UNIVERSITY OF ILORIN

THE ONE HUNDRED AND SEVENTY-THIRD (173RD) INAUGURAL LECTURE

"ENERGY THAT WORKS"

By

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Dedication

This One Hundred and Seventy-Third (173rd) Inaugural Lecture is dedicated to the memory of my late father

CHIEF THOMAS OJO LASODE

(1893-1985)

who made full provision for my undergraduate education in his last testament.

Courtesies

The Vice Chancellor,
Members of the University of Ilorin Governing Council,
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The Head, Department of Mechanical Engineering,
Heads of other Departments,
Members of the academic staff,
Members of the administrative and technical staff of the University,
Members of the academic staff of sister Universities,
My Lords Spiritual and Temporal,
Members of my nuclear and extended family,
Distinguished invited guests and friends,
Gentlemen of the print and electronic media,
Members of the University of Ilorin Alumni Association,
Great University of Ilorin Students,
Ladies and gentlemen.

Preamble

It is with great pleasure and immense gratitude to God that I stand before you all to present the 173rd Inaugural Lecture of this great University, which is my alma mater. I thank the Vice-Chancellor and the University for the opportunity to address this great gathering.

This is the 12th Inaugural Lecture from the Faculty of Engineering and Technology and the third from the

Department of Mechanical Engineering. The second one was given by the distinguished Professor J. A. Olorunmaiye on "Energy Conversion and Man" on Thursday, 24th May 2012. The first one was given by Professor M.B. Adeyemi on "Industrial Growth through Research and Development" in 1995. The title of this lecture is "Energy that Works".

Mr. Vice-Chancellor, Sir, permit me to align myself with the submission of the last Inaugural Lecturer that "for our Faculty, inaugural lectures have been few and far between (average of one in three years) for a number of reasons"[1]. The three reasons highlighted then are still true today and may be adduced for the over five years' gap between the last lecture and this one.

Introduction

ENGINEERING is the profession in which the knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilise economically the materials and forces of nature for the benefit of mankind[2]. Engineering is the application of mathematics as well as scientific, economic, social, and practical knowledge for the purpose of inventing, innovating, designing, building, maintaining, researching and improving structures, machines, tools, systems, components, materials, processes, solutions and organisations.

Mechanical engineering is the discipline that applies engineering, physics, and materials science principles to design, analyse, manufacture, and maintain mechanical systems. It is the branch of engineering that involves the design, production, and operation of machinery[3].

Energy is the measure of the ability of a body or system to do work or produce a change. No activity is possible without energy. Energy exists in several forms such as heat, kinetic or mechanical, light, potential and electrical energy. The fact that energy exists does not mean that it is necessarily available to do work. The amount of work done by a system is determined by the amount of energy put into the system. When the supply of energy is exhausted in a system, the system stops working. For example, when fuel is exhausted in a generating set, it stops working and will no more deliver electricity.

The main sources of energy supply are wood, fossil fuels, nuclear, biomass, bio-diesel, hydroelectricity, wind, geothermal and solar energy**.** These can be broadly categorised as conventional (non-renewable) and non-conventional (renewable) energy sources.

Non-renewable energy (NRE) or fuel sources include 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, and their uses have significant environmental consequences.

Renewable energy (RE) may be described as energy produced from natural resources which do not deplete the sources that feed them; that is, they are technically inexhaustible. This includes geothermal, wind, hydropower, solar, and biomass resources. RE sources have low environmental risks, if used in a sustainable manner. Energy has been, and will remain in the 21st century, fundamental to the development of civilization, from the utilisation of water, wind and animal power in ancient times to the development of national electricity grids and nuclear power[4]. Brinkworth[5] noted that the process of economic growth, which ultimately results in the improvement of the living standards of the society is traceable to, and depends on, the substitution of machine power for muscle power for fast and efficient performance of every type of physical task.

Energy as a commodity is crucial for the economic development, social transformation, and industrial growth of any nation. There is a strong link between socio-economic factors such as Gross Domestic Product (GDP), standard of living, industrialisation and the total energy consumption in any community. Table 1 shows a significant rise in total energy consumed and index of industrialised production between 1920 and 1972 in the United States[6].

Table 1: Energy Consumption in the United States[6]

Year	Total energy consumed (10^{12} Btu)	Population (thousands)	Index of industrialised production	Total energy per capita (10^6 Btu[1])
1850	2,500	24,000	-	105
1900	8,300	75,000	-	110
1920	19,782	106,466	16.6	186
1925	20,809	115,832	19.9	180
1930	22,288	123,077	20.2	181
1935	19,107	127,250	19.4	150
1940	23,908	131,954	27.8	181
1945	31,541	132,481	44.6	238
1950	34,153	151,241	47.4	226
1955	39,956	164,309	61.1	243
1960	44,816	179,992	68.8	249
1965	53,969	193,815	90.7	278
1970	67,444	203,185	106.7	330
1972	72,108	206,073	106.4	345
1973	75,561	210,400	-	359
1974	73,941	213,500	-	346
1976	74,500	217,700		342

Note: [1] A British thermal unit (Btu) is a common unit of energy.
1 Btu = 1.055 kJ

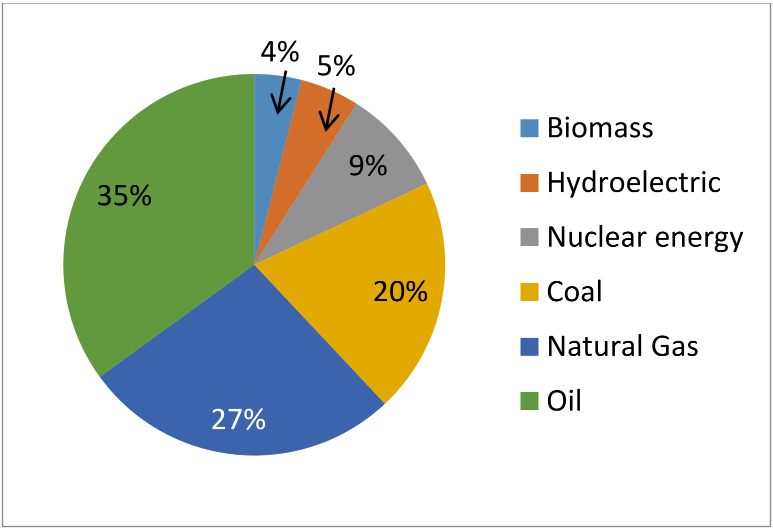
Richard[7] asserted that, "there is a clear trend toward higher consumption of energy as a nation industrialises and increases its Gross National Product (GNP)." Lukman[8] came to a similar conclusion in the National Energy Policy document where he stated: "Thus, our future energy requirements will continue to grow with increase in living standards, industrialisation and a host of other socio-economic factors." Hence, the desire of each nation is to harness the energy resources for the improvement of the standard of living of its citizen.

There has been a steady decline in the rate of industrialisation in Nigeria within the last decade. This might not be unconnected with the poor performance experienced in the various facets of the energy sector in the country. For instance, although Nigeria is an important member of the Organisation of Petroleum Exporting Countries (OPEC)[9] and is ranked the 16th largest producer of crude oil in the world as well as the 11th largest oil reserve[10], a larger percentage of the local consumption of petroleum products is still met through importation. Apparently, the low capacity utilisation of the nation's refineries, among other factors, is principally responsible for the importation of petroleum products. Similarly, the current electric power supply is between 3,500 MW and 4,500 MW, while statistics from National Energy Policy (NEP)[8] and Strategic Plan for the Implementation of the National Nuclear Power Programme also corroborate the fact that electric power supply scarcely reaches 4,000 MW at any given time[11].

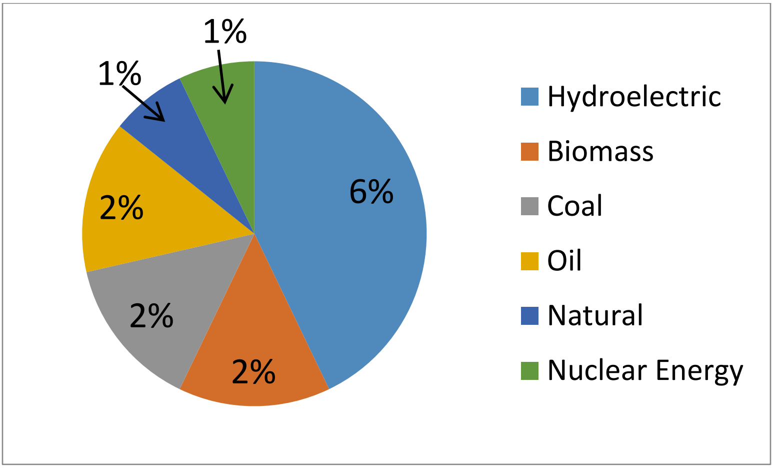
Worst still is the unequal tilt towards the rapid increase in energy consumption as against supply, which is abysmally low. Recent study projected that electricity demand in Nigeria would hit 50,820 MW - 107,600 MW by 2020, 77,450 MW – 172,900 MW by 2025 and 119,200 MW – 297,800 MW by 2030[11]. Thus, the enormous shortfall between supply and demand is largely responsible for the proliferation of generating sets across the country, and this accounts for about 50% of the total installed capacity (approximately 6,000 MW) of the national grid[8,11].

Global Energy Utilisation

The International Energy Agency (IEA)[12] in 2005 put the global primary energy demand at 11.4 billion tonnes of oil equivalent (toe) and it is projected to grow by 55% to 17.7 billion tonne of energy (toe) by 2030. Fossil fuel (FF) is estimated to be the dominant source of primary energy, accounting for about 85% of the expected increase. The IEA also projected that the developing economies, principally China and India, would account for more than 50% of the world's primary energy needs by 2030. Figure 1 shows the primary energy consumption in developed and developing countries. This indicates that fossil fuel sources constitute the largest percentage of energy consumption both in the developed and developing countries.



(a) Developed countries



(b) Developing countries

Figure 1: Typical primary energy consumption in (a) developed, and (b) developing countries[13]

The current trend of energy utilisation, both in the developed and developing economies, calls for concerted efforts to explore, develop and make judicious use of alternative sources of energy other than the present over-dependence on finite fossil fuel (FF) sources. Firstly, FF is being depleted worldwide. Secondly, it is a major culprit in the emission of greenhouse gases (GHG) which the Kyoto protocol[14] seeks to address by setting binding targets for 37 industrialised nations and for the European Union (EU) to cut their GHG emissions.

Several economies, particularly in the developed nations, have broadened their spectrum of energy mix to include an appreciable proportion of renewable energy, and many more are seeking ways of attaining an optimal energy mix. For instance, in the United States of America (USA)[15], RE made up 6.7% of their total energy production in 2006. In Germany[16], RE was 3.1% in 2003 with plans to scale up to 20% by 2020, while in the Netherlands[17], RE was 1.2% in 2000 with plans to increase to 10% by 2020.

The European Union[18,19] however aims at increasing the share of RE in the region to 20% by 2020 and raising RE sources target to 27% by 2030 in the EU[20]. The renewable energy contribution is further expected to increase to 55%–75% of gross final energy consumption in 2050[20].

National Energy Outlook

Non-renewable Energy Sources

Nigeria is endowed with abundant reserves of primary energy resources, which include crude oil, natural gas, coal and tar sands. Table 2 shows the estimated reserve for the various primary energy sources. Aside from tar sands, these fossil fuel sources have contributed significantly to the energy consumption spectrum of the nation. As at 2001, the total commercial energy consumption in Nigeria was 133.35 billion MJ[7]. Oil, which has been a major source of commercial energy consumption over the years, accounted for 31.9%, while natural gas contributed about 61.9%. However, coal's production and utilisation within the same period had experienced a grave decline, recording just about 0.02% of commercial energy consumption.

Table 2: Some Nigerian primary energy resources and capacity in 2005[21]

Resource	Estimated Reserve
Animal wastes	83 x 10^6 tonnes/yr
Coal and lignite	Over 40 x 10^9 tonnes
Crop residues	61 x 10^6 tonnes/yr
Crude oil	36.5 x 10^9 m^3
Fuel wood	1.31 x 10^{11} m^3
Large hydropower	11,235 MW
Natural gas	5.31 x 10^{12} m^3
Small hydropower	3,500 MW
Solar radiation	3.5-7.5 kW h/m^2 /day
Tar sands	4.77 x 10^9 m^3
Wind	2 – 4 m/s at 10 m

Renewable Energy Sources

Hydropower, fuel wood, solar, wind and biomass are some of the non-fossil fuels that are available as RE sources in Nigeria (Table 2). The contribution of RE resources to the total energy consumption in the nation is rather low and fraught with several limitations. In fact, of all the identified non-fossil fuel sources, only the hydropower source contributes significantly to commercial energy consumption and this is estimated to be 6.2%. Technically, however, large-scale hydropower sources in the country has a huge potential for delivering as much as 10,000 MW of power[8,10].

The utilisation of fuel wood, though characterised by low thermal efficiency, and obvious environmental and health challenges, nonetheless still constitutes more than 50% of the overall national energy consumption[8,21]. Currently, in Nigeria, the deployment of other RE sources is quite marginal and in some cases non-existent[8].

National Energy Mix

In Nigeria, today, the energy supply mix is largely limited; and, in some cases inefficient energy conversion methods are employed as seen in the traditional charcoal production (carbonization). Bellais[23] observed that carbonization undergoes slow pyrolysis, which takes a long period (approximately 4–12 h) and is also an inefficient process as only about a third (30%) of the initial wood chemical energy is conserved in the charcoal. In fact, it may be as low as 20% according to Pentananunt et al[24]. Charcoal production in Nigeria is quite laborious and tortuous because it takes as many as 120 h (5 days) with close monitoring to avoid a situation where it turns completely to ash.

The hostile practice of felling trees for energy generation in domestic applications worsens the energy scenario because of its hazardous implications for both humans and particularly the environment. This practice constitutes a sizeable percentage; about 50% of wood consumption is estimated for energy generation in both rural and semi-urban areas in Nigeria[8]. Undoubtedly, this contributes to land degradation, deforestation, and even the threat of extinction of some tree species. The Federal Government of Nigeria (FGN), through its National Energy Policy, seeks to promote the harnessing of all the viable energy resources to have an optimal energy mix, while ensuring sustainable and environmentally friendly energy practices[8]. Moreover, emphasis is being laid on renewable energy production as clearly enunciated by the FGN in its Guideline Policy Statement (Renewable Electricity Action Program, REAP)[25].

National Institutional Framework

The apex organ of government charged with the statutory responsibility for the strategic planning, coordination, and supervision of energy-related activities and the implementation of a comprehensive and integrated energy policy is the Energy Commission of Nigeria (ECN). The ECN was established by Act No. 62 of 1979, as amended by Act No.32 of 1988 and Act No. 19 of 1989[26].
The energy sector comprises a host of other Federal Government Institutions which, hitherto, have operated as separate entities running their respective sub-sectoral policies independently. This arrangement, however, makes

the energy sector prone to policy conflict that could hinder the prospective growth and development of the sector. Apparently, the necessity for a comprehensive and an integrated energy policy occasioned the drafting of a National Energy Policy in 1993 by ECN[8]. This policy was subjected to several reviews by successive governments and a final copy of the National Energy Policy was produced in 2003.

In summary, according to Lukman[8], “The overall thrust of the energy policy is the optimal utilisation of the nation’s energy resources for sustainable development.” The implementation of the policy would help promote cooperation among the Energy Commission, relevant Federal Ministries and Federal Parastatals such as Nigerian National Petroleum Corporation (NNPC), Power Holding Company of Nigeria (PHCN), Nigeria Coal Corporation and others. It would undoubtedly ensure effectiveness and efficiency in the harnessing and utilisation of the country’s abundant energy resources.

From the trends presented, nations and economic blocs set targets in relation to the form of **energy that works** best for them based on the comparative advantage they have in the exploitation of their resources. Conventional energy sources will sooner or later get depleted; hence, they will no more be reckoned with and can no more deliver the work required for development. I submit therefore that the **energy that works,** and will continue to work, on sustainable basis is the renewable energy derivable from the Sun. Notably, there is a gradual shift towards the exploitation of renewable energy resources by many nations so as to increase its percentage share of the energy mix.

Contributions to knowledge through Research

Mr Vice Chancellor, Sir, I joined this great University over two and half decades ago, precisely in 1991 as a Junior Research Fellow. Since then I have had great opportunity of making some modest contributions in the dual core engagement expected of an academic in the areas of teaching and research. I have made modest contributions in wood waste to energy applications, thermochemical conversion of biomass waste to energy products and chemicals, application of solar energy to drying of food crops, water heating and ventilation in buildings, and mixed convective heat energy transfer in rotating elliptic ducts. These will be discussed in the subsequent sections.

Wood Waste for Energy Applications

Waste generation is a concomitant aspect of living which cannot be avoided but can only be managed[27]. Similarly, wood wastes generation is inevitable either during felling of trees for log production in the forest or diverse sawing processes of logs/planks at the mills. Wood residues (wastes) produced during milling and re-sawing activities include tree barks, cut slabs, sawdust, plain shavings, and strips and their generation can be traced back to the 18th century[28]. Locally, these residues are often used as filling material, poultry/animal bedding material, mulch, raw material for particle board making, and cooking fuel. However, as the demand for wood products rises in a quest to meet the developmental drive of the society, the generated wood waste also increases and this increase overwhelms its present utility. The increase in the quantity of unutilised wood wastes have over the years impacted negatively on the environment while crude management techniques have posed health hazards in addition to air and water pollution.

Wood wastes pose several challenges to the environment and health of citizens. When its utilisation is low, saw millers use several crude ways to dispose the generated wastes within the vicinity of sawmills and plank markets. It is, therefore, common for wood wastes to find their way into drainage systems and river channels either advertently or inadvertently, thereby causing obstruction to water flow as shown in Figure 2. Sometimes, these residues are stacked close to the machines as depicted in Figure 3, making maneuverability around workspace extremely difficult, thus compromising occupational safety. They are sometimes burnt in open air in an effort to reduce the volume and size of the recurring huge amount of wood wastes. During such open-air burning, as shown in Figure 4, the smoke given off pollutes the air with carbon monoxide, which is hazardous to health.

A huge volume of wood residue is generated annually from timber processing activities around sawmills, plank markets and furniture making factories in cities within Nigeria. For instance, about 294,798 tons of wood waste is generated yearly in the city of Lagos[29], while about 2288 m^3 is generated daily in Abeokuta and a total of 104,000 m^3 of wood waste is generated daily in Nigeria[30].

Lasode and Balogun[31] reported that the average volume of wood wastes generated daily at sawmills and plank markets in Ilorin metropolis is 119.52 m^3 (100.4tons) and estimated that 31,324.3 tons would be produced yearly in the city. This represents a huge potential for energy generation in terms of electricity production. The study estimated that 100.4 MW of electricity could be generated daily in Ilorin[32]. The generated wood waste can be converted to useful renewable energy product, such as torrefied fuel pellets, which can find application in domestic and industrial purposes such as cooking, barbecue fuel, and co-firing of steam boilers.

Figure 2: Wood wastes disposed along a drainage system[31,32]

Figure 3: Wood residues heaped at a plank market[31,32]

Figure 4: Air pollution from burning of wood waste[31,32]

Availability of feedstock and suitability of location are major decision criteria in siting a waste-to-energy facility. Lasode, et al.[33,34] evaluated the amount of wood waste available for energy generation in Ilorin, Nigeria from twenty potential energy facility sites. Single Facility Location with Rectilinear-Distance Model was used to determine an optimum location for energy generating facility based on the impact of four major constraining factors; the net amount of waste available, transportation cost, social effect, and environmental effect. The study found that 61.25% (73.92 tons per day) of the total wood waste generated was left unutilised and the optimum location for a waste-to-energy facility corresponded to (X, Y) coordinates (940.1253, 507.4959). This spatial position unfortunately coincided with an existing recreational facility, thus making it unsuitable. The most feasible location away from the optimum location was chosen through the construction of a contour map and it corresponded to coordinates (939.2536, 507.8525), which is within the Industrial zone of the city. The result of this research has been implemented by one of the beverage companies in an industrial zone of Ilorin metropolis, resulting in savings on diesel cost to run its boiler to the tune of over ₦100 million in 18 months.

Thermochemical Conversion of Biomass Waste to Energy Products and Chemicals

Biomass has assumed a pivotal role among several alternative energy resources known to humankind. Globally, biomass cultivation and utilisation for energy and chemical production is being pursued vigorously because of its renewable potentials, sustainability prospects and inherent ability to address some environmental concerns engendered by fossil fuel utilisation. Table 3 summarises the variety of biomass resources, their estimated quantities in Nigeria and their energy value.

Table 3: Biomass resources and estimated quantities in Nigeria[35]

Resource	Quantity (Million tonnes)	Energy Value ('000 MJ)
Agro-waste	11.244	147.7
Fuel wood	39.1	531.0
Municipal Solid waste	4.075	-
Saw dust	1.8	31.433

Thermochemical conversion processes, such as pyrolysis (promotes fuel and chemical extraction) and gasification (ensures syngas production for power generation), are viable means for the utilisation of biomass residues[36, 37]. Pyrolysis may be used in harnessing energy potentials of biomass resources. It takes place between 723 and 873 K, essentially to produce condensed liquid (bio-oil)[39]. The chemical composition of the bio-oil is often of interest to scientists for its utilisation as biofuels. The products from thermal processes as well as the energy and matter recovery systems are represented diagrammatically in Figure 5 as presented by Bridgwater[39].

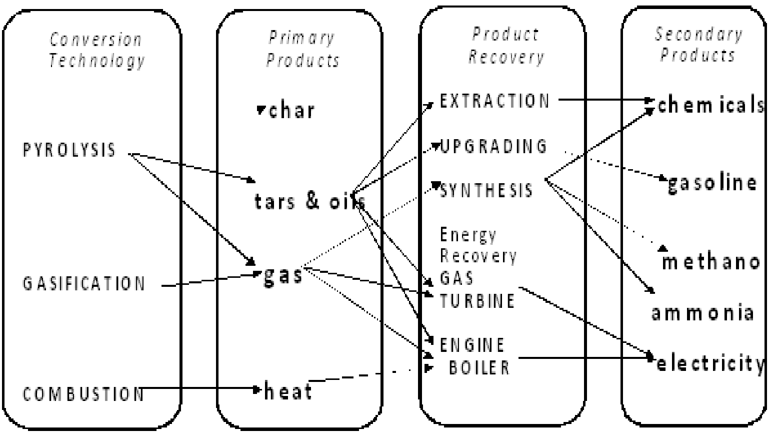


Figure 5: Thermal conversion process and products[39]

Lately, the University of Ilorin, Nigeria, in an effort to apply the principles of sustainable development to the environment instituted an ambitious programme of planting 100,000 seedlings of teak (*Tectona grandis*) for a period of five years and it started off with 70,383 seedlings on 57 hectares of land in 2008[40]. Teak is also one of the common tree species used as wooden transmission poles and for other structural purposes in Nigeria[41]. Teak harvesting and processing evidently generate significant quantities of residues that can be utilised for thermochemical conversion.

Balogun, Lasode and McDonald[35] conducted reaction kinetics using model-free techniques and analytical pyrolysis Py-GC/MS on Teak of Nigerian origin in view of the prospective local production of biofuels from its wastes. They showed that the ash and C contents and the HHV were 0.7%, 49.6% and 19.8 MJ/kg respectively. Biomass sample was subjected to multiple heating rates (5–35 K/min) in thermogravimetric experiments and kinetic parameters were evaluated from the non-isothermal TGA curves. The activation energy (E) varied between 222 and 300 kJ/mol as a function of degree of conversion. Similarly, the pre-exponential frequency factor (A) varied between 9.6×10^{17} and 9.55×10^{24} min^{-1}. Analytical Py-GC/MS showed the presence of CO_2, acetic acid, furan + 2-butanone, levoglucosan, trans-coniferyl alcohol and lignin derivatives. The proportion of phenolic compounds identified was more than one-third with isoeugenol, acetoguaiacone, and 4-vinylguaiacol showing dominance.

Woody (*Albizia pedicellaris* and *Terminalia ivorensis*) and non-woody (guinea corn (*Sorghum bicolor*)) glume and stalk biomass resources from Nigeria subjected to thermo-analytical and physico-chemical analyses to determine their suitability for thermochemical processing were studied by Balogun, Lasode and McDonald[42]. The species investigated were found to have comparably high calorific values between 16.4 and 20.1 MJ kg^{-1}. The woody biomass had very low ash content (0.32%) which made them suitable for biofuel applications, while the non-woody biomass had relatively high ash content (7.54%). Thermogravimetric analysis (TGA) results showed significant variation in the decomposition behaviour of the individual biomasses. Gas chromatography/mass spectrometry (GC/MS) of fatty acid methyl esters (FAMEs) derivatives indicated the presence of fatty and resin acids in the dichloromethane (CH_2Cl_2) extracts. Analytical pyrolysis (Py-GC/MS) results revealed that the volatiles liberated consisted mostly of acids, alcohols, ketones, phenols, and sugar derivatives.

Torrefaction is a thermochemical conversion process which has gained global attention as a viable pre-treatment technology for biomass feedstock in gasification and co-combustion processes[43,44]. The production of high quality char for domestic heating and cooking through the technology of torrefaction has become a subject of scientific research and development[45,46]. Torrefied biomass resource could also be of practical importance in the metallurgical industry[46]. Though similar to pyrolytic conversion process in that it is conducted in an inert atmosphere or in the presence of limited air, other process conditions such as residence time, operating temperature and heating rates differ significantly. Torrefaction experiments, conducted at low heating rates (<100 °Cmin^{-1}), between 220 and 300°C and at approximately 1 h residence time, resulted in the production of a homogenous carbon-rich char[47]. The characteristic properties of torrefied biomass are substantially influenced by biomass type, particle size and mostly temperature[44,48].

Lasode, Balogun and McDonald[49] investigated the influence of torrefaction process conditions on the yield distributions of some Nigerian hardwoods (*Albizia pedicellaris*, AP, *Tectona grandis*, TK, *Terminalia ivorensis*, TI) and non-woody (*Sorghum bicolour* glume, SBG, and stalk, SBS) biomass resources. The laboratory scale set-up for the torrefaction experiments is presented in Figure 6. Table 4 presents the summary of proximate and elemental analyses as well as the higher heating value of various biomass resources. Biomass type played a dominant role in the solid yield recording 71% for woody and 58% for non-woody samples at 270°C, while temperature showed the greatest influence with solid yield dropping from an average of 80% (at 240°C) to 50% (at 300°C). Both volatile matter and fixed carbon contents experienced significant changes after torrefaction and a decline in oxygen/carbon (O/C) ratio from 0.6 to 0.3 was noted. Among the woody biomass, TI experienced the highest increase in higher heating value (HHV) of approximately 38%, compared to AP (32%) and TK (32%), and was subsequently selected for decomposition kinetic study. The decomposition kinetics showed that activation energy, E(α), for the hemicellulose degradation stage ranged between 137 and 197 kJ mol^{-1} for conversion, α, between 0.1 and 0.24, implying that biomass kinetics within this decomposition region is a multi-step reaction. The GC/MS analytical technique revealed that the presence of levoglucosan was highest (7.1%) in woody biomass, while phenolic compounds made up more than one-third of the group of compounds identified.

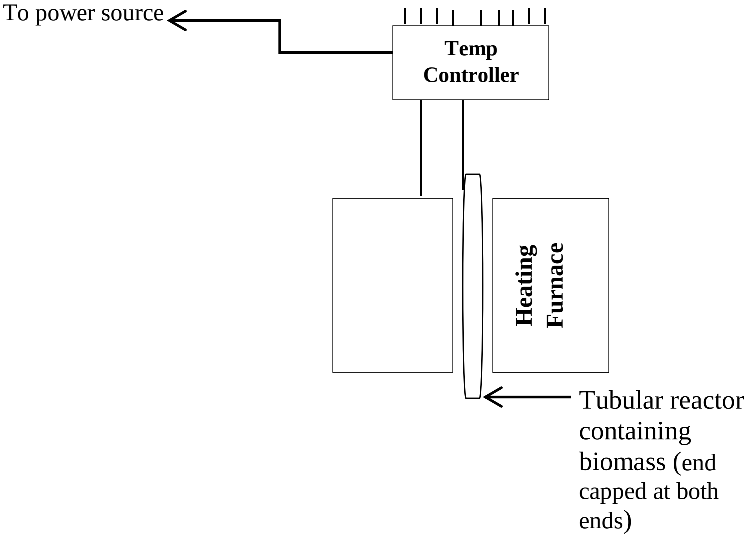


Figure 6. Schematic diagram of laboratory scale set-up for torrefaction experiments[49]

Table 4: Proximate and elemental analyses and higher heating value of biomass resources[49]

	Woody			Non-woody	
	AP	TK	TI	SBG	SBS
Proximate analysis[a] (wt%)					
VM	92.7	95.5	82.3	78.9	82.9
FCC[b]	5/61	3.8	17.4	13.6	13.8
Ash	1.68	0.7	0.32	7.54	3.25
Elemental analysis[a] (wt%)					
C	51.7	49.6	48.6	42.4	46.2
H	5.85	6.3	6.00	5.27	5.85
N	0.54	0.4	0.44	0.74	0.44
O	42.0	43.7	45.0	51.6	47.6
HHV (MJ/kg)	20.1	19.8	17.3	16.4	17.9

[a] Dry basis
[b] Calculated by difference, HHV, higher heating value.

Solar Energy Research

Solar energy is a high-temperature, high radiant energy source, with tremendous advantages over other alternative energy sources. It is a reliable and robust renewable resource which is largely undeveloped. It has a high-temperature, high-exergy energy source at its origin, the Sun, whose irradiance is about 63 MW/m^2 and travels to the earth in the form of electromagnetic radiation[50]. However, Sun-Earth separation geometry dramatically decreases the solar energy arriving the Earth's surface to around 1 kW/m^2. Solar energy is fast becoming an alternative source of energy because of the high rate of depletion of the conventional energy sources like thermal, chemical, and petroleum energy.

The solar irradiation available to a solar collector device varies with its azimuth, pitch and geographical location[51]; and the relative amount of solar irradiation at a given geographical location plays an important role on the type of solar collector device that may be applied. The different devices available for harnessing solar energy include systems with flat plate collector, concentrators and vacuum tube collectors which are employed for heating of building and crop drying[52]. Non-focusing solar collectors like glass and flat plate collectors make use of both diffuse and direct solar radiation with a greater geographical range of application. Focusing solar collectors mainly operate with direct solar radiation[53]. The solar radiation is converted into thermal energy in the focus of solar thermal concentrating systems. These systems are classified by their focus geometry as either point-focus concentrators (central receiver systems and parabolic dishes) or line-focus concentrators (parabolic trough collectors (PTCs) and linear Fresnel collectors)[54].

In a tropical continent like Africa, solar energy is available in abundance. Nigeria is a geographically-favoured region lying approximately between 4°N and 14°N of the Equator and 15°E of the Greenwich Meridian[55], where abundance of sunshine or solar energy can be received[56]. The tropical station under consideration, Ilorin, lies on latitude 8.462°N and has solar radiation of 550-1075 Wh/m^2 or about 17-25 MJ/m^2 per day[57]. This is quite an enormous amount of energy that should be put to the best use[58].

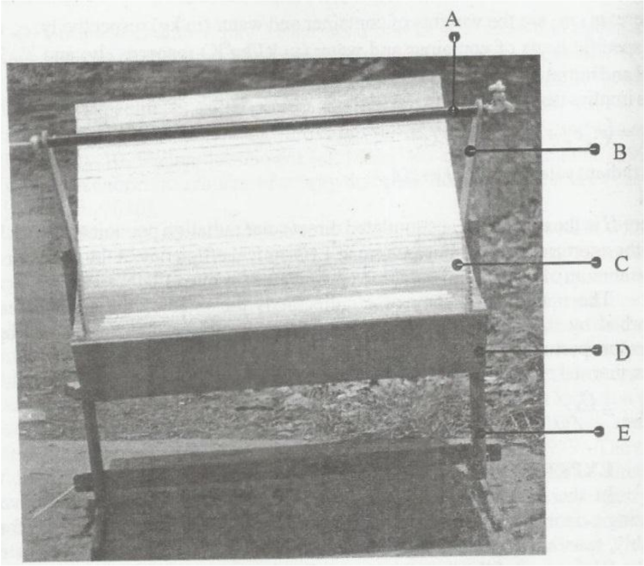
The quest to utilise the cheap and readily available solar energy and also to overcome the shortcomings of open sun drying process brought about the development of solar drying system to improve upon the existing food and agricultural products preservation techniques. The use of solar energy to dry crops is nothing new in the tropics as many edible and even cash crops such as cocoa and coffee beans have traditionally been dried on racks placed in the sun. Although the traditional sun drying process is common and widely embraced by all, the process is slow and sometimes incomplete under unfavourable climatic condition. Often, the drying products are subjected to noxious effects of dust, dirt and insect infestation. As a result of inadequacies of the open sun drying process, research efforts on drying agricultural produce have been on the increase over the years in order to develop and produce an economical, effective and systemised method of drying[59].

Application of Solar Energy to the Drying of Food

Lasode[60] designed solar dryer with a collector that could transmit 125 W/m^2 thermal power to the drying air. The dryer raised the temperature of ambient air from 30°C to 45°C and reduced relative humidity from 80% to 34%. Tests later carried out on the dryer revealed that the yam flake samples in the solar dryer showed no sign of mould formation, was lighter in colour, and had better taste compared with that of open sun. Lasode[61] also designed and constructed an improved, low temperature, and a model solar cabinet dryer based on thermal processes from psychrometric chart and the climatic condition of Ilorin, Nigeria. The dryer operates on the principle of direct radiation and convective heat flow with a collector —a double layer glass that could transfer 334 W/m^2 thermal power to ambient air at 27°C and 70% relative humidity (R.H.) and could be heated up to 53°C at 16% R.H. for drying. The construction was made from locally available materials (plywood, wood, sawdust). Crop dehydration tests showed that the dryer apart from drying faster, also showed a uniform and systemised drying process, as there was no mould formation on samples in the dryer as observed in the open air sun-dried samples. The solar dried crop samples showed better quality in terms of appearance, colour quality, food taste and odour, than the open air sun-dried samples. Drying was enhanced in the dryer at low humidity of 16% and maximum temperature of 63°C.

Use of Solar Energy for Water Heating

Solar radiation can effectively and efficiently be utilised for water heating in the tropical environment by employing a suitable design, selection of time of heating and proper focusing of the reflected rays to the focal spot region. Solar Water Heating (SWH) system is a well-proven and readily available technology that directly substitutes renewable energy for conventional energy in water heating[62]. However, parabolic-trough SWH is a renewable energy technology with considerable potential for application in building facilities[63]. Lasode and Ajimotokan[64] developed a solar water heater to directly utilise solar energy for water-heating purposes (see Figure 7). The average thermal efficiency of the solar water heater was 89.9%.



Legend: A=Absorber pipe, B=Absorber stand, C=Reflector surface (curved mirror), D=Reflector support, E=Stand

Figure 7: Parabolic Trough Solar Water Heater

Improved Ventilation in Buildings through Solar Energy Application

Adedeji and Lasode[65] developed a steady state mathematical model for a solar chimney to enhance the effect of thermally induced ventilation in buildings (see Figure 8). The analytical model employed takes into account different sizes of the openings of a solar chimney with varying values of the discharge coefficients. Numerical calculations performed for different values of ambient temperature and solar radiation show that a solar collector area of 1.80m^2 is able to induce airflow between 2.64 m^3/h to 3.72 m^3/h for solar radiation of 280 W/m^2 and 850 W/m^2 respectively. From the optimisation result, total area of collectors has been estimated to be 10.9 m^2 — rectangular base — for a hall of 4050 m^3.

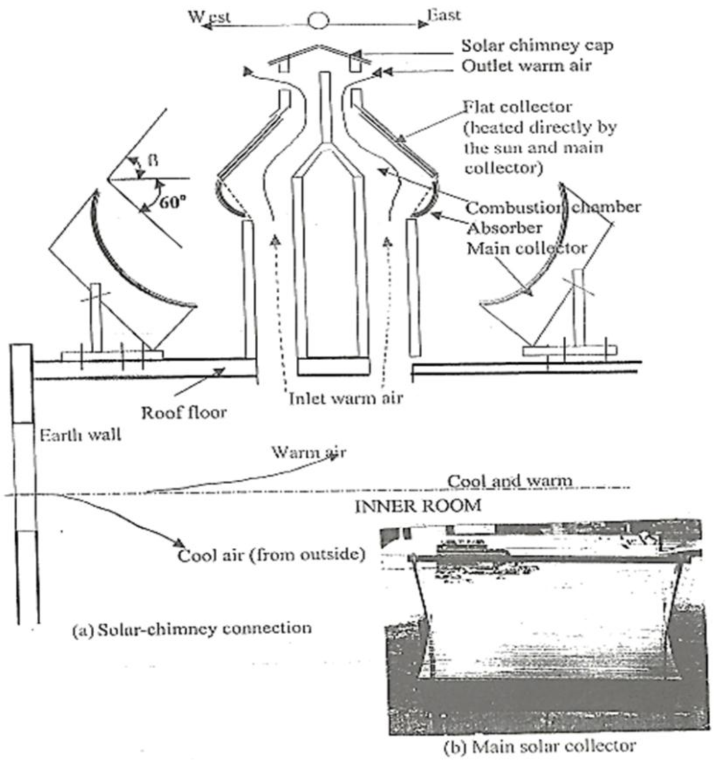


Figure 8: Installation of Solar Collectors and Chimney

Mixed Convective Heat Energy Transfer in Rotating Ducts

The power output from electrical machines is to some extent governed by the permissible temperature rise in the insulation surrounding the rotor conductors. Although cooling these conductors is commonly achieved by the forced circulation of air over the rotor periphery, there are advantages if the heat transfer is effected through a suitable coolant flowing inside the conductors themselves, especially for large machines such as those found in hydroelectric power stations. In practice, axial cooling holes having a variety of cross-sectional shapes are commonly used. It is thus evident that the problem of forced flow through heated rotating channels is interesting both academically and practically.

Bello-Ochende and Lasode[66] studied laminar combined free- and forced-convection heat transfer in rotating horizontal elliptic ducts (see Figure 9) and presented results of heat transfer and fluid flow in graphical forms. They indicated that optimum heat transfer was predicted when the eccentricity e = 0.433 for the range of parameter space $0 \leq Ra_r\, Re_m Pr \leq 640$ for the temperature field and $0 \leq Ra_r\, Re_m Pr \leq 1660$ for the axial velocity field.

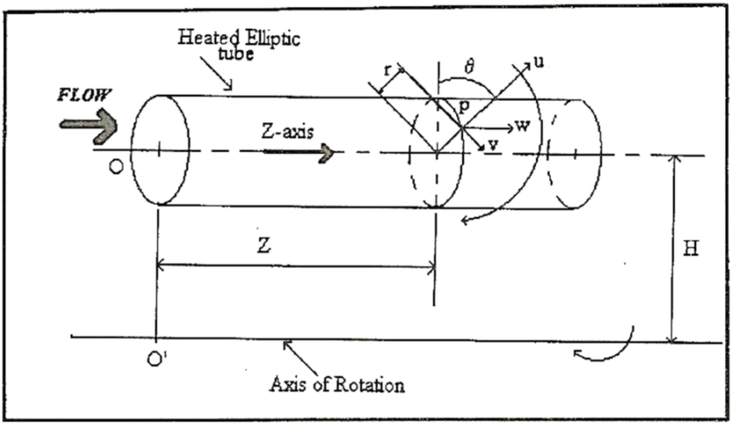


Figure 9: Physical model, co-ordinate axes and regions of the horizontal elliptic ducts.

Lasode[67] used parameter perturbation method to analyse laminar free and forced convective heat transfer in rotating horizontal elliptic ducts (see Figure 9) with the parameter space for the overall validity of the results presented as $0 \leq Ra_\tau \, Re_m \, Pr \leq 640$. At the fully developed flow region considered, $C_{fr} = \eta = W = Nu(\theta) = F(Ra_\tau, Re_m, Pr)$. It was shown that the perturbation parameter Ra_τ was responsible for the lateral shift of the temperature and axial velocity profile away from the origin along the major diameter. It was also shown that this deviation from the usual parabolic profile associated with pure forced convection was caused by secondary flow effects and bouyancy forces. Along the minor diameter, these effects are insignificant. The peripheral local Nusselt number is insensitive to Prandtl number changes for a duct of eccentricity e = 0.866 which is an important result for a designer of rotating heat exchanger.

Lasode[68] investigated laminar mixed convective heat transfer in vertical elliptic ducts containing an upward flowing fluid rotating about a parallel axis (see Figure 10) with the parameter space for the overall validity of the results presented as $0 \leq Ra_\tau Re_m Pr \leq 820$. The coupled system of normalised conservation equations was solved using a power series expansion in ascending powers of rotational Rayleigh Number, Ra_τ – a measure of the rate of heating and rotation- as the perturbation parameter. The mean Nusselt number is observed to be highest at duct eccentricity, e=0 for a given Prandtl number. However, results indicate insensitivity of peripheral local Nusselt number to Prandtl number at eccentricity, e=0.866, which is an important result to a designer of rotating vertical heat exchanger. For vertical elliptic ducts rotating about a parallel axis, the mean Nusselt number is invariant with eccentricity up to e=0.433 for low rates of heating and rotation, and monotonically decreases with eccentricity for high heating rates.

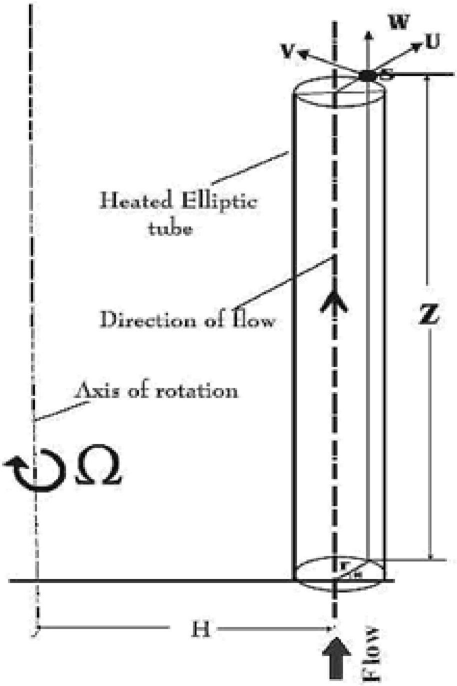


Figure 10. Physical model, co-ordinate axes and regions of the vertical elliptic ducts

Conclusions and Recommendations

Mr Vice Chancellor, Sir, I have attempted in this lecture to examine Energy that Works. I mentioned the relationship that existed between energy use and development of civilization. The important message is that there is gradual shift from reliance on conventional energy resources for development to renewable energy. Nations and economic blocs are setting targets to increase the percentage of renewable energy in their energy mix. Some of these targets were met even before the set dates because of the efforts and seriousness with which the targets were pursued through aggressive research funding.

An attempt was made to relate the global energy outlook with that of the nation. Also considered was the comparison between the energy mix projections of some developed economies with a view to increasing the contribution of renewable energy and that of Nigeria.

I now wish to make some recommendations that I consider might help Nigeria in her efforts to develop and explore the abundant energy resources in the nation. These recommendations will enhance meeting the energy needs of the citizens and engender the required technological development that we so much yearn for.

1. The draft Nigerian Bio-fuel Policy and Incentives[69] aims to help Nigeria develop a low carbon economy and gradually reduce the nation's dependence on imported gasoline, reduce environmental pollution associated with fossil fuels while at the same time create a commercially viable and sustainable agro-industrial clusters across the country where fuel ethanol, biomass co-generation electric power, cattle fattening and the Great Green Wall (GGW) fruit canning programmes may be practised with a view to precipitating pervasive domestic jobs and wealth creation, poverty reduction and the general well-being of the citizenry.

   The focus of the draft policy is on liquid bio-fuels, with the Nigerian National Petroleum Corporation (NNPC) playing a prominent role in its implementation. I wish to recommend that this policy be strengthened and broadened to include solid and gaseous bio-fuels if the aim is to be achieved. The inclusion will help regulate the use of raw fuel wood and encourage the use of alternatives such as solid and gaseous bio-fuels in a sustainable manner.

2. The bio-fuels quality criteria are not specifically mentioned in the draft policy. The bio-fuels should meet a minimum requirement for Green House Gas (GHG) savings of 35% relative to fossil fuels with a view to increasing this percentage. Sustainability requirements for the use of solid and gaseous biomass as energy sources in electricity, heating and cooling should also be addressed.
3. Government should set achievable target for percentage of renewable energy components of the national energy mix and sponsor specific researches with the aim of meeting it within specified time frame. This could be captured as a thematic area in the TETFUND Research Grant.
4. The importance of computational research cannot be overemphasised considering its advantages in developing useful predictions, forecasts and correlations. Computing capabilities determine the accuracy and level of meaningful result that is generated. Computational research should be encouraged and strengthened by Government with the provision of super-computing facilities in Nigerian Universities, starting with the University of Ilorin.
5. In order to boost electricity supply to the rural areas to stimulate development, off-grid hybrid electricity generation stations, comprising mini-hydropower, solar

photovoltaic cells, wind turbine and bio-fuel generators, should be built in areas with multiple energy resources.

6. University of Ilorin should pioneer solar water heating devices on roof-tops of hostel buildings to provide hot water for bathing while solar photovoltaic cells should be used to supply lighting, thus reducing the cost of electrical energy.

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