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ENERGY, ENVIRONMENT AND MODERN CIVILIZATION

Abstract: Energy played a key role in the development and evolution of human society. Modern civilization is especially dependent on energy and some of its most distinct characteristics, such as increase in world and urban population, energy consumption, environmental impact and climate change, societal complexity, and the gap between poor and rich peoples, are related to energy. Neither the divergent need of society for energy, nor the ability of society to cope with climate change and world poverty can be dealt with effectively in the future, without abundant, affordable and "clean" energy. Sustainable civilization requires sustainable development, and sustainable development needs sustainable energy sources – energy sources environmentally friendly and economically feasible, which can support life in the long run. The basic challenge for new societies is their moral responsibility to make modern forms of energy accessible to and affordable by all peoples.

Key words: *energy, energy poverty, energy sources, environment, modern civilization, sustainability*

INTRODUCTION

a) ENERGY IS A BASIC ELEMENT OF THE PHYSICAL WORLD

Energy is prevalent SIC It has been this way since the beginning of time. Physics tells us that if the big bang is the beginning of space and time, it is also the beginning of energy. From the primordial radiant energy in the beginning, emerged everything that is – the cosmos, the Earth, the environment, us. Today, we know many things about energy, foremost that energy appears in various forms and that it can be transformed from one form to another; for instance, from electrical energy into light or heat, or from electromagnetic energy into chemical (as in photosynthesis) or electrical (as in photovoltaics). Every new form of energy comes from some other form or forms of energy and every energy transformation produces a quantity of low-grade "exhaust" energy normally in the form of heat. All known forms of en-

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ergy are necessary for life. We, and the rest of life, need energy for everything we do and everything we do is connected with energy transformation and energy flow.

b) ENERGY IS A BASIC ELEMENT OF CIVILIZATION

Energy is also a basic element of civilization [1]. It has played a key role in the development of human society and it is the key for a sustainable civilization and a better quality of life. Indeed, the evolution of human society and civilization parallels man's ability to discover and to master new sources of energy. History tells us that man utilized every source of energy he had discovered. In the last two centuries in particular, the standard of living of society crucially depended on the use of continuously larger amounts of energy of increasingly more concentrated forms: *wood, coal, oil, natural gas and uranium* (see Table 1).

Table 1: Energy density of various energy sources SIC

Fuel	Energy density (kWh/kg)
Fire Wood	4.4
Coal	8.0
Oil	12.0
Natural Gas	14.9
Natural Uranium (fission of only U_{235})	160,000
Natural Uranium (100% fission in a breeder reactor)	22,800,000

While in the past the amount of energy necessary to support civilization was small and the then known forms of energy were few, today, civilization needs incredible amounts of energy in vastly varied forms. The basis of modern civilization is in fact an incessant flow of energy, which relies on the production and use of electrical energy and its delicate "conditioning" to meet the needs of modern technologies; for instance, delicate pulses of electrical energy or of light for information technologies. It fact, it can be said that every technology relies on the *availability of energy of a particular form,* and that every conceivable technology that can be realized in the future, will be realized, *as long as there is energy available for it in the particular form required.*

Since the 18th century, the ascendancy of modern civilization is grounded on science, technology and increased consumption of energy, consisting, up until recently, largely of cheap and abundant fossil fuels. The basic criterion of progress of modern civilization has been and remains the *continuous growth, the continuous increase of the Gross Domestic Product (GDP). In pursue of this goal, modern civilization has largely ignored the natural limits of the energy sources and the impact of energy production and use on the Earth.*

1. DISTINCT CHARACTERISTICS OF MODERN CIVILIZATION RELATING TO ENERGY

Let us briefly look at a few such distinct characteristics of the last two centuries, which especially relate to energy [2]

1. 1. INCREASE IN WORLD POPULATION

Figure 1 shows the precipitous increase in world population (from ~1 billion in 1800 to ~7 billion in 2000) during the so-called energy revolution [3] UN-2011-estimates [4] project the world population to surge past 9 billion before 2050 and to reach 10 billion by the end of the century. Most of this increase is in the low-income parts of the world [4].

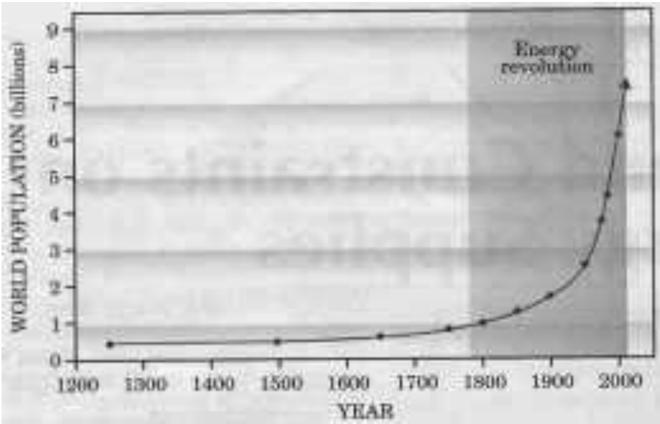

Figure 1: World population growth since the 13th century and the precipitous increase in the population of the Earth in the last two centuries as a result of increased energy consumption [3]

1. 2. INCREASE IN URBAN POPULATION

Mainly as a result of increased energy consumption, the cities grew bigger and the number of big cities increased precipitously (Table 2), some becoming megacities. This trend is still continuing, especially in the developing countries. Today ~50% of world population and ~ 70% of the children live in cities. The functioning and the support of the complex life in the cities relies on interdependent technologies and infrastructures, which all require energy.

Table 2: Increase of the number of big cities and their size (based on Refs. [1[, [5] and [6]).

Cities with more than one million inhabitants		Cities with over ten million inhabitants		Percentage (%) of the Earth's population living in cities	
Year	Number	Year	Number	Year	Percentage (%)
1800	1	—	—	1800	<3
1900	13	1900	0	1900	~ 10
2000	375	2003	20	2000	~ 50
2010	>472	2010	>26		

1. 3. INCREASE IN THE CONSUMPTION OF ENERGY, PRINCIPALLY FROM FOSSIL FUELS

Energy consumption has risen continuously since the start of the industrial revolution. Today's society needs enormous amounts of energy, which constantly increase. In the past 50 years energy production has increased more than four-fold. In the year 2000, the annual total world energy consumption exceeded 400 billion billion Joules (400 EJ) [1], [7]. The world energy needs are anticipated to reach 623 EJ by 2035, that is, to be ~ 55% higher than in 2000 [8]. One therefore wonders if such a rate of energy consumption is sustainable, especially when considering the energy needs of the entire humanity.

1. 4. INCREASE IN ENVIRONMENTAL POLLUTION AND CLIMATE CHANGE

Figure 2 shows the well-known IPCC scientific data on CO_2 concentrations in the atmosphere over the last 10,000 years and, in the inset, over the last 250 years. Up to the beginning of the 18^{th} century, the concentration of CO_2 in the atmosphere was almost constant (~280 ppm) and it was principally from natural sources. Since then, the concentration of CO_2 in the atmosphere increased substantially (today it approaches 400 ppm) and this increase comes from anthropogenic sources, principally energy-related. The same holds true for the other, more potent greenhouse gases, e. g., CH_4 and N_2O.

While climate change and environmental impact of energy production and use began in Europe and North America long before the recent industrial development of the underdeveloped countries, today, the developing world is catching up fast. Figure 3 shows the recent data [10] for China. Because of the increased consumption of energy, the GDP of China has been increasing by almost 10% annually for the last 30 or so years. As a direct consequence of this, the CO_2 emissions in China have

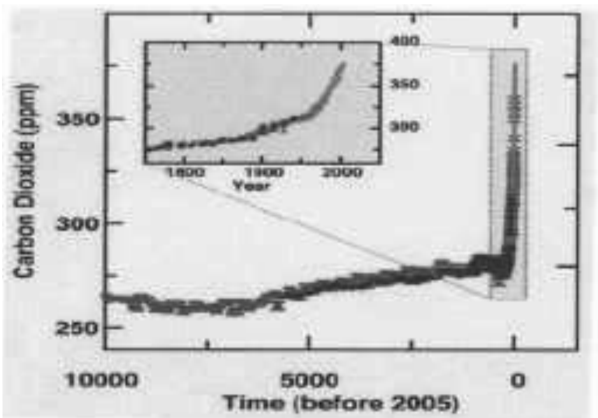

Figure 2: Concentrations of CO_2 in the atmosphere over 10,000 years (inset: since 1750) [9]

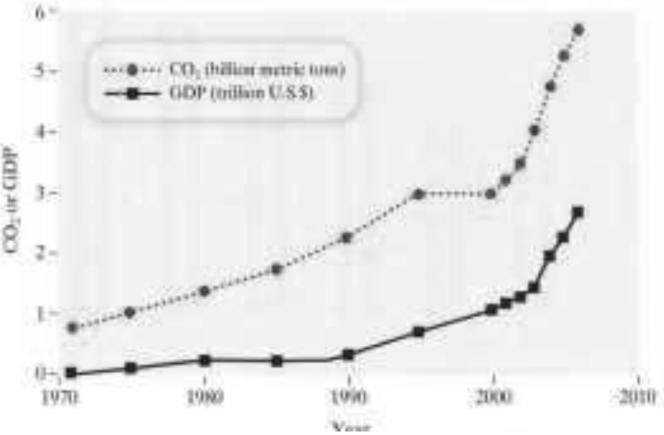

Figure 3: The GDP of China has increased substantially over the last 30 years, but a parallel increase has resulted in the emissions of CO_2 [10]

increased alarmingly. The greenhouse emissions in China in 2007 have surpassed those in the USA and in 2010 amounted to 24% of the world's total emissions [11].

Especially serious are the environmental and climatic consequences of the burning of large quantities of coal by China. Coal-fired electricity generators in China, in 2011, represented 78% of the 1 billion kilowatts of installed capacity [11]. Without developing other types of generating capacity, such as nuclear, China's demand for coal will likely exceed 4 billion metric tons in 2015 and will account for more than half of the world's total demand for coal [11] According to Liu and Diamond [10],

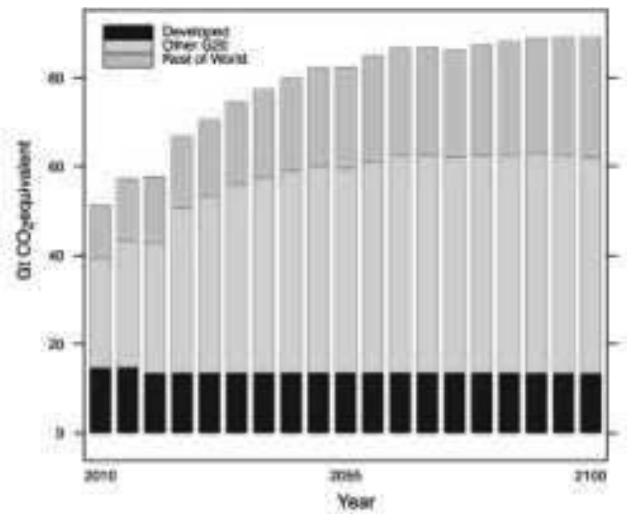

Figure 4: Greenhouse gas emissions by major groups [4]

environmental pollution and deterioration in China are such that two thirds of China's cities suffer from lack of clean water.

Figure 4 shows the recent (2011) UN projections of greenhouse gas emissions S 4 Cfor developed countries (dark blue), other G 20 countries (green) and the rest of the world (light blue) in this century. Quite apart from climate change, some fear that, as Asia's more populous nations follow the Western route out of poverty, the strain on global energy, food and water supplies will become severe.

1. 5. INCREASE OF SOCIETAL COMPLEXITY

It has been argued that the more energy a certain society uses, the higher is its complexity. Thus, when the amount of energy a society has at its disposal and uses is reduced, or when the amount of energy a society needs stops increasing while its energy needs continue to grow, that society is at risk if it fails to secure new sources of energy, or if it is unable to use more efficiently the energy it has. Many historians actually believe that a significant common reason of the collapse of past civilizations was their weakening by over exploitation of their energy resources which made them vulnerable and ultimately unsustainable.

For how long then will modern civilization continue to increase its energy consumption and complexity before it becomes non-sustainable and hence unstable? If the energy consumption and the complexity of today's society are the determining factors which define societal progress, for how long could these factors continue to grow before today's technological society becomes unstable? Complex systems which have no other option but to go on increasing, to go on growing, eventually collapse. It, thus, seems that the continued increase of complexity of modern civilization makes it fragile and operationally vulnerable. Modern civilization crucially depends on the smooth operation of a multitude of complex and interdependent and interconnected systems and *each and every one of these systems depends on energy.* It suffices the malfunctioning of some of the components of the system to trigger a cataclysmic failure in the operation of the entire system, causing its collapse. *One is thus forced to conclude that the sustainability of modern civilization is in danger without huge new amounts of energy* [1].

1. 6. INCREASED GAP IN THE STANDARD OF LIVING BETWEEN THE ENERGY RICH AND THE ENERGY POOR PEOPLES

It is well recognized that there is an asymmetry in the consumption of energy between the peoples of the world, which separates them into poor and rich. The widening gap between the rich and the poor peoples of the world largely reflects the existing difference in their energy consumption levels and the lack of access to modern energy services by the latter. *Peoples' poverty is in fact peoples' energy poverty.* The industrialized nations rely on abundant fossil fuels and electricity for their standard of living, while the poor regions of the Earth (especially their rural areas) rely, as a rule, on animal energy sources and biomass. It is estimated (e. g., see [12]) that some 1.3–1.6 billion people in the world have no access to electricity and some

2.4–3.0 billion rely on traditional use of biomass for cooking and heating and have incomes less than $2 per day. Many believe that the enormous energy consumption in the advanced countries impacts on the *energy poverty* of the developing countries. To wipe out poverty and to secure decent life for the billions of people in the poor countries of the world, we need to wipe out the energy poverty of these countries, *and this requires more energy consumption in the future.*

Access to energy, especially to modern forms of energy, can be an effective way out of poverty. Yet, one wonders. According to Ferguson [13] "nearly one in ten people in China live with the equivalent of $1.50 a day or less and an estimated 0.4% of Chinese households currently own ~ 70% of the country's wealth"; to these disparities can be added chronic problems of air, water and ground pollution [13]. If then the recent increase in the use of fossil fuels by the developing countries, foremost of Asia (China and India), has caused such an abrupt and sharp increase in the cost of energy and such serious negative environmental impact, and it has resulted in rather marginal improvements in the standard of living for the majority of their people [13], [14], pessimistically, one is led to conclude that the health of the Earth will continue to be in danger and the survival and dignity of a large part of humanity will fall to still lower levels without the development of new energy sources, economically feasible and environmentally friendly. *Without abundant clean energy, neither the environment nor poverty can be dealt with effectively.*

2. ELECTRICAL ENERGY AS A BASIC ELEMENT OF MODERN CIVILIZATION

2. 1. CORRELATION BETWEEN THE CONSUMPTION OF ELECTRICAL ENERGY OF A COUNTRY AND ITS GDP

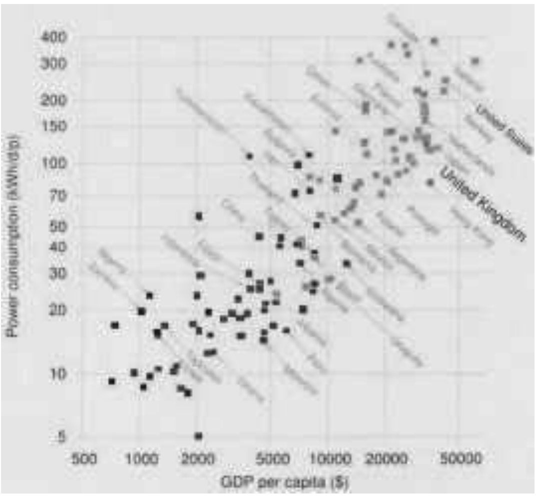

Figure 5: Relation between the consumption of electrical energy of a country and its GDP per capita [15]

Today's society needs especially increasing amounts of *electrical energy*. It is difficult to imagine modern society without electricity; electrical energy is the form of energy which sustains modern technological societies. Today, there is a clear relationship between the consumption of electrical energy and the GDP of a country – the GDP increases with increasing electrical energy consumption (Fig. 5).

The correlation between the consumption of electrical energy and the GDP of a country shown in Fig. 6 is more impressive for the USA where the increase in the GDP and in electricity consumption go hand-in-hand [1], [16] The demand for electricity is, and probably will continue to be, closely tied to income.

2. 2. THE POOR REGIONS OF THE EARTH AND THEIR NEED FOR ENERGY, ESPECIALLY ELECTRICITY

Contrary to the case of the developed countries, electrical energy is not available in sufficient quantities to the poor regions of the Earth. This can be seen from the data in Fig. 6 where countries with a large portion of their population living on an income of less than $2 per day tend to have very low access to electricity. Access to and affordability of modern forms of energy is a prerequisite for human development, increased productivity and income, poverty eradication and better quality of life (e. g., it has been known for a long time that there is a correlation between health and income [17]).

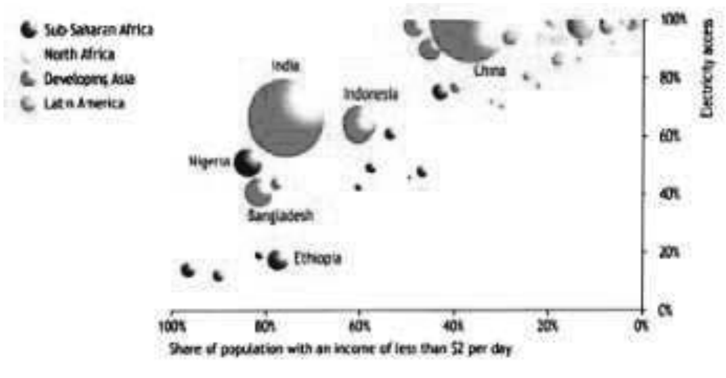

Figure 6: Share of population with an income of less than $2 as a function of access to electricity [18]

Yet, energy poverty is hard to define and even harder to measure. Some have defined it in terms of access to modern energy services: affordable access to reliable electricity and clean household and cooking facilities ([12], [18], [19]). Others, defined energy poverty in terms of the electrical energy required to satisfy basic human needs: 1 kWh per person per day (500 Wh for fuels and electricity, and 500 Wh for other goods) ([20], [21]), which is close to the *energy poverty level* of 250 kWh per household per year for rural households and twice that amount for urban households suggested by IEA [22] and that of Sanchez [23] of 120 kWh per person per year (about 500 kWh per family of four). These threshold energy values have been criticized as inadequate to meet basic human needs. More generally, energy poverty has been referred to as the situation of large numbers of people in developing countries whose well being is negatively affected by very low consumption of energy, use of polluting fuels and excessive time spent in collecting fuel for basic needs (see [24][25]).

Based on such definitions of energy poverty, it is estimated ([12], [18], [25], [26], [27]) that some 1.3–1.6 billion people in the world have no access to electricity and some 2.4–3.0 billion rely on traditional use of biomass for cooking and heating; it is argued (e. g., see [28], [29]) that, if present trends continue, by the year 2030 some 1.4 billion people will still lack access to electricity and more than 2.6 billion will still rely on traditional biomass fuels, largely because of increasing population in the poor areas of the world. While the number of people without access to electricity will decline in certain regions (especially East Asia/China and North Africa), it will change only slowly for South Asia and it will keep increasing in Sub-Saharan Africa ([29], [30]).

Let us look at the data in Fig. 6 a little differently, as shown in Fig. 7.

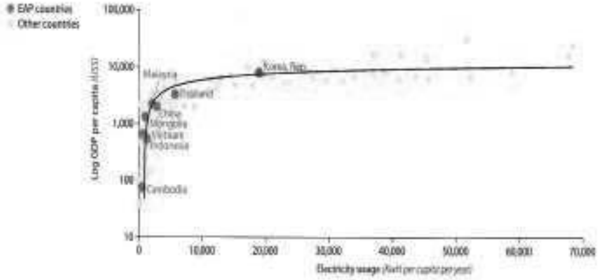

Figure 7: Gross Domestic Product per person as a function of electricity use [26] 2008, (semi-logarithmic plot).

Two key features become evident: (1) the drastic difference in the slops of the low and high income regions, and (2) the spread of the data (a factor of 4 to 5) in the high-energy consumption region. Let us then consider the low-electricity consumption data, say, below 52,000 kWh per person per year. If we accept 365 kWh per person per year as the *poverty level of energy consumption,* raising this amount, say, to 1,000 kWh per person per year would substantially increase the GDP above the poverty level, while reducing by this amount the electricity consumed by the people in the consumption range above 20,000 kWh per person per year would hardly impact their standard of living and, in fact, any such change is within the spread of their incomes. The Earth Institute S 30(claims that at the level of electricity usage of 52,000 kWh per person per year, access to modern society needs – modern energy services, more domestic appliances, increased requirements for cooling and heating, private transportation, etc. – becomes possible. Nevertheless, the IEA [22] envisage that the poverty line would rise slowly and reach 800 kWh per household per year by 2030. By comparison, the annual household consumption in the 27 EU countries in 2008 was just under 18,000 kW.

The significance of energy poverty has been recognized as a global challenge, albeit only recently. Characteristically, although the close relationship between development and access to modern energy services has long been recognized, the UN Millennium Development Goals (MDGs) declared by the UN General Assembly in the year 2000 do not explicitly refer to energy; yet, none of the MDGs can be achieved without the availability of adequate amounts and affordable energy. The provision of modern energy services is now broadly recognized as a critical foundation for sustainable development (e. g., see [29], [31–34]). It is encouraging that a decade after the MDGs were drafted, the basic role of energy in eradicating world poverty has been recognized by the UN, when the UN General Assembly designated the year 2012 as the *"International Year of Sustainable Energy for All"* [35] It is also encouraging that other international bodies, among them the European Union and the World Bank, have attempted to focus attention on this problem.

In supplying electricity to the energy-impoverished regions of the Earth, the tendency has been toward building major fossil-fuel plants located in urban areas and extending existing electricity grids to rural areas, which while sparsely populated carry most of the energy-poor peoples. Many argue that this approach and its associated infrastructure, can serve well the poor in urban areas, but it is expensive to extend to the poor in rural communities (For rural electrification see [36]). Beyond the reach of national grids, and independently of them, lie opportunities for energy production in mini-grids and stand-alone off-grid systems from renewable energy sources such as small hydroelectric plants, solar, wind, geothermal and biomass. By all counts, solar electricity will play a big role in improving energy access. Solar power can be installed quickly, providing enough power for light and basic services. Solar photovoltaics are especially significant and constitute a basic element of the so-called "Smart villages" programs [37].

3. ENERGY SOURCES AND ENERGY NEEDS – ENERGY IN THE FUTURE

Each of the *main primary sources of energy today – fossil fuels, renewable energy sources,* and *nuclear power* – has its advantages and its disadvantages. They all generate undesirable by-products and rely on suitable materials and technology to become more efficient and less damaging. The environmental/climate impact of these energy sources are different. This can be seen from Fig. 8 where the total amount of greenhouse gases emitted to the environment from the use of these primary energy sources for electricity production (in gram carbon equivalent per kWh, gC_{ecl}/kWh) is compared.

An important aspect of *Fossil Fuels* is that today they provide ~ 80% of the world-wide energy needs, and that the burning of these fossil fuels, especially coal,

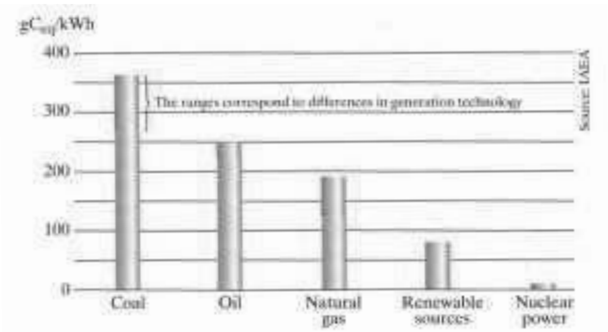

Figure 8: Total emission of greenhouse gases in the production of electricity from various primary energy sources [38]

is the most damaging to the environment. Yet, their use (especially coal) is expected to continue and to considerably increase due mainly to the rapid world-wide demand for electricity and the large reserves and low cost of coal compared to other fuels. The substantial increase in the use of coal in the future is incompatible with efforts to stabilize CO_2 concentrations in the atmosphere. Clearly, more efficient and cleaner fossil fuel technologies are needed, better combustion, effective capture and storage of CO_2, and replacement of oil with other energy sources whenever possible.

Renewable Energy Sources are cleaner compared to fossil fuels, but they are more disbursed and diffused. They must be further developed and expanded on a massive scale world-wide, and this requires massive penetration of renewable electricity to the electrical grid, "smart grids", and economically feasible ways to store renewable electricity on a large-scale and to transport it efficiently over long distances. The critical role of new materials for renewable technologies, energy storage, electrical energy transmission and distribution can hardly be overemphasized.

Nuclear Electricity: Society is still hesitant to embrace nuclear energy principally because of fears associated with the safety of nuclear reactors, the handling and safe disposal of nuclear waste, and the danger of proliferation of nuclear materials. Science and technology must address these issues: substantially improve the safety of new generations of nuclear reactors, resolve the lingering problems of nuclear waste and permanent repositories, implement strict international oversight for all nuclear power reactors, and explore alternative nuclear fuels to reduce plutonium production.

In the future, electricity will become the main energy carrier, more so than it is today, and it will accelerate the transformation of many economies which presently rely on fossil fuels to economies which are based on electrical energy (e. g., electric cars), especially if society is successful in generating electricity from solar radiation on a massive scale and finds effective ways to transport and to store it. Some envision and optimistically predict that by the year 2050, ~ 95% of the Earth's population will have access to electrical energy [1].

CONCLUSIONS – CONDITIONS FOR SUSTAINABILITY

Undoubtedly, the future will bring along new sources of energy and new technologies of energy, some not yet imagined. Through science and technology, society may discover *new forms/sources of energy, new sources of the known forms of energy,* and *new technologies to access existing forms of energy.* In may become possible to produce biomass using sea water or artificial photosynthesis; humanity may also accomplish its goal to generate electrical energy from controlled nuclear fusion, and have a truly *sustainable energy source.*

The future will also bring new responsibilities to balance the dangers inherent in the various forms of energy and the technologies associated with them, with their respective benefits. The future will also bring increased demands for individual and social responsibility to balance the energy needs of humanity and the environmental consequences of the production and use of energy. Indeed, the future of civilization will depend not only on the total amount of energy humanity will have at its disposal, but perhaps more so on how that energy is distributed among the peoples of the world; *access to sustainable energy will be considered a human right of every person and a moral responsibility of civilization.* For this, man will need *wisdom and courage to achieve a precious balance between the restrictions society will impose on him in order to secure for him adequate supply of energy and materials on the one hand, and on the other hand, to secure his cultural and civil rights, foremost, his freedom, without which there is no civilization at all.*

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