate. As regards the temperature range for non-electric geothermal energy use, there are three options:

	Temp range °C
(a) Heating	20–80
(b) Drying	80–160
(c) Chemical processes	150–200

Fluid flow rate is strongly dependent on the respective application capacity. In this respect a rough estimate of the power range for the mentioned applications is the following:

	Power range [MWt]
(a) Heating	10–25
(b) Drying	1–10
(c) Chemical processes	10–100

For each geothermal well temperature, the respective flow rate can be determined and the number of boreholes is estimated in order to meet the specific requirement.

Technologically the geothermal energy application for non-electric use has been demonstrated in a number of countries. The available know-how for different applications has proved its maturity so that, within the defined parameters it can be considered as a demonstrated entity in the technological assessment of NRSE.

Electricity production from geothermal sources cost is around 4 U.S. cents/kWh and for the heat generation the cost is around 2 U.S. cents/kWh [79].

6.5.3. Biomass energy resources

Biomass provide about 14% of the world energy or about 25 million barrels of oil equivalent per day (Mboe/day) [82, 83, 84]. It is the most important source of energy in developing countries. In general, it is rather difficult to estimate biomass resources because they are strongly dependent on natural vegetation. Detailed analysis shows that if it is assumed 35 GJ/capita the consumption for developing countries, the land required per capita with biomass yield 2, 5 and 10 t/ha/year, will be 1.0 and 0.2 ha/capita, respectively. It is estimated that for biomass use for energy production a minimum of 5 t/ha/year yield would be needed and it could be used in an area where local energy consumption is substantially below the average for developing countries. Commodities such as lighting, water for people, water for livestock and irrigation are of primary interest for the biomass electricity production. As was shown, cooking gas also is estimated for the potential consumer of biomass energy.

In the local resources assessment for biomass energy, main emphasis is given to the land needed and yields of biomass production. The second requirement is strongly dependent on the geographical location and may substantially vary in different locations. For example: in tropical regions the yield is 16 t/ha/ a, while in subtropical the yield is 22 t/ha y. So, the parameters to be used in the assessment of biomass local resources are: local demand for land and yield of biomass production.

Biomass energy production can be obtained through different routes for biomass conversion processes. The great versatility of biomass as a feedstock is evident from the range of wet to dry materials, which can be converted into various solid, liquid and gaseous fuels using biological and thermochemical conversion processes. Solid fuels are wood, charcoal, crop and forestry residual, agroindustrial and municipal wastes and briquettes. Biomass derived liquids are mainly ethanol and methanol. Gases are mainly biogases from anaerobic digesters, gasifiers-producing gases which can be used for electricity generation and, possibly, coupled to efficient gas turbines.

There are two main branches of biomass conversion, i.e., bioconversion process and thermal process, The bioconversion processes are alcoholic fermentation and anaerobic fermentation. The thermal processes are pyrolysis and combustion of the biomass. In this analysis, priority will be given to those technologies which are demonstrated in industrial scale and could be used as reference for the technological assessment of their maturity. In this respect, bioconversion technology for the ethanol production falls into a category of technologies which are presently commercially available. For the ethanol production there are three options:

	Capacity [l/day]
Micro system	<200
Mini system	200–20,000
Macro system	$>20,000$

Among these options, the mini system is ideal from the technical, economical, social and environmental standpoint. It appears to be a highly viable solution to the liquid fuel energy problem, especially for developing countries. The second option in bioconversion technologies is biogas production. Biogas production is a well-known technology based on anaerobic fermentation. There are a vast number of technical systems used for biogas production. From this analysis it is omitted the biogas production facility based on a primitive technology for individual use.

Pyrolysis and combustion processes are based on high temperature conversion processes with partial or full combustion of biomass fuel. They are used for charcoal of heat production, depending on the process of biomass conversion. The charcoal production plant has not proved its maturity and is not yet available as commercial technology. Cooking stoves are presently commercially available as a combustion technology based product. There are three sizes of the wood fuelled thermal energy plants in cottage, medium and large industry processes and enterprises. The combustion process of biomass is not substantially different from the combustion of any solid fuel. This implies that specially designed boilers are used for the biomass combustion plants. In this respect there are a variety of boiler designs, which may serve this purpose. In particular there is a great interest for the waste incineration boiler as energy source. Figure 23 shows schematic representation of typical biomass power plant.

It is expected in the medium term, that at a biomass cost of 2 U.S. cents/GJ the electricity produced will reach 10–15 U.S. cents/kWh [79].

6.5.4. Wind energy resources

The world technically exploitable resources are estimated about 300 TWh/year [85, 86]. They are rather heterogeneous and strongly dependent on geographical location. It was recognized that the most economical turbines are those with a rating between 1–350 kW. This means that the wind velocity at the potential location of the wind power plant should be a minimum of 6.5 m/s with an availability of 25–40%. In this respect, the wind energy to be used for electricity production will depend on the single unit production of the specific size but the total installed capacity may be dependent on local demand or grid capacity. Grid connected turbines in the form of wind farms are a forthcoming entity for the wind use for electricity production. In connection with this approach the land occupied by wind farms is to be taken into consideration

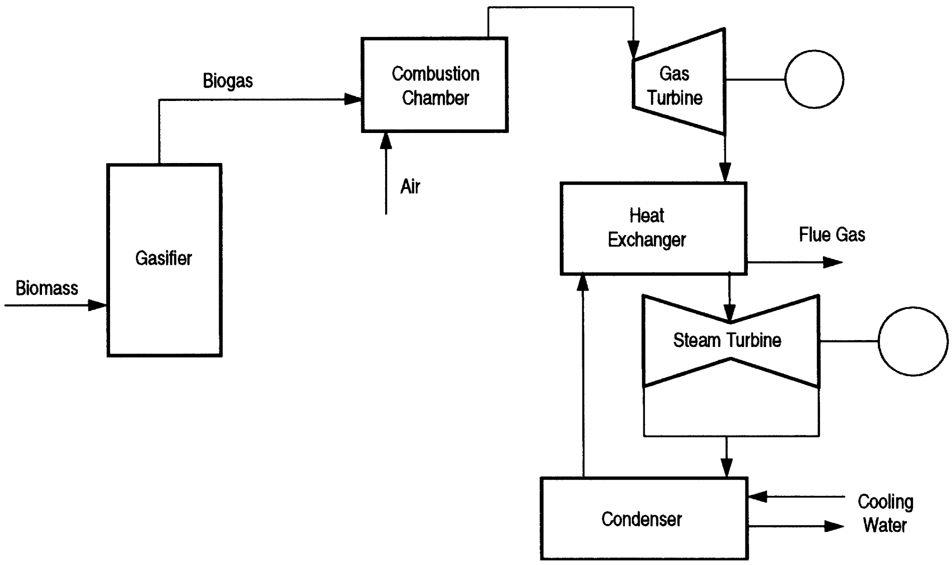

Fig. 23. Biomass thermal plant.

as local resource of the specific location. It is estimated that 4–8 MW could be installed on 1 km^2.

In defining the resource conditions for the wind energy utilization the following parameters are needed:

(a) average wind velocity at the specific location
(b) probability distribution of wind velocity.

Wind turbine technology is available in two arrangements of the rotor, in relation to the direction of the wind, i.e.,

(a) Horizontal-axis wind turbine
(b) Vertical-axis wind turbine.

The horizontal-axis wind turbine in which the direction of the wind is parallel to the axis has been technologically developed. At present, horizontal-axis wind turbine generators represent approximately 95% of the capacity installed in wind plants. The developed wind turbine plants presently in operation and new turbine could be classified in the following three categories:

	Capacity	Diameter [m]
(a) Small-size wind turbines	100 kW	< 20
(b) Medium-size wind turbines	100 kW–1 MW	20–50
(c) Large-size wind turbines	> 1 MW	> 50

Small sized wind turbine generators are used in a large number of applications. Most of these applications are limited to the supply of isolated dwellings: pumping, desalination, and integration with diesel, storage, integration with other renewable energy sources. In all these applications the storage capacity is an essential factor.

Medium size wind turbine generators are commercially available and grid connected. Figure 24 shows an average size wind turbine installed in the European Community in the period 1986–1992.

The configuration of the plant is conventional and the blades are made of glass fibre reinforced plastic or laminated wood bound by epoxy resin with a power regulation by adjusting the pitch of the blades. The technology of large-size wind turbine generators is still in the developmental stage. Prototypes of the capacity up to 4 MW and rotor diameters up to 100 m are available in some countries. The obtained results have confirmed the substantial feasibility of large wind generators but have also shown that these machines are still far from being competitive with medium-size machines.

Lowest current electricity cost from wind resources is 6 U.S. cents/kWh [79].

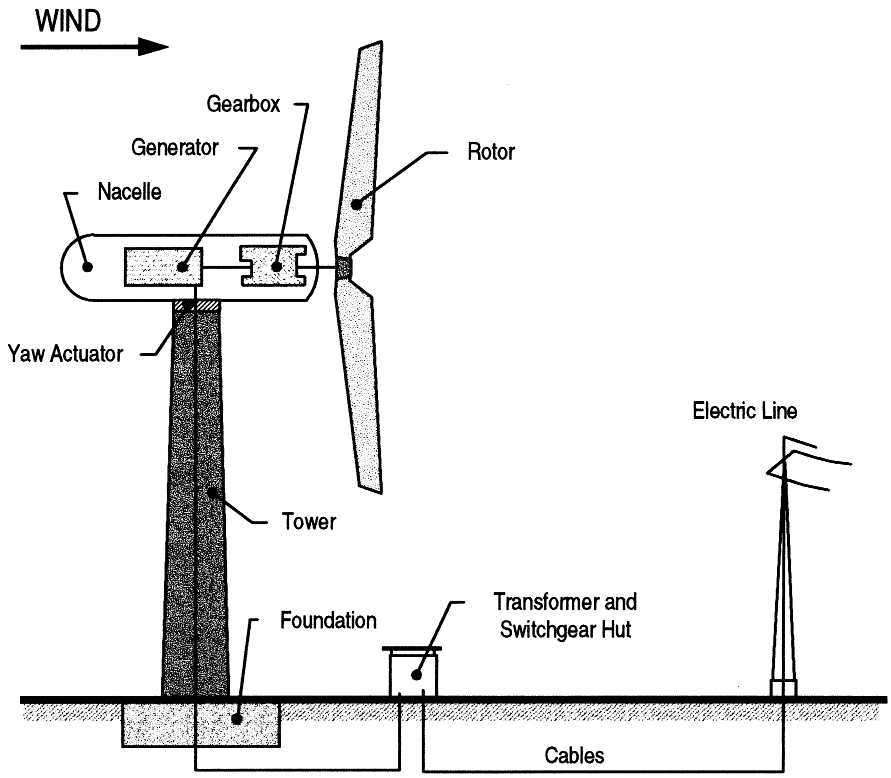

Fig. 24. Wind turbines.

6.5.5. Hydro energy resources

It is estimated that the gross theoretical productivity of hydro energy is about 30 million GWh/year with an exploitable production of about 13 million GWh/year [87, 88]. The present production of the existing plants is of the order of 2.2 million GWh/year. The main reason for the large discrepancy between exploitable and present production is the financing capacity of the countries. The average percentage of hydro electric energy production is for developed countries 7% and for developing countries 54%.

In many countries, emphasis is given to the utilization of the small-scale hydropower potential. The total capacity of the mini/micro power plant is about 1.5% of the total installed hydropower potential. An equal amount of small-scale plant capacity is currently in the planning stage.

Inventories of suitable hydropower sites have been established for many areas and a vast catalogue of the exploited sites is available. The best sites have already been explored. There is still a lack of knowledge of the potential of small plant sites.

As for any hydraulic turbine, the parameters to be known in the assessment of the specific location are the available hydrostatic pressure and the water flow rate. Hydrostatic height is usually constant for mini/micro hydropower plants. The water flow rate is a very sensitive parameter for small hydropower plants. It varies seasonally and sometimes daily. Knowing the respective accumulation, the minimum flow rate can be established. In order to obtain reliable data of the water flow for a small turbine hydropower plant, a rough estimate of the accumulation volume has to be determined and divided by dry season time. Small hydropotential plants can be grouped in three classes:

	Flow rate [m^3/h]	Height [m]
Small hydro power plant	5–1000	10–300
Mini hydro power plant	0.5–50	2–100
Micro hydro power plant	0.2–3	2–50

The hydro energy conversion technology is a mature technology. The long-term development of hydro turbines has reached a state where commercially available hydro turbines of all sizes can be purchased in accordance with the respective resource potential. Large hydro turbine plants have been in operation for decades in a number of countries. Demonstration of modern small hydropower plants has been achieved in many countries. These achievements have offered experience and practical training to test the value of the small hydro power development to be used in rural and remote locations.

According to UNIPEDE classification there are three types of hydropower plants:

	Power [kW]
Small power plants	< 10,000
Mini power plants	< 2000
Micro power plants	< 500

Technically there are three main types of hydro turbines, depending on the water flow rate and available height

	Height [m]
Kaplan turbines	2–20
Francis turbines	5–200
Pelton turbines	50–1000.

In Kaplan turbines, a mechanical momentum is produced by helical blades formed to develop a pressure difference at the front and rear surface of the blades.

The Francis turbine is designed to uptake the water radial flow through fixed blades into rotating blades on the turbine rotor.

The Pelton turbine is designed in the form of one-row double spoon blades exposed to the injected water stream.

The diagram shown in Fig. 25 gives the possibility to select the respective hydro turbine type in accordance with the available flow rate and potential height. It also

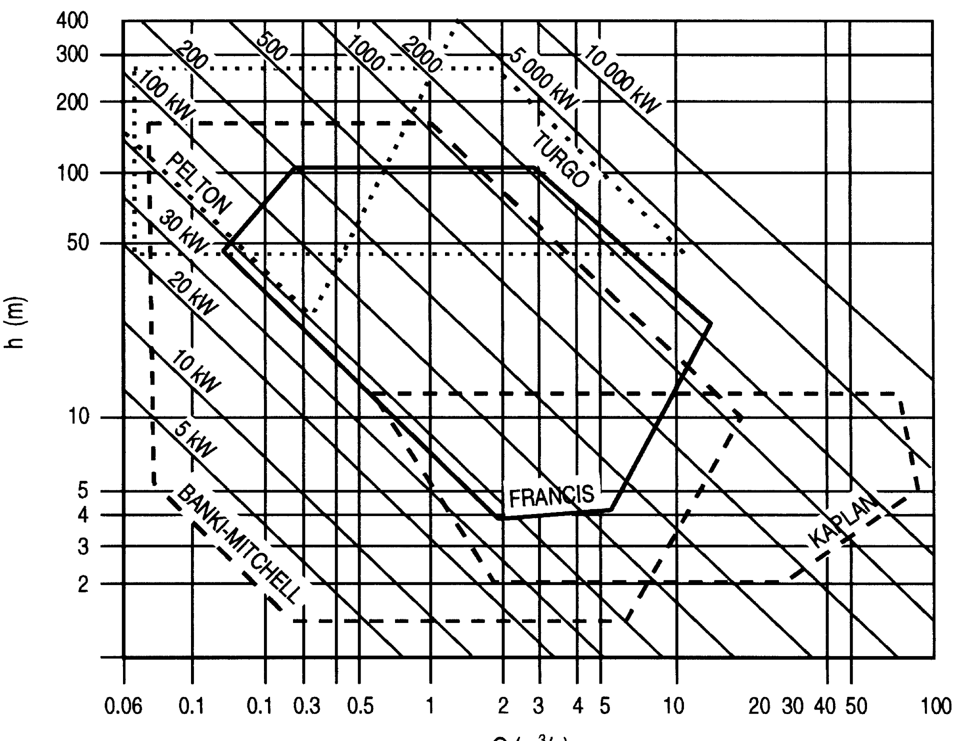

Fig. 25. Selection of hydro turbine.

shows the power of the respective turbine to be obtained for the specific parameters of the respective location.

6.6. Environment capacity for combustion products

Sustainability is closely related to the environment capacity of our plant. It has been shown that natural processes in the biosphere possess the maximum rate of change. This rate of change exceeds by orders of magnitude the contemporary rates of the parameters defining the anthropogenic impact to the environment and by four orders of magnitude, the mean rate of change of the parameters defining the geophysical processes [89]. The concentration and the rate of change of chemicals involved in the biochemical cycles may be characterized by the changes of organic and inorganic carbon. The capacity of biologically active organic and inorganic carbon chemical species in the environment is equal and ten times larger than their annual primary production. Therefore it may be expected that this resource of environment capacity could be considered in the next ten years, if only synthesis or decomposition of organic matter is taking place. This means that all life processes will end.

The fluxes of the organic material produced by the synthesis and decomposition processes in the biosphere are within the accuracy of one hundredth percent of the anthropogenic fluctuation resulting in the environment in the geological time scale. This slow change in the environment in the geological time scale can be compensated by biological processes leading to the biosphere control of the chemical composition of the environment. It is known from the Le Chatelier principles that any external perturbation of the equilibrium state of a system will induce the process to compensate for these perturbations. The compensation of the perturbations in the environment can be obtained by the synthesis and decomposition of organic processes in the biosphere. Since the preservation of the biosphere is affecting the biodiversity of our planet, it is of primary interest in long-term evolution, to have the control of the organic processes in the biosphere. For this reason, the preservation of the biosphere is the main requirement for the global ecological security for the sustainable development of our planet.

In order to observe the sustainability of the environment, the ecological system has to be monitored and followed with modern methods and techniques. It is obvious that an interdisciplinary approach is needed to understand all aspects of the changes which are introduced by human activities. In this respect the world energy system is responsible for the production and emission of a number of chemicals which are proven to have adverse effects on the environment.

The energy use is a major source of emissions. In the same time it is essential to the economic and social development for improved quality of life. There have been recognized several threats as signals for potential hazard to the environment. The emission of air pollutants is usually considered in three groups, i.e.: carbon dioxide, nitrogen oxide, and sulphur oxides.

The adverse effects of the emission gases are recognized by two processes: the greenhouse effect, leading to global warming and depletion of the ozone layer in the stratosphere. Global warming is observed by the increase of the mean earth temperature. It can be noticed that recent changes in concentration of CO_2 in the atmosphere are correlated with the changes in the global temperature. This has led a number of specialists in the field to conclude that the damage is irreversible. Figure 26 shows the estimated trend of CO_2 production.

6.7. Mitigation of nuclear power threat to the environment

Besides the effects of energy systems on the environment, by the emission of flue gases in the atmosphere due to the combustion of organic fuels in power production plants, there are possibilities which are imminent to some old power plant systems to have hazardous effects on the environment in a very short time with long lasting consequences. Nuclear power plants are very beneficial in the light of greenhouse effects because they have no exhaust gases [90]. But it is known that present nuclear power reactors have the potential to be enormous sources of radioactivity emission. Besides affecting their immediate surroundings, these hazardous events may lead to regional and global threats to the environment. The low probability of this kind of event has been the only barrier to the disastrous event to spread its consequences to the global environment. Examples recently learned are requiring different approach to face and master potential hazardous events. Human society is not in a position to lean its existence on man-made probability actions without possibility for any correction.

Opponents of nuclear energy outline two points that are crucial for them: the possibility of major radiological releases following accidents and the heavy inheritance of long lasting radioactive waste for future generations. Obviously, both these points are very relevant for the sustainability development of this form of energy. Let us

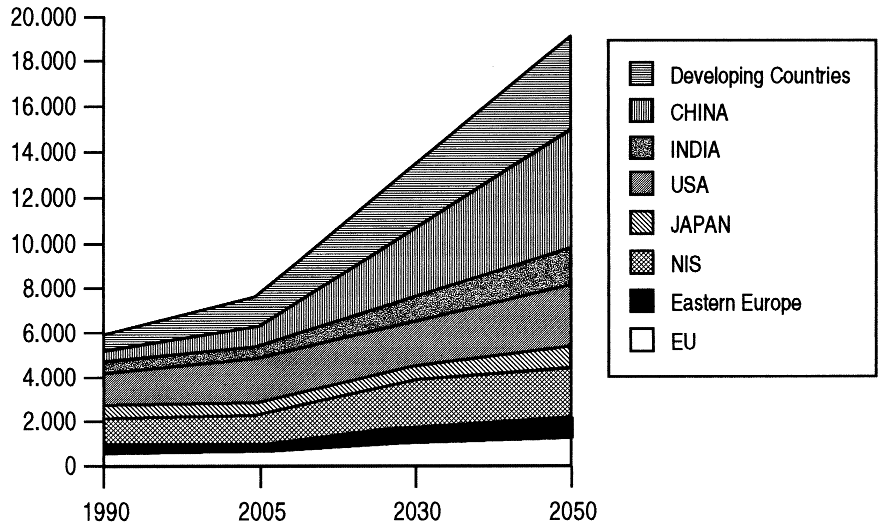

Fig. 26. OECD Scenario for CO_2 emission.

discuss these separately. Major accidents may be generated by a reactivity excess (Chernobyl) [91], or by a loss of coolant (Three Mile Island) [92] or by a loss of flowrate or by anticipated transients without the interruption of the nuclear chain. Even if the chain reaction during the accident has been broken with a prompt insertion of control rods, the radioactivity decay residual heat, if not adequately removed to a heat sink, may cause the melting of the core threatening the integrity of the reactor vessel. Against these possible accidental chains a 'defence in department' strategy has been developed with three main lines: a 'preventive line', a 'protective line' and a 'mitigative' line. This strategy worked at the Three Mile Island accident with external releases of few curies of radioactivity, but did not work at Chernobyl due to its absence of external containment and many other design deficiencies.

Present reactor designs for the second line of defence have a majority of 'active' safety systems and a minority of 'passive' ones. An 'active' system needs an external energy supply for intervention and a 'passive' one is based on physical laws like natural convection, thermal dilation, stress-strain relations, etc to operate [93, 94]. The present trend of designers is to increase the percentage of passive safety systems to counteract the possible accidental chains, proposing the so called 'advanced passive' reactors for a transition period from the first to the second generation of nuclear reactors. This trend is also associated with a preference of a deterministic approach instead of the more scientific probabilistic one, for better gaining the acceptability of common people who often remember the old saying 'if it can happen, it will happen".

A design of the second generation of nuclear reactors with 100% passive safety systems already exists, i.e., the MARS (Multi-purpose Advanced Reactor inherently Safe). Figure 27 shows a schematic representation of the MARS reactor [97].

This reactor has been conceived for small electric networks and for co-generation purposes, to increase the overall efficiency and multiply the possibilities of utilization. It is modular and assembled in small parts that are totally built and controlled, with quality assurance produced in factories. In this way the construction time is shortened, the related cost reduced, and the assembly procedures inverted in order at the end of useful life, to guarantee an easy and total decommissioning of the metal pieces. All these characteristics meet the requirements of sustainability.

The second point of the fear of nuclear opponents, related to the long lasting wastes, is still opened to interesting solutions. It is possible to separate the long-life radionuclides (actinides) from other radioactive fission products. The actinides may be recycled in 'ad hoc' reactors and converted in the radionuclides of the (i.e., short life) radionuclides. The radionuclides with long lasting lifetime can be converted into short life isotopes by their mutation through nuclear reactions in high flux nuclear reactors or in a coupled device of subcritical nuclear reactor in which a beam of high energy particles are injected by means of a powerful accelerator. The total amount of long lasting wastes will be substantially reduced so as to be conveniently placed in suitable geological formations, which remained dry and intact for millions of years in the past.

A device of this type has been recently proposed by Rubbia and co-workers [95], with a subcritical fast reactor cooled by lead in natural convection, fed by spallation neutrons generated by a beam of protons accelerated until 1 GeV. Figure 28 shows a

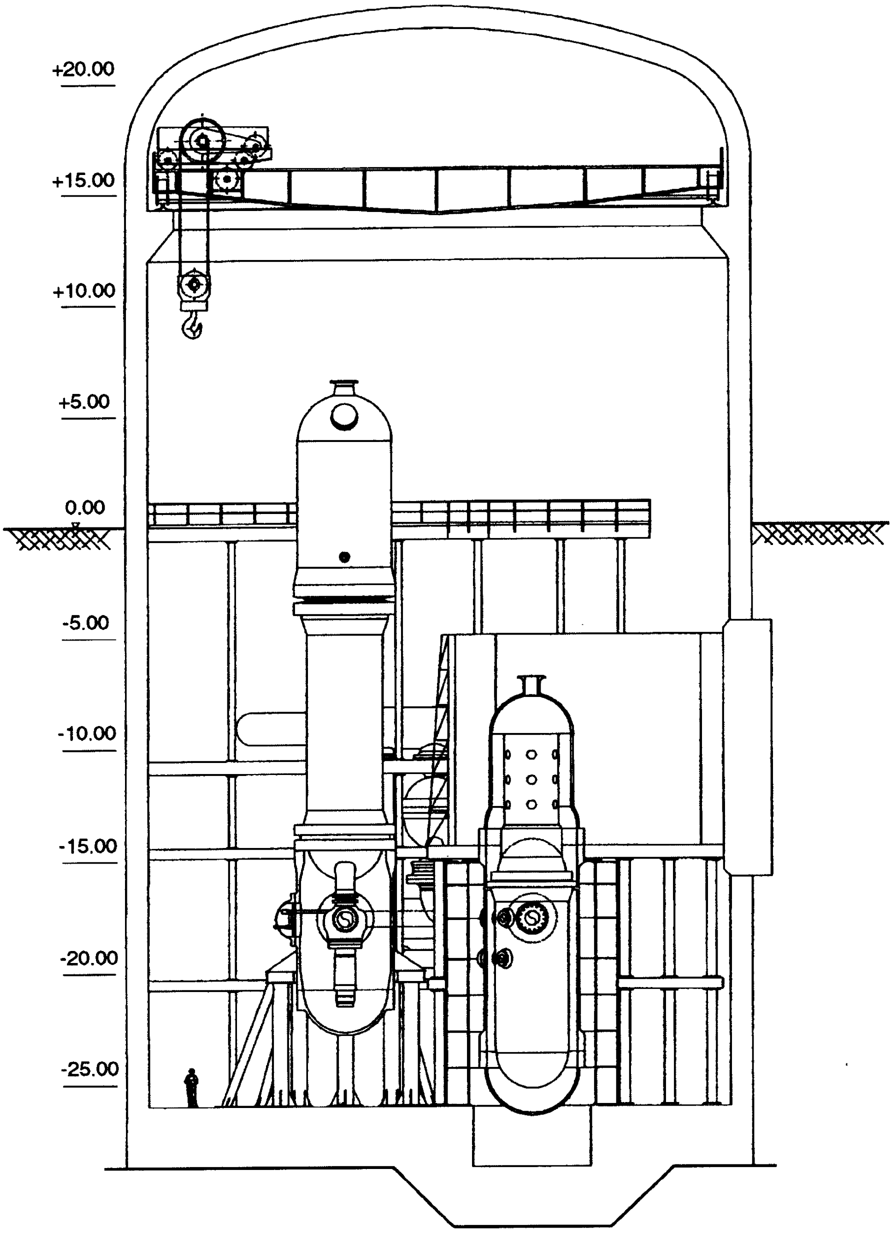

Fig. 27. Multi-purpose advanced reactor inherently safe (MARS).

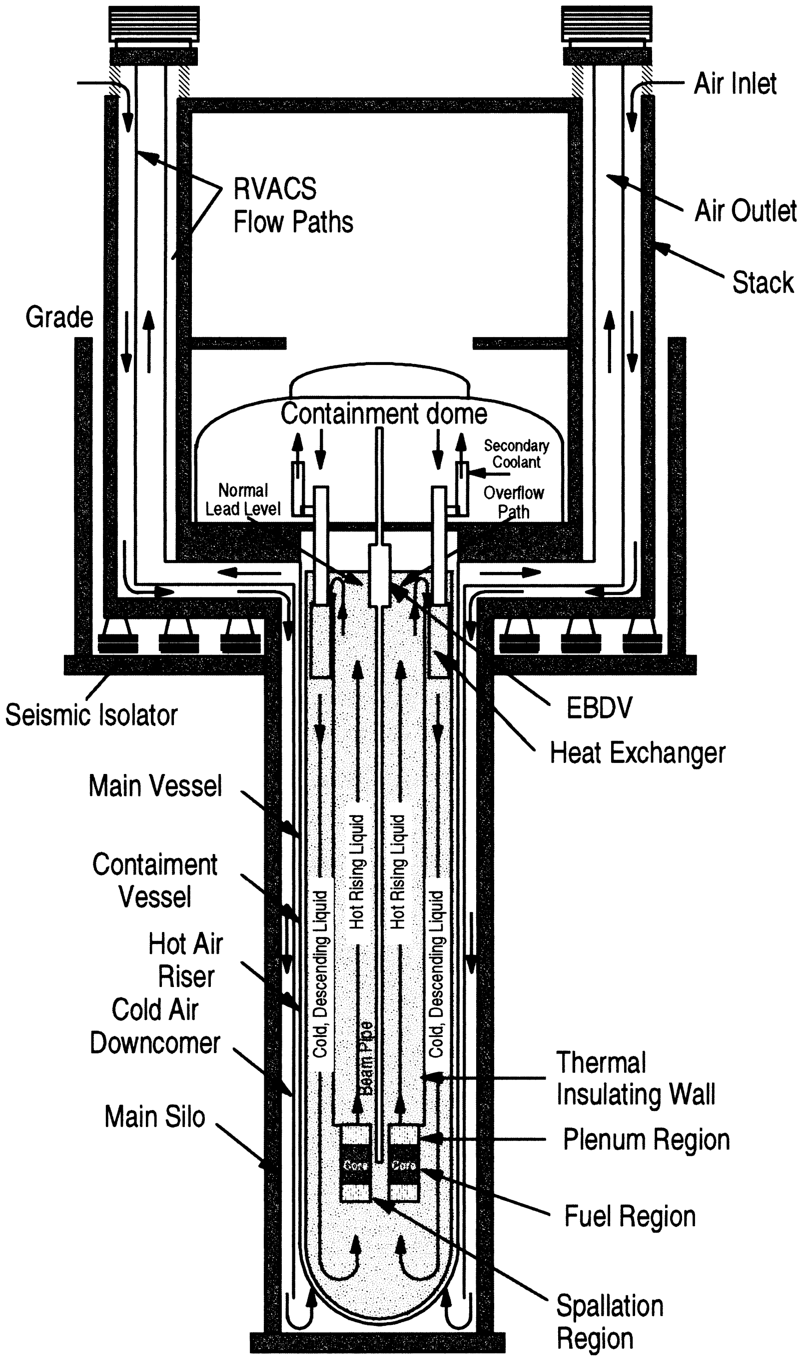

Fig. 28. Energy amplifier.

schematic representation of the conceptual design of this fast neutron operated high power energy amplifier.

7. Energy education and sustainability

The contemporary development of information technology has substantially contributed to the promotion of new means of dissemination of information and its multiple use. The set of information itself is a value which may be taken as the entity representing the individual system. The thermodynamic approach to the information has defined it as the state variable which defines the system. It has been shown that the information is the extensive variable of the system and is equal to the logarithm of the number of information. The similarity of the information and entropy of the physical system has led to the use of 'negentropy' as the parameter which describes the respective system. With the development of the information theory and the respective concept of information system, it becomes obvious that the socio-economic system can be described with the approach used in thermodynamics. It was recognized that the socio-economic system goes through changes from one state to other states similarly as in thermodynamic system. This has led to the definition of socio-economic system including information as the extensive parameter of system, defined as the negentropy. The information may have different forms and the knowledge is one of them generated by the scientific and technological research. The knowledge is transferred by the education system. In this respect the scientific and technological development from one side and education system from the other side can contribute to the information exchange in any socio-economic system. So, we can consider socio-economic changes in the two processes, i.e., the generation of information by scientific and technological development and the exchange of information by the education process. In this case, to have the harmony in the global system, between the use of its resources and at the same time to take care of the preservation of [96, 97] environment, it is of paramount interest to the development of science and technology and the education process in achieving this goal. Also, we can say that the sustainable development of our civilization will require besides using immediate action to preserve resources and environment capacity for future generations to devote a substantial attention to the science and technology development as well as the development of the education process. The science and technology development has to be focused on these problems which will affect the consumption of available material resources and environment capacity.

In the development of the sustainability issue there are three fundamental dimensions which have to be taken into consideration in the assessment: knowledge dissemination, science and technology development and exploration of new resources. The knowledge dissemination implies the development of the respective education system which will meet increasing demand for continuous refreshment of the knowledge in order to follow the contemporary development of new technologies.

Life-long education is presently recognized as a continuous learning activity to follow the needs of modern society [96, 97]. It can be seen as the education system with different levels in accordance with the aim, need and individual perception capability. In particular, the aim of lifelong education is diversified by specific requirements of the professional scope. These programs of lifelong education could be aimed to increase the fundamental knowledge of the specific subject or to the design or technical operation guidance for the respective equipment, system or structure. The need for lifelong education may come from the individual desire for the increase of his/her competency and also can be the result of the organized University–Industry programs for the upgrading of the workforce [98, 99]. Finally, the individual perception capacity may require additional help in adapting himself/herself to the normal working condition.

There are different educational schemes which are suitable for an organized approach to lifelong education. Distance learning has been introduced in the education system as the associate system to bridge difficulties arising from the lack of space for all those wishing to enter the higher education institution. In this respect, distance learning education methodology has proved advantageous which is of interest to be exposed to the public at large in order to be evaluated through its application in lifelong education. In particular, it becomes relevant to take advantage of modern communication systems, which are offering great possibilities to convey information to any distance, as desired. If the information to be transferred is adequately organized and structured, the messages will become the knowledge needed to be adapted for the learners. For this reason, education and training, coupled with the recent development in telematics, is opening a new venue for the revolutionary changes in the higher education system.

It is also recognized that the present education system is too rigid to accommodate new challenges of the lifelong education system [100]. To assimilate the distance learning education with a modern information technology and its prominence at this time, it is important to realize the changes in relationships between higher education and society. It is obvious that the present status of the higher education system will no longer enjoy a monopoly on the provision of learning service. Its eminence is blurred by the increasing competency of other institutions penetrating in the education service. Distance learning education with multimedia background has risen to prominence because it has the potential to address the social changes imminent to modern society as an alternative education system. The new distance learning systems will accommodate the time and space of the part-time learner, giving the opportunity to those outside metropolitan areas without the prominent education institution to have access to high quality education and to be exposed to outstanding professional specialists in the specific field.

In a number of countries it was proved that the distance learning methodology is a powerful tool for the dissemination of knowledge of different levels. The development of an in-house training and education capacity by business and other agencies not only signals the rise of importance for the changes of training and education methodology, but also reflects a dissatisfaction with the ability of mainline public institutions to provide adaptive, flexible relevant and problem centred approaches to training and education—at a reasonable cost.

Particular attention has to be devoted to postgraduate education, which is socially independent and can be organized without the personal interaction between the teacher and the learners and learners among themselves, as it is necessary for undergraduate education. In the context of the need for efficient and appropriate timing of postgraduate education, the demand and perspective of multimedia distance learning education is of high expectation. Technology oriented postgraduate education programs will be linked into regional, national and international networks and will be a great possibility for the integrated education environment, leading to the democratization of the world education system. The postgraduate engineering education in many contemporary education programs is printed to the continuation of the undergraduate education with emphasis on the fundamental knowledge to be learned or gives the deep knowledge related to specific systems, objects or entities. This subdivision will offer two types of postgraduate education programs, namely, the subject oriented and the object oriented postgraduate education programs.

The modern development of information technology is offering a challenge for its use in the education process. The multimedia information telematics is one of the new achievements, which is opening a possibility to use the distance learning methodology for postgraduate education. A limited number of qualified teachers for the specific subjects of modern technology is one of the limitations for the knowledge dissemination in the field, needed for the promotion of economic development The scarcity of competent teachers in specialized disciplines can be adequately subsidized by the respective use of distance learning methodology, which will allow the exposition of the valuable professionals in the field to larger audiences. If consideration is given to the future need for postgraduate education, it becomes obvious that a new lifelong education system is needed to meet the constantly increasing demands for higher education in different engineering fields.

7.1. Energy and environment engineering education

The energy and environment problems in the contemporary world are the challenging engineering fields requiring the constant increase of our attention in order to meet the increasing demands and also face the potential adverse effects on the environment. In this field, a new strategy is in development which compulsorily requires the respective efficiency of the systems, increases the global energy system structure use of new and renewable energy sources, meets a new social aspect of the energy and environment. Also it will better understand in depth all consequences which possibly promote global changes in the environment. These requirements could only be met with the respective education systems which will be able to accommodate the needs for an increasing number of specialists with a high level of education, capable of understanding in depth all energy and environment problems [101]. It is becoming obvious that the present energy and environment engineering education system is facing difficulties in many countries to meet forthcoming demands. Even more, in a number of developing countries this problem is open and will require outside assistance to be overcome. In this respect, the future energy development strategy has to include the development of the respective energy education system, which will ensure its promotion and practical application. It is of paramount interest to the society to combine its effort in the economic development with the change in the structure of the education system.

Engineering education is closely linked with economic development [102]. The promotion of new technology advances by the use of information technology is important to the further development of the engineering education [103]. In particular, the increase of the engineering knowledge body leading to the larger number of the engineering specializations is only the tip of the iceberg of the problem in engineering education. In this respect, energy and environment engineering education is of primary interest for modern society. For this reason, it is needed to look for the new achievements in the education methodological developments. Particular emphasis in this respect has to be given to postgraduate education in order to ensure the benefits coming from the development in the different fields of science and technology.

Efficiency, reliability, new energy sources and environment are among those issues of energy engineering which are to be recognized as the main driving forces to increase the demand from the energy systems. The efficiency of the energy systems has been recognised since Sady Carnot defined the Second Law approach for its assessment. In this respect, it has become important to understand the quality of energy in order to obtain the maximum from a potential source of energy. Exergy analysis has become a powerful tool for the engineering evaluation of the respective energy system. The Second Law efficiency assessment requires knowledge about principles of exergy analysis, technical characteristics of the respective system and equipment. The correct efficiency evaluation of the system will also require a social aspect of the energy cost, which includes the environment interaction with the respective energy system.

The reliability and safety of the energy systems have become main issues of the adverse effects which might have regional, national and global effects. It is a complex issue which requires in-depth knowledge about the system: its functionality and limitations. This knowledge is required at different stages of the energy system development including design, construction and operation. The risk evaluation is a specific issue, which has to be introduced at each stage of the development. Learning about reliability and safety aspects of the energy system requires a high degree of sophistication of all the subjects to be taught in the normal engineering curriculum. It is known that any malfunction of the energy system leading to the degradation of reliability and the decreasing safety margins of the system is a result of complex processes, which are time dependent and interrelated. This implies that in order to gain the knowledge needed for the assessment of reliability and safety of the energy system, the engineering education programs should include time and space dependent processes with the respective mathematical and numerical tools to be used in modern computer systems.

New and renewable energy sources are based on modern achievements in physics and chemistry. So, it is important to the new energy sources assessment and evaluation to have respective knowledge in these fields. In particular, the engineering aspect of the new and renewable energy sources should be emphasized in order to introduce them into the strategy of the energy system development. It is obvious that the energy engineering education has to reflect the needs for the competitive evaluation of these sources of energy. For this reason it is necessary to design energy education programs, taking into consideration the need for society to introduce the new energy sources in everyday life.

The increased environmental concern in modern society has led to the internationally recognized requirements for higher attention to the adverse effects of human activity towards its surrounding. In this respect, the energy-producing systems have been called for special attention to introduce the different kinds of measures to prevent consequences leading to the degradation of the environment. In view of the impact of energy systems on the environment, increased emphasis is given to the assessment of such impacts at the stage of energy programming and the project design in order to take into consideration environment problems caused by the energy production, transport and consumption. Besides updating traditional curriculums in energy engineering with the environment aspect of the problem, it is necessary to include subjects such as biology and social sciences in energy engineering curriculums. It has to be emphasized that the engineering education aspect has to be developed and introduced in the energy programs.

7.2. Lifelong education in energy engineering

It is known that the need for upgrading professional capability of the manpower in engineering is the result of constantly growing demand for the increase of efficiency of technical systems and increasing awareness of the environment problems [104, 105]. The organized effort is streamed to meet challenges for the benefits obtained with a new approach to future technical systems and their incorporation in the human environment without adverse effects. One of the lines in this effort is a new lifelong education system. In order to meet this requirement the distance learning education methodology offers the advantages proved to be cost effective and revealing new features to be enjoyed as the incentive challenge for the learners. In particular, it seems appropriate to focus the attention to advantages which are of common interest for the public at large. In this respect, the distance learning with multimedia is proved to be easily accommodated for the on-job training for the Industry–University cooperation. The education programs could be designed for specific needs and adapted in the on-job environment with limited teaching assistance.

As a milestone of further progress in the process of large-scale extension of the application of scientific and technical achievements, university and other educational institutions should attach importance to the development of postgraduate engineering education closely related to the technology research centers. In this respect, the distance learning with the multimedia education used in an appropriate environment can prove to be cost-effective. The multi-use of teaching material with a limited number of professionals in many cases has shown to be adaptive to the learner's demands and wishes. As most of the postgraduate education programs are closely linked to the specific technology developments, it is of great interest to the design respective courses having in mind the customer interest and local environment. The energy engineering postgraduate courses in this respect has to be aimed to meet the recent strategic demands in the modern development of the global energy system. The variety of options for the specific programs will require a polyvalent approach in the design of the respective postgraduate energy engineering program [106]. It will have to accommodate the different discipline-oriented modules, to be used in the construction of multiple options as required by the individual learners. With this approach, it will be possible to launch the individual education programs, which are to be custom-made to the specific needs of the individual learners or their employers. This will lead us to take full advantage of the multimedia environment and if connected with the recent development in telematics may lead to the formation of a global engineering education system. This means that future learners will have the opportunity to connect themselves to any available education programs in the world network designed as a part of the global system. In this respect, lifelong engineering education is at the beginning of network formation, which will, similarly to the existing Internet or similar global network, offer the education commodity to any individual wishing to increase his/her competency in the specific field of interest.

8. Conclusions

It is shown that present energy strategy requires adaptation of new criteria to be followed in the future energy system development. No doubt there is a link between energy consumption and environment capacity reduction. This is an alarming sign, which recently has become the leading theme for our near and distant future. Together with social aspects of future economic development, it is of paramount interest for modern society to implement the world leaders adopted resolutions before it is too late.

Modern engineering science has to be oriented to those areas which may directly assist in our future energy planning. In this respect, it is a demanding need that our attention be oriented to the global aspect of energy development. Modern technologies will help to adopt essential principles of sustainable energy development. With the appropriate renewable energy resources introduction in our energy future and relief of nuclear energy threat, it will be possible to comply with the main principles to be adopted in the sustainable energy strategy.

In order to promote sustainable energy development, the respective education system is required. It is recognized that the present energy education system cannot meet future demand for knowledge dissemination. It is shown that the potential option for the future education system is distance learning with multimedia telematic systems.

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