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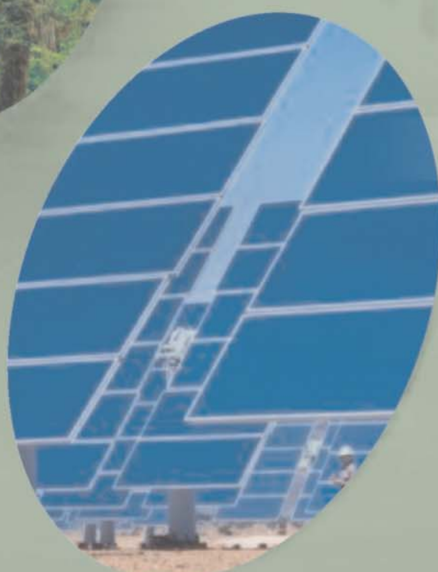

Thematic Issue:

RENEWABLE, CLEAN AND ECONOMICAL ENERGY RESOURCES FOR DEVELOPMENT

Commission on Science and Technology for Sustainable Development in the South

SCIENCE VISION

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RENEWABLE, CLEAN AND ECONOMICAL ENERGY RESOURCES FOR DEVELOPMENT

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Commission on Science and Technology for Sustainable Development in the South

EDITORIAL

COMSATS has been constantly endeavouring towards the socio-economic development, especially of the developing world that has lagged behind – economically, scientifically and industrially. In this regard, COMSATS' efforts have been largely focused on bringing together necessary skills and resources to meet their common challenges relating to various fields of S&T that include Information and Communication Technologies (ICTs), Natural Products, Agriculture Biotechnology, and Climate Change and Environmental Protection.

One such effort is the publication of COMSATS' scientific journal 'Science Vision' since 1995, as an attempt to publicize articles containing thematic material on advances in science and technology that have direct relevance to COMSATS' efforts for sustainable development. The scientific content of this journal is especially aimed to disseminating the findings and suggestions of scientists and researchers, to relevant decision-making bodies and individuals, with the hope that the connected benefits would then trickle down to the public. Naturally, the contributions included in the journal over the years have been a mix of applied research and review articles, as well as those addressing social issues.

Over the period 2002 to 2007, the proceedings of specific national and international workshops and conferences organized by COMSATS on various scientific themes, independently or in collaboration with other organizations, were included in Science Vision. Lists of contents and abstracts from thematic publications of COMSATS were also included in combined issues of Science Vision from 2004 to 2008.

Lately, Vol.15 of this journal (for 2009) had been planned as two thematic issues, devoted primarily to:

i) Environmental Challenges for the Developing World; and
ii) Renewable, Clean and Economical Energy Resources for Development.

However, the strict thematic concept has been kept flexible, in order to accommodate high-quality papers on a variety of topics, offering new openings for the future. Accordingly, the 1st issue of the Volume 15 included three such papers, two of them co-authored by eminent scientists, who are Fellows of the Pakistan Academy of Sciences, and the third one co-authored by a Norwegian scientist.

Like the previous thematic issue, the present (2nd) issue has been bifurcated to offer a convenient reading. The two sections of the journal's present issue are:

i) 'Renewable Energy Technologies: A Panacea for Future Energy Concerns of the Developing Countries', and
ii) 'Specific Renewable Energy Technologies'.

These sections include papers by eminent scientists, notably Dr. Naim Afgan, Professor Emeritus, holding the UNESCO Chair at Lisbon, Portugal; Prof. Dr. Wan Ramli Wan Daud, Director Fuel-Cell Institute, Kuala Lumpur, Malaysia; and Dr. M. Asif, CEng MEI, Glasgow Caledonian University, UK.

The next edition of Science Vision, Volume 16, would not be theme-bound and would cover multiple aspects of S&T and R&D, to accommodate intellectual inputs from various fields.

We hope that policy-makers, scientists, researchers and scholars, especially those from the Centres of Excellence of COMSATS, would feel inclined to send us appropriate contributions for the future issues of the journal.

(Dr. M.M. Qurashi)
Chief Editor - Science Vision

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RENEWABLE, CLEAN AND ECONOMICAL ENERGY RESOURCES FOR DEVELOPMENT

ENERGY CONSERVATION STRATEGIES, WITH SPECIAL REFERENCE TO PAKISTAN

*Abdul Qayyum Kazi**

ABSTRACT

As a result of limited fossil-fuel resources, slow adoption and propagation of renewable energy technologies, spiraling prices of petroleum products and worsening environmental conditions, due to climate change, every country is faced with the need to define new directions with respect to energy consumption, conservation, and energy-options. These aspects are discussed in some detail in this article, which proposes that a multi-pronged strategy, encompassing (i) a change in overall life style, (ii) energy-efficient construction, distribution and utilization, (iii) effective environment-management and energy-discipline, be adopted to control and conserve energy in the increasing energy-demand scenario.

1. ENERGY CONSERVATION

Energy conservation contributes to the security of energy-supply, economic growth and the resolution of problems of fuel-poverty. Controlling transmission-losses is just one aspect of energy conservation. More critical is conservation of energy in the industrial, commercial, transportation and domestic sectors and at the consumer-end.

According to a World Bank Report, the world's lighting market is constituted of 28 per cent household electricity users, while the services and commercial sectors consume 48 per cent, industry 16 per cent and street lighting eight per cent. The report predicts that global lighting saving potential is 40-60 per cent for residences, 25-40 per cent for commercial sectors, 15-25 per cent for industry and 25-30 per cent for street lights, thus indicating the considerable potential for energy-saving in countries where demand for energy far exceeds the energy resources.

It is of interest to mention here that, even in the United States, upto 60 per cent of the energy-content in the supply is wasted through inefficient conversion to electricity at the power-plants and during delivery to the consumers. So, one can imagine the state of energy losses in the Third World countries. For example, power theft and system losses in Pakistan are as high as 25 to 27 per cent in case of 16 power distribution companies, and could be upto 47 per cent in the case of Karachi Electric Supply Company (KESC).

The Third World countries are presently faced with the need to (i) increase their energy production and energy conservation while, at the same time reducing the cost of energy production, (ii) make it affordable for the end-users, and considerably reduce the energy-related pollution. In order to accelerate energy-production to meet the burgeoning demands of various economic and social sectors, the majority of developing countries have been compelled to live with increasing cost of energy-production. Above all, power-losses and theft are rampant, even in the big cities. The transmission and distribution related power-losses often range between 20 to 35 per cent.

A multi-pronged strategy, encompassing a change in consumers' overall life-style, effective environmental management, energy-efficient construction, distribution and utilization, and strict energy-discipline needs to be adopted in order to control and check the increasing energy usage.

2. EFFICIENCY IN OPERATIONS

Reducing the amount of energy and materials used, per unit in the production of goods and services, can contribute both to the alleviation of environmental stress and to greater economic and industrial productivity and competitiveness. The government needs to encourage the environmentally sound use of new and renewable sources of energy as well as dissemination of appropriate technologies suited to the particular circumstances.

Many Third World countries, including Pakistan, import oil (at the cost of a major portion of the export portfolio) to run their transportation vehicles and factories. In Pakistan, 60 per cent of transportation depends on petroleum products, as large numbers of cars, buses, trucks, and other means of transportation on the road need oil to function, which has to be imported at any cost and so we succumb to unannounced oil crises. It is not possible to shift to alternative sources in the immediate future, but conservation measures to improve operational techniques, adhering to vehicle-maintenance standards and improving modes of transport can help to reduce the costs (railroad transport should be preferred to road transport).

ENERCON was established by the Government of Pakistan in 1986, evaluating, planning and implementing energy-conservation programmes at

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the national level, and for training and educating the required human resources in the field, but it has yet to play its role effectively, particularly in the area of creating awareness for saving oil and, thereby, saving the import bill. Following are some options for energy conservation:

2.1 Energy-Saver Lamps

China, India, Sri Lanka, and South Africa have launched programmes to replace incandescent lamps with compact fluorescent lamps (energy savers) having guaranteed life of 8,000 hrs. This has not only reduced energy-bills, but power-consumption has also dropped significantly. Pakistan Electric Power Company (PEPCO) submitted a project proposal to provide 10 million ‘energy-savers’ free of cost to its consumers in a bid to conserve electricity, but the proposal was declined by the Planning Commission of Pakistan, due to high cost. Individual consumers in Pakistan as well as in the above mentioned countries have installed ‘energy-savers’ on their own. However, replacement with energy-savers has a price tag.

Recently, the Government of Bangladesh decided to distribute about 28 million compact fluorescent light (CFL) bulbs under a World Bank project costing US $ 43 million. In the project’s first phase, 5.5 million bulbs are to be handed out to nine million consumers in 27 districts, including Dhaka. The project would save up to 500 mega watts/day. Only about one-third of the residents of Bangladesh have access to electricity. City residents are subjected to a power cut every other hour, while those living in rural areas are deprived of electricity for a much longer duration. The solution is replacing the regular bulb with energy saver bulbs reducing the demand which will ease the chronic electricity shortage.

2.2 Promotion of Clean Fuel Technology

The Hydrocarbon Development Institute of Pakistan (HDIP) introduced Compressed Natural Gas (CNG) in 1989 as an alternative environment-friendly fuel in the transport sector. Within years, the number of refueling stations and CNG-based vehicles increased astronomically. By 2009, over two million vehicles had shifted to CNG use and some 3,116 CNG stations were operating in the country. Research, development and demonstration efforts led to the successful commercialization of CNG in Pakistan, as an environment-friendly, economical and safe road-transport fuel. Introducing CNG for city buses for intra-city urban transport and for auto-rickshaws that are on the roads in towns have helped in reducing pollution and improving air-quality.

With these developments, Pakistan has become the leading country in Asia and the world’s third largest user of CNG. Instead of importing costly motor gasoline that causes air-pollution, locally accessible CNG-units have been fitted in the vehicles, as natural gas is locally available at an affordable price, and infrastructure for transmission and distribution of CNG is already in place. Just for illustration, Table-1 (IANGV, 2001) shows the ranking of Pakistan in world’s population of CNG-based vehicles. There is so much demand for CNG that the government has to introduce rationing in certain parts of the week/year.

Table - 1: World’s Population of CNG-based Vehicles

Country	Natural Gas Vehicles	Refueling Stations	Data Received Month - Year
Argentina	1,807,186	1,851	December 2009
Italy	628,624	730	December 2009
Pakistan	2,300,000	3,116	December 2009
Brazil	1,632,101	1,704	December 2009
USA	110,000	1,300	December 2007

Source: *IANGV, 2001*

Table - 2: Percentage Consumption of Various Forms of Biomass in Pakistan as Source of Energy

Biomass	Percentage (%)
Fuelwood	54
Bagasse	16
Shrubs	06
Cotton Stubs	06
Animal Dung	16
Others	02

The experience gained by Pakistan can be used by other developing countries.

2.3 Increasing Fuelwood Requirements

Notwithstanding the growing demand of energy and scarcity of energy-sources, it is estimated that 80 to 90 per cent of all rural households still meet their fuel requirements (for heating and cooking) from fuelwood and other biomass resources. The percentage of various forms of biomass used as a source of energy in Pakistan is given in Table-2.

Increasing population exerts more pressure on forest resources; depletion of forest resources due to mismanagement is threatening the socio-economic fabric of the mountain people. Many countries have less than 25 per cent forest-cover, which is the world's average. As there is no other immediate energy-source available, it is essential that extensive community reforestation programmes be undertaken. The local people need to be involved in protecting and nurturing the forests. There is a need to develop fuelwood plantation, as a part of the reforestation effort, through a community-based approach. Planting fast-growing species calls for trainings on plantation and tending the young trees. The Government should formulate national action-programmes, to promote and support reforestation and national forest-regeneration, as well as to promote energy-efficient cooking stoves, with a view to achieving sustained provision of the biomass energy to meet the needs of the low-income groups in urban and rural areas.

2.4 Addressing Problems of Energy Consumption in Irrigation System

Many developing countries have established irrigation systems to enhance agriculture and livestock production and for generation of electricity. Pakistan possesses the world's largest continuous irrigation system, spread across an area of about 35 million acres, and encompasses the Indus River and its tributaries. The system includes three large reservoirs (Tarbela, Mangla and Chashma), 23 barrages/ headworks/siphons, 12 inter-river links and 45 canal-commands extending for about 60,800 km. Irrigated agriculture is the backbone of the national economy. However, mismanagement of the irrigation system has rendered the land infertile due to water logging and salinity. Thousands of acres have become useless due to this twin menace. One solution is to dig tubewells to irrigate the land.

According to the Water and Power Development Authority (WAPDA) of Pakistan, there are about 1.1 million sanctioned tubewells, out of which about 0.2 million work on electricity and the remaining 75 per cent run on diesel. Tubewells working on the national grid consume about 2,700 MW of electricity, whereas the remaining take a toll on the country's import bill since they consume large amounts of diesel-fuel. The consumption of electricity for operating these tubewells is almost equal to the total power deficit. Further, there is a huge wastage of power and water during the working of the tubewells. The experts assert that there is a dire need for introducing solar-based tubewells, coupled with water-conservation techniques, like drip and sprinkle irrigation systems. Unavailability of finances and lack of awareness about the availability of renewable energy technologies are also creating hurdles in installing the required machinery. Also, there is little realization of the important training component with regard to functioning and maintenance of the solar-based tubewells.

2.5 Replacing Inefficient Industrial Equipment

Due to an alarming rise in energy costs and load-shedding for several hours a day and 2-3 days a week, all industries in Pakistan are looking for ways to save energy and reduce cost. In this regard, the textile industry particularly has taken the lead. The larger groups have achieved efficiencies that have reduced their energy bills by 40 to 45 per cent, against those who still adhere to inefficient ways. Some industries have gone for the low-cost option, under which inefficient motors and fans are replaced with efficient equipment. M/S Nishat Mills is installing high-tech heat-exchangers to capture heat escaping from its six stenters and recycle it, which could reduce the cost by 25 to 30 per cent. The larger textile groups have exploited every avenue that could save them energy and thus millions of rupees monthly. Other industrial units should follow a similar approach for utilizing energy efficiently.

3. REDUCTION IN ENERGY LOSSES

Energy conservation can be simply defined as "the more efficient and optimum utilization of energy". Efficient utilization of available energy resources is the prime objective of all countries, irrespective of their development phase and industrial advancement. This is because: (i) the need for energy-services continues to increase; and (ii) the available energy resources are not sufficient to meet the present and future requirements. The conventional energy resources are limited and the burdens of high cost of importing fuels, plus energy security and distribution, are alarming. The oil crises since 1973 have compelled different countries to adopt energy-saving measures, including fiscal measures, regulations and quality standards and educating the masses.

Energy conservation can play a central role in global and national energy-strategies. Some of the energy-conservation measures for reducing losses are enlisted below:

a) Technical Measures

- Improvement in transportation system (e.g. oil-saving auto-technologies);
- Planned replacement of old, insufficient equipment;
- Efficiency improvements (e.g. switching away from overwhelming dependence on oil);
- Energy-efficient construction of commercial and residential units;
- Use of energy-efficient technologies in agriculture;
- Cogeneration of heat and electricity in industry;
- Introduction of energy-efficient processes wherever possible.

b) Education and Regulatory Actions

- Changes in social patterns and norms giving conservation a high priority;
- Educating the general public to save energy;
- Research and development;
- Development of energy-pricing policies;
- Fiscal measures (e.g. tax relief, loans and grants);
- Government standards affecting safety, environment and fuel-economy;
- Intelligent legislation.

Energy-conservation in industry is assumed to be more price-sensitive than other sectors, as it requires nearly 20 to 30 years for turn-over of major equipment used. In residential units, energy can be conserved through replacement of incandescent lamps by energy-saving tube-lights or fluorescent lamps, or simply by cutting down the use of lights, fans, T.V. and refrigerators. The developing countries are becoming wealthier and more industrialized; some are now designated as newly industrialized countries, like China, India and Korea. These countries will now be able to afford more efficient technologies already in use by more developed nations. The caution for other countries is to stringently follow the energy-conservation measures.

4. ENERGY EFFICIENCY AND ENERGY-RELATED POLLUTION

At present, the developing countries are faced with the need to increase the energy production in an efficient manner so as to accelerate development and improve the quality of life of their populations, while at the same time reducing both production-costs of energy and energy-related pollution. In this exercise to increase the efficiency and energy-use while also reducing the effect of pollution, priority must clearly be given to promote the use of new and renewable energies. For this purpose, we need to:

- Formulate a national action-programme to promote integrated development of energy-saving and renewable technologies, particularly the ones based on the use of hydro, solar, wind and biomass;
- Promote wide dissemination and commercialization of renewable technologies, through suitable measures, inter alia, fiscal and technological transfer mechanisms;
- Review current energy-supply mixes to determine how the contribution of environmentally sound energy-systems as a whole, particularly new and renewable energy systems, could be increased in an economically, efficient manner, while taking into account the respective country’s unique social, cultural, physical, economic and political characteristics;
- Promote the development of institutional, scientific planning and management capacities, to develop, produce and use increasingly efficient and less polluting forms of energy;
- Carry out information and training programmes directed at administrators, manufacturers and users, in order to promote energy-saving techniques and energy-efficient appliances;
- Address the inefficiencies in power generation, transmission and distribution; this may cost less as compared to the cost of constructing and generating new power units.

5. CONNECTING RENEWABLE ENERGY TO THE NATIONAL GRID

Promoting the renewable energy technologies based on hydro, solar, wind and biomass provides an option for a more sustainable energy in future. Large investments and long lead-times are required to produce alternative fuels on a scale large enough to fill the shortage of oil and gas. The continuous increase in energy-demand calls for a vigorous development of renewable energy resources. It is also required that the energy thus produced is utilized efficiently and distributed properly. The electricity business consists of four key functions, namely: Generation, Transmission, Distribution and Supply. At each stage, connecting renewable energy to the national grid needs different parameters and set of equipment, and a proper environment.

Transmission efficiency can be improved over long distance by using a high-voltage direct-current transmission system and installation of smart meters to foster energy-saving. The grid of the future will thus be able to integrate more energy produced by solar, wind and other renewable energy sources. Since these sources will be widely distributed throughout the country, energy will have to be bundled and distributed more intelligently and the grid would need to accommodate varying energy-generation sources coupled with varying loads. The energy produced from different renewable energy sources may not be utilized immediately and at the place where it is produced, so it has to be (i) stored and (ii) connected with the national grid. “Smart-grid” provides an opportunity to make wise decisions about energy use, and ultimately save energy and money. Further, interconnecting the national grids regionally could provide benefits in terms of supply, security, economy, efficiency and environmental impact.

6. ENERGY-CONSERVATION LITERACY

With limited fossil-fuel resources, slow propagation and adoption of renewable energy technologies and worsening environmental conditions due to climate change, every country now needs to define new directions with respect to energy consumption, conservation, resources and independence. An informed energy-literate public is more likely to be engaged in the decision-making process and will be better equipped to make thoughtful, responsible energy-related decisions, choices and actions.

A number of surveys conducted in the developed countries to access energy-related knowledge, particularly in areas of energy conservation, have indicated that many people have not even heard or read about nuclear energy, renewable energy or hydrogen cars. Even if the technological knowledge is available, the ability and willingness to use that knowledge for practical purpose is absent. Specifically, an energy literate person is one who:

- has a basic understanding of how energy is used in everyday life;
- has an understanding of the impact that energy production and consumption have on all spheres of our environment and society;
- is sensitive to the needs of energy conservation and to the development of alternative energy resources;
- is cognizant of the impact of energy-related decisions and actions on the global communities; and
- strives to make choices and decisions that reflect these attitudes with respect to energy resource development and energy consumption.

An energy literate person would have the desirable characteristics of: (a) a sound knowledge and understanding of energy issues; (b) ability to share a common attitude and; (c) has common energy-related intentions and behaviours.

In the Third World countries, where literacy ranges from as high as 90% to as low as 30%, the energy literacy is minimal. Either at institutional or individual level, energy wastage is high, with little or no consideration for energy saving. Government, educational institutions, non-governmental organizations and the electronic media should play their role in spreading energy literacy/education among policy-makers, planners, administrators, field workers, the student community and the general masses, to highlight:

- Basic scientific energy facts;
- Issues related to energy resources;
- Importance of energy-use for individual and societal functioning;
- Impact of energy-resources development and use on people, society and the environment (for instance coal for energy);
- Energy conservation strategies;
- Impact of import of oil and gas on economy and environment ;
- Global, regional and sub-regional situation and changing attitude towards utilization of energy; and
- Need to advocate change, in order to reduce costs of energy-use in homes, shops, factories and transportation.

Seminars, workshops, panel discussions, field demonstrations, popular articles and, above all, direct mass-contacts should be regular features to reduce the energy consumption, loss and theft, and for utilization of energy for more beneficial uses in industry, agriculture, transport and service sectors, and reducing the environmental hazards.

7. ENERGY MIX

Global oil supplies are increasingly becoming scarce and costly, the GHG emission concerns establish the need to develop cost-effective solar and wind resources for domestic use and to invest in these resources, in collaboration with other advanced countries. However, most of the renewable technologies are still not at par with conventional energy.

Sharing of resources among the countries of a region is gaining importance, for instance supply of excess gas and electricity to Pakistan by Iran, or supply of electricity from Nepal to India are examples of sharing of energy resources. Necessary infrastructure and protocols have to be developed for resource-sharing and trade. Iran and Pakistan signed an accord on June 13, 2010, whereby the former would supply natural gas to Pakistan from 2014; costing $ 7.5 billion. The construction of pipelines is essential, not just to meet the growing energy needs, but also help to create job opportunities, to keep the factories functioning and for social uplift in the rural areas.

Countries have to depend on their own resources for generating energy, but very few countries can meet their entire demand while others resort to import of oil, gas and coal. Eighty four per cent of energy needs of Asia is met using oil and coal. In China, oil accounts for only 24% of the country's energy consumption and coal for 70%. Primary energy-mix is balanced by 56% coal in India and more than 50% in the USA, whereas coal contributes to meeting only about 9% of the energy needs in Pakistan. Pakistan's total energy-consumption (2008-9) of about 37.7 million tons of oil equivalent (MTOE) is met by a mix of gas, oil, coal and LPG sources, with different levels of shares. A major portion of the oil has to be imported to meet the energy need.

The upward trend of the world energy costs would make the economies depending on utilization of gas and hydro resources among the countries of the region a feasible venture. The Association of South East Asian Nations (ASEAN) prepared Vision 2020, in 1997, for long-term energy development and consumption programme among the 10 countries of the region. The concept is to interconnect the natural gas-market centres to the supply point in the region, with the objective of enhancing greater security of energy/natural gas for the ASEAN. Proper joint agreements have to be drafted for the long-term energy development in improving the regular supplies and lowering energy costs.

In Pakistan, short supply of oil/gas to power plants has been aggravated and is causing a 3,000 to 4,000 MW supply demand gap compared to 1,000 MW, in 2006. On the other hand, there are 1,750-2,000 billion tons of coal available in the Thar zone of Sindh, which can be mined and utilized optimally through gasification and clean coal technologies. These technologies are available in Japan and China and need to be applied through bilateral/multilateral agreements. The "black gold" (coal) has to be used to light up millions of houses and run hundreds of factories presently lying idle. The energy mix with increasing percentage of coal can narrow down the demand-supply energy gap.

8. ROLE OF PRIVATE SECTOR IN ADOPTING ENERGY-CONSERVATION MEASURES

The Prime Minister of Pakistan announced a 10-point energy-conservation plan in May 2010 aimed at saving at least 500 MW of electricity on a daily basis. This is to provide some respite to the population from the constant power outages. It was the result of unannounced long spells of load-shedding, compelling the public to come out on the streets and damage the properties of the public sector power companies. The short-fall in energy-supply has greatly damaged the manufacturing sector, agriculture, trade and business activities and growing domestic needs leading to unrest and slowing down economic growth. The salient features of the energy-conservation strategies are as follows:

i. A five-day working week, i.e. two weekly holidays in the public sector;
ii. Closure of all commercial markets by 8pm (special exemption provided to bakeries and pharmacies);
iii. Power to neon signs and billboards to be cut off;
iv. Air-conditioners not to be used before 11am in government offices, and officials below grade 20 not to be permitted to use air-conditioners;
v. There would be a reduction of 300 MW in power supply to Karachi from Pakistan Electric Power Company (PEPCO);
vi. Industrial units to be closed down on alternate days;
vii. Agricultural tubewells not to be provided electricity during peak hours;
viii. Sufficient funds to be provided by the government to retire the 'circular debt';
ix. A 50 per cent reduction in power usage in the

houses of the President, Prime Minister, Provincial Chief Ministers and other public offices;

x. Scheduled load-shedding to be reduced by 33 per cent.

The industry barons, business community and the public sector organizations have serious reservations about the implementation of the above mentioned conservation strategy. Moreover, there is no mechanism available to implement the energy conservation strategies. Prolonged unannounced load-shedding has compelled the general public, shop-keepers and corporate organizations to buy generators and install uninterrupted power supply (UPS) units. This is resulting in additional daily expenditure and foreign exchange drainage in buying these units and oil.

Also, there is little realization on part of the Government and the policy-makers that apart from the loss of billions of dollars in manufacturing and trade due to long hours of load shedding, these prolonged load-shedding hours are also affecting the academic performance and output of the student community and R&D workers, creating social conflicts.

9. RECOMMENDATIONS AND CONCLUSIONS

The energy-conservation strategies stated above are worth considering by the Government, non-government organizations and civil society, to save energy, utilize the natural resources economically and tap the renewable energy sources optimally. Following are the key observations made in this paper:

a) Pakistan should build capacity for energy planning and programme management for energy efficiency and conservation, as well as for the development, introduction and promotion of new and renewable sources of energy.

b) Cleaner coal burning technologies available in China and Japan may be acquired to help in reducing energy cost by improving efficiency and reduction in particulate emissions.

c) Biomass in all its forms will continue to be a major source for cooking, heating be used and be used in small-scale service industries in villages, towns and slums of cities. Any improvement in efficiency in its use will assist in conserving energy and abating environmental degradation.

d) Renewable energy is an abundant resource that can be harnessed in various forms, including solar-thermal, wind energy and biomass. The costs of most commercial forms of renewable energy have declined considerably over the past three decades. Local research, development and demonstration will be necessary to help adapt and popularize these technologies.

e) Cooperation should be sought in identifying and developing economically viable and environmentally sound energy-sources, to promote and conserve the availability of increasing energy-supplies to support industry, agriculture and sustainable development and to provide electricity to millions of houses in rural areas.

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CRITICAL FACTORS IN DETERMINING THE SUCCESS OF RENEWABLE ENERGY PROJECTS IN SOUTH ASIA

Muhammad Pervaz and*
*Md. Lutfar Rahman***

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In South Asia, as in other parts of the world, a number of renewable energy projects were started with a great deal of enthusiasm after the oil shock in the seventies. Many of these collapsed within a few years of their implementation, either due to the declining oil prices or because of the institutional and other reasons. In the backdrop of rising demand for commercial energy, while constrained with shortage in indigenous supply and price volatility of imported fuel coupled with environmental concerns, Renewable Energy (RE) development has become an important issue in energy-management and economic development in all the countries of the region in recent years. Each country has initiated actions to formulate RE policy for the country. Bangladesh, India, Pakistan and Sri Lanka have formulated RE policies exclusively, or as a part of energy policy for renewable energy development. Some of the countries have specific policies in respect of certain RE resources and have made institutional arrangements for promotion of renewables. Most of the national policies focus on providing incentives to promote Renewable Energy Technologies (RETs) by way of subsidy or tax concessions. The use of feed-in-tariff to encourage the sale of electricity through the use of RETs is slowly gaining momentum. It is encouraging that all countries are aware of the importance of development of RETs for energy security and environmental protection. In fact, all the countries in the region have, often with the technical and financial assistance of external agencies, experimented with many renewable energy technologies, devices and methods of dissemination. Among the projects, some have proved to be of outstanding success, while others launched with high expectations could not deliver as anticipated. Even among the unsuccessful projects, some are still languishing as pilot schemes, some have been abandoned. In respect of the successful projects, the countries are attempting to replicate these to the best extent possible.

Keeping in view the above-mentioned facts and the importance of renewable energy, the SAARC Energy Centre under its Technology Transfer Programme conducted a study in 2008 on renewable energy projects in SAARC Member States, by engaging seven country experts and a regional expert. Country experts prepared reports of their respective countries and the regional expert, Prof. T. L. Sankar, from India, synthesized them to prepare the regional report. The study covers brief energy status, status of RE policies, RE potential and overview of RE projects in the past 30 years with special emphasis on identification of factors responsible for successes as well as failures of the projects in the region. The study also attempted to identify the scope of technology-transfer and sharing of best practices in renewable energy projects, especially for rural development. The lessons derived from analyses can contribute greatly to planning and development of renewable energy projects in South Asia. Identification of risk factors will help the policy-makers and developers avoid steps that would lead to failure of similar technology projects contemplated to be built now. The study concludes that success of the renewable projects require appropriate policy initiatives, institutional mechanisms, national and international financial support, capacity-building, selection of appropriate technology and community participation, etc. This paper highlights some selected projects and lessons learnt, in general, from RE initiatives in the region.

A. COUNTRY-WISE SUCCESSFUL PROJECTS

A.1 Bangladesh: Solar Home Systems (SHS)

Grameen Shakti (GS), the sister organization of the pioneering micro-financing institution Grameen Bank, has made commendable contributions in popularizing RE, especially Solar PV. By 2008, GS has installed nearly 210,000 SHS with installed power capacity of 10.0 MWp. It has emerged as the fastest growing SHS-provider, with present installation rate of 8,000 units per month. Countrywide network, patronization of micro-financing institution and innovative payment mechanism have contributed greatly to the success of Grameen Shakti.

A.2 Bhutan: Chendebji at Trongsa Hydel Project

The country has surplus energy in the form of large hydro-electric potential and has plans for extending the grid-supply to all villages. A micro-hydel project, Chendebji, at Trongsa, commissioned in 2005 has

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been selected as a successful project, mainly because of the innovative and efficient management. It is community- owned and community-managed project, with a capacity of 70kW.

A.3 India: Wind Power Generation Programme

Wind power is the most successful of all RE programmes in India. Wind-power generation by private-sector players has grown so rapidly in the last five years that it contributes over 8,757 MW in 2009, which is 70% of the total contribution of renewable energy resources to power generation in India. This has been achieved without any "cash subsidy", as is the case of most RE programmes. The package of incentives to investments in wind-power generation by private sector included fiscal concessions like, accelerated depreciation, tax holidays, customs-duty relief, and liberalized foreign- investment procedures.

A.4 Maldives: Laamu Atoll PV Project

The most successful project in Maldives is the Laamu Atoll PV project, funded by the Japanese government and implemented by a Japanese contractor. Under this project, solar panels of 2.8 kW (4 in number) were installed to produce about 11 kW power to satisfy the needs of a multi-purpose building and its island office. The project was commissioned in 2006 and has been functioning very efficiently. The factors that contributed to the success of the scheme are selection of superior technical design and good implementation. Cost was not an inhibiting factor, as it was taken as a pilot research project.

A.5 Nepal: Rural Energy Development Programme

The most successful renewable energy programme in Nepal is Rural Energy Development Programme (REDP), which promotes decentralized energy-planning at district level. An establishment of community organization at the village-level for the operation of micro-hydel plants is the underpinning component. The programme relies greatly on community participation in planning and management of the district energy-systems. It has been extended to 15 districts, and is funded by the Government of Nepal and United Nations Development Programme (UNDP). The factors which contributed to the success of the REDP programme in Nepal are: conceiving the programme as a part of the overall socio-economic development of geographically and administratively defined area like a district; development of locally available energy- resources, like mini and micro hydel, which is the core of the development efforts; and generous funding by international aid agencies.

A.6 Pakistan: Agha Khan Rural Support Programme (AKRSP)

The AKRSP is a non-profit organization, which was established in 1982 by the Aga Khan Foundation of Pakistan. The main purpose of the AKRSP is to reduce poverty in Northern Pakistan. The Chitral Office of the AKRSP that manages the micro-hydro programme has a staff of about 50 people. The focus is on the communities in the remote areas of the Hindu Kush Mountains that are scattered and isolated and far away from conventional electricity supplies. Traditionally, they have used smoky and unreliable pinewood torches and, more recently, costly kerosene lamps for lighting. Many fast-flowing rivers of the area, however, make it well-suited for the electricity generation through small-scale hydro power plants without constructing large dams. The AKRSP has installed over 180 micro hydro-power units, with capacity of 20 to 75 kW. These projects supply electricity to about 175,000 people.

A.7 Sri Lanka: Energy Services Development/ Renewable Energy for Rural Economic Development

The most successful renewable energy project that spread through Sri Lanka to reach over 100,000 households was the Energy Services Development/ Renewable Energy for Rural Economic Development (ESD/RERED) project, targeting off-grid electricity supply, from solar home systems and micro hydroelectric systems. In the same project, funding was provided to develop an estimated 126 MW of grid-connected power plants (some of which are still under construction), which may be expected to generate an annual average of 419 GWh. Sustained support from the lending agency, project management by private institutions (DFCC Bank and participating credit institutions), matching funds provided by the government through the provincial councils, minimal dependence on "foreign" expertise for the design and implementation of village hydro-system, and quick move-in by an active group of solar industry players to implement the solar-home systems on a commercial scale, are the important factors that made the project a success.

B. CRITICAL SUCCESS FACTORS

The critical factors that have contributed to the success of RE projects in South Asia are:

i) The presence of an approved policy for the renewable energy sector as a whole, or sub-sector policies relating to each technology or sub-sector;
ii) Availability of reliable resource-assessment data;
iii) Well-established, efficient, institutional arrangements for planning and implementation of RE projects/programmes;
iv) Incentives: financial, fiscal, and supportive feed-in tariff systems;
v) Participation of the community in the management and operation;
vi) Project activity identification and prioritization, with reference to the needs of the beneficiaries under the programme /project;
vii) Project financing tied up fully, in advance, for smooth flow of funds for implementation;
viii) Standardization of design, technology and specifications;
ix) Due diligence of the needs, locally available capability, and resources of the area, in advance;
x) Identification of training needs and provision of capacity-building assistance ahead of launching a programme and continuous capacity-augmentation support throughout the life of the project;
xi) Availability of efficient consultancy companies and well-established and reliable contracting firms; and
xii) Availability of knowledge-support from reputed academic or technical institutions.

C. COUNTRY-WISE UNSUCCESSFUL PROJECTS

C.1 Bangladesh: Wind Power

The most unsuccessful RE programme of Bangladesh is its Wind-Power Programme. A few small wind-turbines were installed in the late 90s and early 2000s. They all failed within a short time. This appears to be mainly due to the design-deficiency and use of non-validated wind-energy data.

C.2 Bhutan: Solar Photovoltaic

Efforts in developing solar PV systems in Bhutan have not been successful. It has not been popularized as a scheme to bridge the time-gap between the present situations of non-supply of electricity to a distant date, when there will be grid-connected electricity supply. The failure to appreciate and address the issue of differential cost between PV-based power and Hydel power from large power stations, like Tala Hydel Power project, have led to the consumers showing very little interest or enthusiasm for such projects. The lack of trained manpower to provide technical support for maintenance and repair has also contributed to the failure of the project.

C.3 India: Improved Cooking Systems

An unsuccessful RE project in India is ‘Improved Cooking Systems’ for poor households. The project aimed to reduce the use of firewood and, thus, the adverse health-impact of the indoor pollution. Many enthusiasts of the RE technology might object to the naming of this scheme as a failure.

National Programme on Improved Chulhas (NPIC) has led to the introduction of millions of smokeless chulhas (stoves) to many households in villages. It still is not considered as commercially and convenience-wise preferable over traditional cooking stoves by the users. Modern-tech models did not consider women’s socio-culture aspects and zero cost of traditional chulhas (stoves).

C.4 Maldives: Landfill Gas Project at Thilafushi

In 2004, a project was undertaken with UNDP’s assistance, to explore the possibility of utilizing the gases produced from landfill for power-generation in Thilafushi Island of Maldives. This island receives waste from Male, Villigili and other surrounding tourist resorts. However, on commissioning the project, it was found that the burning of waste in fire produced foul smell, which was spreading in the neighboring islands. The contamination of sea and air triggered strong objections from environmentalists. Poor project-investigation; selection of ineffective technologies; lack of critical evaluation of the appropriateness in selection of project parameters with reference to local conditions; and the failure to visualize the adverse environmental impacts, made the project a non-starter from the beginning.

C.5 Nepal: 10 KW Wind-Turbine at Kagbeni

The first effort to harness the wind-energy potential in Nepal was the installation of a 10 kW wind-turbine in the Kagbeni by Nepal Electricity Authority (NEA), in 1989. The feasibility study of wind-power plants in Mustang and Myagdi districts, in 1985, estimated the wind speed in Kagbeni to be about 10 m/s during the day time. However, improper dimensioning of the turbine vis-à-vis the wind speed at the location resulted in the breakdown of the plant after two months of its installation. Lack of sufficient wind-data and rugged topography resulting in variations in the wind-speeds within a region, has posed a significant challenge in harnessing the wind-energy resource in Nepal.

C.6 Pakistan: Solar Photovoltaic

In the early 1980s, Directorate General of New and Renewable Energy Resources (DGNRER) installed eighteen imported PV-systems, with an installed capacity of nearly 440 kW for village electrification, in different parts of Pakistan. The project was unsuccessful, due to: lack of technical know-how and inadequate follow-up, since the package of project-development did not include capacity-building (both for working team and the beneficiaries); non-sustainable methodology; high cost with no community cost- sharing.

C.7 Sri Lanka: Pattiyapola Project

In Sri Lanka, an example of a failed project is one of the earliest attempts to promote a village-energy system, integrating several resources, to demonstrate that all the village energy-needs could be met from local renewable-energy resources. The project, along with two others, established in Africa and Latin America, was intended to serve as models for the rest of the world. This project, Pattiyapola Rural Energy Centre, was financed and implemented by the UN Agency for Habitation. It must be emphasized that the project, though classified as a failure, as it was unsustainable, had some positive outcomes as well. For example, it was able to demonstrate the workings of new technology to Sri Lankan professionals, enabling them to understand its capabilities and limitations.

D. LESSONS LEARNT

A number of very useful lessons regarding the design and implementation of RE policies, programmes and projects can be learnt from the analyses of the factors leading to the successful and the not-so-successful experiments made and large RE programmes/ projects implemented in South Asian countries. The major lessons learnt are:

i) Each country, small or large, should set up an agency to deal exclusively with RE resources;
ii) The RE development agency should first organize a well-designed and time-bound programme for the scientific assessment of the RE resource-potential of the country;
iii) The agency should draft an appropriate and comprehensive renewable-energy policy for the country and work towards obtaining enthusiastic support and cooperation from all concerned agencies in implementing the policy;
iv) For each RE resource, like wind power, solar and small hydro-power generation, etc., at least one pilot-plant should be established in the public or private sector, using state-of-the-art technology and through reliable contractors;
v) These model projects should be used to induce external development aid agencies, bilateral, multilateral and philanthropic organizations, to take up large programmes of RET applications in each country;
vi) Furthermore, procedures for identifying project-locations, obtaining licenses, permissions and clearances by investors in RE projects should be simplified and quickened;
vii) Fund-flow to RE projects in public and private sector, whether it be grant or loan, should be smooth and timely;
viii) Academic and technical institutions should be incentivized to take up research on all aspects of RETs and its adoption on a wide scale in the respective countries;
ix) Encouragement should be given for setting up efficient energy-consulting organizations and large number of contracting firms to support implementation-efforts in RE sector; and
x) Nation-wide campaigns should be launched to educate civil society on the need and benefits of adopting RE, using equipment and energy-conservation technology.

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HOW TO MAKE RENEWABLE ENERGY ECONOMICAL FOR THE PEOPLE OF PAKISTAN

*Muhammad Ibrahim Khan**

ABSTRACT

Energy is the key to economic success of any country. Pakistan is heavily dependent on imported fossil-fuels for generating electricity from thermal power plants and for mobility of its transportation system. On the other hand, Pakistan is blessed with plenty of renewable energy resources, such as hydro, solar, wind and biomass. The country has one of the best systems of canal-irrigation, electricity transmission-grid and natural-gas distribution in the world. In spite of this, Pakistan is facing acute power-shortage. More than 58,000 villages[†] *are to-date without electricity. The gap between demand and supply in electricity is increasing by 10% every year and this gap in the demand and supply of natural gas is around 0.8Bcfd*[#]*, which will widen in the years to come.*

Using a combination of renewable energy sources within the existing infrastructure can be the best solution for eliminating this power short-fall in the country. Even in remote rural areas, where transmission-lines are not viable, decentralized power-generation using renewable energy technologies could prove to be the best sustainable solution. In this article, the use of Renewable Energy (RE) as a clean and sustainable source that provides a viable economic solution to the developing countries like Pakistan is highlighted.

1. INTRODUCTION

Much has been written and talked about the advantages of renewable energy in its various available forms, such as solar, wind, bio and hydro. The developed countries have set targets to escalate the implementation of these technologies; for example, in 2007 EU leaders agreed to source 20% of their energy needs from RE by 2020, while Germany is set to have 100% of its electricity power through RE by 2050 (EurActiv, 2007). Table-1 shows the individual targets of EU member States based on their respective Gross Domestic Product (GDP). India is investing heavily in renewable energy technologies (RETs), to become a regional market leader having 20% of the country's energy requirements met from RE by 2020 (Merinews, 2007). Pakistan, on the other hand, has set the target to have a 10% share of renewable energy in its national grid by 2015 (AEDB & GTZ, 2005), which seems difficult to achieve with the present pace of implementation. Due to acute power-shortage, Pakistan's economic development has been badly affected and it is losing US$ 3.34 billion per annum. The cumulative effect of the energy crises on the national economy is estimated at upward of 2% of the GDP during 2009-10 alone (GOP, 2010). According to the World Bank (Trading Economics, 2010), Pakistan's GDP is worth 167 billion dollars. Today, energy is the major issue that can destabilize any political structure. In order to avoid worsening law-and-order situation, due to longer periods of load-shedding and keeping the Kalabagh Dam on the back burner (due to political reasons) and the fact that any major dam would take seven to 10 years to complete, the policy-makers of Pakistan have to consider sustainable, short-term economical solutions in order to cater to the energy needs of the country. This goal can only be achieved if effective policies w.r.t energy conservation (EC) and RETs are adopted.

1.1 Approach

a. For any developing country, the upfront cost of any renewable energy technology (RET) is high. Therefore, the approach should be to focus on conserving energy before implementing any renewable energy project. It is a proven fact that energy-saving could be much more effective and cheaper than building conventional power-plants. Saving 1MW of electrical energy means that one would need to produce 1.3MW of electricity less to meet the demand. In short, energy conservation *is a pre-requisite* for implementing RETs.
b. Transformation of power-production to decentralized, clean & affordable renewable energy forms: Pakistan's major dams are located in the North, and most of the thermal power-plants are situated in the South, while major demand of electricity is in the centre, due to which there are considerable line losses. Therefore, Pakistan should *set up RE farms near areas of high demand*, which will also help to prevent the pilferage of electricity.

2. MAJOR ENERGY-CONSERVATION MEASURES

Major energy-conservation technologies must be used that are viable and can dramatically reduce the

† Energy Situation in Pakistan and Global Prospective, Presentation by Mr. Sabir Ali Bhatti, Consultant NESPAK, Lahore, May 2008.
\# Presentation by Chief Engineer SNGPL, Mr. Ijaz-Ur- Rehman at Serena Hotel, Faisalabad, on 30 December, 2009.

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Table - 1: Renewable Energy Targets Set by EU Member States [EurActive, 2007]

Member State	Share of renewable energy in 2005	Share required by 2020
Austria	23.30%	34%
Belgium	2.20%	13%
Bulgaria	9.40%	16%
Cyprus	2.90%	13%
Czech Republic	6.10%	13%
Denmark	17%	30%
Estonia	18%	25%
Finland	28.50%	38%
France	10.30%	23%
Germany	5.80%	18%
Greece	6.90%	18%
Hungary	4.30%	13%
Ireland	3.10%	16%
Italy	5.20%	17%
Latvia	32.60%	40%
Lithuania	15%	23%
Luxembourg	0.90%	11%
Malta	0%	10%
The Netherlands	2.40%	14%
Poland	7.20%	15%
Portugal	20.50%	31%
Romania	17.80%	24%
Slovak Republic	6.70%	14%
Slovenia	16%	25%
Spain	8.70%	20%
Sweden	39.80%	49%
United Kingdom	1.30%	15%

gap between demand and supply of electricity and gas. These technologies include the following:

2.1 Durable Induction Lamps

The lighting load of street lights, flood and security lights, and that of production-halls can be significantly reduced if the existing mercury lamps, as well as sodium and metal halide lamps are replaced with the latest durable induction electrode-less lamps (Figure-1). This will bring a 50 to 70% savings in electricity, depending on the height of light pole and lighting requirements. The life of these lamps is 100,000 hours, while conventional lamps last about 20,000 hours. This means that labour and maintenance cost can also be saved. By replacing 5 million 250W conventional street lights (which in fact consume about 300W each, with choke losses) with durable induction lamps of 80W for 20-ft pole and further 5 million street lights with 120W for 30-ft pole, an average 2,000MW of grid power can be saved. The saved amount is equivalent to the construction-cost of one major water-reservoir and would eliminate half of the prevailing load-shedding in Pakistan.

Figure - 1: Energy Efficient Durable Induction Lamp in Round Shape

Figure - 2: SMD Tube Light

2.2 Replacing Conventional Tube Lights and Bulbs with their LED Equivalents

LED is the future domestic, industrial and commercial lighting-source, which can save more than 70% of electricity. The Surface-Mounted Diode-based (SMD) tube lights (Figure-2) are better and feasible for industrial sectors, such as spinning or weaving mills, where 2,000 to 3,000 tube lights are used 24 hrs/7 days. The pay-back period for such industrial sector is around one year. The cost analysis of good-quality LED tube light is given in Table-2.

Considering Pakistan's climatic conditions, one should be careful in selecting the right quality and source of LED lights, otherwise the financer will lose the investment, as these tube-rods may fail due to high temperature and grid fluctuations. M/S Sustainable Renewable Solutions (SRS Pvt. Ltd.) based in Lahore, Pakistan, introduced these lights few years ago and found the problems of fusing individual LED due to bad soldering, failure of their power-supply resulting from moisture or hot environment, reducing luxes with passage of time, and humming noise in its drivers.

Through continuous R&D and in cooperation with the foreign principal, the team at SRS has eliminated these problems and now the next generation of SMD tube lights has been introduced, which are being used in many factories of Pakistan. These tubelights are operating for quite some time now without any problem.

Table - 2: Cost-Benefit Analysis of 100 LED Tube Lights

	Existing 40W Tube lights	**15-watt LED Tube light Option**
Number of lights	100	100
Lux from 6ft	66	161
Actual Power consumed by each light (Watt)	73.92	15
Present Wholesale price of each light (Rs)	300	3,600
Total price of lights (Rs)	30,000	360,000
Working hours	24	24
Life of light (hrs)	8,000	50,000
Current electricity rate (Rs)	5.5	5.5
Annual Replacement cost (Rs)	38,054	0
Total power consumed (Watt)	7,392	1,500
Units consumed per month	5,322	1,080
Electric cost per month (Rs)	29,272	5,940
Annual electric cost @ present rate	351,268	71,280
Annual Saving with Replacement Cost	**Nil**	**Rs.279,988**
Saving during life time (Rs)	Nil	Rs.1,749,925
Payback period (yrs)	Nil	1.28 or 14 months

Note: Actual readings have been taken of power consumed by (i) 40W Philips Conventional Tube lights, with magnetic choke & starter installed at SRS display centre, and (ii) 342 LED 15W tube lights.

Figure - 3: Split Air Conditioners Fitted with Solar AC Kit at the Factory Office in Faisalabad

2.3 Installation of VFD or VSD on Heavy Motors

It is a proven fact that proper installation of variable frequency drives (VFD) on compressors, pumps and motors can conserve 20 to 40% of power. Usually, the pay-back time of VFD project is less than a year. These are the observations made by SRS & Cutes Corp. of Taiwan, through their Pakistani representatives who installed their variable speed drives (VSDs) in various textile mills.

2.4 Reducing Fan & Air Conditioners' Load by Solar Hybrid Kit

During summer season the duration of load-shedding increases, because of the increasing demand and heavy use of air conditioners and fans. SRS has developed a solar-thermal collector with electronic AC kit (Figure-3), which can bring 20 to 40% saving in air conditioners. These figures are based on studies conducted at SRS Laboratory. If 3.5 million air conditioners are fitted with Solar Hybrid AC Kit, and supposing an average of 30% of electric savings is achieved through this kit, then the resultant grid-power saving will be to the tune of 2,100 MW during hot season.

Similarly, Pakistan's fan industry should concentrate on manufacturing energy-efficient fans, rather than focusing on their cosmetics. Most of our ceiling fans consume more than 100W, while in the United States efficient fans made of plastic only consume 30W.

2.5 Saving Natural Gas by using Gas-Saving Kits

Since the cost of fossil-fuel based energy has gone up, considerably, measures need to be taken to conserve energy and shift focus on Renewable Energy Technologies (RETs).

- SRS has developed a mechanical electric gas-saving kit, which if installed on gas geysers can pre-heat the cold water and electronically shut down the gas on pre-set times. It is estimated that 33 to 60% of natural gas can be saved by using this kit. The cost of the kit is about Rs. 5,500, while its baffle cone can be purchased for nearly PkR.600/-
- A policy should be made for all the manufacturers of electrical and gas appliances to develop such energy-saving products. Also, there should be some monitoring system for implementation of such a policy.

Going parallel with implementation of energy conservation technologies and practices, one should look for sustainable economical solutions provided by renewable energy technologies. For developing countries like Pakistan, the focus should be on the use of the following technologies, systems and appliances:

3. SOLAR HEAT/POWER

Solar Energy can be further sub-divided into Solar Thermal and Solar Photovoltaic (PV) systems.

3.1 Solar Thermal System

The direct conversion of infra-red radiation of the solar spectrum into heat energy is called the 'Solar Thermal process'.

3.2 Solar Water Heater (SWH)

Solar water heater is the best example of viable solar thermal technology. The conventional gas geysers are 70% inefficient[†], which viciously waste the natural gas resources. Pakistan is not left with enough gas-reserves to meet the country's energy demand. Solar water heaters can replace gas-geysers to prevent further wastage of country's natural resources. The habit of lavishly using hot water, coupled with other local conditions and problems in the product, such as leakage, hinders the widespread adoption of solar water heaters. Therefore, R&D is required for proper product-design of solar water heater, adaptable to local conditions, while gas burners can be used as a

† Energy Situation in Pakistan and Global Prospective, Presentation by Mr. Sabir Ali Bhatti, Consultant NESPAK, Lahore, May 2008.

backup. According to Alternative Energy Development Board (AEDB), 3,500 solar water heaters have been installed throughout Pakistan. There are 2 million consumers of Sui Northern Gas Pipelines Limited of Pakistan (Qamar-uz-Zaman Ch., et al., 2009), who have installed gas-geysers. If 5% of these are replaced with solar water heaters in the next three years, then there will be a positive impact on natural gas usage and on lowering the carbon foot-print.

3.3 Solar Process Heating

Hot water is used in many industries. The vacuum tube technology is the most efficient one provided the requirement for hot water is below 100°C. Tanneries, textile, pharmaceutical and food industries can save millions of rupees by installing large solar heating systems. If investment is an issue for adopting large solar systems, then at least partial load should be shifted to solar-thermal systems, which will resultantly help save natural gas and reduce GHG emissions. Pakistan's first large solar system, at Saddiq Leather Works on Sheikhupura Road (near Lahore), is delivering 40,000 litres of hot water daily. There is a need to study this system for annual output and cost benefits.

3.4 Solar-Thermal Power Plant

So far, no mega Solar-thermal power plant (STPP) has been installed in Pakistan. The National Electric Power Regulatory Authority (NEPRA) of Pakistan has determined the price of one unit of electricity to be US 18 cents for rental power plants, which makes the STPP a viable solution. It is recommended to install plants with capacity of 5MW to 50MW of combined-cycle STPP near Choulistan, Multan, Bhakkar as well as in South Punjab, where water is available and grid transmission lines are within 40 kilometres. It is recommended that a 5MW system be installed initially, because it is easy to manage and the initial problems, typical in such pilot-projects, can be indigenously rectified. This will build the technical capacity of the people and enable them to run large systems of 50 MW capacity.

STPPs can also be developed as a hybrid system, using natural gas or coal-fired turbines. The estimated cost of an American parabolic-trough technology is around US$ 3.45 million/MW. International financing can be arranged for such a project, provided the Government of Pakistan acts as a guarantor.

3.5 Solar PV System

The conversion of solar light into DC current is carried out by photovoltaic cells. A lot of research in this area has resulted in the development of some new efficient technologies. China has set up many large plants for the production of PV modules, due to which the cost of PV panels has been reduced from US$ 4/Wp to less than US$ 2/Wp in the last few years. The upfront cost of solar system is still higher for domestic users. With four hours back-up time, the cost of a solar PV system is around Rs.500/Wp. With some support from the Government and financial institutions, the Chinese PV technology can be introduced in the domestic market. If one million homes install 2 kW solar PV systems, then 2,000 MWp of grid power can be saved, which is half the electricity gap between demand and supply.

3.6 Thin-Film Cylindrical PV Modules

These modules are suitable for commercial or industrial units that have large roof-tops (Figure-4). It produces more power-per-unit-area and is easy to install. The roof is coated with white heat-resistant material, which can not only reduce the heating load of the building, but also reflect the solar radiation that can be absorbed by the thin-film cylindrical PV panels for generating DC current. This technology is successfully working at Masdar City, Abu Dubai, UAE, and in many parts of the Untied States and Europe. .

3.7 High-Concentration Photovoltaic (HCPV) Modules

For setting up large PV farms on expensive land, the high-concentration PV technology (HCPV) can be useful, as it requires 33% less land than conventional PV systems. In this module, light is concentrated through lens onto a single PV cell, due to which highest efficiency (29%) of PV module can be achieved (Figure-5).

For remote areas, where transmission and distribution of grid lines is not viable, small solar PV system is ideal to uplift the living standards of villagers.

There are still many villages without grid power in Pakistan. Many villages only have electricity poles but no electricity. These villages can be electrified with PV system by establishing a task force, consisting of NGOs, PV system suppliers, installers, donors and financial institutions.

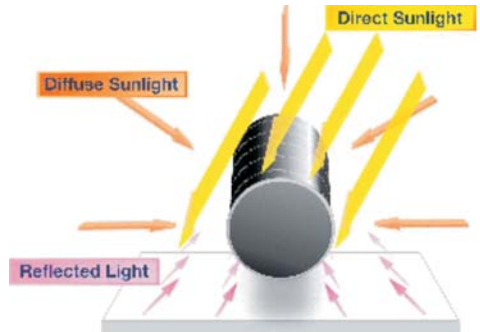

Figure - 4: Thin Film Cylindrical PV Module

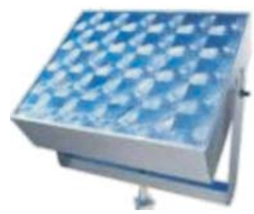

Figure - 5: High-Concentration PV Module

4. WIND POWER

Pakistan has an excellent wind corridor, starting from Keti Bandar that goes into Rajhistani Indian border. Such corridors are also present in Northern Areas and at Kalar Kahar, where 20 to 100kW wind turbines can be installed. Based on the wind data of Kalar Kahar, showing 293W/m^2 wind density at 50m, the site falls in marginal wind class-2 (Qamar-uz-Zaman Ch., et al., 2009). India is successfully running more than 900 wind turbines on the tail of this wind corridor and had installed a total of 11,807 MW of wind power capacity by March 2010 (INWEA, 2010), while Pakistan has installed only four 1.5 MW wind turbines. AEDB has issued more than 100 Letters of Intent (LOI) to different companies, for each of them to install 50 MW of wind farms. Out of these, only three have been issued Terms of Reference (TOR). There is a need to investigate the major hurdles, due to which investors are reluctant to initiate such projects in Pakistan.

It is to be kept in mind that generating power from wind is cheaper than solar energy. In contrast to solar energy, wind is also available during night. Small domestic wind turbine is a mature technology. For a city like Karachi, an ideal solution is a hybrid system of solar and wind energy. An affordable solution for city government is to install solar-wind hybrid street lights on the main roads. Citizens living in localities near the sea should be encouraged to install 1 to 3 kW wind turbines.

5. GENERATING ENERGY FROM WASTES

The organic waste can be converted into methane gas through biogas fermentation plant or syn-gas through gasification plant. PCRET has installed more than 4,000 biogas units of 5m^3, 7m^3 and 10m^3 capacities throughout Pakistan, mainly for cooking purposes (PCRET, 2010). According to PCRET, 19.125 million m^3 biogas can be produced daily by anaerobic fermentation of dung through installation of about 3.825 million family-size biogas plants, which could meet the cooking needs of about 50 million people (PCRET, 2010). Today, R&D is required to find ways for cheap and efficient digesters and the way to purify methane, in order to run large electric generators. Biogas as a power source is much cheaper than solar or wind power and, in the near future with proper policy and design, it can become a major source for pumping water, cooking food and supplying electricity in villages.

At present, the CNG stations in the country are subject to two to three days of load-shedding of natural gas. There is a need to develop large biogas plants for feeding gas to CNG stations on highways.

There is a need to develop a policy to set up a biogas plant along with treatment plant on every large drain, like the Hidyara Drain near Walton (Lahore), to get clean water for agriculture and useful gas for cooking or for running generators. This plant can be connected to the natural gas distribution network.

6. HYDRO POWER

Large water-turbines are the cheapest means for producing electricity. Due to the country's internal politics and divergent views on water distribution, population displacement, royalty fee and other issues, main hydro-power projects could not take off. Such projects require five to seven years for completion. Another problem, which policy makers are unable to address, is the continued availability of water in rivers due to the climate change. It is recommended to give attention to mini and micro-hydro turbines, wherever the site permits supply of local power. These turbines require small head to operate. Some 538 mini/micro turbines have been installed by PCRET (PCRET, 2010). The Aga Khan Foundation and other NGOs are also active in installing these turbines in Northern Areas of Pakistan.

7. MAJOR CONSTRAINTS

Despite the readily available renewable energy resources and presence of good infrastructure, the present share of renewable energy is less than 1% in the total energy generation of Pakistan. Following are some of the constraints/hinderences to the adoption of renewable energy technologies in the country:

a. *Lack of Political Will:* Many countries of the world have formulated policies to use RETs for their national electricity generation and have set a target of 5-10 years to implement these policies. In Pakistan, such a will seems lacking and a serious effort is needed to actively achieve these targets.
b. *Cost:* The upfront cost of all renewable technologies is high, due to which their widespread adoption among the general public becomes a hurdle. With the increase in electricity, diesel and natural gas tariffs, and reduction in technology costs, many of the RE technologies are now commercially feasible. The availability of a large number of Chinese PV products in the Pakistani markets have resulted in the lowering of prices of PV panels to half in nearly three-year time. If this trend continues, then PV rate is expected to come down to 1 US $ / Wp, which is almost the same as of a coal power plant (Bundanoon, W. M., 2009).
c. *Absence of Subsidies:* In Europe, USA, Japan, and South Korea, and even in India, renewable energies are subsidized just like health and education sectors. Unfortunately, except for bio-gas, the Government of Pakistan gives no subsidy on the adoption of RETs. In accordance with the agreement with IMF, the government has to remove subsidy on electricity, due to which the tariff rates increase after every six months. However, there is no restriction to give subsidy to the clients adopting renewable energies, therefore the government should consider implementing a subsidized action-plan to promote renewable technologies.
d. *Lack of Professionals:* There are very few professionals of renewable energy technologies, who have good practical experience and know-how of the local conditions. The technical colleges and universities do not offer major courses in these technologies to educate people. It is recommended to develop criteria whereby only the companies that have trained employees and staff are authorized to design and install RE technologies. REAP (Renewable & Alternative Energy Association of Pakistan) should be given mandate by the Government to issue such certification programme.
e. *Social Issues:* Many of the renewable energy projects initiated by the Government of Pakistan or NGOs in the past failed because only the financial and technical aspects were accounted for, while social aspects had been ignored. In most parts of the country, the social system of feudalism that exists needs to be taken into account while planning any development activity in the area.
f. *Maintenance and After-Sales Service:* Another major factor, due to which renewable energy projects have failed in the past, is the lack of maintenance and poor after-sales service by the installers. It is, therefore, necessary to train the local people, so that they can maintain and repair minor faults and keep the systems operational. It is also recommended to install a system that is durable and requires minimum maintenance.
g. *Proven Technology under Local Conditions:* Pakistan has harsh climatic conditions. Also, the grid supply usually has spikes, dips and surges. The technologies that are successful in Europe and other countries fail in Pakistan, due to one or more of the reasons mentioned earlier. Thus, there is a need to customize and upgrade the renewable energy technologies according to the local conditions. Every solution-provider should offer the proven technologies, rather than experimenting at client's cost.
h *Investors' Risk:* Investors in large RE projects can face steep and unpredictable changes in the value of their assets due to rapid technological changes – changes that are much larger than the expected

physical life of their assets and, thus, can lower their assets' value before the end of their useful life. This issue can be addressed by basing the value of assets on the principle of accelerated depreciation and also by taking necessary measures to help encourage increased investment in RETs.

8. CONCLUSIONS

The strategy to make renewable energy available, at affordable and low cost, must take into account the following on fast-track basis:

i. Creating a think tank of renewable-energy experts and economists empowered to implement new policies. One of the important objectives of the think tank should be to examine the treatment of capital expenses in RE sector, with particular emphasis on the need to introduce accelerated depreciation and tax-breaks to help encourage new investments in alternative sources of power.
ii. Investing in R&D for developing low-cost and efficient renewable energy products.
iii. Creating public awareness and undertaking pilot-projects throughout the country, supervised by professionals.
iv. Attracting direct investment through subsidies, incentives and better feed-in tariff policy, which would result in early commercialization of emerging RETs.
v. Developing a highly skilled and capable human resource base, by educating and training engineers, architects, and technical personnel.
vi. The Government should adopt the "carrot and stick" approach, in order to give tax-breaks to users of RETs and to increase taxes on industries or power houses that pollute the environment.
vii A bill should be passed to define the different conditions/parameters for using varied RETs for 5 to 10 years so that financiers of RE projects are enable to recover their investments through depreciation deductions.

Several energy conservation measures & renewable energy technologies are discussed in this paper. *If only three technologies, namely Induction Durable lamps, solar hybrid air conditioning kit and solar PV systems, are focused upon, as described,* Pakistan can get a net benefit of 6,000MW, which provides for sufficient energy to not have load-shedding. The only thing needed to ensure this, is 'political will' and fair implementation of recommended policies by think tanks, comprising energy professionals.

Pakistan needs to move forward on the adoption of renewable energy technologies in order to meet its energy needs for effective socio-economic development.

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REVIEW OF SUSTAINABLE ENERGY DEVELOPMENT

*Naim H. Afgan**

ABSTRACT

This paper presents an overview of the sustainable energy development and aims to emphasize the important aspects of the relevant activity. A short introduction to the present energy outlook with a survey of available data is presented. Also, special attention has been given to the definition of sustainability and its generic meaning. In this respect, particular attention is given to the discussion on different aspects of sustainability in the present world scenario. In order to present an engineering approach to sustainable development, a review has been made of sustainability criteria as they are of importance to future energy-related products.

The main emphasis of this paper is on reviewing the potential development in energy-engineering that may lead to sustainable energy development. Seven major areas having relevance to sustainable energy development and with specific problems are listed. These are: energy resources development; efficiency assessment; clean air technologies; information technologies; new and renewable energy resources; environment capacity; and mitigation of nuclear power threat to the environment.

A sound education system is an important milestone for any nation to achieve economic development. In this respect, special focus was needed to consolidate the concepts of sustainable development education system. Distance-learning education system is envisaged as the potential option for dissemination of knowledge and information on new energy technologies.

1. INTRODUCTION

Energy resources have always played an important role in the development of a society [Marchetti C,1995]. Since the Industrial Revolution, energy has been a driving force for the development of civilization. Technological development, consumption of energy and the increase in the world-population, are interrelated. The Industrial Revolution in the nineteenth century, resulted in a drastic increase in both population of the world and its consumption of goods and services [Marchetti C., 1979].

Boltzmann, one of the fathers of modern physical chemistry, wrote in 1896 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 cold Earth [Boltzmann, 1896]. Energy and matter constitute Earth's natural capital and many suggest that this natural capital is being rapidly degraded. The contemporary economic theory does not adequately account for the significance of natural capital in techno-economic production.

Our use of natural material resources is associated with no loss of matter as such. Basically, all Earth's matter remains with it but in a form in which it cannot be used easily. The quality or useful part of a given amount of energy is invariably degraded due to use, thus resulting in increased entropy.

The industrial development was based on the thinking that energy-resources are unlimited and there are no connected repercussions that might affect human welfare/development. It has been recognized that the pattern of the energy-resource usage has been strongly dependent on the technology-development. In this respect, it is instructive to observe [Marchetti C., 1991] the change in the consumption of different resources throughout the history of energy-consumption. Worldwide use of primary energy-sources, since 1850, is shown schematically in Figure-1 [Marchetti C. 1991]. 'F' indicates the fraction of the market taken by each primary-energy source at a given time. It could be noticed that two factors have had an effect on 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 using a certain energy resource is developed under constraint due to the total level of energy-resources consumption and reflects the existing social structure, both in numbers and diversity [Afgan, N.H., et al, 2009]. The world energy-consumption from 1850 to 1992 is shown graphically in Figure-2 [Farinelli, U., 1994].

Looking at the present consumption-pattern of energy- resources, it can be noticed that oil is the major contributor, supplying about 40% of the total energy share. Other major contributor are, coal and natural gas, supplying around 30 and 20%, respectively, of the energy, while nuclear energy contributes about 6.5%. This means that the current fossil-fuel supply is about 90 % of the total present energy-use. During the last several decades, our civilization has witnessed changes that are questioning our long- term prospects. Fossil-fuels (non-recyclable) are exhaustible natural resources. In this respect, it is of common interest to learn how long

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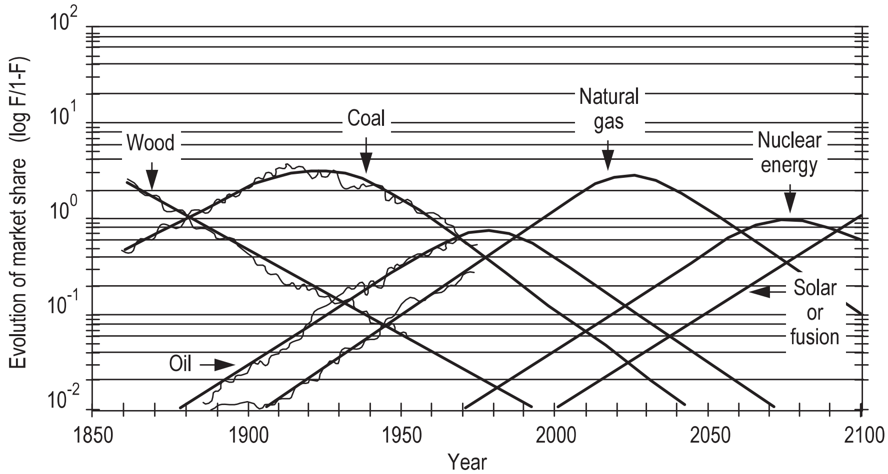

Figure - 1: Market Penetration of Primary Energy Sources

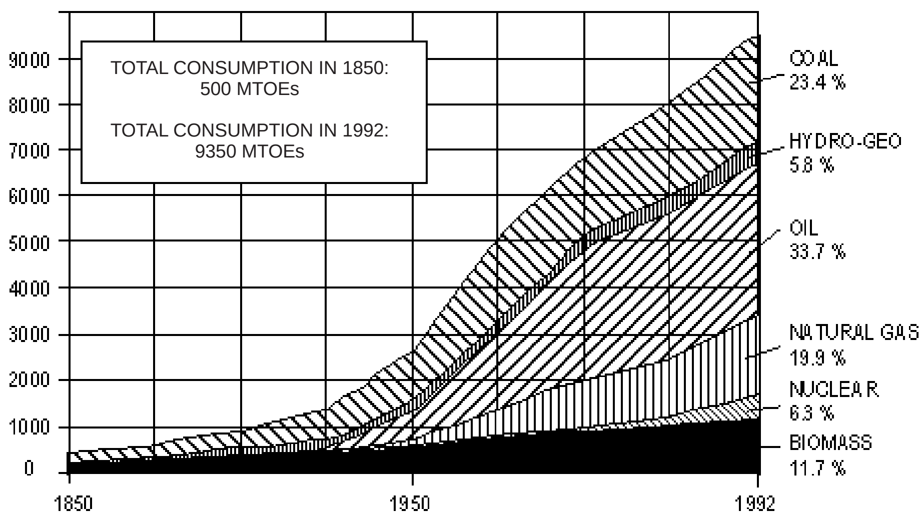

Figure - 2: World Energy-Consumption

will the fossil-fuel resources remain available, as so far they are the main source of energy for our civilization. This question has attracted the attention of a number of distinguished authorities that are trying to forecast the future energy scenario. The Report of the Club of Rome 'Limits to Growth', published in 1972 [Medows D. et. al, 1972], was among the first studies that pointed to the finite nature of fossil-fuels. After the first and second global energy crises, the world community at large has become aware of the expected physical exhaustion of fossil-fuels. For now, the amount of fuel available is dependent on the cost involved. For oil, it was estimated that proved amount of reserves has leveled off at 2.2 trillion barrels produced under $ 20 per barrel over the past 20 years. Over the last 150 years, we have already consumed one-third of that amount or (about 700 billion barrels) and are left with only 1.5 trillion barrels. If compared with the present consumption rate, it means that oil is now available only for the next 40 years. Figure-3 shows the ratio of discovered resources to the yearly consumption of the fossil-fuels over the period 1945 to 1990.

From this figure it can be noted that in 1994 coal was available for the next 250 years and gas for the next 50 years. Also, it is evident that 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 estimated for the depletion of the available non-renewable energy sources.

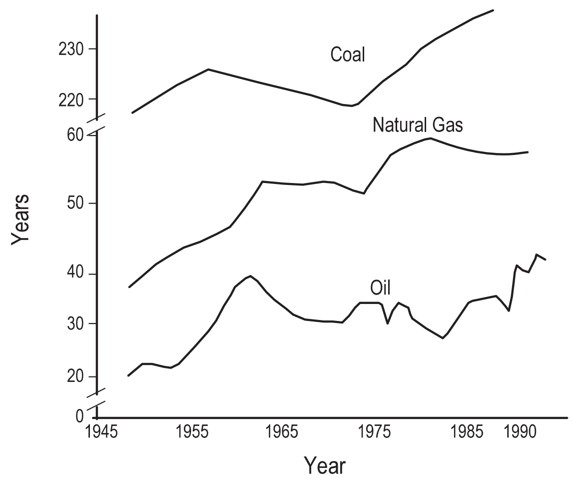

Figure - 3: Residual Life Forecast of Energy Resources

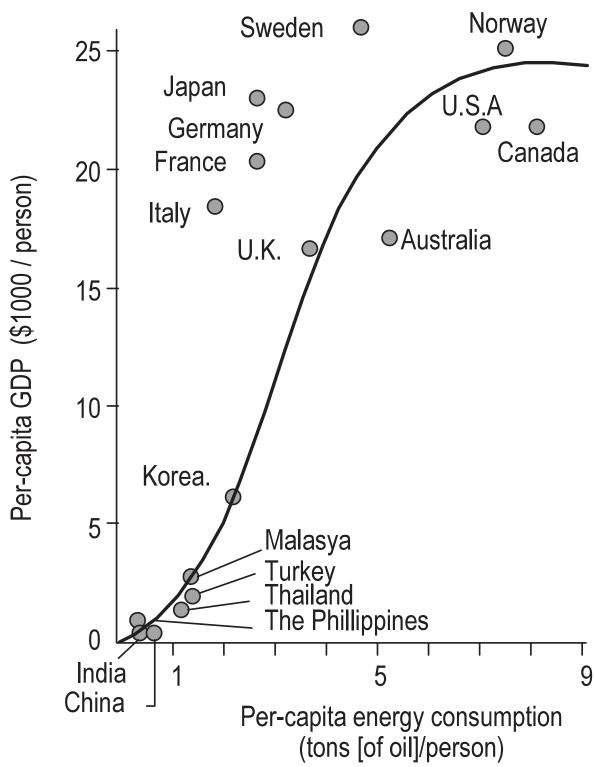

Figure - 4: Economic Growth and Energy-Consumption

It is known that energy-consumption is dependent on two main parameters, namely, 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 (GDP) and energy consumption per capita. Figure-4 shows the relationship between economic growth and energy-consumption for a number of countries, in 1990 [Keatiny M., 1993].

A number of scenarios are used to predict trends for the world's economic development. With the assumption that the recent trend in the economic development will last 50 years, and the demographic

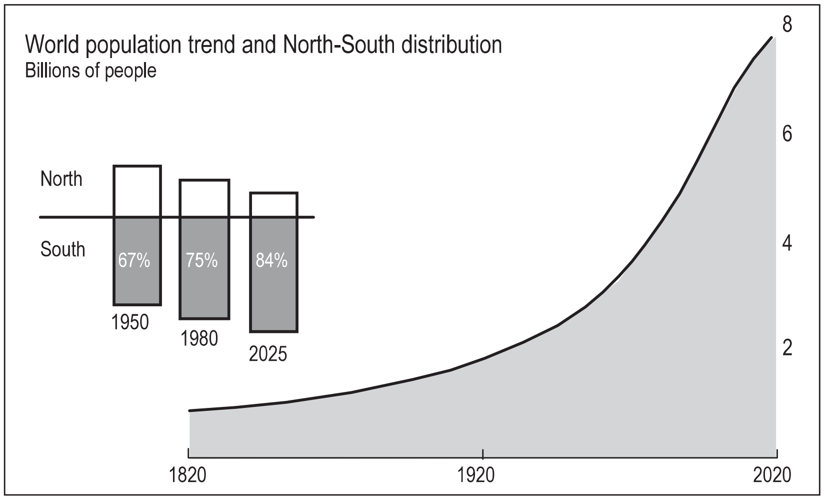

Figure - 5: Demographic Forecast of Human Population

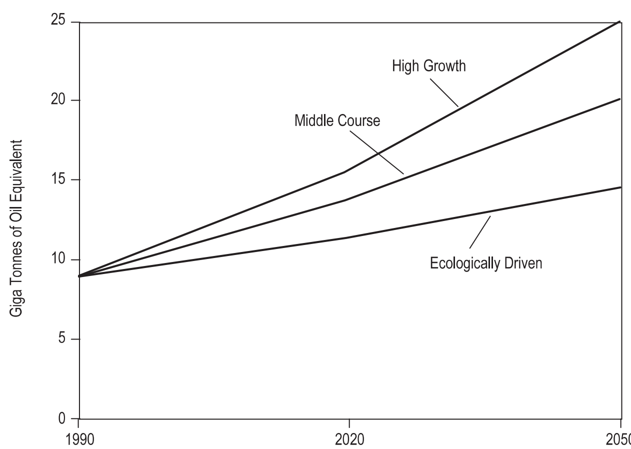

Figure - 6: Future Energy-Consumption Forecast

forecast of the growing human population is as shown in Figure-5 [WEC Message for 1997], the future energy-consumption could be estimated as shown in Figure-6.

Comparing the availability of energy resources at different points of time in history, it can easily be foreseen that the depletion of the energy resources is an imminent process, repercussions of which our civilization will have to face in the near future. Nevertheless, whatever the level of accuracy of our prediction methods and models is, it is obvious that any inaccuracy in our calculations may affect only the time- scale but not the essential understanding that the depletion-process of energy-resources has begun and needs to be addressed urgently.

Scarcity of natural resources and economic growth are in fundamental opposition to each other. The study of the contemporary and historical beliefs showed [Barnett H.J., Morse Ch., 1963], that:

a. Natural resources are economically scarce and become increasingly so with the passage of time;
b. The scarcity of resources hampers economic growth.

2. ENVIRONMENT

Use of the primary energy-resources is a major source of emissions [Mackey R.M., Probert S.D., 1996, Price T., Probert S.D.,1995, Mackey R.M., Probert S.D,1995]. 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, the gases

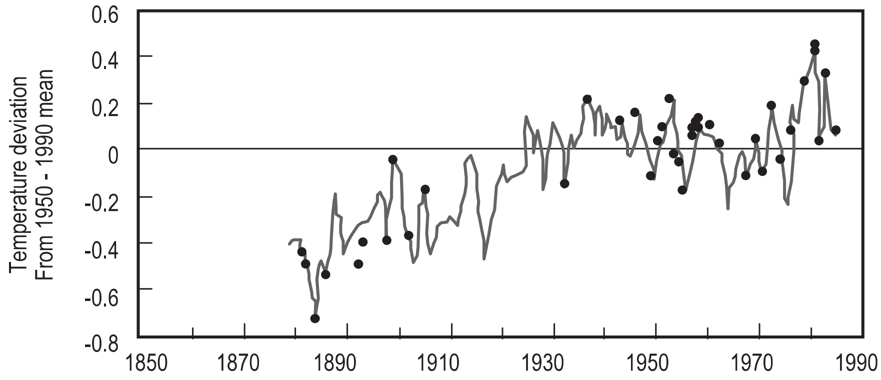

Figure - 7: Global Warming Trend (1880-1990)

emitted from the combusted fuels have accumulated to an extent that serious damage is being done to the global environment. The accumulated amount of CO_2 in the atmosphere is estimated at about 2.75 x 10^{12} tons.

The trend of global warming from 1880 to 1990 is shown in Figure-7 [Hought R.A., Woodwell G.M, 1989]. It is quite obvious that further increase of CO_2 will lead to disastrous effects on the environment. Also, the emission of SO_2, NO_x and suspended particulate matters will substantially contribute to exasperate the effect of the emissions of these gases on the environment.

On a global scale, coal will continue to be a major source of fuel for the electric-power generation, and many developing countries, such as China and India, will continue to use inexpensive, abundant, indigenous coal to meet growing domestic needs [Wu, K.,Li, B., 1998; Painuly, J.P., Rao, N., Parickh J, 1990]. 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 of carbon dioxide due to combustion.

It is expected that coal will continue to dominate China's energy usage in the future. In 1993, China had produced a total of 1.114 billion tons of coal. Since China is the third biggest energy-producer in the world, USA and Russia being the first and the second, its contribution to the global accumulation of the CO_2 will be large if the respective mitigation strategies are not adopted. The example of China is important for the assessment of the future progress of the developing countries and their need for accelerated economic development.

3. SUSTAINABILITY AND SUSTAINABLE DEVELOPMENT

The energy resources are the bricks for building our civilization [Sustainable Energy Strategy, 1995]. Their polyvalent use has offered a great service to the society. Sadly however, production and consumption of energy are going hand-in-hand with certain 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 cleanly and efficiently as possible. Crucial importance is added to this need due to the rapidly growing world population and the need for accelerated economic growth of the developing countries. This is the reason why energy takes a centre-stage in the debate surrounding an important dilemma of today: how to achieve economic development and a habitable environment simultaneously in a world that is undergoing rapid changes.

In the last few years, 'sustainability' has become a buzzword in the discussions on the resource-use and environment policy. The word 'sustainability' has its roots in the Latin word 'sustinere', meaning 'to hold up'. Before any further discussion on 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? Some definitions of the concept are as follows:

a. *Development that meets the needs of the present, without compromising the ability of future generations to meet their own needs.*
   World Commission on Environment and Development (Brundtland Commission) [Report of the United Nations Conference on Environment and Development, 1992];

b. *The development that 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.*
Agenda 21, Chapter 35 [Science for Sustainable Development, 1992];

c. B*alancing of economic, social environmental and technological considerations, as well as the incorporation of a set of ethical values.*
Council of Academies of Engineering and Technological Sciences [Declaration of the Council of Academies of Engineering and Technological Sciences];

d. *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.*
Earth Chapter [The Earth Chapter, 1995];

e. *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.*
Thomas Jefferson, September 6, 1789 [Jenkinson, C.S. White House].

All five definitions emphasize a specific aspect of sustainability. Definitions a) and e) both imply that each generation must bequeath enough natural capital to permit future generations to satisfy their needs. The common meaning of all these definitions is that we should spare our descendants the ability to survive well and meet their own needs.

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 programmes in accordance with the available scientific and technological knowledge. In particular, in definition c), the ethical aspect of the future development actions to be taken to meet the needs of sustainable development should be noted.

Definition d) is based on the religious beliefs fulfilling the responsibilities and duties towards nature and, hence, the Earth. In this respect, it is of interest to note 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 Quran, while humankind is God's vice-gerent 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 Prophet Muhammad (PBUH) and to the Quran regarding nature and natural resources.

Sustainable development focuses on the role and use of sciences in supporting the prudent management of environment and for the survival and future development of humanity [Curzio A.Q., Zobali R,1996, Domingos J.J.D., 1994, Sustainable Concept as Applied within Countries (Norway),1998].

It is recognized that scientific knowledge should be used to articulate and support the goals of sustainable development, through scientific assessment of current conditions and future prospects for Earth's system. The Rio Conference suggests the following as means to achieving sustainable development:

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

It is essential for implementation of a programme based on these to be long-term and conforming to the global changes of life-support systems. In particular, there is a need for a constant interaction with governmental, industrial, political, educational, cultural and religious authorities participating in the realization of such a programme. It is of crucial importance for the realization of such a programme, that 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 the developing countries will overcome any deficiency by an academic approach in dealing with the problems, which are related to their environment.

4. SUSTAINABLE ENERGY DEVELOPMENT

It is beyond the scope of this paper to dwell on all the characteristic entities for the definition of sustainability. Energy is one of the essential commodities required for human life and is affecting the achievement of sustainable development [Cafier G.,Conte G.,1995]. For this consideration, we will focus our attention only to the entities which are in direct correlation with energy-sustainability, which calls for a balance in: i)

Natural resources; ii) Environment-capacity; iii) Population-increase.

Since the Brundtland Commission in its 1987 report, “Our Common Future”, warned of growing threat to Earth against increasing 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 on how to make development socially, economically and environmentally sustainable. Agenda 21 calls on governments to adopt national strategies for sustainable development.

In the assessment of sustainability in energy use, the current trends in consumption-change has to be taken into consideration, which is reflecting the current change in energy-consumption for the reference 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 the energy- resources strongly depends on the efficiency of their use, which may be classified into 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 a sustainable energy supply-system. Even if there are a number of options taken into consideration, the common issues are as follows:

4.1 Prevention of the Energy-Resources Depletion with Scarcity-Index Control

All the scarcity-models show that the energy- resource scarcity is in direct relation to the industrial production output. In this respect, the efficiency of resource-use and technology development is 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 [Mitro B., Lukas N., Fells I.,1998, Trennman J., Clark A., 2004]. As regards the technology-development, long-term research and development is needed. In some cases, it will require social adjustments, in order to meet the requirements of the new energy-resources.

The availability of energy resources is limited by two factors: capital to be invested in exploring new resources and developing technologies for energy resources. From recent experiences it was learnt that there is a direct correlation between capital invested in exploration and the value of the available resources. It was proved that a fixed amount of 18 $/t is needed for exploring 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 first is the geological survey, 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 it 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 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 resource-body.

From the beginning of exploration of energy-resources, the existing drilling-technology was limiting the acquisition of new resources. The development of drilling technology has marked a new direction for the discovery of new resources. A recent example of new drilling-technology has led to a gas resource in the Bay of Mexico. Also, North Sea gas-resources are being discovered as a result of the new off-shore drilling technology. The same has been proved in the discovery of new gas resources in Algeria. The deep-sea drilling has become one of the global issues, which may possibly remove the scarcity problem of energy resources for the next few centuries. It should be mentioned that 2/3 of the Earth’s surface is covered by deep sea, so the breakthrough in deep-sea technology may lead to a substantial change in the energy-resource scenario of the world.

4.2 Efficiency Assessment

The potential improvement of the energy-conversion process is a driving force for its development [Hein K. 1995, Hanjalic K. et. al, 2007]. 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 a 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 us to determine an absolute limit to any transformation of the deposit of free energy [El-Sayed Y., R.Evans, 1970, Sama D.A., 1994].

Following the first energy-crisis, many countries have organized an energy-efficiency assessment campaign, with the aim to improve the efficiency and gain/saving, which has helped address the increase of energy prices. It was proved that this approach has resulted in the increase of efficiency of energy-use upto 10 to 20 % in a number of European countries. The main emphasis has been given to the evaluation of efficiency of different technologies and utilization of energy. It is of great importance that effort be directed to the evaluation of the technological processes for energy-saving [EU White Paper, COM (95),682,1995, Furfare S.,1995]. Also, a new development of products is recently 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, which offer a saving of about 40%, in comparison with traditional light bulbs.

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 desalination in regions where water and energy are needed, are an example.

Recent projects with gas-fired cogeneration plants have demonstrated an extremely high efficiency [Darwish M.A., 1995]. 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 development of new energy systems.

4.3 Clean Air Technology Development

Combustion is an irreversible thermodynamic process, with a high degree of 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 that might lead to an efficiency increase of the combustion process. Among these are:

4.3.1 Catalytic Combustion

The low-temperature catalytic combustion of lean natural-gas mixtures represents an effective method for heat generation [Klvana D. et. al,1995]. Coexistence with the reactant catalysts enhances the chemical reaction, but is stoichiometrically 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 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 efficient use of the fuel-cell technology. 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 active compositions of La, Ni, Co, and O (LSNC powder) leads to promising results.

4.3.2 Fluidized Bed Combustion

Recent progress in the fluidized-bed combustion has led to substantial development of the new energy-system [Van Swaaj W.P.M., Afgan N.H., 1985]. In the combustion that is made to take place in fluidized beds, coal is depressed in a mass of its ashes and absorbent lime, and the concoction is exposed to a temperature of 850^{o}C.

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 as compared to the present pulverized-coal plant. A factor significantly contributing to these problems is 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 its ability to burn low-grade coal, while meeting the required NO_x, SO_x 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 is conceived for medium and good quality coal.

4.3.3 Low NO_x Burners

The present, advanced energy-technology is focused on further improvements in the emission-control [Mitchelfelder S., 1997]. In principle, there are two approaches: the first one is by reorganization of combustion-processes in burners, and the second one is by post-combustion processes in furnaces.

In order to minimize the emissions of SO_x, NO_x and particulates, a new burner-design is envisaged to meet the requirements for minimization of initial NO_x formation. It is expected that the new burners in properly designed new furnaces [Durao D.F.G., et. al, 1992, Weinberg A,1995], will reach 370 to 490 mg/Nm^3, which is the limit for present emission control.

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

Numerical modeling of the processes in combustion-chambers has become important in design and analysis of tools [Carvalho, M.G. et. al, 1988; Carvalho M.G.,1988; Coelho P.J., Carvalho,1986] 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 [De.Jong B., 1995] are available as computational fluid-dynamic software, which allows practical analysis of power-plant furnace behaviour with minimum emissions of SO_x, NO_x and particulate. Retrofitting of existing power-plants with advanced combustion technologies will lead to substantial increase in efficiency and minimize harmful emissions into the environment.

4.3.4 New Boiler Designs

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

The development of high-performance power-systems is an ultimate goal for upgrading pollution-control, with corresponding combustion-system improvements and the control of SO_x and NO_x, 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 [Afgan N., 1995] has substantially contributed to new boiler- designs and will lead to the increase in availability of modern power-plant systems [Bergles A.,1985].

4.4 Development of Intelligent Energy Systems

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

4.4.1 Expert-System in Energy Engineering

The expert-system development in energy-engineering is focused in two directions: (i) expert-system for energy system design and (ii) knowledge- based for on-line diagnostic [Application, ed. by W. Rohsenow, J. Hartnett, E. Ganic, 2002; Leontiev A.I., 1993; Goldstein R.J, 1971]. It has been shown that the expert systems for energy system design can be an efficient tool in selection, optimisation and assessment of power-plant designs. 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 used in the design of thermal equipments is demonstrated by the heat-exchanger design [Makansi, J. 1997]. Further developments of knowledge-based system to design energy-system will improve efficiency and reliability.

The knowledge-based system for fault-diagnostics 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.

There have been several attempts, which have proved the possibility of using knowledge-based systems in the fault diagnostics of thermal power-plants. The efficiency-monitoring and respective logistic-evaluation of the diagnostic parameters have been demonstrated to be good and reliable tools for the advanced diagnostic of operational deficiency. The boiler-fouling and tube-leakage knowledge-based system prototypes demonstrated the possibility of detection of the processes leading to the degradation of power-plant-efficiency [Afgan N. H., et. al, 1991]. The diagnostic systems are based on the online monitoring of diagnostic variables and their fuzzyfication.

4.4.2 Fuzzy-Logic Control

The new fuzzy-logic control-system proved to be a qualitatively efficient system [Jamshidi, M., 1971]. While similar control-systems designs are based on hit and trial; the knowledge-based controller is ‘ad hoc’ at present. A gap exists between solid theoretical results, such as stability and controllability. A real-time implementation of intelligent control-system uses fuzzy logic, neural networks, generic algorithms, expert-systems, etc.

4.4.3 Intelligent Energy Systems

The generic design procedure to be adopted for the intelligent product design of the thermal equipment has to be in line with 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 [Afgan N. et. al, 1991; Afgan, N., Carvalho, M. Coelho, G., P, 1996; Afgan, N.H., Carvalho, M.G., 1996]. These indicators should be based on optimization of the efficiency of respective thermal equipment, resource-use assessment and validation, environment-capacity use and degradation, modular structure with multi-purpose elements, end-of-life assessment and economic justification of specific designs.

4.5 New and Renewable Energy Sources (NRES)

Besides taking steps for improving the efficiency of power-generating units, there is a great need to introduce sources of the energy in the energy mix for optimal results. The connected 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 also be based on the use of renewable-energy resources. Renewable energy is available in abundance. New technologies based on these resources highlighted below exhibit a great deal of promise viz sustainable energy development:

4.5.1 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; and
- By converting sunlight directly into electricity.

Solar energy resources do not have clear limits. The annual influx on the Earth's surface is 10,000 times the current human energy-consumption; the fraction of energy reaching the land surface is 3,000 times as large, and so even 35% of this could generate 1,000 times more energy than our current demand. As we can notice, the resource of solar energy is huge but diluted. In scientific literature, it is assessed that feasible tool-use of solar energy from the technical standpoint is approximately as shown below [Zafran M., 1993]:

i)	Thermal solar for	170 MTOE/year
ii)	Decentralized electric solar	450 TWh/year
iii)	Network electric solar	230 TWh/year

In the local resources evaluation for these three solar energy systems, one could take into consideration its minimum and maximum installation capacity as described below:

	Minimum	Maximum
Solar power plant	50 kW	10 MW
Thermal solar	150 kW	80 MW
Decentralized electric solar	30 kW	5700 kW

From the present status of development, the following capacities can be taken into account .It should be noted that for insolation lower than qR = 4 kWh/m^2/day, it might be difficult to adopt the same method of validation.

Solar-energy use is demonstrated in three options: solar thermal, solar photovoltaic and solar power-plant. Solar-thermal energy-production plant have now reached an industrial level and are available in world markets [Fritz, W., 2000; Berkovski, B. 1989, Afgan, N. 1989, Zafran, M., 1993; Best, Kwschik, 1993].

The solar photovoltaic system is well-advanced in its demonstration stage, with a variety of applications. It has been demonstrated in three levels, namely:

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 various remote areas and has been demonstrated as a reliable energy-source.

Solar power plants are under development. They are available as photovoltaic-cell modular units and can be installed when the power-demand requires a system augmentation.

4.5.2 Geothermal energy resources

Resources exploitable at current energy-prices correspond to aquifers in narrowly localized volcanic zones [Fridleifsson I.B., Freston D., 1993; Dickson M., Farnelli M., 1995]. Presently, installed and "under-construction" plants provide a total electrical capacity of 7,100 MW (high enthalpy energy). Low enthalpy hot water to be used directly for heating is estimated at about 13 MTOE/year.

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

These two groups of geothermal-energy systems are limited by the temperature and flow-capacity of individual well. From the experience, the following limits are adopted:

	Min.temp [°C]	Min. capacity [m^3/h]
High-enthalpy geothermal	90	2,900
Low-enthalpy geothermal	35	1,000

Particular resources-evaluation requires a specific assessment of the respective aquifer-volume, in order to estimate uncertainty in the lifetime of the geothermal energy-system. It is desirable the volume of the aquifer should exceed several times the capacity needed for the respective system lifetime. The local resource-evaluation for the geothermal system should also account for the land required for the brine to be deposited during the lifetime of the plant.

Conventional electric-power production is limited by fluid temperatures above 140°C, but a considerably lower temperature may be used with the application of binary fluids. Geothermal electric-energy plants have proved to be very reliable sources of energy. They are used in 21 countries with a total world installed-capacity of 6,017 MW distributed over 330 individual turbine-generator units.

The geothermal power plants are built in four versions, namely: 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 five MW.

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

4.5.3 Biomass Energy Resources

Biomass provides about 14% of the world energy or about 25 million barrels of oil-equivalent per day (Mboe/day) [Wereko-Brobby Ch.Y.,Hagen E.B Hall D.O., 1995]. It is the most important source of energy, especially for developing countries. Various applications of biomass energy may be for lighting, water filtration, cooking food and irrigation.

Biomass energy can be obtained through different means of biomass-conversion processes. The great versatility of biomass as a resource is evident from the range of wet to dry materials, which can be converted into various solid, liquid and gaseous fuels, using biological and thermo-chemical conversion processes. Solid fuels are wood, charcoal, crop and forest residuals, agro-industrial and municipal wastes and briquettes. Biomass-derived liquids are mainly ethanol and methanol. Gases are mainly biogases from anaerobic digesters, gasifiers-producing gases that can be used for electricity generation. There are two processes involved in biomass conversion, namely: 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 technologies that are demonstrated at 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 in a category of technologies that are presently available commercially. For the ethanol production, there are three available options:

	Capacity [l/day]
Micro system	< 200
Mini system	200 - 20 000
Macro system	> 20 000

Ethanol is being used as a fuel for automobiles in many countries in the United States, Europe and Africa.

4.5.4 Wind Energy Resources

The world's exploitable wind resources are estimated at about 300 TWh/year [Walker J.F., Jenkins N., 1995, Sesto E., et al., 1993]. These are rather heterogeneous and strongly depend on the geographical location. It was recognized that the most economical wind-turbines are those with a rating between 1kW and 350 kW. This requires 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 prospective entity for the use of wind for electricity production. In connection with this approach, the land occupied by wind farms is to be brought under consideration as local resource of the specific location. It is estimated that wind farms with a capacity of 4 to 8 MW could be installed on an area of 1 km^2. In defining the resource conditions for wind-energy utilization, the following parameters are to be kept in view:

i) Average wind velocity at the specific location; and
ii) Probable distribution of wind velocity.

The wind-turbine technology is available in two arrangements of the rotor, in relation to the direction of wind, namely:

- Horizontal-axis wind turbine
- Vertical-axis wind turbine

The horizontal-axis wind turbine, in which the direction of the wind is parallel to the axis is technologically more developed. At present, horizontal-axis wind-turbine generators represent approximately 95% of the capacity installed in wind plants. The developed wind-turbine plants are presently in operation and resulting in new turbines that could be classified in the following three categories small, medium and large sized wind turbine:

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

- Medium-sized wind-turbine generators are commercially available and connected to the grid. The configuration of the plant is conventional and the blades are made of glass-fibres, reinforced with plastic or laminated wood bonded by epoxy resin, with power-regulation by adjusting the pitch of the blades.

- The technology of large-size wind-turbine generators is still under development. Prototypes of the turbines having a capacity up to 4 MW and rotor diameters of up to 100 m are available in some countries. The results obtained have confirmed the feasibility of large wind-generators, but have also shown that these machines are still far from being as efficient as medium-size machines.

Wind Turbines	Capacity	Diameter [m]
Small-size	100 kW	< 20
Medium-size	100kW - 1MW	20 - 50
Large-size	> 1MW	> 50

4.5.5 Hydro-Energy Resources

It is estimated that the gross theoretical production of hydro energy is about 30 millions GWh/year, with an exploitable production of about 13 million GWh/year [Jiandong, T., et al., 1995; Cazenave, P. et al, 1993]. The present production of the existing plants is of the order of 2.2 million GWh/year. The main reason for the large disparity between exploitable and present production is the financial capacity of the countries. The average percentage of hydro-electric energy-production for developed countries is 7% while for developing countries it is 54%.

In many countries, emphasis is laid on 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.

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

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

Accordingly, there are the following three main types of hydro turbines, depending on the water-flow rate and available height of waterfall:

Type	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.

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.

4.6 Environmental Capacity for the Combustion Products

The sustainability is also closely related to the environmental capacity of our planet. It has been shown that the natural processes in the biosphere exhibit the maximum rate of change. This rate of change exceeds 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 [Kyoto Protocol, 1992]. The concentration and the rate of change of chemicals involved in the biochemical cycles may be characterized by the changes in the concentrations of organic and inorganic carbon compound. The capacity of biologically active organic and inorganic carbon chemical species in the environment is 10 times larger than their annual primary production. Therefore, it may be expected that this resource of environment-capacity could be considered in the next 10 years if only synthesis or decomposition of organic matter is taking place (in the absence of all the life processes).

The fluxes of the organic material produced by the synthesis and decomposition processes in the biosphere are within the accuracy of one hundredth percent (0.001%) of the anthropogenic fluctuation resulting in the environment in the geological time-scale. This slow change in the environment on the geological time-scale can be compensated by biological processes leading to the biosphere-control of the chemical composition of the environment. Since the preservation of the biosphere is affecting the biodiversity of our planet, it is of primary interest in long-term evolution to have 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 ensure 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 changes that are introduced by human activity. In this respect, the world energy-system is responsible for the production and emission of a number of chemicals, which are proved to have adverse effects on the environment.

The energy-use is a major source of emissions. At the same time, it is essential to the economic and social development for improved quality of life. Several threats have been recognized as signals for potential hazards to the environment.

The emission of air-pollutants is usually considered in three groups, namely: carbon dioxide, nitrogen oxides, and sulphur oxides. The adverse effects of these gases are recognized by two processes: the greenhouse effect leading to Global Warming; and depletion of the ozone layer in the stratosphere. The Global Warming is observed by noting the increase in 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 [Marchuk, G.I., Kondrotyev, K.Ya.,1992].

4.7 Mitigation of Nuclear-Power Threat to the Environment

The nuclear power-plants are very beneficial in order to mitigate the greenhouse effect, because they have no exhaust gases [Marchetti, C, 1993]. But it is known that the present nuclear power reactors have the potential to be enormous sources of radioactive emissions. Besides affecting the immediate surroundings, these hazardous events may lead to regional and even global threat to the environment. The low probability of this kind of event has been the only barrier to the increase of their disastrous effects in the global environment. Examples recently noticed require a different approach to face and master such potential hazardous events. Human society is not in a position to base its existence on the man-made probability actions, that may cause hazards beyond retification.

Opponents to nuclear energy stress two points that they consider crucial: the possibility of major radiological releases following an accident; and the enormous heritage of long-lasting radioactive wastes for the future generations. Obviously, both these points are very relevant to the sustainable development of this form of energy. Both need to be discussed separately. 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 ‘defense indepth’ strategy has been developed with three main lines: a ‘preventive line’, a ‘protective’ line, and a ‘mitigative’ line. This strategy worked for Three-Mile Island accident, with external releases of a few curies of radioactivity, but did not work for Chernobyl event due the absence of external containment and many other design-deficiencies.

Present reactor-designs for the second line of defense 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 dilatation, stress-strain relations etc to operate it [Nenat J.C., et. al, 1996, Three Mile Island Unit # 1, 1995]. The present trend of the designers is to increase the percentage of passive safety-systems, so as 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 for a deterministic approach, instead of the more scientific probabilistic one, for gaining the acceptability of common people who believe in the old saying “if it can happen, it will happen” [Cumo M.,1995].

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 to guarantee an easy and total decommissioning of the metal pieces at the end of its useful life. All these characteristics meet the requirements of sustainability.

The second ‘point of fear’ of nuclear opponents related to the long-lasting wastes is still open 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 into the (short life) radionuclides. The radionuclides with long lifetime can be converted into short-life isotopes by their mutation through nuclear reactions: (a) in high-flux nuclear reactors; or (b) in a coupled device of subcritical nuclear reactor, in which a beam of high-energy particles is introduced by means of a powerful accelerator. The total amount of long-lasting wastes will be substantially reduced to be conveniently placed in suitable geological formations that remained dry and intact for millions of years. A device of this type has been recently proposed by Rubbia, with a subcritical fast reactor cooled by lead in natural convection, fed by spallation neutrons generated by a beam of protons accelerated to 1 GeV [Rubbia et al., 1995]. The conceptual design of fast-neutron operated as high-power energy amplifier is ADS.

5. SUSTAINABILITY EDUCATION

People around the world recognize that current economic development trends are not sustainable and that public awareness, education and training are the keys to move towards sustainability. Beyond that, there is little agreement. People argue about the meaning of sustainable development and whether or not it is attainable. They have different visions of what sustainable societies will look like in the future and how they will function.

It is interesting to note that while we have difficulty envisioning a sustainable world, we have no difficulty identifying what is unsustainable in our societies. We can rapidly create a laundry list of problems – inefficient use of energy, lack of water-conservation, increased pollution, abuse of human rights, overuse of personal transportation, consumerism, etc. But we should not chide ourselves because we lack a clear definition of sustainability. Indeed, many truly great concepts of the human world – among them democracy and justice – are hard to define and have multiple interpretations in cultures around the world [Aleksander Lingen et. al, 2006].

Education is an essential tool for achieving sustainability [Saif R. Samady, 2006]. Development of a sound education-system is a milestone towards any economic development. In this respect, sustainable energy development will require special attention to be devoted to designing a new education-system.

An important distinction is the difference between education *about* sustainable development and education *for* sustainable development (ESD). The first is an awareness lesson or theoretical discussion. The second is the use of education as a tool to achieving sustainability. In our opinion, more than a theoretical discussion is needed at this critical juncture in time. While some people argue that ‘for’ indicates indoctrination, ‘we think for’ indicates a purpose. All education serves a purpose, otherwise society would not invest in it. Driver education, for example, seeks to make our roads safer for travelers. Fire-safety education seeks to prevent fires and tragic loss of lives and property. Similarly, ESD promises to make the world more livable for this and future generations. Of course, a few will abuse or distort ESD and turn it into indoctrination. This would be antithetical to the nature of ESD, which, in fact, calls for giving people knowledge and skills for lifelong learning to help them find new solutions to their environmental, economic, and social issues.

Information and computer technologies have become essential tools for the presentation and dissemination of information, knowledge and entertainment visualization. New development in this field is opening many different areas to the large exposition. In particular, it was seen as the advanced promotion of advertisement, music, entertainment, arts and, to a lesser extent, in education. It is almost impossible to imagine any modern product without a multimedia presentation. Now, most of the products are rated by the success of its multimedia presentation. It has become obvious that human perception is multidimensional and comprises listening, seeing and eventually, touching. Quality of each of the approaches to human perception is strongly effecting its adoption and reception. There is no doubt that the multimedia approach has gained great role in conveying the message to human recognition. The multimedia approach may activate all perception-channels to convey the message to a more effective human adoption. It has been demonstrated in the entertainment industry, in particular, that the multimedia approach has gained high visibility in public as large multimedia have opened a new process of democratization of all those values being reserved for the nobility. The exposition in some museums used to be accessible only to those in the near surrounding or those who are able to afford high travel expenses. Now, masterpieces from different museums are made available in the multimedia environment on CD with a high-quality reproduction and the respective audio introduction.

Education has been to a lesser extent exposed to the multimedia environment. There are, however, excellent language courses with video presentations and multimedia editing. Also, similar elementary teaching for children has been successfully presented and introduced in the education. Graduate and post-graduate education has undergone only limited success in presenting learning-material in the multimedia environment. There are some good examples proving that the future presentation of high-technology knowledge will become a demanding tool for progress and economic development in many countries. It is obvious that the present educational system with classical methods of teaching will not be able to meet the future requirements of higher education. A number of concerns have been expressed about the potential options, which may lead to the development of new higher education system. One of those options is the distant-learning system. It has been recognized that the distant-learning education may become a powerful tool and may offer challenge for a new development of higher education system [Afgan N.H., 1991].

6. CONCLUSIONS

It is concluded that:

a. The present energy-strategy requires adoption 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 has recently become the leading concern for our near and distant future. Together with social aspects of the future economic development, it is of paramount interest for the modern society to implement the concerned resolutions adopted by world-leaders, before it is too late.

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

c. Finally, in order to promote sustainable energy development, the respective educational system is required. It was recognized that the present energy educational system is not geared to meet future needs of knowledge dissemination. It is clear that the best possible option for the future education-system is the distance-learning with multimedia telematic system.

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HYDROGEN FUEL-CELLS: THE FUTURE OF CLEAN ENERGY TECHNOLOGY

*Wan Ramli Wan Daud**

ABSTRACT

Fuel-cell technology, using hydrogen energy, is an advanced green energy technology for the future that is green, sustainable, clean and environment- friendly. Emission of Green-house gases from human activities has been proven beyond doubt as the main cause of global warming and climate-change. The finite world energy-supply, which consists nearly of 90% fossil-fuel, will be depleted in a short period of time precipitating an energy-crisis because of a widening gap between fossil-fuel production and demand. Many countries responded to the anticipated energy crisis by diversifying their fuel-resources to include renewable and alternative energy, and developing green-energy technology for the future. Despite political announcements on renewable energy, fossil-fuels will continue to dominate energy resources for some time in future, and carbon emission will increase; but global nuclear energy expansion is uncertain because of international tensions and general public fears of another Chernobyl disaster or a nuclear attack by terrorists. Biofuels too are plagued by the conflict between crops for fuel and crops for food, and there is a shift of interest towards crop-biomass waste. Further expansion of hydrogen energy is constrained by costs and by safety of hydrogen transport and storage. Fuel-cell R&D has shifted from older Alkaline Fuel Cell (AFC), Phosphoric Acid Fuel Cell (PAFC) and Molten Carbonate Fuel Cell (MCFC), whose entry into the market was stalled by intractable operational and durability problems, to the more promising Polymer Electrolyte Membrane Fuel Cell (PEMFC), Direct Methanol Fuel Cell (DMFC) and Solid Oxid Fuel Cell (SOFC). A new type of fuel cell, the microbial fuel-cell (MFC), is also gaining attention because it provides a sustainable way of simultaneously reducing BOD & COD of waste-water and providing power: combined wastewater treatment and power (CWTP).

The main thrust in R&D of PEMFC is cost-reduction of membrane and electrocatalyst, by substitution with cheaper but more efficient organic/inorganic nanocomposite membranes and nano-inorganic electrocatalyst, as well as lower electrocatalyst loading, and by cost-reduction of bipolar plate by material reformulation with nanomaterials for injection or compression molding. In addition, cost-reduction can also be achieved by reduction of system complexity, using non-hydrated or self-hydrated membranes that eliminate water management sub-system and CO tolerant anodes that eliminate CO removal of reformate hydrogen feed. PEMFC system efficiency can be further enhanced by better designing of flow field in bipolar plates, fuel and air manifold in the stack as well as through process-optimization using process system engineering tools. The main thrust of R&D in SOFC is reduction of its operational temperature by replacement with low-temperature electrolytes, anodes and cathodes. Future DMFC R&D focuses on methanol crossover reduction, better water-management and lower manufacturing costs. Future R&D on MFC focuses on understanding the electron-transfer mechanism and redox reactions in cells and developing more efficient nanostructured electrodes and cell immobilization. The main thrusts of R&D in production of hydrogen from liquid fuels are in the development of low-temperature auto-thermal steam reforming catalysts, purification of reformate hydrogen through pressure-swing adsorption and membrane processes, as well as membrane reactors, and higher hydrogen-storage capacity in carbon nano-tubes and other nanostructures. The main focus of R&D for sustainable hydrogen production is using photolysis of water into hydrogen and oxygen in solar photovoltaic-electrolyzer system, direct solar photoelectrochemical reactors and solar photo-biological fermentors.

Keywords: *Hydrogen economy, green energy, fuel cell, nanomaterials, nanostructures, and solar hydrogen.*

1. INTRODUCTION

The worldwide annual consumption of energy was 474 exajoules (474×10^{18} J) in 2008, with 80 to 90 % of it derived from fossil-fuels [1]. The finite world energy-supply that consists of up to 90% fossil-fuel will peak during 2020-2030 and will be depleted in 30 to 40 years [2]. This will generate an energy crisis because of widening gap between fossil-fuel production and demand [2]. Green-house gases emission from human activities has been proven beyond doubt to be the main cause of global warming and climate change [3]. The Kyoto Protocol has forced governments to cut CO_2 emission but the post Kyoto-Protocol world has been facing problems.

Many countries responded to the threats of energy crisis and global warming by (i) diversifying their fuel-resources to include renewable and alternative energy; and (ii) developing green energy technology

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to replace conventional energy technologies. Fuel-cell technology, using hydrogen energy, is an advanced green energy technology that is green, sustainable, clean and environment-friendly. Hydrogen fuel-cells emit only water and their introduction in the energy-industry will reduce carbon emission significantly [4, 5].

2. HYDROGEN ENERGY

Hydrogen can be produced from fossil-fuels, and used alongside fossil-fuels in hybrid fuel systems in the transportation, electricity-generation, residential, commercial and industrial sectors. Subsequently, as solar hydrogen and other renewable hydrogen technologies mature and become more viable, hydrogen will be used in fuel-cells for all sectors of the energy market. Ultimately, both solar and hydrogen energy will merge to produce renewable hydrogen. This is considered the most likely path towards a fully commercial application of hydrogen-energy technologies, where solar energy and fuel-cell technologies play crucial roles [5, 6].

Research activities on hydrogen production and storage technologies were focused on (a) auto-thermal steam-reforming catalysts for both gas and liquid fossil-fuels, gasification/pyrolysis, thermochemical cycle, (b) solar photovoltaic-electrolyzer splitting of water, photo-electrochemical and photo-biological splitting of water and carbon nanotube hydrogen storage. The first three are improvements of current technologies, but the latter three are new technologies for hydrogen production and storage. Solar photo-electrochemical splitting of water – a one-step process of splitting water directly from solar energy by using a combination of photovoltaic electrode and electrolysis in one cell – is touted potentially as the ultimate renewable hydrogen-production technology of the future. Major barrier in commercializing this technology is the low efficiency (of about 8%), large energy-band gap for redox electrochemical reaction and electrode corrosion.

2.1 Fuel Processed Hydrogen

Hydrogen needed for operation of fuel-cells should ideally be produced by using renewable energy resources but, in order to introduce fuel-cells technology early, hydrogen should be produced from fossil-fuels using catalysts. The Fuel-processing Group at the Fuel Cell Institute (FCI), UKM, Malaysia, has developed catalysts for autothermal reforming of methanol for hydrogen-production based on CuZ_n [7, 8, 9]. The Group studied the effect of metal-loading in the alumina-supported catalyst on CO reduction [10] and multi-metal composition of ZSM-supported catalyst for hydrogen-production [11].

Hydrogen produced by autothermal reforming of methanol contains CO, which can poison the catalyst in membrane electrode assembly (MEA) and reduce PEMFC's performance. The group has developed a pressure swing adsorption (PSA) system, using activated carbon impregnated with SnCl that can remove CO to less than 10 ppm [12-16]. The group has also developed a four-stage compact PSA that can reduce CO level even further [17], using adsorption [18]. A membrane reactor, consisting of a Palladium (Pd) membrane on a ceramic tube surrounded by the catalysts in the shell, has been developed to produce and separate the hydrogen in one unit [19, 20]. Hydrogen storage, a critical issue in commercial applications of fuel-cells, was critically reviewed by the fuel-processing group at UKM [21].

2.2 Solar Hydrogen

Hydrogen was successfully produced by electrolysis of water, using power from a hybrid solar photovoltaic and wind-energy system [22]. Hydrogen can also be produced by direct photolysis of water by solar energy in photo-electrochemical cells. The Solar Hydrogen Group at the FCI, UKM, has successfully synthesized and characterized three forms of the tetraalkylammonium tetrathiotungstate, a precursor to a tungsten tris (1-acarboxyl-2-phenyl-1,2-ethylenodithiolenic-S,S') [23], – a dye photocatalyst complex, which was subsequently synthesized and characterized successfully [24]. The group has also successfully synthesized and studied the stability of the photocatalyst tungsten tris (1,2-bis(3,5-dimetoksifenil)-1,2-etilenodithiolenik-s,s') (MTDT) through four organic-steps. The photoelectron current produced from the photoelectrode, sensitized by MTDT in a homogenous photoelectrochemical test, was found to be larger than those produced without it [25].

Photoelectrochemical cell produces oxygen when the anode is illuminated and hydrogen at the cathode. The main issue in a photoelectrochemical cell is the availability of a stable anode, maximum light exposure to the anode, collection of hydrogen gas [26] and unimpeded ionic movement [27]. The Solar Hydrogen Group at UKM compared the performance of photoelectrochemical cells, using TiO_2, WO_3, Fe_2O_3 and combined TiO_2-WO_3-Fe_2O_3 electrodes, for water splitting and has shown that the photoelectrode WO_3 gave the highest current density [26, 28].

2.3 Biohydrogen

Renewable hydrogen could also be produced from photoautotrophic microorganisms, such as *cyanobacteria* and *microalga* in anaerobic condition using CO_2 with hydrogenase, which is cheaper, and by photoheterotrophic microorganism, such as nitrogen-fixing bacteria, using more costly organic carbon with nitrogenase. The first process is cheaper than the second one. The main weakness of biohydrogen is low efficiency (1–10%) and enzyme inhibition. The Biohydrogen Group at FCI, UKM, has recently produced hydrogen from *clostridium saccharoperbutylacetonicum* by glucose fermentation at the rate of 3.1 moles of hydrogen per mole of glucose at pH 4.0, 37°C, and initial glucose concentration of 10 g L^{-1} [29]. A second Biohydrogen Group at UKM has produced hydrogen from clostridium acetobutylicum by glucose fermentation at the rate of 391 mL hydrogen per gram of glucose at pH 7.0, 30°C and initial glucose concentration of 25 g L^{-1} [30, 31].

3. FUEL CELLS

Fuel cells play an important role in the renewable hydrogen economy, because it is the most efficient, sustainable, clean and environment-friendly energy-converter of hydrogen. A fuel cell is an electrochemical energy-conversion device that converts chemical energy of hydrogen and oxygen into electricity and heat, by means of electrochemical redox reactions at the anode and the cathode of the cell, respectively, with only water as its by-product.

The six common types of fuel-cell technologies are Alkaline Fuel Cell (AFC), Phosphoric Acid Fuel Cell (PAFC), Molten Carbonate Fuel Cell (MCFC), Solid Oxide Fuel Cell (SOFC), Polymer Electrolyte Membrane Fuel Cell (PEMFC), and Direct Methanol Fuel Cell (DMFC). The seventh less common type of fuel cell is the Microbial Fuel Cell (MFC). Although R&D activities on the first three fuel-cell types have been well-established, yet their niche commercial applications are still facing teething problems. Whereas, intense R&D activities on the latter four fuel-cell types are now being carried out all over the world [32].

The major areas of fuel science and technology, and research and development work include: efficient process-system engineering of fuel cells on more efficient fuel- cell systems; low Pt/non-Pt nanostructured electrodes and nanocomposite proton-exchange membranes, nanocomposite bipolar plates; μdirect methanol fuel-cells; low temperature SOFC and microbial fuel cells for power from waste-water.

3.1 Process System Engineering of Fuel Cells

The main problem of process system engineering of PEMFC is the lack of good engineering understanding of major components of a PEMFC system, such as the PEMFC stack, gas humidifier, pressure swing adsorbers, fuel-processing reactor and membrane gas-separation module, as well as water management. The Fuel-cell Process-system Engineering Group at FCI, UKM, has successfully developed models for pressure swing adsorbers [17, 18, 33], gas separation membrane modules [33, 34, 35, 36, 37, 38] and studied the interaction between the two technologies [39]. The Group has also modeled a 5 kW PEMFC system, with an on-board fuel-processing system [40, 41] and with various methods of hydrogen purification [42,43]. The failure of water-management in the PEMFC stack can lead to PEMFC failure, because of flooding and short-circuiting. The Group has successfully modeled a humidifier system for fuel cells [44] and has proposed a new model of water-flow in the PEMFC and a better way of managing water in the fuel cell [45]. The Group is also developing a better model for design of PEMFC [46], a better gas flow field design [47], as well as the effect of mechanical stress on the electrical contact resistance in PEMFC stacks [48].

The Group has also designed and built the PEMFC prototypes: (i) hydrogen-fueled, air-cooled, open cathode, 50-500W PEMFC system; and (ii) a water cooled, 1-5 kW PEMFC system have been developed. Two motorcycle prototypes powered by fuel cell called SERINDIT-I (50 W) and SERINDIT-II (200 W) have been designed, fabricated and tested. A 500W to 1kW portable fuel-cell power-module called LESTARI 1000 and 5 kW portable fuel-cell power-module, called LESTARI 5000, have also been designed, fabricated and tested.

3.2 Proton-Exchange Membranes and Membrane Electrode Assemblies

Currently available proton-exchange membrane fuel cells (PEMFC) that use Nafion from Dupont as its proton-exchange membrane cannot operate more efficiently at a temperature higher than 90°C because its proton-exchange membrane suffers from thermal instability above that temperature. The Fuel-cell Electrochemical Processes Research Group at the FCI, UKM, has successfully developed a new high-temperature composite Nafion-silicon oxide (SiO^2)-phosphotungstic acid (PWA) composite-membrane with lower resistance, higher proton-conductivity, higher current density and better thermal stability at 90°C than the Nafion membrane from Dupont [49, 50, 51] and the Aciplex membrane from ASAHI [51]. The research group has also started research on inorganic membrane that can operate at high temperature, without humidification-based cesium diphosphate (CDP) [52].

Membrane electrode assemblies loaded with costly Ptalimium (Pt), key component of the PEMFC, contribute to the high cost of PEMFC, which prevents the latter's early commercialization. The Group developed a local carbon-source for the electrode [53, 54]. The research group has successfully developed high-performance MEAs with low Pt loading and gas diffusion layers [56, 57]. The group has also developed a new dimensionless spray number for the manufacturing of improved MEAs, using a spraying machine [58].

3.3 Bipolar Plate Material and Manufacturing

The cost of manufacturing bipolar plates can be reduced by substituting the graphite material with polymer composite. Suitable polymers for the polymer composite are thermoplastic polymers, such as polyethylene, polypropylene and polivenylfluoride; and thermoset resins, such as phenolics, epoxy and venyl ester. The Fuel-cell Material and Manufacturing Group at the FCI, UKM, has successfully developed a polymer composite from polypropylene and graphite [59, 60, 61].

3.4 Micro Direct Methanol Fuel Cells

The main problems of micro direct methanol fuel-cells are: methanol crossover and electrode-degradation that diminishes the power of DMFC after a short time of operation; high cost of catalysts and electrolyte membrane; and heat and water management [62, 63]. The Micro Direct Methanol Fuel-cell Group at the FCI, UKM, has developed a design advisor tool, to help predict the performance and optimize the design of the direct methanol fuel-cell [64]. The Group began by developing a passive air-breathing single cell direct methanol fuel-cell, to study the effect of methanol concentration on direct methanol fuel cell performance [65]. It went on to develop a passive single-cell based on air-breathing polymethyl methacrylate (PMMA) and a multi-cell stack micro-direct methanol fuel cell (DMFC) with 1.0 cm^2 active area, and a novel cathode plate structure and assembly layer for better air-access and water removal by gravity [66]. A µDMFC, with low catalyst loading, was also developed by the Group [67]. The effect of methanol concentration and mass transport on the current density of unsteady- state operation of a direct methanol fuel cell was also studied by the Group [68, 69]. Hybrid membranes were also considered to replace Nafion [70]. The use of nanomaterials and nanostructures as nanocatalysts in DMFC was explored [71, 72]. The design of µDMFC was also optimized [73].

3.5 Solid Oxide Fuel Cells

Solid oxide fuel-cells research is primarily undertaken on low and intermediate temperatures (500–600°C). The Solid-oxide Fuel-cell Group of the FCI, UKM, is developing intermediate and low-temperature cells using ceria (CeO_{2-x}) doped with Gd, lanthanum gallate (Perovskite) doped with Sr and Mg (LSGM) and inter metallic bismuth oxide [74, 75], and cathodes from lanthanum cobaltite (perovskite) embedded with Fe, such as $La_{1-x}Sr_xCo_{1-y}Fe_yO_{3-\delta}$ (LSCF, typically x ~ 0.2, y ~ 0.8) [76].

3.6 Biofuel Cell

Palm Oil Mill-Effluent (POME) is a waste-water, reeking of very high chemical oxygen demand (COD) 50 g L^{-1} and very high biochemical oxygen demand (BOD) 20 mg L^{-1}. Biofuel Cell Group at the FCI, UKM, used the biohydrogen produced from anaerobic fermentation of POME, using mixed culture from POME at pH level 7 directly without combustion, to produce electricity in a dual chambered microbial fuel cell that could reach a current density of 500 mA cm^{-2} and power density of 250 mW m^{-2} [77]. The Group has also studied microbial fuel-cell, using pure culture *Clostridium butyricum* from POME at pH level 4, producing a current density 150 mA cm^{-2} and power density 56 mW cm^{-2} [78]. The open-circuit voltage obtained ranged from 0.3 to 0.5 volt [77-81]. The microorganisms used vary from mixed culture from POME [73,74]: *Clostridium butyricum* [74], *Pseudomonas putida, Lactobacillus, Escherida coli, Aspegillus niger* and *Saccharomyces cerevisia* [79, 80, 81]. The microbial fuel cell has been proven to produce power from waste-water and also reduce the COD and BOD of the wastewater.

A recent study on future hydrogen demand and supply network in Peninsular Malaysia concluded that liquefied hydrogen produced by natural gas steam-reforming and delivered via tanker trucks is the optimum hydrogen supply-chain method [82]. Eighteen new hydrogen plants of 50,000 tonne/year capacity are required for the optimum supply-chain, which is, therefore, more expensive than the future hydrogen infrastructure cost in the UK because the existing hydrogen infrastructure in the latter is better established.

4. CONCLUSION

Research and Development in hydrogen energy is focused on (a) catalyst- development for autothermal reforming of liquid fuels into hydrogen; (b) solar hydrogen by solar energy assisted water splitting using photoelectrochemical cells; and (c) biohydrogen by anaerobic fermentation of waste-water. On the other hand, research and development in fuel cells are centered around design and prototyping of PEM fuel cells, membrane electrode assemblies, bipolar plate materials, micro direct methanol fuel-cells, intermediate and low temperature solid oxide fuel-cell materials and microbial fuel-cells producing power from waste-water. Hydrogen is currently produced by steam reforming and electrolysis, and is used mainly in the petrochemical and oleochemical sectors, as well as in metal cutting. Renewable hydrogen will be produced by electrolysis, using excess capacity of hydropower or off-peak electricity and, ultimately, directly from solar energy by photoelectrochemical means.

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THE BANGLADESH MICRO-GENERATION ENERGY MODEL: LESSONS FOR DEVELOPING COUNTRIES

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ABSTRACT

Lack of access to sufficient and affordable energy is one of the major challenges for a large population in the developing countries. Renewable energy is an appropriate option to meet the energy requirements of people in these regions. In this respect, many countries in Africa, Asia and Latin America have initiated micro-generation renewable energy programmes. In Bangladesh, the renewable energy programmes based on micro-credit have experienced an unprecedented success. The Bangladesh model was pioneered by Grameen Shakti – the largest and most successful organization in the country – that is now installing over 20,000 solar- home systems per month. Other developing countries can learn a lot from the best practices of the Bangladesh micro-generation model. By highlighting the prominent features of the Grameen Shakti programme, this article reflects upon the important lessons that can be learnt from the Bangladesh model, for launching similar programmes in other developing countries.

Keywords: *Renewable energy, micro-generation, solar home systems, Grameen Shakti .*

1. INTRODUCTION

Energy is one of the fundamental commodities in the present age. It is a pre-requisite for the economic, social, industrial, agricultural and infrastructural growth of every nation. Since the advent of the industrial revolution, fossil-fuels have been the backbone of the world energy-supply base. Presently, the three main types of fossil-fuels – coal, oil and gas – collectively contribute to over 80% of the total supplies (IEA, 2009). Continuation of the use of fossil-fuels is, however, set to face multiple challenges: depletion of fossil-fuel reserves, global warming and other environmental concerns, geo-political and military conflicts and, of late, continued and significant fuel-price rise. These problems indicate an unsustainable situation. Renewable energy is a solution to the growing energy-challenges. Renewable energy resources, such as solar, wind, biomass, and wave and tidal energy, are abundant, inexhaustible and environment-friendly.

There is a great deal of disparity in the world, in terms of availability of energy. The developing countries have very limited access to electricity and other refined forms of energy, in comparison with the developed countries. Since the 1970s, attempts have been made to employ renewable technologies, like solar photovoltaic and biogas systems, for the benefit of rural communities in the developing countries. Over the last couple of decades, a number of developing countries around the world have initiated micro-generation renewable-energy programmes. Examples of such programmes can be seen in Asian, African and Latin American countries. However, in many cases, owing to various technical and socio-economic constraints, these initiatives have fallen short to achieve the desired purpose.

In four South Asian countries, Bangladesh, India, Nepal and Sri Lanka, micro-generation programmes dealing with technologies like solar home systems (SHS) and biogas systems have experienced considerable success. Owing to their innovative and distinctive business-model, the micro-generation programmes of Bangladesh, however, are far more successful than similar programmes elsewhere in the world. Grameen Shakti is the first and most successful micro-generation programme in Bangladesh. This article explores the salient features of the Bangladesh micro-generation model, taking Grameen Shakti as the reference case.

2. ENERGY AND SUSTAINABLE DEVELOPMENT

Energy is the backbone of all human activities. The accomplishments of civilization have largely been achieved through the increasingly efficient and extensive harnessing of various forms of energy, to extend human capabilities and ingenuity. Providing adequate and affordable energy is thus essential for eradicating poverty, improving human welfare, and raising living standards worldwide. The per-capita energy-consumption is an index used to measure the socio-economic progress in any society — the Human Development Index (HDI) of a country has a strong relationship with its energy prosperity (WEO, 2004). A direct correlation exists between access to electricity and economic well-being in a range of countries (Weynand, 2007).

Poverty, hunger, disease, illiteracy, and environmental degradation are amongst the most important challenges being faced by the world. Poor and inadequate access to secure and affordable energy is one of the crucial factors behind these issues. For example, electricity is vital for providing basic social services, such as education and health, water supply

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and purification, sanitation and refrigeration of essential medicines. Electricity can also be helpful in supporting a wide range of income-generating opportunities.

There appears to be a global consensus that the provision of secure, affordable and socially acceptable energy-services is a pre-requisite for eradicating poverty, in order to achieve the Millennium Development Goals (MDGs). The Earth Summit 2002 strongly urged the nations to:

> “Take joint actions and improve efforts to work together at all levels to improve access to reliable and affordable energy-services for sustainable development, sufficient to facilitate the achievement of the MDGs, including the goal of halving the proportion of people in poverty by 2015, and as a means to generate other important services that mitigate poverty, bearing in mind that access to energy facilitates the eradication of poverty.”

The United Nations also acknowledges that ‘without increased investment in the energy sector, the MDGs will not be achieved in the poorest countries’ (UNDP, 2006). It is estimated that if the MDG’s target is to be achieved, 500 million more people would need to be provided with electricity by 2015 (WEO, 2004).

With the growing world-population and people’s innate aspirations for an improved life, a central and collective global issue, in the new century, is to sustain socio-economic growth within the constraints of the Earth’s limited natural resources while preserving the environment. The target of sustainable development can only be met by ensuring sustainability of energy.

3. ENERGY AND ENVIRONMENTAL CHALLENGES FACING DEVELOPING COUNTRIES

Energy drives human life and is crucial for continued human development. Throughout the course of history, with the evolution of civilizations, the human demand for energy has continuously risen. The global demand for energy is rapidly increasing with increasing human population, urbanization and modernization, and is projected to rise sharply over the coming years. The world heavily relies on fossil-fuels to meet its energy requirements; fossil-fuels, such as oil gas and coal, are helping to meet almost 80% of the global energy demand. On the other hand, presently renewable energy and nuclear power are only contributing 13.5% and 6.5% of the total energy needs, respectively (IEA, 2009).

This enormous amount of energy being consumed across the world is having adverse implications on the ecosystem of the planet. Fossil-fuels, the main source of energy, are inflicting enormous impacts on the environment. Climatic changes driven by human activities, in particular the production of greenhouse gas emissions (GHG), directly effect the environment. According to the World Health Organization (WHO) estimates, as many as 160,000 people die each year from the side-effects of climate-change and the number could almost double by 2020. These side-effects range from malaria to malnutrition and diarrhea that follow the occurrence of floods, droughts and warmer temperatures (Asif, 2011).

The presently employed energy-systems will be unable to cope with future energy requirements as fossil-fuel reserves are depleting, and the developed countries predominantly employ nuclear power. Production and consumption of fossil-fuels are closely linked to environmental degradation that threatens human health and quality of life, and affects the ecological balance and biological diversity. It is, therefore, clear that if the rapidly increasing global energy-needs are to be met without irreparable environmental damage, there will have to be a worldwide drive to exploit energy-systems that do not endanger the life of current and future generations and do not exceed the carrying capacity of eco-systems. Renewable energy sources that use indigenous resources have the potential to provide energy-services, with almost negligible emissions of both air pollutants and greenhouse gases.

Access to sufficient and affordable energy is a much greater challenge for the under-developed countries. Statistics suggest that the average value of the per-capita energy-consumption in industrialized and developed countries is almost six times greater than that in the developing countries. For the latter, the situation with electricity, one of the most refined and useful forms of energy, is even more complicated. Although, during the last twenty-five years, over 1.3 billion people living in developing countries have been provided access to electricity, more than 1.4 billion people (over 21 per cent of the world’s population) do not have access to it (UNDP, 2007-08). Furthermore, around 2.4 billion people rely on traditional biomass, including wood, agricultural residues and dung for cooking and heating. Statistics also suggest that more than 99 per cent of people without electricity live in the

Table - 1: Countries with a Large Population having no Access to Electricity

Country/region	Population without Electricity	
	Millions	% of world total
India	487.2	34.6
Bangladesh	96.2	6.8
Indonesia	101.2	7.2
Nigeria	71.1	5.0
Pakistan	71.1	5.0
Ethiopia	60.8	4.3
Congo	53.8	3.8
Myanmar	45.1	3.2
Tanzania	34.2	2.4
Kenya	29.4	2.1
World Total	1410	100.0

Source: *UNDP, 2007-2008*

developing countries and four out of five live in rural areas of South Asia and sub-Saharan Africa (RU, 2010). The leading countries in the world, in terms of population without access to electricity, are shown in Table-1(UNDP, 2007-08).

4. RENEWABLE ENERGY: KEY TO ENERGY SUSTAINABILITY

Renewable energy, as the name implies, is the energy obtained from natural sources, such as wind power, solar energy, hydropower, biomass energy and geothermal energy. Renewable energy sources have also been important for humans since the beginning of civilization. Biomass, for example, has been used for heating, cooking and steam-production; wind has been used for moving ships and both hydropower and wind have been used for powering mills to grind various grains. Renewable energy sources that use indigenous resources have the potential to provide energy services with zero or almost zero emissions of both air pollutants and greenhouse gases. Renewable energy resources that are abundant in nature and are presently meeting almost 13.5% of the global primary energy-demands are acknowledged as a vital and plentiful source of energy that can indeed meet the entire world's energy demand. Renewable energy sources have enormous potential and can meet many times of the present world energy-demand. They can enhance diversity in energy-supply markets, secure long-term sustainable energy-supplies, and reduce local and global atmospheric emissions. They can also provide commercially attractive options to meet specific needs for energy-services (particularly in developing countries and rural areas), create new employment-opportunities, and offer possibilities for local manufacturing of equipment.

Renewable energy is growing at a very healthy rate across the world. Wind power is one of the fastest growing renewable energy technologies. In the recent past, the annual market for wind-energy has continued to increase at a staggering rate of over 25 per cent per annum following the 2005 record year, in which the market grew by 41 per cent. Over 27GW of wind power was installed in 2008, led by the US, China and Spain,

Table - 2: Top 10 Countries in the World, in Terms of Installed Wind-Power Capacity

Country	Installed Capacity (GW)
United States	25.4
Germany	23.9
Spain	16.7
China	12.2
India	9.6
Italy	3.7
France	3.4
United Kingdom	3.3
Denmark	3.2
Portugal	2.8

Source: *OE, 2011*

bringing world-wide installed power capacity to 120.8 GW. The top five countries in terms of installed power capacity are the US (25.4GW), Germany (23.9GW), Spain (16.7GW), China (12.2GW) and India (9.6GW), as shown in Table-2 (OE, 2011).

Solar water-heating is also growing at a remarkable rate. Since 2002, it has been experiencing a rapid growth across the world, including Asia, EU and the North America. Despite the global economic downturn, the international market for solar water-heating grew at a remarkable pace in 2008. Statistics suggest that in China, where almost 75% of the world's total capacity exists, the solar water-heating market during 2008 grew by 28%. With an annual addition of 23.4 million square meter of the collector area, China's solar water-heaters have covered around 108 million square meters of area. In 2008, EU's solar water-heating market jumped by 60% (Asif & Muneer, 2007).

5. THE BANGLADESH MICRO-GENERATION MODEL

Bangladesh is one of the developing countries, which faces serious energy-challenges, as it has limited indigenous resources. The per-capita commercial energy-consumption of the country is about 200 kg of Oil Equivalent (kgOE), around 66% of which comes from natural gas, with the remainder being mainly contributed by oil, coal and hydropower (Nes, Boers and Islam, 2005). The installed power generation capacity in the country is 5,269 MW. More than 97% of the electricity is generated from thermal power, while the rest is contributed by hydropower. Lack of access to electricity is one of the major issues affecting the socio-economic conditions of people. According to International Energy Agency statistics, nearly 96 million people, making up 58% of the total, do not have access to electricity (EIA, 2010). In terms of per-capita electricity-consumption, the country has a ranking of 177 in the world, with an annual value of 148kWh (Nationmaster, 2011 & SEC, 2011). The poor availability of electricity is a major hindrance towards economic prosperity in the country.

To overcome the issue of lack of access to energy, Bangladesh has seen a large number of micro-generation renewable-energy programmes emerging on the scene in recent years. The first micro-credit based renewable energy programme was established by Grameen Shakti in 1996. Presently, there are more than 30 organizations in operation, with similar micro-credit based programmes. The basic business-model, pioneered by Grameen Shakti and now followed by the other organizations, can be regarded as the Bangladesh model. As of December 2010, over 800,000 solar-home systems have been installed in Bangladesh, of which more than 520,000 have been installed by Grameen Shakti alone (IDCOL, 2011 & GS, 2011).

5.1 Grameen Shakti Programme

Grameen Shakti is one of the world's largest micro-generation renewable energy programmes. Grameen Shakti was established in 1996 as a not-for-profit organization, with the aim of providing environment-friendly and affordable energy to the people of Bangladesh. The main emphasis of Grameen Shakti is on addressing the needs of people living in rural and remote areas, without access to national electricity and gas networks. The electricity grid has a weak penetration in Bangladesh, especially in rural areas, where only 10% of the population has access to it. People without access to electricity rely mostly on kerosene lanterns for lighting needs. Having realized

Figure - 1: A Solar Home System being Installed in Bangladesh

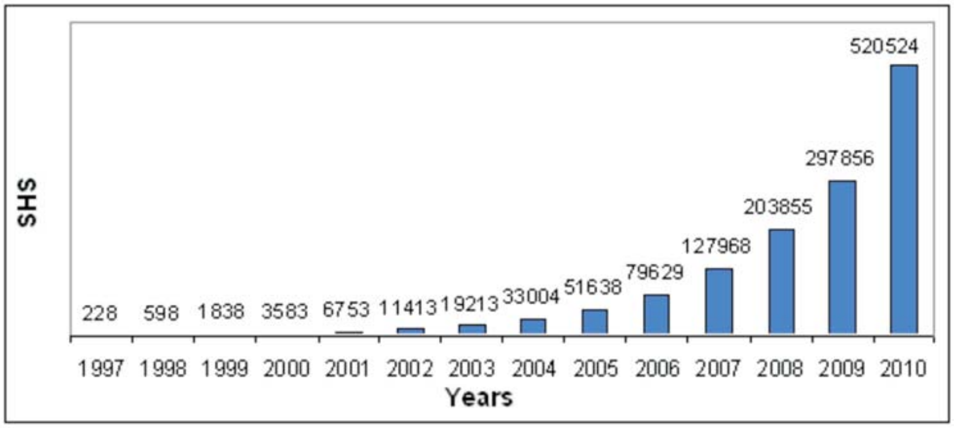

Figure - 2: Cumulative Growth of Installed Solar Home Systems

the importance of electricity for the socio-economic well-being of people, Grameen Shakti initiated the solar home systems (SHS) programme in 1996. Figure-1 shows the installation of a solar home system.

It started to deal with biogas and improved cooking stove (ICS) in 2005 and 2006, respectively. Grameen Shakti, is now one of the largest and fastest growing micro-generation programmes in the world. As of December 2010, Grameen Shakti has installed 520,000 solar-home systems, 14,353 biogas systems and 172,516 improved cooking stoves, as depicted in Figures-2 to 4. Owing to its rapidly expanding capacity in terms of trained human resource and infrastructure over the years, these technologies have experienced a remarkable growth. It is estimated that around 3.5 million people are benefiting from the services of Grameen Shakti. Some of the most important infrastructural features of Grameen Shakti programme that have contributed to its success are described below.

5.1.1 Vast Operational Network

In order to support its typical business-model and growth-strategies, Grameen Shakti has ensured its expansion in terms of not only human resource but also infrastructure. Its employee-base has grown from around 50 in 2001 to over 8,500 in 2010. Since 2001, a great emphasis has also been placed on the extension of operational/field network across the country. Having operated from its headquarters in Dhaka for the first 5 years, Grameen Shakti decided to expand its network in 2001, setting up 49 branch offices across the country by the following year.

The primary aim of branch offices was to improve the sales and after-sales services. Regional offices were also established to coordinate the newly created branch offices. Gradually, many of the functions of the headquarters were decentralized to the regional offices. Presently, there are 972 branch offices across the country, which are coordinated by 128 regional offices, as indicated in Table-3 (GS, 2011).

Table - 3: Network-growth of Grameen Shakti

Year	Employees	Branch Offices	Regional Offices
2002	88	49	8
2003	134	79	10
2004	201	105	17
2005	392	125	20
2006	906	227	32
2007	1683	340	55
2008	3155	515	77
2009	5053	670	104
2010	8510	972	128

Source: *GS, 2011*

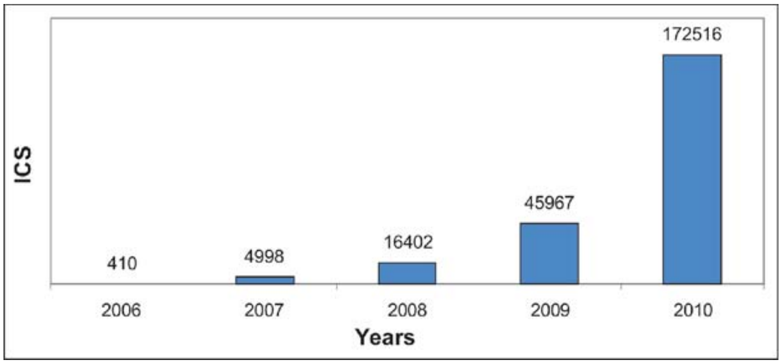

Figure - 3: Cumulative Growth of Installed Improved Cooking Stoves

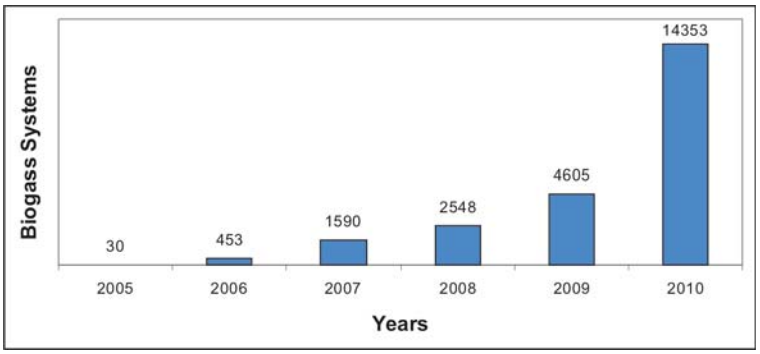

Figure - 4: Number of Biogas Systems Installed

5.1.2 Grameen Technology Centres

Grameen Shakti has established a wide network of technology centres, called Grameen Technology Centres (GTCs). The key objectives of GTCs include development of trained human resource, training of customers, improved after-sales services. The establishment of GTCs has been a very successful initiative and there are now 46 GTCs across the country. These centres have greatly contributed to the rapid growth and expansion of Grameen Shakti in the recent years. GTCs have already trained over 3,000 female technicians, who are either working at these centres or are working as renewable-energy entrepreneurs (GS, 2011).

5.1.3 Micro-utility Systems

In order to adopt the customers that cannot afford a solar-home system or a biogas system of their own, Grameen Shakti has introduced micro-utility models of these technologies. In this case, the system is owned by an individual customer who becomes a micro-utility by selling the generated electricity/gas to neighbours. There are now more than 10,000 micro-utility systems, which are mostly used within the commercial sector (GS, 2011).

5.1.4 Cost Optimization through Indigenous Production

In order to develop its renewable-energy systems at a lower cost, Grameen Shakti aims to develop

Table - 4: Financial Options Available to Grameen Shakti Customers

Package	Down Payment	Monthly Instalments	Service Charge (Flat Rate)
1	15%	36	6%
2	25%	24	4%
3 (for micro-utility)	10%	42	None
4	100% cash payment with 4% discount		

Source: *GS, 2011*

of the constituent components locally to the extent possible. In this respect, it has set-up a strong base of manufacturing and assembling facilities. In case of solar-home systems, for example, it locally develops a number of auxiliary components, including charge-controllers, lights and mobile chargers. Ultimately, the benefit of this strategy helps the customer, in terms of reduced system-cost. It has also helped Grameen Shakti develop a large pool of green technicians in the country.

5.1.5 Micro-credit Based Financial Model

One of the key-drivers behind the success of Grameen Shakti is its supportive financial model. The vast majority of its targeted customers-base–households and businesses in rural areas–cannot afford to purchase SHS or biogas systems on their own. Through its micro-credit programme, Grameen Shakti offers a range of financial and technical support-packages, to make renewable-energy affordable for its customers. Presently, Grameen Shakti is offering four alternate options to its customers, as shown in Table-4 (GS, 2011).

6. CONCLUSIONS

Lack of access to sufficient and affordable energy remains a major hindrance in the socio-economic progress of the developing countries. Owing to the limited economic and infrastructural resources in these countries, the extension of national grid is taking place at a very slow rate. Renewable energy is, therefore, considered as an appropriate alternative to meet the energy requirements in the areas far from grid. Bangladesh has established a micro-generation renewable-energy model that can be adopted by other developing countries as a role model. Grameen Shakti pioneered this micro-credit based model in Bangladesh.

The Grameen Shakti programme has grown at a remarkable rate, since its inception in 1996. Having installed 520,000 solar-home systems, 14,900 biogas systems and 195,000 improved cooking-stoves, Grameen Shakti has reached out to around 3.5 million people. The credit of its accomplishments goes to its innovative business-model. The key drivers of its success include financial model based on micro-credit, vast operational network, cost-effective production, Grameen Technology Centres (GTCs) and micro-utility systems.

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BIOGAS DEVELOPMENT IN RURAL AREAS OF PAKISTAN: A SUSTAINABLE OPTION FOR DOMESTIC ENERGY

*Muhammad Khurshid**

ABSTRACT

All those developmental activities that meet the needs of the present generation without jeopardizing those of the future are sustainable in terms of social, economic and environmental parameters. Energy, a major 'agent' of development, is mostly produced from fossil-fuels that are not only finite and costly to extract but also contribute to polluting the environment. Renewable energy sources, on the other hand, offer environment-friendly and economically viable options for energy generation in the rural areas. Biogas offers an opportunity for decentralized energy-generation in rural areas to all those potential households possessing livestock.

Rural communities traditionally use fuel-wood and cow-dung cakes as a source of energy in Pakistan. It has been reported that the annual per capita fuel-wood requirement is 0.52 m³ that implies a consumption of 5.20 m³ of fuel-wood for a family of 10 per year. Thus, a single family may cut three to four fully grown trees in a year just to meet its domestic energy needs. Over the years, this has been leading to degradation of natural forests, besides depriving the agricultural fields from decomposed organic manure.

Possessing a huge potential in the form of 10 million livestock for biogas development, Pakistan can produce 150 million m³ of biogas per day, i.e. 54,000 million m³ per annum. This huge untapped potential can prove to be a major source of income generation in rural areas through energy production, organic farming and trading carbon credits that could be earned under the Clean Development Mechanism (CDM) of the Kyoto Protocol, besides reducing emission of greenhouse gases in the atmosphere.

It would be advisable that the relevant policy-making organizations may work for devising a policy that encourages biogas development and promotion. One of the best ways to this end is to completely stop extension of natural gas pipelines to the rural areas in future and divert the cost of establishing such pipelines/networks to the development and promotion of biogas technology in rural areas of Pakistan.

1. INTRODUCTION

Sustainable development encompasses interventions that are socially acceptable, economically viable and environmently-benign and, thus, offers great prospects for future development, without leaving any environmental footprints. Countries or States that have adopted sustainable development agenda are in fact on the right path towards achieving their national development objectives. Renewable-energy development is an excellent means to sustainable development as, on the one hand, it can replace the fossil-fuels with a clean and environment-friendly source of energy and on the other hand, it offers cheap alternatives to fuel-wood in rural areas.

Pakistan is currently facing its worst ever energy-crises, as the energy demand and supply exhibit a great and increasing gap. Therefore, the Government of Pakistan implements load-management of electricity and natural-gas supply. The domestic and commercial consumers are consequently suffering badly. This situation has forced the policy-makers and planners to opt for various alternative sources of energy in Pakistan that are economically viable. One such option is the development of biogas technology, using cow-dung to produce biogas for domestic and commercial uses. Like other parts of the world, decentralized energy production based on biogas sources has been successfully demonstrated and adopted on large scale in rural areas of Punjab, Khyber Pakhtunkhawa and Azad Jammu & Kashmir (AJK). Hundreds of Chinese-style dome-shaped fixed concrete biogas plants of eight to 20 cubic metre capacity have successfully been demonstrated in supplying biogas for meeting domestic energy-needs during the past few years.

2. DOMESTIC ENERGY SOURCES

Currently, rural communities in Pakistan use fuel-wood and cow-dung as sources of domestic energy. Traditionally, rural households are used to keeping five to 10 heads of livestock (mostly buffaloes and cows) for their agro-pastoral livelihood activities. It has been estimated by FAO (2004) that about 50% of animal-droppings in the country are collected. Of this recovered quantity, about 50% is used as fuel for cooking, resulting in barely a quarter of the animal-droppings being available for use as organic fertilizers. The animal-droppings, together with an equal quantity of stable bedding material, left-over fodder and household-waste, provide for the total quantity of farmyard manure (FYM) available. About 50% of the farmers reported that they use FYM on one crop or another. Mostly, the communities pile up the cow-dung in their courtyard, which not only creates unhygienic

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conditions and emits green-house gases (GHG) into the atmosphere leading to global warming, but also serves as a breeding place for mosquitoes and flies. Burning of cow-dung cakes as a source of domestic energy pollutes the indoor environment by emission of dangerous gases, like carbon monoxide, that may cause various diseases. Cutting of trees for fuel-wood in rural areas is a major cause of deforestation and desertification in Pakistan, as 0.52 m^3 of wood-per-capita is used for meeting domestic energy-needs every year. Poultry farms also produce a huge quantity of poultry-waste that can potentially produce biogas but, currently, it is being dumped out in the open, causing pollution in the surrounding environment, and emission of greenhouse gases.

Traditionally, fuel-wood claims the largest proportion of biomass fuels used in developing countries (in some regions up to 90%), where about 40% of the total wood-cut annually is used for domestic purposes (cooking and heating). Estimating an average per capita consumption of 3 kg of wood per day for energy (cooking, heating and boiling water) in rural areas of Asia and Africa, the daily per capita demand of energy equals 10-15 kWh, which could be covered by about 2 m^3 of biogas. A biogas plant, therefore, directly saves forests, assuming that even deadwood is collected for fuel.

A biogas digester uses cow-dung and even poultry-waste in slurry form, and produces biogas and decomposed solids as organic manure. Pakistan possesses 63 million buffaloes and cows that yield 990 million kg of cow-dung per day. About 6 kg of cow-dung can produce 1 m^3 of biogas (natural gas). Thus, Pakistan possesses the potential of producing over 150 million m^3 of biogas per day and over 54,000 million m^3 per annum.

Pakistan has tremendous potential of developing small, medium and large-size decentralized biogas plants for domestic energy, as it possesses 10 million potential livestock-owning households. This huge untapped potential can prove a major source of income-generation in rural areas, through energy-production, organic farming and trading carbon-credits that could be earned under the Clean Development Mechanism of the Kyoto Protocol, besides reducing emission of greenhouse gases into the atmosphere. It is estimated that by developing biodigester, a family can actually earn PkR 3,150/- per month in the form of various products and, thus, the programme can help alleviate poverty in rural areas of Pakistan.

3. BIOGAS ENERGY TECHNOLOGY

Biogas typically refers to the gas produced by the biological breakdown of organic matter in the absence of oxygen, i.e. anaerobic fermentation. Biogas is the product of food-chain, in which the Sun's energy is trapped by green plants that are eaten by livestock as fodder to produce energy, fats, carbohydrates and proteins that the animals' body uses. The waste-products that are disposed of contain a lot of carbohydrates and other food nutrients and fibers, which are the major source of methane (CH_4) produced during the process of dung-fermentation by anaerobic respiration of bacteria.

Biogas originates from biogenic material and is a type of bio-fuel, which primarily consists of methane and carbon dioxide. Biogas can be used as a low-cost fuel for heating, cooking and power generation. Biogas can also be compressed, much like natural gas, and used to power motor vehicles. Being a renewable source of energy, biogas qualifies for renewable energy subsidies in some parts of the world. Biogas consists of the following gases:

Methane (CH_4)	50-75%
Carbon dioxide (CO_2)	25-50%
Nitrogen (N_2)	0-10%
Hydrogen (H_2)	0-1%
Hydrogen Sulphide (H_2S)	0-3%, and
Oxygen (O_2)	0-2%

Biogas offers a highly cost-effective and decentralized energy-production option at community and household levels. During 1970s, efforts were made to have large scale biogas production for energy use, but these efforts did not bring the expected results due to lack of technological capacity and awareness among the communities. However, recent technological advancements in biogas digesters have greatly helped in developing a highly efficient, economically viable, environment-and user-friendly biogas plants. The Chinese model of dome-shaped concrete biogas plant is successfully being used in China, India, Thailand, Vietnam, and, recently Pakistan, for biogas production from cow-dung. In rural China, anaerobic digesters are used to produce biogas energy for households, as well as organic fertilizers. Other benefits of this system include improved sanitation and conservation of environment. In China, approximately 5 million households are using anaerobic digesters.

A small and medium-scale domestic biogas plant constructed in the courtyard of a rural house costs not more than PkR 50,000/- to 70,000/-. It can generate 10 to 20 m³ of biogas, which contains 50 to 75% methane, a major source of energy that burns and produces heat energy instantly. Biogas could also be used to produce electricity, using common petrol based generators with little alteration. This clean source of domestic energy can replace the use of fuel-wood and cow-dung cakes, normally used as a source of domestic energy in rural areas. As a result, not only forests would be saved from cutting of fuel-wood but also cow-dung use in the biogas digesters will produce organic manure – a rich organic fertilizer.

4. SIZES AND COSTS OF DOMESTIC BIOGAS PLANTS

Depending on the requirements of biogas energy and the number of livestock heads that a typical rural family possesses, a domestic biogas plant with capacities of 8 m³, 10 m³ and 20 m³ could be developed. For 8 m³, three buffaloes; for 10 m³, four buffaloes; and for 20 m³, six buffaloes or their equivalent cow-dung is required for biogas production on a regular basis. The cost of developing domestic biogas plants depends on the location and varies from PkR 65,000/- to Rs. 140,000/- (US$ 700 to US$1,500) for these sizes. It has been observed that the investment can be recovered in about 15 months. The construction material is mostly indigenous and may not require any imported material.

5. DESIGN OF THE CHINESE DOME-SHAPED BIOGAS PLANT

Though the design and construction of the Chinese dome-shaped biogas plant is highly technical and may require the services of specialized experts and firms. The design of the smallest domestic biogas plant (8 m³) is given in Figure-1.

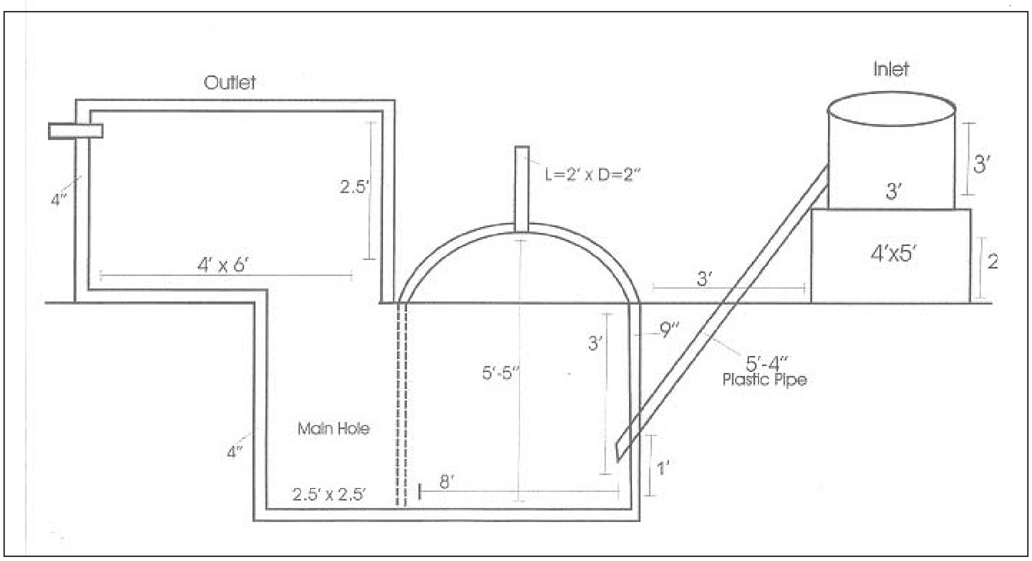

Figure - 1: Dome-Shaped 8M³ Biogas Plant

6. SOCIAL BENEFITS OF BIOGAS PRODUCTION

As the biogas digester produces decentralized natural gas in the courtyard of a household, this innovation can bring about a revolution in the rural society in terms of improved cleanliness, health and hygiene, as well as environment conservation. Women, mostly responsible for cooking, dish-washing, fuel-wood collection and making cow-dung cakes, will greatly be relieved from the agonies of: cutting wood from far off places and their transportation on head; dirty and unhygienic process of making cow-dung cakes and; above all, reduced exposure to indoor health hazards due to emission of smoke from burning of wood and cow- dung. Emission of smoke from burning cow-dung cakes increases the chances of tuberculosis. These chances can be completely eliminated if a household shifts to biogas plants. Heaps of cow-dung, normally dumped in the courtyards of rural households – a major source of diseases, insects and pests – will no longer exist, as cow-dung will be dumped in the biogas digesters on a daily basis. In addition, use of organic manure in agriculture will result in high yields and reduced health-bill.

7. ECONOMIC BENEFITS OF BIOGAS

The economic impact of biogas production on a rural family (with an average seven to 10 members) is a saving of Rs. 3,150/- per month spent on two cylinders of LPG, three mounds of fuel-wood, cow-dung cakes and cost of chemical fertilizer. Such saving is a big economic gain for a rural family and can help in poverty reduction in rural areas of Pakistan. In addition, adoption of this technology can also help in improvement of social, health and environment indicators of these areas.

Adoption of this simple technology can increase the income of poor rural communities, besides increasing organic energy production. Organic agricultural products can reduce the health-bill of rural communities and, thus, help in promoting sustainable production and consumption. These decentralized energy-production units can bring self-sufficiency to the rural households, save forests and provide organic fertilizers for the soil, increasing its productivity. The Government of Pakistan, local and international donor agencies interested in poverty-alleviation and decentralized organizations working for alternative-energy development may consider tapping this huge alternative-energy potential in Pakistan. This will greatly help in reducing the energy crisis in the country in the shortest possible time. The estimated economic impact of biogas production on a rural family (average 10-12 members) is given in Table-1.

8. FOREST PROTECTION/ENVIRONMENTAL BENEFITS

Communities in rural areas traditionally use fuel wood and cow-dung for cooking and heating. Apart from other environmental benefits, the most important environmental indicator of the project is conservation of natural forests. Based on the per capita fuelwood demand of 0.52 m³ per annum, an average family of eight members will need 4.0 m³ of fuel-wood to satisfy their annual domestic energy needs. Thus, at least four mature coniferous trees, or equivalent volume of other tree species, would be cut to satisfy this demand. The fuelwood supply sources are mostly State or community-owned forests. Consequently, this huge demand for fuel wood leads to rapid deforestation. By installing a single biogas plant, 10 mature trees will be saved from being cut to be consumed as a source of fuelwood annually.

Moreover, the annual demand of cow-dung for cooking alone ranges between 3,000 to 4,000 kg. Consequently, agricultural land is deprived of an enriched source of organic manure. The organic manure from the biogas plants, which is otherwise burnt as a source of domestic energy, would be used as rich organic manure that can increase soil fertility. It has been observed that using organic manure produced by the anaerobic digesters has increased the yield of various crops (almost three-fold), besides increasing soil moisture, improving soil-texture and producing organic products – a source of healthy food.

9. RECOMMENDATIONS FOR DEVISING AN IMPLEMENTATION STRATEGY

Biogas energy offers the most cost-effective and sustainable source of renewable energy in the rural areas of Pakistan. A huge untapped potential exists all over the country, especially in the Punjab. However, so far no serious effort has been made to make legal framework, institutional arrangements and provide incentives to the private-sector for duly exploiting this huge potential. Pakistan is already experiencing shortage of gas and electricity, and is resorting to load-management in both domestic and commercial sectors. Consequently, developmental activities aiming at income-generation in rural areas are being adversely affected. It is high time to devise policies and regulations for exploiting the available potential. In view of the above exposition, the following recommendations are made:

It is advisable that the relevant policy-making

Table - 1: Monthly Energy and Fertilizer Budget

	Cost before Biogas Plant (Rs.)	Cost After Biogas Plant (Rs.)
LPG=2 cylinder	1,800	0
Fuel-wood=3 maund	750	0
Dung cakes	Daily labour cost	0
Chemical fertilizer	600	0
Approx. Total Cost	**3,150/-**	0

organizations work for devising a policy that encourages biogas development and promotion, based on the following:

- Creation of awareness among the communities in rural areas for the promotion of biogas energy technology;
- Encouragement of participation of the private sector in biogas energy development in Pakistan; incentives and public-private partnership arrangements need to be made;
- Extension of natural gas pipelines to the rural areas in future, and diverting the cost of establishing such pipelines/networks to the development and promotion of biogas technology in rural areas of Pakistan;
- Enforcement of laws, rules and regulations for domestic, commercial and even compressed biogas energy technology development in Pakistan need to be made.

EXPLORING THE POTENTIAL OF SOLAR AND WIND ENERGY SOURCES FOR IRRIGATION: AN OVERVIEW FOR PAKISTAN

Abdul Wahab, Muhammad Yasin** & Muhammad Munir Ahmed****

ABSTRACT

Energy is one of the major concerns for pumping of water through tubewells, as it incurs high electricity tariffs and rising prices of diesel fuels. Cost-effectiveness (Capital and O&M) is essential for adopting solar and wind powered micro-irrigation for smallholdings.

Solar and wind-energy systems could provide economical ways to produce electricity for domestic and farm use, as well as pumping water for agriculture. This paper presents an overview of the potential of solar and wind energy-resources, and explores means to better understand and adopt pumping technologies with renewable energy sources, in an agrarian country like Pakistan. Some details of system design and comparison of solar and wind-powered systems are given.

Keywords: *Solar, Wind, Tubewell, Energy, Agriculture and Pakistan*

1. INTRODUCTION

The ever-increasing population of the world has increased the pressure on limited available fossil-fuels. The situation has forced the world to explore and develop the alternate sources of energy. The consumption of fossil-fuels (oil and natural gas) has reached the turning point, in view of confirmed energy reserves in Pakistan. The energy requirement of Pakistan is growing at a rate of 10-12% per year. It was 57.9 Million Tonnes of Oil Equivalent (MTOE) in 2006 and will rise to 177 MTOE in 2020.

Energy availability and usage have been and will continue to be important factors in improving the productivity of agriculture system (Lewis, 1984). Increasing energy costs can be one of the biggest expenses for a small business or agricultural operation. Therefore, one must carry out its management in a systemic fashion. Due to low availability of electricity and high fuel prices, the farmers face difficulties in using the existing water pumping systems. Fortunately, by virtue of Pakistan's location and natural endowments, many technologically feasible alternate energy resources, like solar and wind, are available to meet the country's growing energy requirements. These systems can be applied without the worry of fuel-supply or electricity transmission lines. Energy from the wind and sun, coupled with appropriate pumps, could help to meet the irrigation requirements. This new arrangement would bring down the running costs and, subsequently, the costs of agricultural produce (Becenen and Eker, 2005). Provision of alternative energy and upgrading the existing practices relating to energy production to more energy-efficient machinery may be a good solution to the prevailing energy crisis. Keeping in view the scarcity of energy and importance of irrigation in the agriculture sector, exploitation of alternate energy resources for enhancing irrigation and pumping efficiency will not only conserve conventional valuable energy-supplies but also reduce pumping-costs leading to lower cost of crop production. This paper also describes the method to calculate the required energy and required amount of resources to harness the necessary energy for irrigation.

2. AGRICULTURAL POWER SCENARIO OF PAKISTAN

The agricultural production system in Pakistan is in transition from the traditional, i.e. low energy-input methods of farming, to the modern agricultural production system that requires higher energy-inputs. Agriculture sector is an important but not the most dominant user of energy in Pakistan, as indicated in Figure-1. Generally, insufficient mechanical and electrical energy is available for agriculture and, hence, the potential gains in agricultural productivity through the deployment of modern energy-services are not being fully realized. Maintaining adequate energy-services for rural people would ensure increased energy-inputs to agriculture, leading to increase productivity, food-security and rural economic development. Moreover, to feed the constantly increasing population, it is of utmost importance to examine the current level of energy-use in agriculture sector and project future trends.

Lately, the agriculture sector of Pakistan is consuming energy of above 200 thousands Tonnes of Oil Equivalent (TOE) in the form of petroleum-products and almost 500 thousands TOE in the shape of electricity (Pakistan Energy Yearbook, 2003-04). During 2007-08, there were 895,511 public and private tubewells in Pakistan. Around 86% of these tubewells were located in the province of Punjab and the rest (14%) were located in the three other provinces of Pakistan, namely Sindh, Khyber Pakhtoonkhwa and Balochistan. The distribution of tubewells (based on

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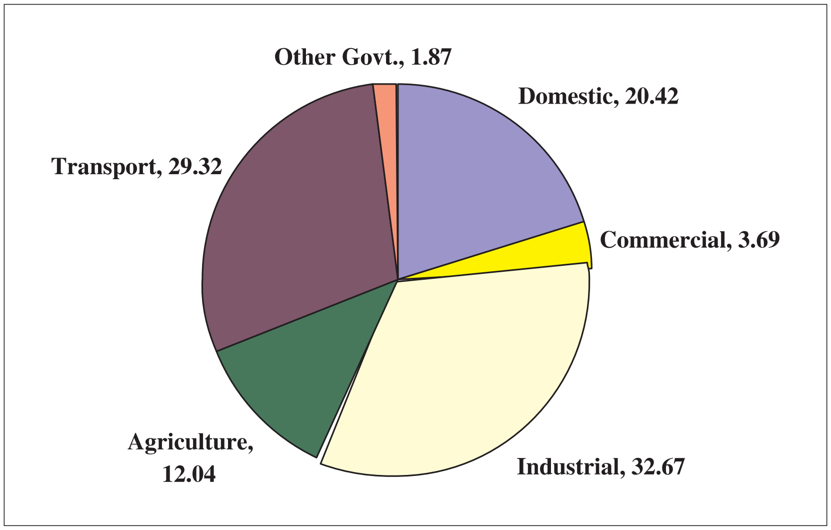
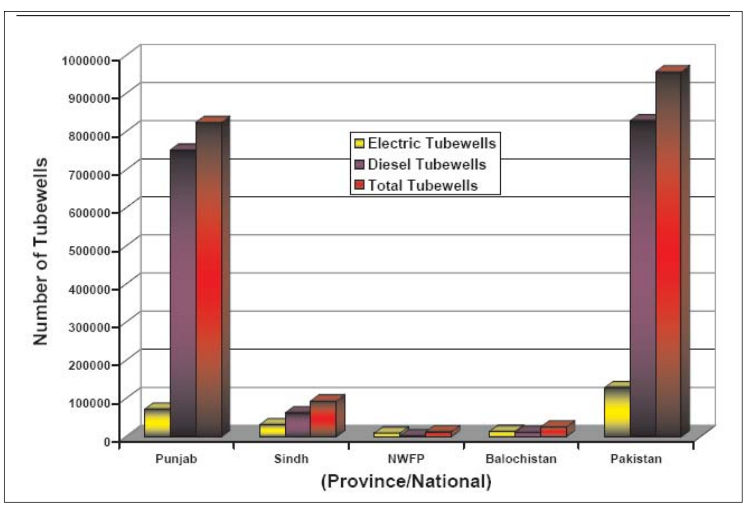


Source: *Pakistan Energy Yearbook 2007-08*

Figure - 1: Pakistan's Energy Consumption (% by Sector in 2007-08)

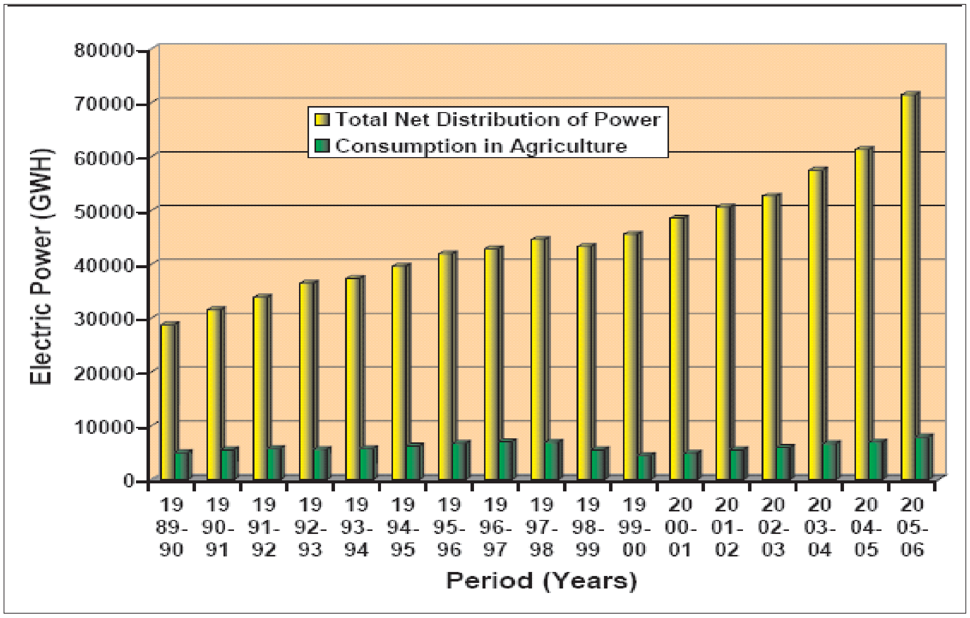
size of power) indicated that majority of electrically operated tubewells are in the range of 10-20 hp. The diesel-operated tubewells were in the range of 16-20 hp, because the diesel engines are normally available in this range. Population of diesel-operated tubewells in Pakistan was around 87% of the total number of tubewells available during 2005-06, whereas this percentage is around 88 in the province of Punjab. Thus, around 13% tubewells in the country were operated using electricity (Figure-2). Qureshi et. al, (2003) reported that more than 70% tubewells were operated using diesel in the province of Punjab. The total energy cost was PkR 16 billion for diesel tubwells and PkR 2.6 billion per year for electric tubwells. As a whole, farmers are spending about PkR 4 billion per year on repair and maintenance of private tubewells. Many efforts have been made to exploit the existing conventional energy-resources to build a strong indigenous exploration and production base. Inspite of all these efforts, the results achieved so far are neither cost-effective nor helpful in reduction of import dependence and promotion of self-reliance.

During 1990-2006, the net distribution of electricity to all the sectors had increased from 28,769 Giga Watt Hours (GWh) to 71,466 GWh.The growth-rate was



Sources: *Agricultural Mechanization Census 2004 of Pakistan*

Figure-2: Distribution of Electricity & Diesel Operated Tubewells at Provincial & National Levels



Source: *Ministry of Petroleum and Natural Resources, (2006)*

Figure - 3: Consumption of Electric Power in Agriculture at the National Level

5.85% per annum and the total increase during this period was 148%, which is a huge increase in availability of electricity in the country. The use of electric power in agriculture sector also increased from 5,027 GWh to 7,949 GWh during this period with annual growth rate of 2.9%, which is almost half of the overall growth in the power sector (Ahmad S., 2007) (Figure-3). Thus agriculture sector is a slow consumer of power in Pakistan. The per cent share of agriculture sector in usage of power was around 17% during 1989-90, which came down to 11% during 2005-06. This was primarily due to the increased availability of power, as a whole. There is a clear indication that availability of power to the agriculture sector is an issue, as the rural power infrastructure is limited and farmers have to pay considerable amounts of money for getting an electricity-connection. Thus, only resourceful rich farmers can have access to electric power.

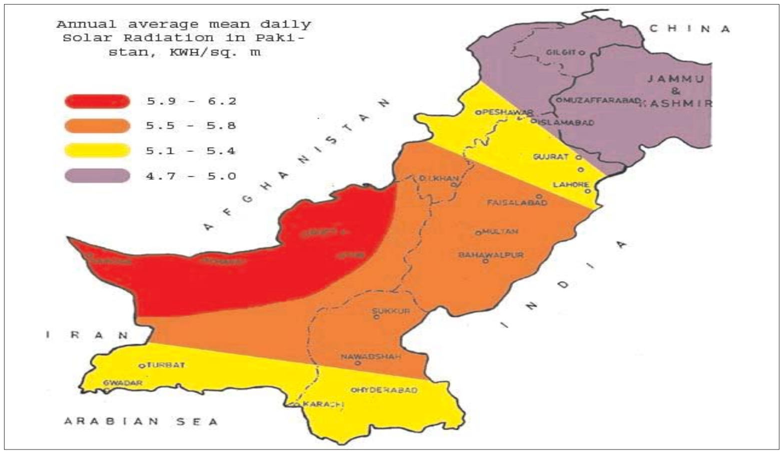
3. POTENTIAL OF SOLAR AND WIND ENERGY RESOURCES IN PAKISTAN

The energy-production and consumption of a country have a significant impact on its economic development. To be economically feasible for agricultural applications, the cost of water delivered must be less than the value of the benefits obtained through the use of irrigation water, either through improved yields or by enabling more crops to be grown per year. So we present here some relevant figures for solar and wind energy pumping.

3.1 Solar Energy

Solar energy is pollution free and can replace a part of conventional energy. It is available in abundant quantities and is free of charge. The annual average mean daily solar radiation in Pakistan is 4.7 to 6.2 KWh on each square meter area, and most parts of the country enjoy clear sky for 300 or more days per annum (Figure-4). The monthly daily mean solar-energy profile of major cities of the country is shown in Table-1, which indicates that it is the most promising potential source of energy for Pakistan. The average Rabi irradiation is 20 M.J/m^2/day in Quetta; 25 in Peshawar; 24 in Multan; and 22 in Lahore (Zakir et. al, 2000).

Solar energy is used mainly for pumping water for livestock or for domestic use. It is seldom used for irrigation, because of the large amounts of water needed for growing crops. However, solar pumps are feasible for irrigation that use very low heads or has very low lifting requirements, such as drip irrigation, which uses less water than other types of irrigation-systems. Solar pumps work by converting solar radiation into electricity, through the use of photocells made of silicon, usually called photovoltaic (PV) cells. The PV cells are enclosed in a glass frame making the



Source: *National Renewable Energy Laboratories (NREL) of USA*

Figure - 4: Annual Average Mean Daily Solar Radiation in Pakistan

solar module. Usually, an array of solar modules is needed to produce enough energy for the pump. The modules are mounted on a frame in an assembly called a PV array. The PV array is connected to a controller and then through an electrical power cable to the motor/pump subsystem in a well. Solar pumps usually use a direct current (DC) motor (The motors that use alternate current (AC) must have an AC to DC inverter). DC motors are recommended because using an inverter costs more, and some power is lost in the AC to DC conversion.

A problem with DC motors in the past has been that they needed carbon brushes, which wore out and needed regular replacement. Maintenance-free DC motors have recently been developed that use an electronic circuitry to perform the same function as the brushes. Today, most submersible pumps use brushless DC motors or AC motors with an inverter. The cost of photovoltaic modules has come down by a factor of 400 per cent in the last 30 years (Helikson et. al, 1991). This trend continues and will help in reducing the cost of photovoltaic-powered water pumping systems. A solar pump requires low maintenance and can operate without any attendant. With the rapid decline in the price of cells and associated equipment, the system has a potential to spread widely in the coming years of probable energy shortage. Photovoltaic technology will also continue to improve the power-conversion efficiency of the photovoltaic cell. Increase in photovoltaic cell efficiency will decrease the cost of photovoltaic power, because fewer modules will be required to produce the same amount of power.

Table - 1: Monthly Mean Solar Radiation in $kWh/m^2/day$ in Major Cities of Pakistan

Month	Karachi	Lahore	Multan	Peshawar	Quetta
January	4.38	2.97	3.52	0.35	3.91
February	4.97	3.86	4.27	4.06	4.59
March	5.82	5.04	5.20	5.07	5.64
April	6.23	5.79	6.30	6.02	6.63
May	6.44	6.32	6.70	6.96	7.61
June	6.30	6.18	6.52	7.19	8.22
July	5.31	5.70	6.42	6.50	7.45
August	4.94	5.20	6.02	5.91	7.32
September	5.50	5.06	5.65	5.37	6.70
October	5.38	4.19	4.64	4.40	5.64
November	4.66	3.44	3.84	3.53	4.48
December	4.12	2.83	3.20	2.90	3.77

Source: *Pakistan Meteorological Department (PMD)*

Table - 2: Monthly Benchmark Wind Speeds for Jhimpir site

Month	Monthly Benchmark Wind Speed				
	30 m	50 m	60 m	67 m	80 m
January	4.25	4.70	4.90	5.02	5.24
February	4.50	4.98	5.18	5.32	5.55
March	4.77	5.28	5.50	5.64	5.89
April	6.39	7.03	7.29	7.46	7.75
May	8.29	9.05	9.36	9.56	9.90
June	8.79	9.50	9.78	9.96	10.25
July	8.83	9.59	9.89	10.08	10.40
August	8.20	8.89	9.16	9.34	9.63
September	6.63	7.28	7.54	7.72	8.01
October	4.22	4.68	4.87	50.00	5.22
November	3.59	3.98	4.14	4.24	4.43
December	3.96	4.38	4.56	4.67	4.88
Annual Average	**6.0**	**6.6**	**6.8**	**10.8**	**7.3**

Source: *Pakistan Meteorological Department (PMD) & Alternative Energy Development Board (AEDB)*

3.2 Wind Energy

Pakistan has a considerable potential of wind energy in the coastal areas of Sindh, Balochistan, as well as the desert areas of Punjab and Sindh. Sites having good wind-speed will be useful for modern windmills, which require minimum wind speed of more than 7 MPH for achieving wind power for pumping drinking water and small scale irrigation. This renewable source of energy, however, has so far not been utilized significantly. The coastal belt of Pakistan is blessed with a natural wind-corridor that is 60 km wide (Gharo ~ Keti Bandar) and 180 km long (up to Hyderabad). This corridor has the exploitable potential of 50,000 MW of electricity generation through wind energy. The wind-data of selected areas have been collected by Pakistan Meteorological Department (PMD) and analyzed by the Alternative Energy Development Board (AEDB) to make a wind-resource study to setup the benchmark for wind-speed values at different levels from Gharo and Jhimpir regions (Table-2).

Wind is often used as an energy source to operate pumps and supply water to livestock. Because of the large quantity of water needed for crops, wind power is rarely used for irrigation. As larger and more efficient wind-mills are developed, single or groups of these wind-mills are expected to be used for irrigation projects.

A windmill consists of the following parts:

- A very large fan with 15 to 40 steel or galvanized blades;
- A gear-box mechanism driven by the blades. This mechanism converts the rotary motion of the blades to an up-and-down motion;
- A piston pump, which is driven by the up-and-down motion produced by the gear box mechanism;
- A pump-rod that descends from the windmill to the well;
- A pump cylinder, which is placed in the water near the bottom of the well and is driven by the pump rod.

The propeller should have many blades to develop a high starting torque, which is needed to start the piston pump. Generally, windmills begin working when the wind speeds exceed 7 MPH.

3.3 A Comparison: Advantages and Disadvantages of Solar and Wind Energy

The main advantage of using renewable energy for pumping water to meet irrigation needs is that there is no energy cost. The power source – either wind for a wind pump or sunshine for a solar pump – depends on the weather conditions of the given place. However, these conditions generally are constant at a given location from year to year, but vary with the season.

The water pumped from wind and solar systems is generally stored in tanks. In case of breakdowns or poor pumping conditions (unfavourable weather), the storage tank needs to be big enough to store a supply of water for several days. When the water tank is full, the extra generated energy can be stored in batteries. However, there are several drawbacks of storing energy in batteries:

- It is expensive.
- Only a small amount of energy can be stored (less than 1,000 or 2,000 watts per hour, depending on the number of batteries and their capacity).
- The batteries need to be replaced at least every 5 years.
- Storage batteries raise the initial cost of the total system.

Some advantages and disadvantages of using solar or wind energy are presented in Table-3.

4. SYSTEM DESIGN AND INSTALLATION

To make a wise decision on renewable energy sources, some basic aspects should be kept in mind, including:

- How solar and wind energy pumps work?
- The main components of these pumps;
- The advantages and disadvantages of solar and wind energy pumps;
- How to calculate pumping requirements?

It is also important to consider the costs of buying and using a pumping system, which include the initial cost, energy cost and maintenance cost.

4.1 Energy for Pumping Water

For pumping water, first the hydraulic energy (E_h) is calculated by using the following equation:

$$E_h = \mu g v h$$

where

E_h = required hydraulic energy in joules
v = required volume of water (m^3)
h = total head (m)
μ = density of water (1000kg/m^3); and
g = gravitational acceleration (9.81 m/s^2).

Example: The energy requirement for pumping 60m^3 of water through a head of 10 meter will be:

$$\begin{aligned} E &= \mu g v h \\ &= 9.81 \times 60 \times 10/1000 \\ &= 5.89 \text{ MJ Approx.} = 1.64 \text{ kWH} \end{aligned}$$

The power required to lift a given quantity of water depends on the length of time for which the pump is

Table - 3: Comparison of the Advantages and Disadvantages of Solar and Wind Energy Systems

	Factor	Wind System	Solar System
Advantages	Favorable Weather Portability	Steady winds are most productive	Pumping of water is consistent round the year. Can be portably mounted to use in different locations.
Disadvantages	Lifetime	Can exceed 50 years, except for the piston pump, which requires maintenance every 1 to 2 years.	More than 20 years. The pump lasts less time.
	Stormy weather	Wears more rapidly in high winds. Destructive winds can ruin system.	Panels can be damaged by hail. Cloudy weather and short days reduce energy production.
	Time of year power requirements	Power production stopped when wind speeds are low, which occurs in July and August when water is needed most.	
	Initial cost	Lower initial cost.	Higher initial cost.
	Maintenance cost	Requires more maintenance.	Less maintenance.

Source: *Encisco and Medic, 2004*

used. Power is the rate of energy supply, so the formula of hydraulic power is obtained from the formula for energy by replacing volume with flow-rate Q in cubic meters per second.

$$P = \mu g Q h \text{ Watts}$$

If flow rate Q is in litres per second, then hydraulic power is:

$$P = 9.81 \, Qh \text{ Watts}$$

For example, the average hydraulic power required to lift 60 m^3 of water through a 5 m head in a period of 8 hours, i.e. an average flow rate of 2.08 lit/sec, would be 9.81x2.08x5 = 102 watts (approx). With a typical pump efficiency of 60%, the mechanical power required would be 102/0.6 = 170 watts.

The head has a proportional effect on the energy and power requirements, with the result that it is cheaper to pump water through lower heads. A pump consists of two parts: static-head or height, through which the water must be lifted, and the dynamic-head, which provides pressure equivalent of the velocity of the fluid. The static-head can easily be determined by measurement and there are formulae for calculating the dynamic head. The latter depends on flow-rate, pipe-size, and pipe materials. The smaller the pipes and greater the flow-rate, the greater pressure required to force the water through the pipes (Chaurey et. al, 1992).

For a solar system, the number of solar panels should produce the number of watts needed by the pump. Solar panels or modules have different capacities; there are modules of 25, 50, 70 or 75 watts.

4.2 Estimating the Size of the Windmill

Before installing a wind-mill, it is necessary to know the requirements of a particular area, such as: wind speed, type of head and daily water-consumption. A wind-mill's pumping output is affected by three factors: wind speed, wheel or blade diameter, and the diameter of the cylinder (Table-4). Wind speed has an important effect on the pumping output. In fact, the power available from the wind is proportional to the cube of the wind speed. This means that *when the wind speed doubles, the power increases upto eight times.* Most windmills do not operate at wind speeds of less than 7 MPH or more than 30 MPH, as the mill can be damaged by high-speed winds.

5. PROSPECTS OF SOLAR AND WIND POWERED PUMPING SYSTEMS IN PAKISTAN

Recognizing the importance of sustaining the fulfilment of agricultural energy-requirements, the Government of Pakistan should take initiatives to formulate solar and wind-powered water pumping programme and explore the viability of widespread use of these renewable energies, to satisfy the irrigation requirements of the agriculture sector. From a macro-perspective, solar and wind-powered pumping systems can prove to be the most

Table - 4: Pumping Capacities as Influenced by the Diameter of the Cylinder and Blade Diameter of the Windmill

Cylinder diameter (inches)	Pumping capacity (gallons per hour) Wheel diameter (feet)		Blade diameter (feet)					
	6	6 to 8	6	8	10	12	14	16
			Pumping elevation (feet)					
2	130	190	95	140	215	320	460	750
2 1/2	225	325	65	94	140	210	300	490
3	320	470	47	68	100	155	220	360
3 1/2	440	640	35	50	76	115	160	265
4	570	830	27	39	58	86	125	200
4 3/4	-	1,170	-	-	41	61	88	140
5	900	1,300	17	25	37	55	80	130
6	-	1,875	-	17	25	38	55	85
8	-	3,300	-	-	14	22	31	50

Source: *Encisco and Medic, 2004*

appropriate and economical solution if direct and indirect subsidies are given to renewable energy sector. Seventy per cent of agricultural production is in the hands of small farmers who are the backbone of agricultural production of Pakistan, but unfortunately are not in a position to absorb the up-front payment required to procure solar and wind-powered pumping systems. In addition, there is little effective infrastructure in place, even if investment solutions are found. On the other hand, the private sector has insufficient expertise to provide systematically designed solutions for farmers' energy-requirements. The private sector depend is only on some thumb rules and general information. That is why almost all systems installed throughout the country are either over or under-designed, resulting in great failure and a sense of disappointment to the farmer-community.

6. CONCLUSIONS

a. The introduction of solar and wind-energy systems could provide economical ways to produce electricity for farm-use and pumping water for livestock and irrigation.
b. The solar and wind-powered pumping systems can play a significant role to replace electricity and diesel operated tubewells, provided the government takes initiatives at mass level and formulates a policy at national level to provide subsidy on initial costs of solar and wind-powered pumping systems.
c. Furthermore, there is a need to develop a comprehensive strategy and approach to promote the private sector to take a technological lead in this field.

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