PUBLIC LECTURE SERIES

SOLAR ENERGY, A FRIENDLY RENEWABLE ENERGY OPTION FOR NIGERIA.

ELISHA. B. BABATUNDE
Professor of Physics
Covenant University

Corporate & Public Affairs
Covenant University
Canaanland, Km. 10, Idiroko Road, Ota, Ogun State, Nigeria
Tel: +234-1-7900724, 7901081, 7913282, 7913283

Covenant University Press
Canaanland, Km. 10, Idiroko Road, Ota, Ogun State, Nigeria

ISSN 2006---0327
Vol. 1, No. 15, June, 2007

Public Lecture Series Volume 15. 28th June, 2007

ELISHA. B. BABATUNDE

Professor of Physics
Covenant University

INTRODUCTION

It was said by Brinkworth(1972) that the process of economic growth, which ultimately results in the improvement of the living standards of the society is traceable to, and depends, to a large extent, on the substitution of machine power for muscle power for fast and efficient performance of every type of physical task. Therefore, the provision of abundant and inexpensive energy to run machines to do work is inevitable for the building of modern society and for accelerating its economic growth. In this sense, it is not difficult to identify **Energy** as one of the main factors responsible for disparity and widening of "developmental gap" between the **developed, developing** and the **underdeveloped** nations of the world. Nigeria is regarded as one of the underdeveloped countries of the world. Talking about Nigeria being underdeveloped, we heard sometimes early this year, that Nigeria is one the nations in the world with the highest population of hungry people. Put otherwise, Nigeria can hardly feed her self. Nigeria's per capital is less than US$ 1.0.

The increase in the living standards, through which Europe first began to draw away from the rest of the world, stemmed directly from the Industrial Revolution which began in Britain about 200 years ago. Mechanization and other associated technological developments are seen as a key to a general promotion of economy thus improvements in the living standards. It is important to note that the success achieved in mechanization and technology was as a result of the provision and development of diversified sources of energy. And since the industrialization of society began in Britain over 200 years ago, the demand for energy soon passed far beyond the level which could be provided for by non-renewable sources of energy alone. The utilization of power went from the usual non commercial fuels like wood, agricultural wastes and animal dung to coal, oil, natural gas, hydroelectric and nuclear power. The total demand for energy escalated from about 3 10^{12} kWh in 1825 to about 13 10^{12} kWh in 1982, and to about 200 10^{12} kWh by the year 2000 (Brinkworth, 1972). The last figure represents an increase of about 16 times within 18 years of recent time, whereas it was only an increase of about 4 times from the beginning of the Industrial Revolution to 1982.

Khan (1983), in projecting the future world "final" energy demand came up with the following:

for the year 2000 - 10.71 TW yr
for the year 2030 - 19.16 TW yr.

These figures represent what is known as the “final energy” or “processed energy” after which a lot of energy must have been lost through various conversions and transmissions. Thus, it is expected that the primary energy supply figures would at least double the above, considering the inefficiency of the conversion machineries.

FORMS OF ENERGY

Energy is the property of a system that enables it to do work. That is, work cannot be done without having energy; energy is expended to do work. In other words, the amount of work done is determined by the amount of energy put in. When the supply of energy is exhausted in a system, the system stops working. For example, when fuel is exhausted in a vehicle, the vehicle stops moving.
According to the law of conservation of energy, energy is transformed from one form to another, but cannot be destroyed nor created. Hence energy exists in various forms and can be transformed into various forms depending upon need. Major forms of energy are:

- ***mechanical,***
- ***chemical,***
- ***electrical,***
- ***heat,***
- ***light,***
- ***Sound etc.***

Transformation or conversion of energy takes place from one form to another. For example, ***chemical energy*** of oil or gasoline is transformed via combustion to ***mechanical energy,*** which is manifested in motion (kinetic energy). Another common transformation is electrical energy, which is converted or transformed to mechanical energy or light energy or heat energy and vice versa according to need.

The use of energy is enumerable, and of common knowledge in everyday life. For example, food is a form of chemical energy transformed into heat and motion energy in human beings. Human being, in a sense, is a form of thermodynamic engine which takes in energy, does work and rejects some energy.

Motion is a prime action in any life activity. Consider motions in everyday life, from the motion of atomic particles to that of Galaxies and planets in the universe, motions of machines in industries, and human beings moving from one place to another. All activities involve one type of motion or the other: circular motion, oscillatory motion, translational motion, etc.

Motion, therefore, is said to take place when an object is displaced from one point to another. To start motion, or increase motion or stop motion, force must be exerted to overcome the inertial of the moving body and therefore the force is considered to have done work, and this implies that energy has been expended. It is plausible therefore to conclude that energy is the prime mover of life and bedrock of the development of any nation.

CONVENTIONAL ENERGY SOURCES AND THEIR LIMITATIONS

The main sources of energy supply in use, depending on the standard of living, in the world today are:

? ***Wood***
? ***Fossil fuels***
? ***Nuclear***
? ***Biomass***
? ***Bio-diesel***
? ***Hydroelectricity***
? ***Wind***
? ***Geothermal and***
? ***Solar energy.***

These can be classified as conventional and non-conventional energy sources.

The Conventional Energy Sources

These are non-renewable energy or fuels sources such as wood, fossil fuels (which include coal, petroleum, and kerosene) and nuclear energy. They are non renewable energy sources because they are exhaustible, depletable or not reproducible. The world's current main sources of energy are the fossil fuels, which are coal, oil, natural gas and nuclear, which are exhaustible. They, however, are needed to be complemented in many countries, like ours, by hydroelectricity, wood, animal dung and agricultural wastes particularly for cooking. Oil and gas are considered processed energy which are more convenient fuels than coal and have therefore steadily replaced coal in power generation and heating plants.

Among the conventional energy sources, fossil fuels are the chief. The fossil fuels are unfortunately depleting fast to a point where it is unlikely to be able to sustain the great rate of the world energy consumption within the next 200 years. It is in fact understood that about 80% of the world's oil reserves have been consumed by 1980 at the rate of the world energy consumption in 1975 (Meinel and Meinel 1975).On the home front (Nigeria), it was reported that, by 1984, 23 years ago, after 22 years of production of oil then, over 40% of our proven petroleum reserves had been exploited (Marinho, 1983).It is certain that today, at the rate of production of about 2.2 million barrels per day (2004 budget) now, our oil reserves may be completely dry up in few decades. However natural gas is reported to be available in very large quantity, but we cannot accurately estimate its life span considering its uncontrolled flaring and wastage due to mismanagement(Aladekomo, 1983). The remaining reserves of coal in the world is estimated to last for about 25 years, while the life expectancy of the oil and gas reserves in the world is not definitely known.

As of now, oil remains the chief source of energy of the world. According to Eden (1983), the projected world total energy demand, if oil were the only source, is 130 10^{6} barrels per day by the year 2000, whereas at that time the oil production was about 53 10^{6} barrels per day. This would represent about 38.5% of the demand. This indicates the incapability of oil to continue to meet the energy demands of the world. As the world population increases and the economic standard of third world countries improves, there is an expectation of an unprecedented rise in the global energy demands. Therefore to allow the traditional energy sources, that is, fossil, nuclear, or hydro fuel, to meet these increasing energy demands now and for too long in the future will be unwise and suicidal. The reasons for this strong opinion being:

? There is a strong international consensus on the threat of dangerous climate change due to pollutants emitted from fossil fuels powered engines. This threat is heightened by the rapidly increasing demand for fossil fuels, which in recent years propelled the price of crude oil above US$ 60 per barrel for the first time. This has demonstrated that production of "cheap" fossil fuels, which we may deplete completely by the middle of this century, can no longer cope with the demands. We therefore have to pay more to quickly bring about dangerous climate change, and if we survive that, wait for the highly probable energy crisis.

? The ecological impact of turning every river into a dam for hydroelectric power if possible, is scary and hard to imagine.

It has also been recognized that the heavy reliance on fossil fuel has had an adverse impact on the environment. For example, gasoline engines and steam-turbine power plants that burn coal or natural gas send substantial amounts of sulphurdioxide (SO_2) and nitrogen oxides (NO_2) into the atmosphere. When these gases combine with atmospheric water vapor, they form sulphuric and nitric acids, giving rise to highly acidic precipitation which endangers plants and human beings. Further more, the combustion of fossil fuels also releases carbon dioxide into the atmosphere; the amount of this gas in the atmosphere has been observed to have steadily risen since the mid-1800, largely as a result of the growing consumption of coal, oil and natural gas. More and more scientists believe that the atmospheric built up of carbon dioxide (along with that of other industrial gases such as methane and chlorofluorocarbon) may induce green house effect, causing the rising of the surface temperature of the earth by increasing the amount of heat trapped in the lower atmosphere. This condition could bring about climate changes with serious repercussions for natural and agricultural ecosystems.

Similarly, nuclear power generation as a source of alternative energy faces lots of social objections due to the possible radiation hazards that it may cause during production. Scientists cannot estimate the extent and gravity of destruction, both immediate and long term, that nuclear radiation hazards can cause when nuclear power reactor accidents occur as was the case of the Russian's Chernobyl nuclear power plant accident in 1987.

Moreover the nuclear power material, if inappropriately stored, could end up in wrong hands and get turned into weapons of mass destruction that could make terrorism assume a much more dangerous dimension.

However, nuclear energy appears to be potentially capable of at least obviating world energy starvation for a long time. In fact it may be capable of taking over the bulk of energy supply as the fossil fuels become exhausted.

ENERGY CRISIS IN THE WORLD AND ITS IMPLICATIONS

The world energy crisis in 1973 arising from the international oil politics resulted in the oil glut of 1982 and placed the world, particularly the industrialized nations, in precarious position energy wise. One immediate consequence of the crisis was the high price of oil, which is still in place today. The response to this was the prudent energy management embarked upon and the search for alternative sources of energy by the world. The industrialized nations in particular, began to make frantic efforts through their policy makers and scientists by formulating imaginative energy policies and developing alternative sources of energy.

The oil price, as the market leader, will possibly continue to determine the ceiling price of other fuels, and will determine the extent and rate of oil substitution and investments in alternative energy resources and conservation. The price fluctuation in oil will continue to adversely affect the economic growth of many nations particularly the developing nations. The price increase, which we are witnessing today, may continue to increase to such a point that only very few countries will be able to rely on increasing their oil imports. Not only this, the richest oil countries themselves are also likely to follow very prudent policies regarding the depletion of their non-renewable energy resources.

Within a year, we have witnessed the price of oil rising from about US$18 per barrel to about US$ 78 per barrel, an increase of about 300%. We heard, a few months ago at a public lecture as this, that America, as a result of this incessant oil price rise, called on her scientists to develop alternative sources of energy. There is therefore a need to diversify the energy mix and gradually move away from the traditional energy sources to alternative environmental friendly energy sources like the renewable energy (EPIA/Greenpeace Blueprint, 2004).

RENEWABLE ENERGY SOURCES

These are energy sources that are not exhaustible within human time scales. They include **wind**, **marine**, **geothermal**, **biomass**, **bio-diesel, hydro power**, **landfill** and **solar energy**. Many countries have initiated programs of development of Renewable Energy sources to enable them reduce their fossil fuel consumption and its attendant problems. They have even gone far, not only in utilizing them but commercializing them. Some of these sources whose utilization may be feasible and practicable here in Nigeria are discussed briefly.

a. Biomass Energy

Biomass energy or bio energy is energy produced from organic matter by an anaerobic digester. Technically, biomass can be defined as the bio degradable waste products and residues from agriculture (including vegetables and animal substances), forestry and related industry as well as the bio degradable action of industrial and municipal waste. Thus, in another sense, biomass can summarily be the defined as the products consisting of any whole or part of a vegetable matter from agriculture or forestry that can be converted to fuel for use as energy. The following wastes for example are used for such fuel production:

? Vegetable waste from agriculture and forestry.

? Vegetable waste from food processing industry if the heat generated is recovered.

? Fibrous vegetable waste from virgin pulp production and from production of paper from pulp if it is co-incinerated at the place of production and the heat generated is recovered.

? Cock waste.

? Wood waste with the exception of that which may contain halogenated organic components or heavy metals as a result of treatment with wood preservatives or coating, and which includes wood waste originating from construction and demolition waste.

? Fumes from landfills can be considered as a biomass energy source.

Biomass generates about the same amount of CO_2 as fossil fuels, but every time a new plant grows, CO_2 is removed from the atmosphere. The net emission of carbon dioxide will be zero as long as plants continue to be replenished for biomass energy purpose.

The energy crops such as the fast growing trees and grasses, which are called biomass feed stocks, are the raw material for producing bio-energy. The production of the biomass feed stocks can help increase profits for the agricultural industry (Nakicenovic et al, 1998).

The following statistics in Table1, on the amount of biogas produced and producible from the common biomass feed stocks in our country, will indicate the potential of energy available to us in this country:

Table 1. Energy Potential of Biomass Sources (Renewable energy World March April 2004, vol. 7, No.2)

S/N	WASTES	BIOGAS	AVAILABILITY
1	1 Tonne of Pig manure produces	$30m^3$ of biogas	All these are Biogas material available in Nigeria. note: $1lt.=10^{-3}\ m^3$
2	1 Tonne of Corn produces	$200m^3$ of biogas	
3	1 Tonne of Grass silage produces	$230m^3$ of biogas	
4	1 Tonne of Vegetable produces	$90m^3$ of biogas	
5	1 Tonne of Chicken slurry produces	$50m^3$ of biogas	
6	1 Tonne of Cow slurry produces	$30m^3$ of biogas	

b. Bio-Diesel

? Bio-diesel is a naturally oxygenated fuel produced from organic feed sources such as soybeans, cooking oil, and animal fats. Bio-diesel can be used in its pure form (B100) or blended in any ratio with petroleum diesel to achieve cost efficiency and cold weather performance. It is commonly used as B20 - a blend of 20% bio-diesel and 80% petroleum diesel.

? Bio-diesel can be used in any diesel vehicle without modification.

? Bio-diesel performs like traditional diesel.

? Bio-diesel results in significantly lower emissions of particulate matter, carbon monoxide, toxic contaminants, sulfuroxides, hydrocarbons, etc. than petroleum diesel.

? Bio-diesel is non-toxic and biodegradable and therefore poses no threat to water or soil resources. It is environmentally friendly.

c. Ethanol

Another form of biomass energy is ethanol. Ethanol fuel is produced from sugarcane and cassava. The potential of such energy is demonstrated by Brazil which initiated a national programme to produce **ethanol** fuel from sugarcane in 1975. By 1980, only five years after, 20% of their fuel energy is ethanol. Within 1983 1989, large majority of cars sold in Brazil consume neat ethanol. Other data are:

? Ethanol production reached 13 16 billion litres per year in 1990.

? At the same time the cost of producing ethanol steadily declined due to the improvement in sugarcane production cost.

? Ethanol now provides about one third of the fuel consumed by cars and light trucks in Brazil.

? Not only that, ethanol fuel programme provides 700,000 jobs, farmers earned more, more sugarcane farms and ethanol industries were established.

? $33 billion in oil imports was saved in the period 1976 1996 as a result of Ethanol production.

? The introduction of ethanol fuel has also improved urban air quality, reduces carbon emission, water pollution and soil degradation.

? Brazilian government was able to achieve this, by giving low interest loans for the construction of distilleries, guaranteed purchase of ethanol by the oil companies and sales tax incentives.

Nigeria has fertile lands on which sugarcane and cassava, an ethanol production crop also, can be produced in large quantities at various locations all over the nation with the establishment of associated distilleries.
The following parts of the country are possible locations of feasible ethanol programmes:

? Papa Lanto and surrounding areas in Ogun State,
? Jebba and Bachita in Kwara State, and
? The vast areas of Zaria, Yahuri in the Northern part of Nigeria, are a few of such places in Nigeria for large scale production of sugarcane, and setting up ethanol production plants.

d. Wind Energy

Wind energy is used to generate electricity using wind turbines. Wind turbines, like wind mills, are mounted on a tower to capture most of the wind energy at 30m or more above the ground. They can take advantage of the faster and less turbulent wind. The turbines catch the wind energy with their propeller- like blades.
By the end of 2003, the installed capacity of wind power rose from 108MW to 32037MW in over more than 40 countries of the world.

e. Hydro- Power

Flowing water generates energy that can be harnessed and converted to electricity. This is called hydroelectric power or hydropower.
The most common source of hydroelectric power is a dam on a

river storing water in a reservoir. The water is released from a height from the reservoir and flows through a turbine which in turn activates a generator to produce electricity.

But hydroelectric power does not necessarily require a large dam. Some hydroelectric power plants use small canals to channel the river water from a great height through a turbine.

Small hydropower plants of about 10MW harness small rivers and streams. This resource has been a main stay of rural energy development. China alone accounts for 80% of the small hydro capacity in developing countries (Goldemberg, et al, 2000). Nigeria has large hydropower, but could harness the small pockets of hydropower from her numerous streams and rivers.

f. Geothermal Energy

This is heat energy from inside the earth. Geothermal heat pumps constitute one of the fastest growing applications of Renewable energy option in the world with an annual growth rate of 10% in about 30 countries over the past ten years. Its main advantage is that it uses normal ground water temperatures (between $5^{o}C$ and $30^{o}C$) which are available in all countries of the world (Sanner, 1999). The ground source heat pumps (GSHP) use the relatively constant temperature of the earth to provide heating, cooling and domestic hot water (DHW) for homes, school, government and commercial buildings. A small amount of electric input is required to run their compressors. This technology causes heat to flow up hill, that is, from lower to higher temperature location in compliance with Claussius statement of the second law of thermodynamics. Geothermal energy has the advantage of being neither weather dependent, unlike hydropower nor subject to fluctuating fuel prices. It was discovered that Africa has an estimated total of about 7000MW of Geothermal potential (Rafferty, 1997).

g. Marine Energy (Wave, tidal and ocean current)

The energy of the ocean through its tides offers a number of possibilities for commercial exploitation. Developments in this have picked up in recent years. Broadly speaking, two types of technology exist for generating energy from the ocean and sea waves, and tidal or marine current systems.

Wave energy is ultimately a form of solar energy. Solar radiation gives rise to pressure difference gradient in the atmosphere, giving rise to air movement (wind) in the earth's atmosphere. This in turn generates waves on the surface of the seas and oceans. Tidal energy on the other hand is derived from the movement of enormous bodies of water in tidal currents, as a result of the effect of the gravity of the sun and the moon upon the seas. Both have significant potential for power generation.
Estimates suggest that there are 2.3 million MW worth of power in the waves breaking on all the coastlines in the world. Since three quarters of the earth's surface is covered by water, the World Energy Council (WEC) estimates that the energy that can be harvested from the world's ocean is twice the amount of electricity that the world produces now. To this, an offshore wave energy conversion device has been developed by Aqua Energy group ltd of Mercer Island in Washington, United States of America.

SOLAR ENERGY

The quotation from Genesis 1:3, **"Let there be light, and there light"**, srefers to the coming into being of **"Sun"** and

"Energy." The sun is a common feature in our sky; it is seen crossing the sky from one extreme horizon to the other every day, giving us light and heat. But little did the world realize what a free and prodigious source of energy it is for mankind? Among these alternative renewable energy sources, solar power is a prime choice in developing affordable, feasible, decentralizable global power source that can be used in all climate zones around the world. This energy is free but the equipment to collect it and convert it to electricity can be costly. The energy from the sun is radiated in all directions in space in the form of electromagnetic radiations (sun rays).

The average amount of solar energy radiated to Earth is about $1360kW/m^2$, depending on latitude and regional weather pattern (Green, 2001). Solar energy is very viable in Nigeria because her average sun hour is about 4.5hours. The development of solar power system as alternative source of electricity could play significant complementary roles in providing isolated power systems for lighting non-urban areas, powering water pumping stations, powering communications packages in remote areas or medical appliances in cottage hospitals. Its simplicity as solar power system, stand-alone electric power, is however not matched by its relatively high capacity charges or rated costs per unit kilowatt.

ORIGIN OF SOLAR ENERGY: THE SUN

Here we will not bother ourselves with the detailed specifications of the Sun; it suffices to give some relevant data. The Sun is one of the many billion of stars in the Milky Way Galaxy, the galaxy of our solar system in the universe. It is the closest star to our planet Earth; its effect and importance therefore to us results from its closeness. The Sun is learnt to be formed about 5000 million years ago (Okeke and Soon) and it is now located at a distance of about $8.5x\ 10^3$ parsecs or (32.6 light years or 2.63 x 10^{17}km) from the centre of our galaxy, the Milky Way, where

1 parsec = 3.084x 10^{13}km,
1 light year = 9.46x 10^{12}km.

These are units of distance in the universe.
The Sun is made up of almost entirely of hydrogen (71% by mass) and helium (27% by mass) - the two most abundant gases found in the universe.

It is a great ball of hot gases with a diameter of about 1.4x 10^{6}km.This is about 109 times that of the Earth, and it is about 1.5 x 10^{8}km distant from the Earth. It is the most important celestial object to us because it supplies the energy that allows life to flourish on Earth.

The Structure of the Sun in brief

From the figure given below, the Sun has a diameter of about 1.4x 10^{6}km, and its interior is divided into three main layers of different densities and temperatures.

? **The Core**: the inner most part of the Sun with density 1.5x10^{5}kg/m^{3} and temperature 8-40x 10^{6}K; it is about 0.2R of the Sun in extent and generates 90% of the Sun's energy.

- ? **The Radiative zone**: It is from about 0.2 to 0.7R in extent. The main mode of energy transfer in this zone is through net outward diffusion of photons through continuous absorption and re-emissions under the high density condition.
- ? **The Convective zone**: the region in which the energy is transferred by the flow of hot gases near the bottom of the convective zone at about 0.7R to the cool region near the surface at about 1.0R. R is the radius of the

Sun.

From the centre of the Sun, the core, the temperature reduces from about 15x 10^6K to about 6000K at the surface, the photosphere, while its density reduces to about 1.5x 10^3kgm^{-3} at the surface. Only the outer surface of the Sun is visible to us on the Earth. The outer surface gives the Sun its definite shape of a disk observed on the Earth during a total eclipse of the Sun. The Sun has an atmosphere which is divided into three layers namely: **Photosphere, Chromosphere and Corona.** We will not bother you with the description of these.

The energy of the Sun is derived from a process similar to that in thermo - nuclear fusion in which hydrogen nuclei are believed to combine to form helium nuclei. The excess mass obtained in the process is converted to energy in accordance with Einstein's theory, $\mathbf{E = mc^2}$**,** where m is the differential mass and c is the velocity of light. Thus, the Sun produces a vast amount of energy but only a tiny part of it reaches the Earth. Since the Sun is a stable star, it promises to remain at the same magnitude in terms of its properties and surface temperature for a long time. It is interesting to note that the Sun is not one of the hot stars, but one of the cooler stars. Cooler stars are yellow in colour and the Sun is yellow in colour. Yet its heat from 93million miles away is very effective in keeping us warm and sustains lives on our planet Earth. The Sun radiates about 3.86 x 10^{26} Joules of energy every second, a value which is more than the total energy man has ever used since creation. Although some of this energy is lost in the atmosphere, the amount reaching the Earth's surface every second, if properly harnessed, is still probably enough energy to meet the world's energy demand (Maniel, 1974). Today it is a common knowledge that the Sun is the primary source of energy for all the processes taking place in the earth-atmosphere system. All lives depend upon its radiant energy directly or indirectly to survive.

The Sun, therefore, is one of the popular emerging feasible sources of energy being looked into and sought by the world today for longterm, possible source of renewable and reliable energy. The Sun is available free for all land and mankind. It is free from politics. It only needs suitable devices to capture its rays and translate it into useful heat or work.

The amount of solar energy available for any land depends only on its location with respect to the Sun.
Consider the following expression for the solar energy, H_o, available on a horizontal surface at the top of the atmosphere of any location on the Earth's surface:

$$H_o = 24/\pi \, I_{sc} \, \mathrm{Cos} \;\; \mathrm{Cos} \;\; (\mathrm{Sin} \;\; _s \; (\pi/180) \;\; _s\mathrm{Cos} \;\; _s)$$

Two angles in this expression are related to the location of a site on the Earth's surface:
Φ, the latitude, and δ, the declination of the Sun. The latitude, Φ, of Lagos, for example, is about 6.3^{o}N, and its declination angle, δ, can be obtained from the solar almanac of each year. **δ** varies from day to day as given in below:

$$\delta = 23.45 \, \mathrm{Sin}\{260/365(d_n + 284)\}$$

The amount of solar energy received per unit area per second at the outer edge of the Earth's atmosphere above a site is known as Extraterrestrial radiation, and is about 3.0×10^{26} Joules. The extraterrestrial radiation being received at the normal incidence (i.e. Sun   earth average distance) at the outer edge of the atmosphere of a site is known as the solar constant I_{sc} which is about $4921 kJm^{-2}h^{-1}$
The Sun emits energy in form of electromagnetic radiation given by Einstein as

$$\mathbf{E = mc^2}$$

where **m** is mass and **c**=$3.0 x 10^8 ms^-1$ is velocity of light.
The energy therefore, radiated by the Sun, is equivalent to a mass loss by the Sun every second and evaluated to be:

$$\mathbf{m=3?10^{26}/c^2 \text{ that is}}$$
$$\mathbf{m=3.3?10^9 \text{ kg}}$$

If the Sun thus loses mass at this rate, it is estimated that the Sun will extinct in about **2?10^4 b** years (Babatunde, 1989). Hence the energy of the Sun can be said to be in-exhaustible, i.e., the Sun is with us for a very long time to come.

However the amount reaching the earth's surface is about 1.00 x $10^3 Wm^{-2}$ at noontime at the equator. The depletion of the Sun's energy as it passes through the atmosphere to the Earth's surface, coupled with the seasonal, night and weather interruptions, constitutes the major impediment to the full realization of solar energy utilization. This notwithstanding, solar energy is proving by far the most attractive alternative source of energy for mankind. The world's fossil fuels may be used up over a period of a couple of centuries, in fact, the middle of this century has been put for total depletion of fossil fuel in the world, a mere instant of time in the history of the planet.
The technological and biological conversions of solar energy via various processes are now possible and feasible, thus making various forms of solar energy utilization possible and a reality.

Solar energy is pollution free, communitarian, conservational, decentralizable, adaptable, and its related devices require very little or no maintenance, safe and cost effective. Solar energy has come to stay as the possible future longterm energy resource. It is the only recurrent source, large enough to meet mankind's demands of energy supply if properly harnessed.

SOLAR RADIATION FUNDAMENTALS

Electromagnetic Spectrum of the Sun

The Sun emits energy in form of electromagnetic waves which are propagated in space with the speed of light. Electromagnetic radiation emitted by the Sun extends from fractions of an Angstrom to hundreds of meters, from x ray to radio waves as shown in the electromagnetic spectrum chart below.

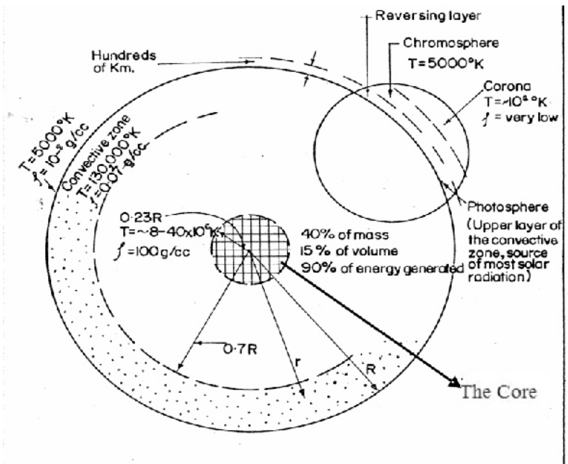


Fig. 1 Structure of the Sun

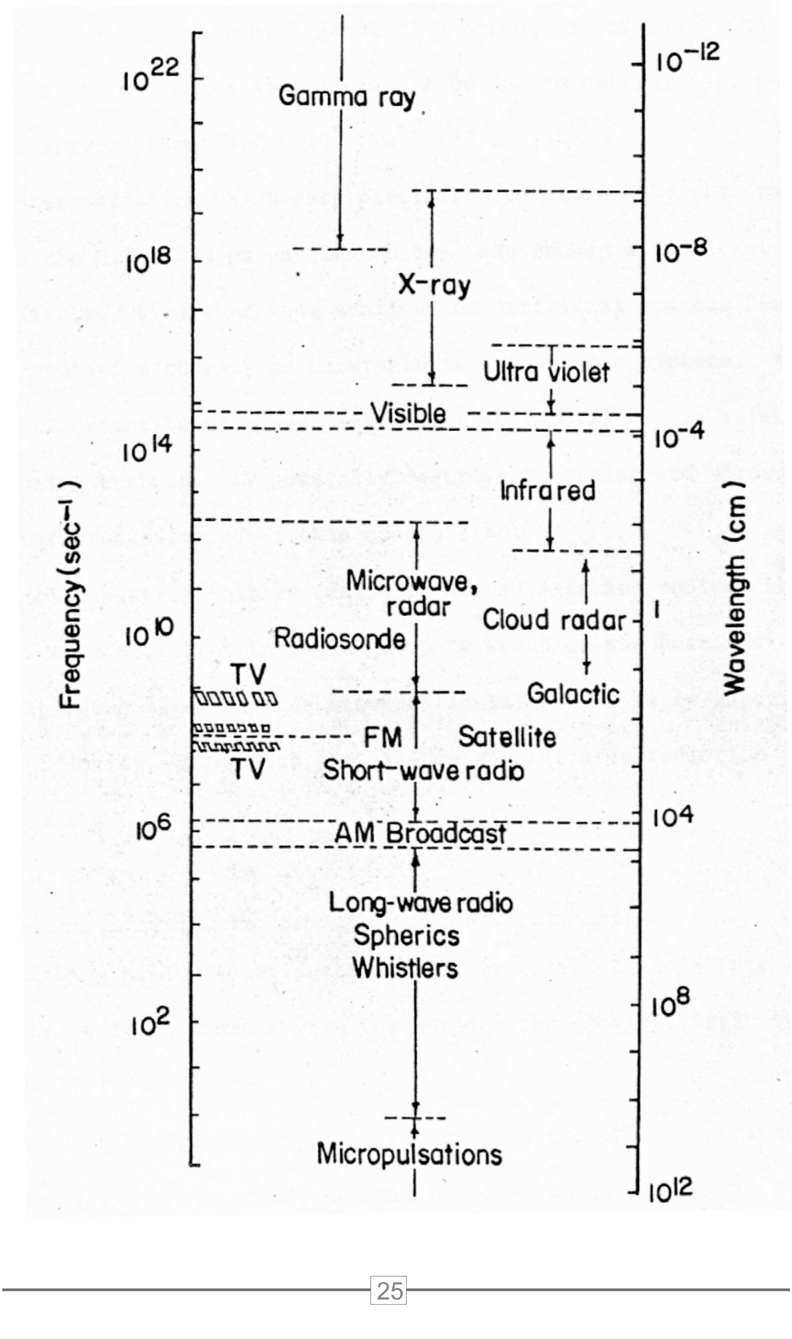

Frequency (sec^{-1})
10^{22}
10^{18}
10^{14}
10^{10}
10^{6}
10^{2}
Wavelength (cm)
10^{-12}
10^{-8}
10^{-4}
1
10^{4}
10^{8}
10^{12}
Gamma ray
X-ray
Ultra violet
Visible
Infrared
Microwave, radar
Cloud radar
Radiosonde
TV
Galactic
FM
Satellite
TV
Short-wave radio
AM Broadcast
Long-wave radio
Spherics
Whistlers
Micropulsations

Fig. 2 The Electromagnetic Spectrum

An (&) angstrom is a unit of length given by 1& = 10^{-10}m = 10^{-4} ìm. Electromagnetic radiations are usually divided into groups of wavelengths. The wavelength regions of principal importance to the Earth and its atmosphere are the;

Ultraviolet (UV) – (0.3 – 0.4 ìm)
Visible – (0.4 - 0.74ìm)
Infrared (IR) – (0.74 – 4. 0 ìm)

It was discovered that 99% of the Sun's radiant energy to the Earth is contained in these wavelength regions, that is, between 0.3ìm and 4ìm and comes mostly from the photosphere part of the Sun.

FACTORS AFFECTING THE AMOUNT OF SOLAR RADIATION ON THE EARTH'S SURFACE

a. Astronomical Factor

As it has been mentioned above, only a tiny portion of the energy of the Sun reaches the Earth's surface. Therefore, the Sun-Earth distance constitutes one of the factors affecting the amount of solar energy available unto us on the Earth. The Earth is known to be orbiting round the Sun once in a year and at the same time rotates about its own axis once in a day. The two motions determine the amount of solar radiation received on the Earth's surface at any time at any place. The path or trajectory of the motion is an elliptical orbit shown in the figure below. The Sun is located at one of the foci of the eclipse. The implication of this is that the distance of the Earth from the Sun is variant; hence the amount of solar radiation received on the Earth's surface varies. For example, from the figure, on Jan 3^{rd}, the Earth is at the position of shortest distance from the Sun, called the perihelion, which is 0.993AU. (Astronomical Unit of distance (AU) = 1.496 x 10^{8}km)

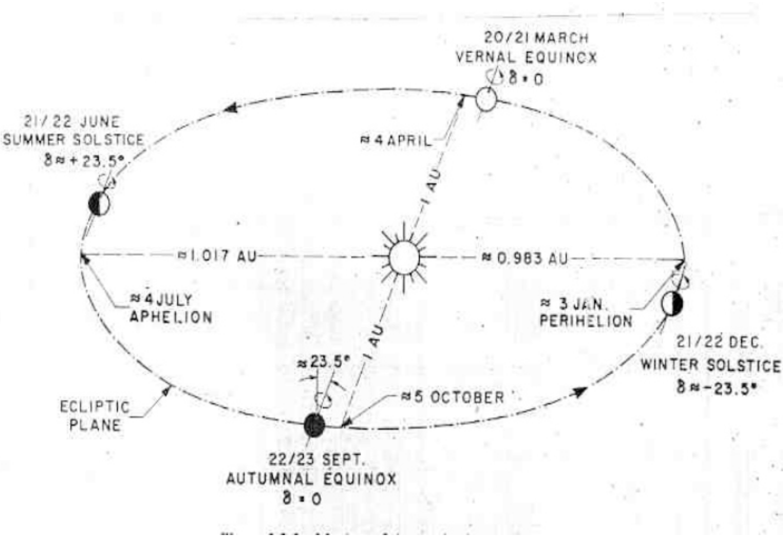


Fig. 3 Motion of the Earth around the Sun

On 4^{th} April and 5^{th} October the Earth is at just 1AU from the Sun. On 4^{th} of July, the Earth is at its longest distance 1.017AU from the Sun. This position is called Aphelion. The path of the Suns rays thus varies with time of day, season of year, and position of site on the Earth's surface. It becomes shorter towards the noon time, it decreases towards the perihelion position and increases towards Aphelion. Thus the variation in the Sun-Earth distance causes variation in the amount of solar radiation reaching the

Earth's surface. The path of the Sun's rays through the atmosphere is perhaps the most important factor in solar radiation depletion. It determines the losses of the radiation through **scattering** and **absorption** in the atmosphere.

The eccentricity (**õ)** of the elliptical orbit is expressed in terms of the Sun-Earth distance (**r**) and the average, $\mathbf{r_o}$**,** of this distance over a year. This is given by

$$\text{õ} = (r_o / r)^2 = 1 + 0.033 \cos (2\text{ð} d_n/365)$$

where d_n is the Julian day number in the year. For example $d_1 = 1$ on January 1 and $d_{365} = 365$ on December 31.

The elliptical motion of the Earth round the Sun gives rise to the seasons we experience on the Earth and its rotation about its own axis determines the diurnal variation of the amount of radiation received. The amount of solar radiation received on a unit horizontal surface area per unit time at the top of the atmosphere is known as the **Extraterrestrial** radiation, H_o, and is given by

$$H_o = I_{sc} (r_o / r)^2 \cos \text{è}_z$$

where $\mathbf{I_{sc}}$ is the solar constant. è_z **is** the local zenith angle. Zenith angle è_z is the angle between the solar ray and the local zenith (See Fig. 4 below). From spherical polar geometry, è_z is given by

$$\text{Cos } \text{è}_z = \sin \text{Ö} \sin \text{ä} + \cos \text{Ö} \cos \text{ä} \cos \text{ù}$$

Where Ö is the latitude of the site,

ä is the declination angle of the sun

ù is the hour angle

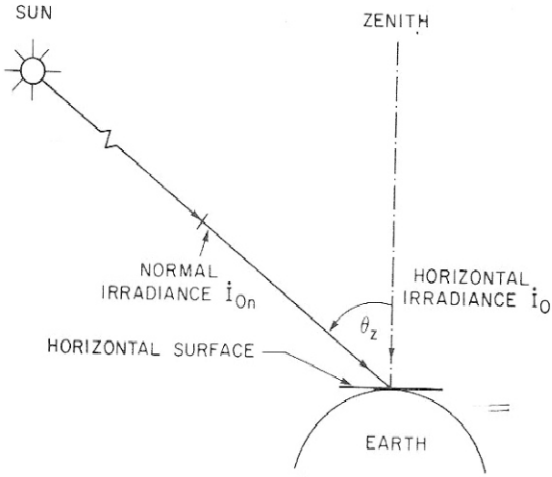


Fig. 4 Relationship between direct normal, the Horizontal Irradiance and the Zenith.

Hence the extraterrestrial radiation at the top of the atmosphere, which is the maximum amount of solar radiation available at the top of the atmosphere for any location, is given by

$$H_o = 24/\pi\ I_{sc} [\ 1 + 0.0334 \cos (2\pi d/365 - 3)]\ [\cos \quad \cos \quad \cos \ + \ \sin \quad \sin \quad]$$

I_{sc} is solar constant measured in W/m^2, is the hour angle measured in radiance, hence, H_o is given in W/m^2 . The equation, when further simplified, is given by

$$H_o = 24/\pi\ I_{sc}\ ?\ \cos \quad \cos \quad (\sin \quad _s (\pi/180) \quad _s \cos \quad _s)$$

This equation gives the daily extraterrestrial radiation, H_o on a horizontal surface at the top of the atmosphere, while

$$I_o = I_{sc} ? \cos \quad \cos \quad (\cos \quad _i - \cos \quad _s)$$

gives the hourly extraterrestrial radiation.
$_i$ is any hour angle and $_s$ is the sunset hour angle.

b. The Atmospheric Factor

The Extraterrestrial radiation mentioned above is the maximum solar radiation available to us at the top of our atmosphere. The variable quantities affecting its amount are the astronomical factors mentioned above.

Solar radiation however has to pass through the atmosphere to reach the Earth's ground surface, and since the atmosphere is not void, solar radiation in passing through it, is subjected to various interactions with the constituents of the atmosphere. These interactions lead to **absorption, scattering** and **reflection** of the radiation. These mechanisms result in the depletion or extinction of the radiation, thus reducing the amount of solar radiation we receive at the ground surface of the Earth.

Absorption: Absorption of solar radiation in the atmosphere reduces the amount of radiant energy on the Earth. Ultra-violet radiation is being absorbed completely by atmospheric contents such as ozone (O_3) and molecular oxygen (O_2). By this absorption, the harmful ultra-violet radiation UV-B is prevented from reaching the ground surface.
There are also selective absorptions by water vapour (H_2O), carbondioxide (CO_2), oxide of Nitrogen N_2O, Nitrogen (N_2), CH_4, O_2, CO and hydrocarbon absorbing mostly in the

infrared (IR) or generally at $= 0.7$ m.

Scattering: Radiation with wavelengths in the visible and infrared bands interact with dry air molecules, dust particles and other aerosols in the atmosphere, but being unable to fracture the bonds of the molecules and particles, the interaction results merely in scattering the radiation uniformly in all directions so that some of the radiation is re-directed back to space.

Some scattering by particles and aerosols whose diameters are comparable or less than the wavelength of the radiation are termed Rayleigh scattering. It gives the sky its bluish colour, and is equally in the forward and backward directions. Some scattering are by large size particles, that is, particles whose diameters are greater than the wavelengths of the radiation. Such particles are water vapour, large size dust particles, coagulated water vapour molecules forming liquid particles, and small dust particles which grow in size due to water condensing on them. The scattering is called Mie scattering. It is more in the forward than the backward direction. It makes the horizon whitish as seen during the period of Harmattan. There is of-course multiple scattering of radiation taking place in the atmosphere, resulting in about 80% loss of radiation to space.

Reflection: Reflection of radiation in the atmosphere is by solid particles, droplets of water in clouds and also by the surface of the Earth itself. Since clouds are just water vapour molecules of different sizes suspended in the atmosphere, they absorb, scatter and reflect radiation depending upon the size of the particles in the cloud. Thus absorption, scattering and reflection of radiation constitute loss of radiation in the atmosphere.

OTHER NECESSARY RADIATION PARAMETERS

It is inevitable and desirable to know the potential of solar energy available on daily and monthly bases at the site for solar energy applications, not only in amount but in quality, particularly its spectral composition. Not only this, the knowledge of radiation parameters, such as cloudiness index, clearness index, turbidity, albedo, transmittance, absorbance and reflectivity of the atmosphere through which the solar rays pass to the ground surface is very necessary for the utilization of solar energy. Also the knowledge of the metrological parameters such as number of **sunshine hours** per day, **relative humidity**, **temperature, pressure, wind speed, rainfall,** etc, is desirable and important for accurate calculations of parameters of some solar energy devices. For example it is needed to know the average number of sunshine hours per day for accurate calculation of PV (photovoltaic) power needed in designing solar power electrification for any location. In Nigeria, for example, we have an average of 4.5 hours of sunshine in a day. In detailed work, however, this value varies with geographical locations. For these, the measurements of solar radiation amounts and their spectral distributions under all atmospheric conditions are undertaken at many radiation networks around the world (Babatunde and Aro, 1990). The groups of wavelengths of solar radiation mentioned above are of paramount importance to the Earth and its atmosphere. Accurate values of the spectral distribution of solar irradiance are needed and important for the calculation of the absorption by gases, clouds and aerosols in the atmosphere and to calculate the spectral variation of the Earth atmosphere albedo.

The knowledge of the spectral distribution of solar radiation available is also important for the development of semiconductor devices such as photo detectors, light emitting diodes, power diodes, photo cells, spectral selectivity of surfaces etc; it is also essential for photosynthesis, photobiology and photochemistry in the atmosphere, as well as in the design of some special solar devices for the direct conversion of solar energy to electricity.

SOLAR ENERGY APPLICATIONS

Solar energy is found utilizable through the principle of energy conversion. That is we can convert solar energy directly to thermal, electrical (PV), photochemical, photo electrochemical and photosynthesis (biomass). The practical applications fall into three broad areas:

A. **Solar Energy Thermal Conversion Applications:**

i. Production of hot water for domestic use.
ii. Cooling and Refrigeration.
iii. Solar passive Drying in;

a. Agriculture produce.
b. Wood seasoning.
c. Mushroom culturing or growing
d. Production of pure water- Distillation.
e. Solar box cooker.

B. **Solar Electrical Conversion Applications:**

i. Thermal to electricity conversion.
ii. Solar electric power systems (PV) Photovoltaic cell.

a. Solar water pumping.
b. Hydrogen Fuel.

C. **Spectral Selectivity Surfaces Applications**

i. Heat mirror.
ii. Cold mirror.
iii. Solar control coatings.

Let us now highlight these three broad regimes of applications:

Solar Energy Thermal Conversion Applications.

a. **Solar heating systems**:

Solar energy can be used to provide hot water in homes, hotels and even in swimming pools. The system consists mainly of the solar collector, which is a flat plate, and a large insulated water storage tank with pipes to convey the hot water. See

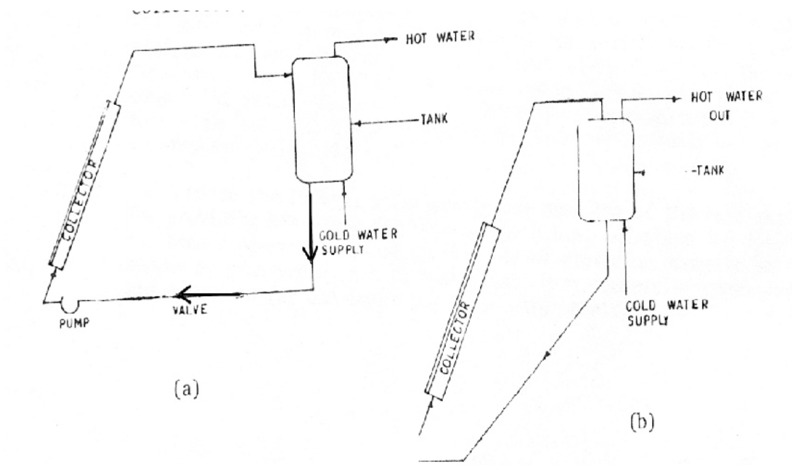


Fig. 5 a. Forced Water Heater. b. Natural Water Heater

By mounting the collector on the roof of a building with the storage tank located above the collector, the hot water is supplied to the storage tank by the principle of thermo-siphon. A solar collector area of about 3 to 4m^2, in combination with an insulated tank of 50 to 100 gallons capacity can provide 50 to 80 gallons of hot water at about 60^{o}C per average on a sunny day (Nat. Aca of sci. Washington DC, 1976). 1gal. = 4.6x$10^{-3}m^3$ or 4.6 lt.

b. Solar Cooling and Refrigeration System:

Solar cooling of buildings seems the most attractive of all applications of solar energy because the demand for cooling as a result of the heating caused by solar radiation in a building matches the supply of energy from solar radiation in Nigeria. Cooling is an aspect of air conditioning in a building to maintain a comfortable temperature and humidity. There are two types of solar cooling processes, namely: Passive cooling and active cooling. Both processes can be employed at the appropriate geographical zone in Nigeria. For this purpose, Nigeria can be divided broadly into the climatic zones: hot and humid, and hot and dry.

In the hot and humid climatic condition found in the coastal lands of Nigeria, e.g. Lagos State, the Delta region and the riverine areas, the nature of air conditioning to obtain the required comfort is more of dehumidification than temperature drop, while humidification is desirable in the hot and dry areas in the Northern parts of the country.

Passive cooling method involves no moving parts and the use of pumps or fans, but employs evaporative, radiative and nocturnal cooling processes to achieve the desired air conditioning of a space. Passive cooling can also be achieved through architectural design as in the Odellio solar house design in France. The radiative cooling method in particular works like a solar heater operating in the reverse. The solar collector radiates heat out in the night from the fluid in the storage tank, thus producing cold fluid in the tank. This cold fluid is circulated to the spaces to be cooled during the day. The same collector can be used with another storage tank at the same time for the hot water system in the house.

Active cooling and solar refrigeration are based on the same principle as the conventional air conditioner; it is just that it is powered by solar energy. The absorption cooling type is preferred because the working fluid, which is a mixture of water as the absorbent and ammonia as the refrigerant, is readily available. At low temperatures, it is compressed to a higher pressure, and passed into the generator where the heat from the solar collector vaporizes the ammonia, thus separating it from water. From here, the remaining process of condensing and evaporating is similar to that of the normal air conditioner. However, at the best performance temperature (107   135^{0}C), the performance of a flat plate collector is completely reduced. A larger area of the plate would then be required, but this will be very costly. Concentrating collectors are suggested as an alternative, the performance of which can be successfully sustained in Nigeria's climate.

c. Solar Passive Drying

A Solar passive dryer is a device system proposed to function without any sort of machines or moving parts. It is a sort of dehydrating ware house designed to harness solar heat energy with little or no moving parts to dehydrate any produce meant for drying. The heating is controlled to produce uniform, fast and hygienic drying. If developed and efficiently harnessed, it will go a long way to help big-time and small scale farmers to produce fast, hygienic and uniformly dry crops. It can also be developed to produce well seasoned wood. Thus, solar passive drying can be developed on small and large scales for preservation of agricultural products, such as

i. well seasoned woods for furniture industries,
ii. Mushroom growing,

iii. Fish drying.

Such a facility is recently commissioned at Bishop Kodji's Island in Lagos State, where fish farmers on the Island were provided with solar cabinet driers for drying their fishes. It is intended here also to construct such a facility to dry woods to be used for furniture making or any other use of that nature.

d. Solar Still or Solar Distillation

The solar still is a device making use of thermal conversion of solar energy of any reasonable size to produce fresh, drinking water for small towns and motels in rural areas. Its construction is simple and employs very simple locally available materials. An enclosure of durable structure is constructed over a pool of brackish water. The structure is covered with slopping glass sheets as the solar collector. However, concentrating collectors can also be used. The condensed water vapour is collected from the sheets as the produce of fresh water for drinking. The efficiency of stills is a direct function of solar radiation received on a horizontal surface. For Nigeria, a tropical country, solar radiation availability is not the problem for the optimum performance for any solar still device.

It is therefore, a very feasible solar device that can be embarked upon as a solution to the provision of drinking water for the rural population in Nigeria.

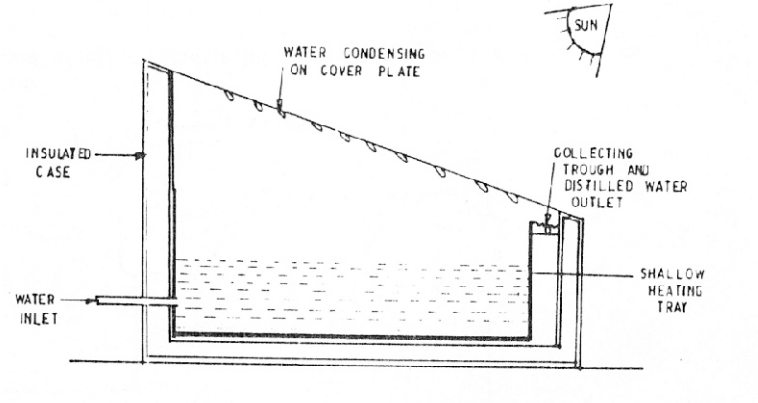


Fig. 6 Simple Solar Still

SOLAR ELECTRIC CONVERSION APPLICATIONS

Solar Electric Power System

Solar electric power systems transform sunlight into electricity. There are several types of solar electric power system based on different technologies such as the following:

Crystalline silicon
Thin films
Concentrators
Thermo-photovoltaic
Organic solar cells

The first four are the major ones while the fifth one is a latest technology in solar energy conversion.

a. Crystalline silicon

The crystalline silicon technology is also known as photovoltaic (PV) cells. Solar cells employ special materials called semiconductors that create or generate electricity when exposed to sunlight, (see figure below).

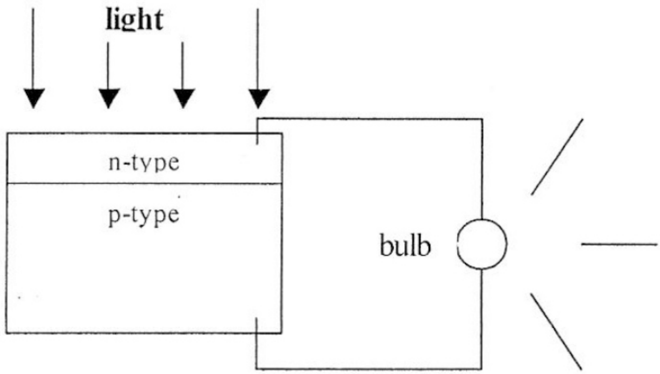


Fig. 7 Insulated Power Cell powering an electric bulb

Solar electric systems based on solar cells are quiet and easy to use; they require no fuel other that sunlight. Because they contain no moving parts, they are durable, reliable and easy to maintain, and can last up to 25-30 years.
Some solar cells are made from polycrystalline silicon. These are cheaper to produce but somewhat less efficient than single-crystal silicon.

A simple silicon solar cell, depicted in figure 7 above, produces only a tiny amount of electricity, from about 2 to 5 amperes and approximately 0.5 volts. But when many are connected together, they form modules that can generate substantial amount of power. Modules are the building blocks of solar electric systems, which can produce enough power for a house, a rural medical clinic, or an entire village as it is seen in Bishop

Kodji Island in Lagos State. Large arrays of solar modules have powered satellites and provide electricity for utilities.

The solar cells, the basic ingredient of solar electric power plant are connected to a variety of other components to make a solar electric power system. Some of the components include batteries, battery chargers, the back up generator and a controller so that people in solar powered homes and buildings can turn on the lights at night or run televisions or appliances on cloudy days.

A solar electric power system usually incorporates inverters or power control units to transform the DC electricity produced by the cell - modules into alternating current (AC) to run AC appliances or sell to a utility grid. Complete system usually include safety disconnects, fuses, and a grounding circuit as well. (See the figure below)

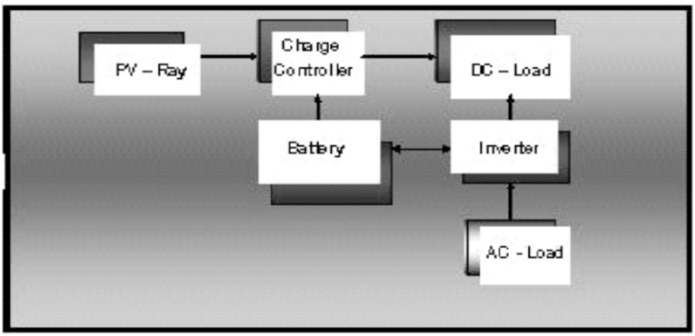


Fig. 8 Stand-Alone PV System with Battery Powering DC and AC Loads

b. Thin Films

Solar electric thin films are lighter, more resilient, and easier to manufacture than crystalline silicon modules. The best-developed thin film technology uses amorphous silicon in which the atoms are not arranged in any particular order as they would be in a crystal. An amorphous silicon film, only one micron thick, absorbs 90% of the usable solar energy falling on it. Other thin-film materials include cadmium telluride and copper indium diselenide. Substantial cost savings are possible with this technology because thin films require little semiconductor materials. Thin films are also produced as large complete modules. They are manufactured by applying extremely thin layers of semiconductor materials to a low-cost backing such as glass or plastic. Electrical contacts, anti-reflective coatings, and protective layers are also applied directly to the backing materials. The films conform to the shape of the backing, a feature that allows them to be used in such innovation products as flexible solar electric roofing shingles.

c. Concentrators

Concentrators use optical lenses (similar to plastic magnifying glasses) or mirrors to concentrate the incident sunlight that falls on a solar cell. A basic concentrator unit consists of a lens to focus the light, a solar cell assembly, housing element, a secondary concentrator to reflect off-center light rays onto the cell, a mechanism to dissipate excess heat, and various contacts and adhesives. The basic unit can be combined into modules of varying sizes and shapes. Concentrators only work with direct sunlight and operate most effectively in sunny, dry climates. They must be used with tracking systems to keep them pointed toward the sun. With a concentrator to magnify the light intensity, the solar cells produce more electricity. Today most solar cells in concentrators are made from crystalline silicon. However, materials such as gallium arsenide and gallium indium phosphide are more efficient than silicon in solar electric concentrators and will likely see more use in the future. These materials are now used in satellite communications and other space applications.

d. Thermo-photovoltaic

Thermo-photovoltaic (TPV) devices convert heat into electricity in much the same way that other PV devices convert light into electricity. The difference is that TPV technology uses semiconductors "tuned" to the longer-wavelength, invisible infrared radiation emitted by warm objects. This technology is cleaner, quieter, and simpler than conventional power generation using steam turbines and generators. TPV converters are relatively maintenance-free because they contain no moving parts. In addition to using solar energy, they can convert heat from any high-temperature heat source, including combustion of a fuel such as natural gas or propane, into electricity. TPV converters produce virtually no carbon monoxide and few emissions. They may be used in the future in gas furnaces that generate their own electricity for self-ignition (during power outages) and in portable generators and battery chargers.

e. Organic Solar Cells

This is a new solar energy electric conversion technology in which a solar cell is currently being developed from various organic matters (dyes). The crystallized silicon solar cells have been standard technology in solar conversion devices for over fifty years. However they are expensive, and relatively inefficient (they have achieved only 50% efficiency so far). Right now, various types of organic solar cells from dye materials are being studied and may soon replace the silicon solar cells, because they (organic solar cells) will be fabricated with low cost processes, and they can be more versatile than silicon solar cells. Further still, they have added advantages of being thinner, lighter and more colourful than silicon solar cells.

Advantages and DesirAble Characteristics

Solar electric systems offer the following advantages:

? Stand-alone systems can eliminate the need to build expensive new power lines to remote locations.

? For rural and remote applications, solar electricity can cost less than any other means of producing electricity.

? Solar electric systems can also connect to existing power lines to boost electricity output during times of high demand such as on hot, sunny days when air conditioners are on.

? Solar systems are flexible as solar electric modules can stand on the ground or be mounted on roof tops.

? They can also be built into glass skylight and walls. They can be made to look like roof shingles.

? They can come equipped with devices to turn their DC output into same AC utilities deliver to wall sockets.

? Individual home owners and businesses can save money on their bills by feeding any excess power their solar electric system produces into the utility grid.

- ? Solar power systems require minimal maintenance.
- ? Solar power systems run quietly and efficiently without polluting.
- ? Solar power systems are easy to combine with other types of electric generators such as wind, hydro, or natural gas turbines.
- ? Solar power systems can charge batteries to make solar electricity continuously available.
- ? For utilities, large-scale solar electric power plant can meet the demand for new power generations, especially in distributed applications.
- ? Solar electric plants are easier to site and are quicker to build than conventional power plants.
- ? Solar electric plants are easy to expand incrementally by adding more modules as power demand increases.
- ? Solar electric power systems are good for the environment.
- ? Solar electric technologies, when used for pumping water, lighting homes or running appliances, they run clean, i.e., have no green house effect.
- ? Solar electric technologies can help to boost the economy of the nation by small and medium scale enterprises (SME).

SOLAR ELECTRIFICATION OF BISHOP KODJI VILLAGE, LAGOS STATE: A CASE STUDY

Solar Photovoltaic System Specifications of the BishoP Kodji VIllage

Right here in Lagos we have an existing evidence of solar electrification. The Lagos State Government has just commissioned a 2.250kW solar electric power system in Bishop Kodji Island for lighting, water pumping and running public television and other utilities. The system's components are:

PV Array

Comprises of a Solar farm that is equipped with 30 (thirty) 12 volt DC, 75W Monocrystaline Solar panels, with a combined output of 2.250 kilowatts.

Solar Charge Controller

The output from the PV's, are fed through 3 (three) charge controllers that regulate, monitor, report the charge condition, residual charged state and voltage of a 12 unit accumulator bank of deep-cycle Valve Regulated Lead-Acid (VRLA) batteries.

Deep Cycle Accumulators

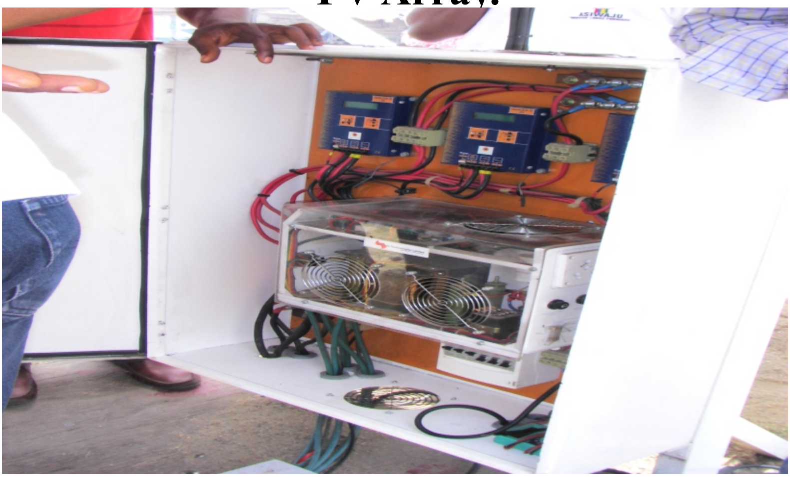
A 4 Level/Stepped accumulator rack installed beneath the PV array, accommodates the 12 Volt Regulated Lead-Acid Batteries.
The total stored and residual power in the accumulator bank is 28.880kw

Operation

The primary line DC voltage from the array of PV's is 24 volts DC. This is achieved by using a serial/parallel connection matrix.
Each Charge Controller is fed from 10 individual PV panels that are connected in series/parallel matrix.

The output of the three Charge Controllers strings is connected via a low voltage disconnection device (LVD) to a 1.8kW Pure Sine-wave inverter. The inverter has an input voltage of 24V DC. The output of this pure sine wave inverter is fed into a miniature distribution panel that is housed within the energy

PV Array.



Solar Charge Controller

Power Distribution Line.

Solar Powered Water Pump.

Solar Cabinet Fish Dryer.

Table 2: PV Module Price Data ($ / W)

Year	Average price
1990	4.5
1993	4.0
1996	4.0
1997	4.2
1998	4.0
2000	3.0
2005	2.0
2010	1.5

The typical cost of a solar electric power system here in Nigeria on the average today is about N1,100 per Watt.

Table 2 above shows the cost of production of a unit solar cell from 1990 to 2010. It can be observed that the cost of production is coming down. Right now it is about US$2.0 per

Watt. As the price comes down the cost of building a solar electric power system is expected to come down as well.

SPECTRAL SELECTIVITY SURFACE APPLICATIONS

Spectral selectivity of surfaces is another dimension in solar energy applications. Some of the applications which are of great interest include:

- ? Selective absorbers,
- ? Heat mirrors,
- ? Reflective materials
- ? Anti-reflective
- ? Fluorescent concentrators
- ? holographic films
- ? Cold mirrors
- ? Radiative cooling
- ? Optical switching
- ? Transparent insulating materials.
- ? Solar control windows

Special selectivity of a surface is achieved by applying special coatings on substrates, which may be transparent or opaque, with the intention of modifying the optical properties of the surface, such that the surface selects what wavelengths of the solar spectrum to transmit or absorb or reflect. These properties are transmittance, absorbance, reflectance and emittance, upon which the relevant applications are based. Surfaces of different material coatings will produce different values of these optical properties at different wavelengths of the solar spectrum.

Solar radiation is transverse oscillating electric and magnetic fields. The electromagnetic fields interact with the electric charges of the material of the surface upon which solar radiation is incident. The interaction leads to the modifications of the solar radiation at different parts of its spectrum. As a result, some parts of the radiation are absorbed, some are transmitted and some are reflected back to space (Granquist, 1985; Loven, et al., 1976). Thus, by spectral selectivity of a surface, it is meant surfaces whose values of absorptance, emittance, transmittance and reflectance of radiation and other related optical properties vary with wavelengths over the spectral region of 0.3 ? λ ? 3µm (Loven, et al. 1976; Maniel and Maniel, 1976).

For example, a spectral selective surface having high absorptance in wavelength range, 0.3µm ? λ ? 3µm, and high reflectance at 3µm ? λ ? 100µm will appear black with regards to the short wavelengths range and at the same time appear an excellent mirror in the thermal region i.e. 3µm ? λ ? 100µm. A device with these properties is called a "heat mirror."
We will discuss briefly only the following spectral selectivity applications of solar energy.

- i Heat mirror
- ii Cold mirror
- iii Solar control coatings.

Heat Mirror

A solar collector with a highly selective absorber in the short wavelengths range of solar radiation, that is, at $0.2 \leq \lambda \leq 3$ µm, will reflect very highly the thermal radiation (IR) component of solar radiation. This implies that the device is black with respect to the short wavelengths range because it absorbs them, and forms an excellent mirror in the thermal region of solar radiation because it reflects them. The device is called "Heat mirror". Thus, heat mirror is essentially a device that transmits or absorbs the short wavelengths radiation (UV-VIS) and reflects the long thermal wavelengths (IR) of solar radiation. That is, it is a window to short wavelengths and a mirror to long wavelengths. It is therefore very suitable for architectural windows in buildings, where low temperature or cooling effect is desired. This device therefore is adaptable for passive cooling in a tropical climate region.

The heat mirror device is obtained by using a Semiconductor-Metal Tandem. It is therefore also called absorber-reflector Tandem. The semiconductor component is arranged to reflect the thermal radiation (IR), while the metal component absorbs or transmits the UV-VIS radiation. A heat mirror device is also called a transmitting selective surface.

In the arrangement of the components, the reflective layer surface is arranged to cover the non-selective absorber base. In this way, the selective reflector reflects the thermal infrared ($\lambda > 3$ μm) and transmits the short wavelengths range ($\lambda < 3$ μm). The short wavelengths radiation transmitted by the reflector is absorbed by the black absorber base. Some highly doped semi-conductors such as InO_2, SnO_2 or the mixture of the two, Indium-Tin-Oxide (ITO), have been used successfully to produce the reflector component of the device (Seraphin, 1979). A heat mirror may therefore be used to separate heat (IR) and light (VIS) of the solar spectrum. The IR energy separated could be used for thermal purposes such as the thermo-photovoltaic.

Cold Mirror Coatings

Spectral splitting coatings can be used to divide solar spectrum into various broad band regions. By this, various regions of the solar spectrum can be separated for use for different purposes such as photovoltaic or photothermal devices (Lampert, 1985).

A "cold mirror" device has opposite spectral response to that of the "heat mirror". That is, cold mirror films reflect highly (low transmittance) in the VIS region of solar spectrum and reflect poorly, but transmits highly in the IR region, thus splitting the spectrum into short wavelengths and long wavelengths. The high energy waves i.e. the short wavelengths are used for photovoltaic generation while the low energy waves, the long wavelengths (IR) are used for photothermal heating. This device can be used in "green house" with special arrangements of baffles on the roofs. The device will reflect the photosynthetic active radiation (PAR), 0.35 ? λ ? 0.75 μm waves into the green house while transmitting the IR into the air channels which can be redeployed to maintain a suitable warm temperature in the green house. ZnS/ MgFs and T_i O_2/ S_i O_2 have been used to achieve these coatings.

Solar Control Coatings

Solar control coating is a design intended to reduce the incoming heat radiation through windows of a building by reflecting off the heat radiation (IR). To achieve comfortable indoor temperature, that is, to achieve cooling in a building, solar control coating surfaces that are transparent at 0.4 ? λ ? 0.7 μm and reflecting at 0.7 ? λ ? 3 μm may be used. This implies that, by this, the infrared part of solar radiation is reflected back and that it is possible, through the use of solar control windows, to achieve a 50% reduction in the internal heating of a building without noticeable reduction in the lightning of the interior of the building. The use of such windows may achieve the same objective of a conventional air conditioner in a building. Solar control coatings are particularly applicable in hot climate countries such as Nigeria.

In solar control and energy conserving windows, low transmittance windows are employed. If a medium is generally opaque to the passage of radiation but selectively transmits a particular small range of radiation, it is said to operate as a window in that range. A low thermal transmittance window reduces the heat radiation through the window. To achieve low thermal transmittance window therefore, surface coatings that transmits at 0.3 ? λ ? 3 μm and reflects at 3 ? λ ? 100 μm may be used. This means that maximum use is made of the solar energy in the short wavelengths range while the transmittance of thermal radiation is minimized.

Solar Control and Low Thermal Emittance Materials

A thin homogeneous metal film is found capable of combining transmission in short wave-lengths up to about 50% with high reflectance in long wavelengths (Okujagu, 1997; Wooten, 1972). The required thickness of such film, using copper, silver and gold is about 20nm. If the films are thinner, they will break up into discreet islands of strong absorptance of the visible wave-lengths.

Enhancement of luminous transmittance to more than 80% without significantly impairing the low thermal transmittance can be achieved by embedding the metal in anti-reflecting dielectric with high refractive index layers, such as T_iO_2. In the alternative to the metal base coatings, we may use dope oxide semiconductor. However a wide band gap is needed in the semiconductor to permit high transmittance in the luminous and solar spectral range. To make the material metallic, electrically conducting and infrared reflecting for wavelengths exceeding a certain plasma wavelength, it must allow doping to a significantly high level. Semi-conductors suitable for this are, oxides based on Zinc, Cadmium, Tin, Lead and Thallium and their alloys.

CONCLUSION

It has been shown that energy is necessary for the economic growth of any nation, and thus essential for improving the standard of living of the nation. Therefore energy has to be made available by the Nation and cheap for rapid and quality growth of the economy.

The fossil fuel energy, the main source of energy for the world, is unable to meet the world's demands of energy and it is, at the same time, rapidly depleting, hence the fever of the world search for alternative sources of energy. Each country therefore is to face the challenges of developing her energy resources.

The renewable energy sources become the object of the search. They are dependable, and are therefore possible alternatives if their technologies are developed. Out of them all, solar energy seems to be the most capable of meeting world energy demands if properly harnessed in the immediate future. The amount of it received per second during day light on the Earth's surface is 10000 times more than the total energy requirement of the world today. The variety of solar energy applications and advantages is enormous but only a few are discussed very briefly in this lecture.

One will therefore use this opportunity to call on the Government of this nation to give serious and positive thoughts and attention to the development of alternative sources of energy particularly the renewable energy sources now. The beauty of the renewable energy sources is that, they are decentralizable in application, and therefore not likely to pose distribution challenges. Solar energy in particular is free of international and national politics and therefore free for all. Solar energy is pollution free and does not produce residues to contaminate the air. Solar energy system devices require very little or no maintenance. Their life span is between 25-30years, therefore they are cost effective.

We call the attention of the Nation, both Government and private entrepreneur to the enormous raw materials for biomass, bio-diesel and ethanol production existing in many different locations in the country. For example, sugarcane and cassava which can be grown year after year are bio-gas and ethanol raw materials. The former President Olusegun Obasanjo launched the campaign, a short time ago for large and small scale cassava growing, not only for food or export, but for other purposes like this. Therefore large and small scale plants, depending upon the volume of raw materials, can be established for the production of biomass and ethanol. Such plants will of course be located at those places where the raw materials are found. Government should give the encouragement as it is done in Brazil.

Table 1 shows the amount of the bio-gas fuel that can be produced from 1tonne of different biomass feed stocks (see Table 1 above).

The Government of Brazil initiated a national program of the production of ethanol and went all the way to grant low interest loans for the construction of bio-gas fuel plants and even guaranteed purchase of the products by the oil companies. Nigerian government can do same. Some of our employment problem will be solved and some of our energy need would be met.

I am happy to be in Covenant University, and proud to be associated with her impact full activities and the tenacious drive for excellence. I am glad that the Chancellor has a genuine, burning passion for raising the living standards of every black man particularly Nigerians and Africans in general. He did not hide his feelings on this, but charges us to be a solution provider to specific problems of the Nation.

I therefore call on Covenant University, through the Management, to pursue vigorously through its Faculty, research in the development of Renewable Energy technologies, aimed at solving energy problem of the Nation. I call on all the Engineering Departments and various Science Departments here in the University, and all the Energy related Groups and Companies to collaborate with us at solving the energy demand problems of this Nation. God helping us, we can do it.

ACKNOWLEDGEMENTS

I thank God for locating me here in this Vineyard of peace and tranquility to work. I thank Him for standing me up to give this lecture. I thank God for the Chancellor Dr. David Oyedepo to whom the vision was given, and the enablement for him to obey and follow the vision tenaciously. In his obedience, we all are beneficiaries and the whole world stands also to benefit from it.

I thank the Management especially the V.C, Professor Aize Obayan and the Registrar, Deacon Yemi Nathaniel for

encouraging me and constantly reminding me as to my turn to give this lecture.

I thank my colleagues both in the Department, particularly Professor C.O. Oluwafemi, HOD Physics, who was kind enough to read through the script, and the College at large, for as one stood up to deliver his lecture, I am reminded of my own turn. I must not forget to thank a dear friend like Dr. O.E. Agboje and others like him in the College for their encouragement always and Dr. Boyo of the Department of Physics, University of Lagos, a very active and knowledgeable partner in solar energy application research. Through him I got to know about the Kodji Island Solar Energy Electrification Project by the Lagos State Government.

I will like to thank my wife, Florence Oladunni Asabi a woman beautiful inside and outside, loving and caring, who though retired, but not tired to be on active service here, with me. I thank and appreciate God for her. Indeed he who finds a wife, finds a treasure and the favour of God. I thank also my wonderful loving children who are always caring and supportive. I thank all my kiths and kens who were called and honored my invitation to be here. I won't forget to thank all my wonderful friends and well wishers, especially, Dr. Sam, Oloruntoba and wife, of Ola-Olu Hospital Ilorin, Kwara State, and my in- laws, Dr. and Mrs. Abifarins and Arch. Abolurin who made an appearance here today, despite your tight schedule. I thank you for your moral support.

Thanks to all my audience, you have been patient and attentive in listening to me. May God Bless You All.

References

Aladekomo, J.B. (1983). Prospects of a technological revolution in Nigeria, Proc. Conf. on Technological Development and Nigerian Industries, 1, 11-16.

Babatunde, E. B. and Aro, T.O. (1990). Characteristics variations of Total (Global) Solar Radiation at Ilorin, Nigeria, Nig. J. of Solar Energy, Vol. 9, 157 173.

Brinkworth, B.J. (1972). Solar energy for Man, Compton Press Ltd., Great Britain.

Eden, R. (1983). Energy planning with special reference to developing countries, Proc. Conf. on Non-Conventional Energy Sources and Summer Workshop on the Physics of Non-Conventional Energy Sources, Trieste SMR/102-1.

EPIA/Greenpeace Blueprint, (2004). Solar Generation.

Granguist, C.G. (1985). Spectrally selective coatings for energy efficient windows "paper presented at workshop on the Physics of Non-Conventional Energy Sources and Material Science for Energy, I.C.T.P., Trieste, Italy."

Greenpeace (2001). Solar generation for the European PV industries association.

Kahn, A.M. (1983). Soft/decentralized renewables as an energy option for the developing countries, Proc. Conf. on Non-Conventional Energy Sources, op. cit.

Lampert, C.M. (1985). Workshop on the Physics of Non-Conventional Energy Sources and Material Science for Energy, I.C.T.P., Trieste, Italy (143).

Lovel, M.C., Avery, A.G. and Vernon, M.W. (1976). Physical properties of materials, Von Nostrand Company New York.

Meiniel, A.B. and Meiniel, M.P. (1976). An introduction to applied solar energy, Addison Wesley, Reading, United Kingdom.

Munner, T. (2004). Solar radiation and daylight models.

Nakicenovic, N., Grubler, A. and McDonald, A. (1998). Global energy perspectives, Cambridge University press U.K.

Okeke, P.N. and Soon, W.H. (1994). Introduction to astronomy and astrophysics.

Okujagu, C.U. (1997). Effect of materials on the transmission of selective transmitting thin films, Nig. J. Physics, 59.

Rafferty, K. (1997). An information survival kit for the prospective geothermal heat pump owner, Oregon Institute of Technology.

Sanner, B. (1999). Prospects for ground source heat pumps in Europe, In Newsletter, IEA Heat Pump Centre.

Seraphin, B.O. (1979). In solar energy conversion solid state physics aspects, B.O. Seraphin (ed), Topics in applied physics (Springer-Verlang, Berlin) 63-76.

Wooten, F. (1972). Optical properties of solids, Academic press, New York.