THE FUTURE OF NUCLEAR ENERGY AS A PRIMARY SOURCE FOR CLEAN HYDROGEN ENERGY SYSTEM IN DEVELPING COUNTRIES

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The limited availability of fossil fuels compared to the increasing demand and the connected environmental questions have become topics of growing importance and international attention. Many other clean alternative sources of energy are available, but most of them are either relatively undeveloped technologically or are not yet fully utilized. Also, there is a need for a medium which can carry the produced energy to the consumer in a convenient and environmentally acceptable way. In this study, a fission reactor as a primary energy source with hydrogen as an energy carrier is suggested. An assessment of hydrogen production from nuclear energy is presented. A complete nuclear-electro-hydrogen energy system is proposed for a medium size city (population of 500,000). The whole energy requirement is assessed including residential, industrial and transportation energies. A preliminary economical and environmental impact study is performed on the proposed system. The presented work could be used as a nucleus for a feasibility study for applying this system in any newly established city.

INTRODUCTION

The risk of global climate changes is of great concern to policy makers and to the public. The relation between the energy generation sector and environmental pollution is being carefully considered in industrialized countries. Before executing any power generation project, extensive and comprehensive studies are performed concerning the impact of such a project on the environment. Measures for decreasing climate change and environmental pollution are considered.

When it comes to the developing countries, the situation is more complicated. Environmental pollution problems are less considered. Also, the rate of increase of power generation is much more than in the case of the developed countries. This means that the environmental impact in the developing countries is much more magnified, which means that the use of nontraditional solutions for less polluting power generation cycles in developing countries is needed.

In this study, the gap in power consumption between developed and developing countries are briefly delineated. The rate of increase of power requirements in developing countries is discussed. The case of Egypt, as examples of developing country is considered. Moreover, a clean nuclear-electrical-hydrogen energy cycle is suggested to be considered by the policy makers. The benefits and the drawbacks of such a system in the developing countries are discussed. The economics of a prototype system in a rural area is also presented.

WORLD ENERGY REQUIREMENTS

Energy consumption growth is closely linked to population growth, although changes in life styles and efficiency improvements have a substantial influence on the per capita annual consumption. The structure of population and the share between urban and rural populations also affect energy demand.

In a recent study [1], two scenarios were considered for the worldwide future energy demand till the year 2050. The two scenarios assume similar levels of global economic growth: 2-3% per year to 2050, with higher growth in developing countries than in industrialized countries. The first scenario (S1) aims to reduce CO_2 emissions to a sustainable level. This scenario will require a dramatic change in attitudes towards energy use. In our opinion, such a change is far from being achieved.

The second scenario (S2), which is more feasible, assumes that the average energy demand per capita in the developing countries increases threefold, to reach 1.5 toe/a by 2050. For the industrialized group, the energy demand per capita will stabilize at the present level of some *5* toe/a.

Assuming that the world population will reach 10,500 million in 2050, the energy demand will increase from 7.9 Gtoe/a in 1988 to 20.5 Gtoe/a in 2050. Table .1 summarizes the results of the mentioned study. Another study [2] shows that, by considering moderate world economic growth of 3%, the world energy demand by 2020 will be between 13 and 17 Gtoe/a. These results are comparable to those given by the previous study [1].

REGIONAL PERSPECTIVES

Comparative studies [2-4] indicate that 70% of the world population lives at a per capita energy consumption level one-quarter of that of Western Europe and one-sixth of that of the United States. Detailed comparisons show more discrimination. For example, the electrical consumption per year per capita is 100 kWh in Pengaladish, while it is 25,000 in Norway and 6700 in France [3]. Other studies [5] showed that 20% of the world population is expected to consume 75% of the total world energy consumption by the year 2000.

Concerning energy supplies, more than 70% of the world energy is to be supplied by the developing countries by the year 2000 [5]. Contrary to general belief, the industrialized countries' natural resources exceed those for the developing countries. The case of the U.S. is a clear example of disparity [5]. Such a situation indicates that the natural resources in the developing countries are depleted in order to satisfy the developed countries energy needs.

In the developed countries, the possibility of using new energy resources is much more foreseen than in the case of developing countries. For example, during the 1973 oil crisis, many researches were initiated in the industrialized world for oil substitutes, such as coal liquefaction, fast breeder nuclear reactors, etc. Most of these research projects slowed down after securing an oil supply and the end of the crisis.

SPECIFIC CASE WITHIN THE DEVELOPING COUNTRIES

If we consider the energy consumption in Egypt as a specific example of developing country, we can abstract the following results:

(1) The annual electricity consumption per capita in Egypt was 654.2 kWh in 1990 [3] and was increased to about 800 in 1994.

(2) The rate of increase in the per capita consumption in Egypt is 15.4% during the period 1974-1990 [3]. It is obvious that such a rate is very high and could not be maintained. However, we can consider a rate of *5%* per year in the subsequent years after 1990, which is higher than the worldwide projection of 3.3% [1]. Accordingly, we can say that the consumption at the year 2050 will be 17 fold that of 1973 (see Fig. 1). Such consumption

needs a lot of increased power generation in subsequent years.

(3) The only two sources of electricity production in Egypt are fossil fuel thermal power and hydropower generation. Tables 2 give some information concerning power generation in Egypt. It is observed that the ratio between thermal and hydropower generation is about 1:3. No other essential sources are available in the county.

Table 1. World energy demand projections and the concomitant growth in annual CO_2 emissions for scenarios S1 and S2 (adapted from Ref [1])

Item	Scenario	Year		
		1990	**2010**	**2050**
Energy demand (Gtoe/a)	S1	8.0	9.9	12.6
	S2	8.0	12.3	20.5
Electricity share of primary energy (%)	S1	33	35	39
	S2	33	35	40
CO_2 emissions Gt C/a	S1	6.9	7.5	8.6
	S2	6.9	10.8	14.0

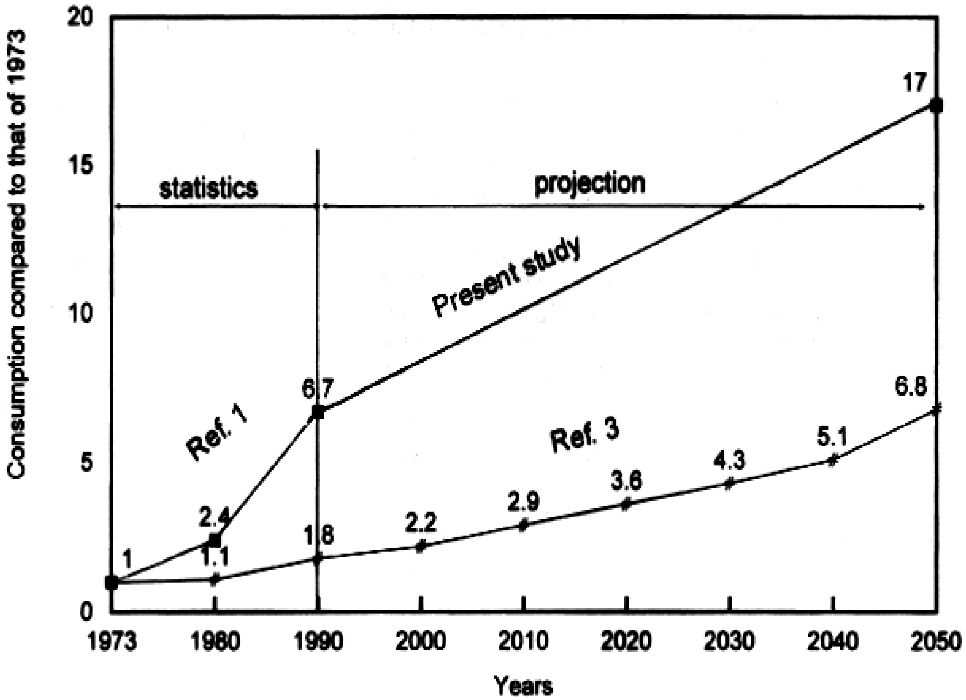

Figure 1. Present and projected annual electricity demand in Egypt and worldwide in the period 1973-2050.

The previous information shows two important facts which are:

(1) The need for tremendous new power generation in Egypt to satisfy the requirements of population growth and to increase the per capita consumption to a reasonable value.

(2) The lack of diverse sources for power generation, since the only two main sources are fossil thermo power and hydropower.

Table 2. Sources of electricity generation in Egypt (1990)

Sources	Number of Station	Nominal capacity (MW)	% of the total produced (1990)
Oil	9	1200	
Thermal Oil + Nat. gas	5	5600	76.7
Coal	1	100	
Hydropower	3	2700	23.3

In this context, it is essential for policy makers to comprehensively assess and compare alternative options, integrating economic, social, health and environmental aspects into the process of preparing the national power generation plan. Energy options, strategy and policy must represent an integrated part of overall socio-economic development.

Among the various alternatives, only nuclear power with the highest practical reliability could have a share with oil, coal and hydropower in the generation of the large amounts of electricity necessary for socio-economic development in developing countries. The technical feasibility of nuclear power in developing countries needs fine assessment. We have to notice that nuclear power represents only 3% of the total electricity production in developing countries and 18% in the industrialized countries.

NUCLEAR ENERGY IN DEVELOPING COUNTRIES

According to previous discussions, studies on energy balances and possible alternatives in developing countries show the importance of considering nuclear energy as one of the main possible and proven alternatives. We have to accept that introducing nuclear energy to developing countries is associated with some restrictions and problems. Many studies [5, 7, and 8] discussed the problems related to the promotion of nuclear power programs in developing countries. We can summarize such problems in the following requirements:

(a) Requirements on the national levels which include: long term policy reasoning for nuclear power, national commitment and legislation, qualified manpower, financial situation and industrial support structure.

(b) Requirements on the international levels including: international agreements, contractual arrangements and channels for technical assistance and technology transfer.

In a recent study [9] concerning the constraints on the Egyptian nuclear program, the author indicated that the claims by Egyptian officials that the country's nuclear progress has been stymied by lack of access to the requisite technology is not true, especially at the present time. The main reasons, according to the author, for the slow progress in the nuclear field in Egypt appears to be more tied to factors such as inadequate political support and an inability to obtain funding. In our opinion, these are the main reasons in most of the developing countries.

However, nuclear power can have a large share in the energy mix proposed to satisfy the growing energy needs in developing countries. One of the main advantages of nuclear power is the low emission of greenhouse gases per unit of electricity produced compared to other energy production sources. For example, fossil fueled chains emit some 50 times more than nuclear energy [10]. Although an expansion of nuclear power alone will not solve the energy/environment problems, these problems cannot be solved without greater use of nuclear power.

NUCLEAR-ELECTRIC-HYDROGEN ENERGY SYSTEM

Development of nuclear energy requires a gaseous vector as a partner for electricity. This partner could well be hydrogen produced by water decomposition as the ultimate gaseous intermediate carrier of energy. A combination of nuclear energy associated with the production of hydrogen gas as an energy carrier could be an excellent solution for remote areas as a clean energy chain. In such a chain, the nuclear power could be a clean source for electricity and also for hydrogen production as a clean energy carrier. This proposed chain may have the following advantages:

(1) Very little pollution, especially greenhouse gas emissions.

(2) Satisfying most, if not all, of the energy needs in any clean, remote and newly developed areas.

(3) Some economical benefits by saving the costs of energy transmission to these remote areas, either as electricity or as fossil fuels.

Hydrogen could be advantageously used as a clean energy carrier for heat supply and transportation purposes. Many studies have been focused on the problems related to the use of hydrogen as a heat supply such as storage and transportation [11, 12] production by electrolytic processes [13, 14], combustion and direct fuel use of hydrogen [15, 16]. We can summarize these research results in the following points:

(1) Hydrogen could be used in its end-use as a non-polluting and versatile fuel or chemical. Also, it has the advantage of being non-fossil. Also, it has the advantage over electricity that it has the fuel nature, which enables direct storability and transmission as a material flow.

(2) The production of hydrogen from nuclear power could be either by electrolysis, or by thermolysis. The efficiency could be as high as 50%, especially in the latter technique. Research in this field is still going on for increasing efficiency and decreasing costs of production.

(3) Storage and transfer of hydrogen could be accomplished with "state-of-the-art" technologies with reasonable cost. Most of these technologies are now in use.

(4) Hydrogen is being used now in many prototype hydrogen automobiles which have been manufactured and tested. The hydrogen motor reaches efficiency close to that of the natural gas motor.

Accordingly, the main advantages of using a nuclear-electric—hydrogen energy chain could be summarized in the following two points:

(1) A pollution free energy chain, especially for greenhouse gases and other air polluting gases.

(2) Saving the cost of long distance transportation costs for energy required to remote areas, either in the shape of electricity (transmission lines) or in the shape of liquid fossil fuel (pipelines, vehicles transportation, etc.).

Taking the above information into consideration, we can propose a specific nuclear-electric-hydrogen system. In the following proposal, the power required for a newly developed area of a population of about half a million inhabitants is given in some detail.

(1) The present electricity consumption in Egypt is around 800 kWh/year. If we consider a three fold increase in the future, an annual consumption of 3000 kWh/capita could be considered reasonable.

(2) If we consider the other direct requirements of the fuel to be nearly the same as the electrical requirements, i.e. 3000 kWh/year/capita, and if this is to be produced with an efficiency of 50%, the required electricity will be 6000 kWh/year/capita to satisfy all other requirements. Therefore, the total annual requirements per capita will be 9000 kWh.

(3) For this proposed consumption, the energy required for half a million inhabitants in any remote area will be a 600 MW(e) nuclear power station (or 2 units of 300 MW(e)) with a power factor of 80%. Such a power station will be enough to satisfy all the energy requirements of this medium sized community.

From the economic point of view, we can consider the following:

(1) In spite of the higher investment costs of nuclear power stations, savings in fuel costs give a comparable power cost for both fossil and nuclear powers (see Table 3).

(2) If the proposed system is to be used in a newly developed remote area (e.g. El-Ewyyenat area at the southwest borders of Egypt), the following advantages could be achieved (a) saving the cost of power transmission to this area either in the shape of electric power using transmission lines or in the shape of liquid oil with pipeline. Saving will include investment costs and maintenance costs; (b) saving of losses in electricity transmission and distribution. For the electrical transmission line, the power loss may reach 15% in long lines [17] as a Maximum loss. The loss percentage figures of electrical networks of the developing countries are considerably higher, up to 20-25% and even higher [17].

Table 3. Comparative cost of power generation base year 1980 (adapted from Ref. [17])

Generation type	Investment cost $/kW installed	Fuel cost C/kWh	Power cost C/kwh
Fossil fuel fired	800-1000	1.0 – 3.0	3-7
Nuclear	1600-2200	2.0 1.0	5-7

CONCLUSIONS

To satisfy the growing electricity demand and the increasing awareness of environmental issues in developing countries, one of the main power generation chains could be the nuclear-electric- hydrogen chain. Such a chain may have the following advantages:

(1) It can cover a part of the national energy requirements in any developing country, especially in the context of developing diverse energy systems.

(2) Such a chain has the potential to contribute significantly to optimized energy system expansion strategies based upon environmental criteria.

(3) Such a chain may have possible economical effects by saving the cost of power transmission to remote areas.

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