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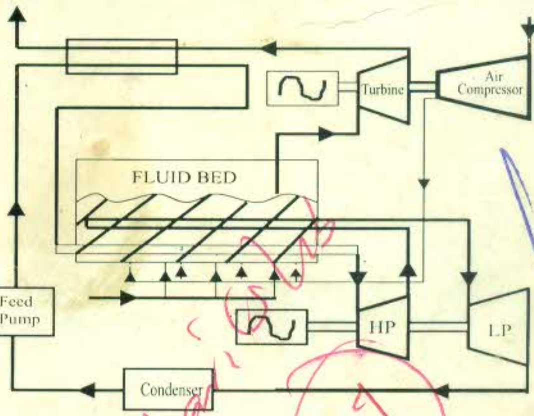
SUSTAINABLE ENERGY TECHNOLOGY FOR THE 21ST CENTURY

INAUGURAL LECTURE Series No.2



COMBINED GAS AND STEAM TURBINE PLANT

pg 25

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PROFESSOR FOLORUNSHO OLAYIWOLA AKINBODE

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Thursday, 26th February, 2004

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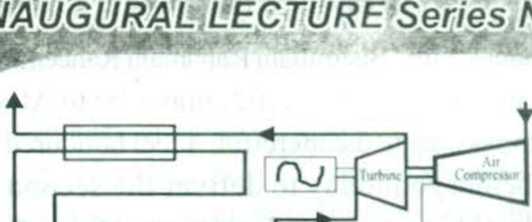

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The Vice – Chancellor
Deputy Vice-Chancellor
Principal Officers of the University
Deans of Schools and Directors of Units
Members of the Academic
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Distinguished Ladies and Gentlemen

PREAMBLE

Hausbillahi Minasetani Rajim. Bisimillahi Rahamani Raheem. In the name of Allah, the compassionate, the merciful, praise be to Allah, Lord of the world, the compassionate the merciful. I feel honoured and highly delighted to stand before you today to deliver the second Inaugural Lecture of the Federal University of Technology, Minna, the first in the series from the School of Engineering and Engineering Technology and the first in the series from the Mechanical Engineering Department.

This lecture titled "Sustainable Energy Technology for 21st Century discusses sustainable near term power generation technology which meet the requirements of high efficiency low environmental impact and economical feasibility, both fossil fueled and renewable energy technology have been evaluated. Among the fossil fueled energy technologies, advanced combined cycle power generation with fuel to energy conversion efficiencies up to 60% and cogeneration plants with fuel energy utilisation factor up to 85 – 90% are the near – term technologies. Pressurized fluidized bed combustion, integrated gasification combined cycle power plants and advanced gas turbines and fuel cell based combined cycle power plants are categorized as environmentally sound and highly efficient power generation technologies. Renewable energy sources and then integration into total energy supply system are also discussed.

1.0 INTRODUCTION

The prosperity of a country is dependent upon the efficient and rational use of energy, which is necessary for industry, transportation and also plays an important role in one's domestic life.

The world population is now 5.85 billion people with 72.3% living in Asia and Africa and it is expected to stabilize at the level of 8 billion people by 2100. The current world primary energy consumption (in 10^9 kWh) is 93.65, including Europe 33.6, North America 26.5 (U.S.A. 23.95), Asia 23.1 Latin America 4.65 middle East 3.1 and Africa 2.65 (Status 1993) B.P. statistical review of world energy, (1994) and Khartehentho (1998).

World's proven fuel reserves in 10^{21} J roughly are: coal 30, oil 6, natural gas 5, with the present rate of consumption, these reserves will be exhausted in 225, 45, and 65 years respectively. The world average energy consumption per capital was approximately 1.6 tonnes of oil equivalent (toe) per year with extremes of 7.5 toe in USA and 0.25 toe in Africa. By 2025, the world average is expected to stabilize at the above level but in developing countries like Nigeria it will double or triple compared to the present level due to growth of population and industrialization.

The shares of different energy forms in the current world energy consumption are oil 33%, coal 23%, gas 19% biomass 14%, hydro-energy 6% and nuclear energy 5.6%. These currently used energy resources are predominantly non-renewable and bound to exhaust. The patterns of the energy production and use are unsustainable and lead to severe deterioration of the environment. The sustainable energy sector is based on the efficient use of existing energy stocks and energy conservation to be able to satisfy the optimized energy needs of current and future generation without significant environmental impact.

To develop the sustainable energy sector the energy policy has to be considered in the light of energy policy and demand in the world and other constraints such as environmental pollution control requirements, the supply of trained scientist and engineers etc. It should also be directed toward:

a. Reduction in energy consumption especially in industrialized countries,
b. Energy conservation in all sectors of economy.
c. Full integration of renewable energy sources into global energy supplies system.

The electricity is currently generated power predominantly in large hydroelectricity power plants and oil and gas-fired steam power plants. Sustainable power generation systems show high energy conversion efficiency, low environmental impact and viable economics. High efficiency energy systems produce more electricity per unit of fuel burnt and thus produce less emissions of green house gases and pollutants such as SO , NO_X, unburned hydrocarbons and CO. Advanced energy systems such as combined cycle power plants and clean energy technologies, offer enhanced efficiencies, improved economics and reduced environmental impact. Efficient emissions abatement techniques can remove up to 97% $SO_2$and 90% NO_X(Khartchenko (1998)).

Mature fuel cell technology will provide combined cycle power generation and cogeneration plants featuring efficiency up to 65-70% (power generation) near zero emissions, quiet operation and load-following capabilities. Base-load and distributed power generation and cogeneration plants, industrial, commercial and residential natural gas, fuel cell power plants and cogeneration plants sized from 500kWe to 20MWe are expected to be economically feasible by 2010 (Khartehenko 1998).

Integration of renewable energy sources into energy supply systems will minimize problems associated with finite fossil fuel resources and environmental deterioration due to emissions from fossil-fuel based energy system. Ultimately renewable energy systems will replace fossil-fuel based energy sector ((Boyle (1996) and Eurec Agency London (1996)). The purpose of this lecture is to provide information on the resources availability of the energy option and the technologies that will sustain them. It is also the purpose of the lecture to provide details of current research and development efforts in environmentally sound and highly efficient power generation technologies.

2.0 ENERGY RESOURCES

Table 1 gives a general view of the energy resources in Nigeria. The consumption rate and the lifetime at present rate of consumption are also given in this table.

Table 1: Nigeria Energy Resources (1987)

Coal – Bituminous } Sub- bituminous } 190 Mt Consumption: 50,000 + Lifetime at present rate of consumption = 380 years.
Oil Proved recoverable reserves 2200 Mto Consumption 62 Mto Lifetime at present rate of consumption = 33 years.
GAS Proved reserves $2.4 \times 10^{12} m^3$ (2210 mtoe) Production: 3.7 mtoe Lifetime: 600 years
RENEWABLE SOURCES Hydropower Biomass Solar Energy Wind Energy

Source: Williams (1990)

2.1 Fossil Fuels: Coal and Lignite

Coal started playing some part in the national economy soon after its discovery in Enugu State in 1909. As of now, seams of sub-bituminous coal deposits of economic significance are identified in five main location: Enugu and Ezimo (in Enugu State), Orukpa (Benue State) and also Okaba and Ogboyoga (Kogi State). Also in Agwatashi and Azara (Obi and Awe local government areas respectively of Nassarawa State), bituminous coal deposit of economic significance and inferred reserves are of the order 190mt and with the consumption rate put at 50,000+, the coal will last about 400 years.

Lignite on the other hand has not effectively entered the energy market. Reserves are said to be about 206×10^9 kg distributed mainly in two zones:-

Ogwashi – Asaba (in Delta State): 64×10^9kg.

Oba – Nnewi (in Anambra State): 142×10^9kg.

It is thus reasonable to expect a national energy reserve in the neigbourhood of 0.0045Q from lignite (where $Q = 10^{18}$kJ)

2.2 Fossil Fuels: Liquid Petroleum and Natural gas

"Reserves" of crude petroleum and natural gas are never easy to determine. Intensive and more expensive exploration had often tended to reveal new sources. The known reserves as at 1987 is shown in Table 1. Gas unassociated with petroleum liquid is not listed since usually all such gas wells are sealed. They are found mostly in the south- east and south-south states (Delta, Rivers, Cross Rivers, Akwa Ibom, Bayelsa, Abia and Imo).

2.3 Hydro Power

Hydropower systems rely on the potential energy difference between water reserves, dams or lakes and their discharge tail water levels down stream. The energy supply therefore is mechanical and conversion efficiencies relatively high.

Nigeria is well endowed with hydro electric resources, three at the moment which are concentrated in the North central states. Feasibility studies are also reported that first priority would be given to the following sites; Lokoja, Makurdi, Ikom, Zungeru and Mambila (Esan (1981) and Ezeilo (1978).

2.4 Shale Oil And Bitumen Sands:

Currently, unquantified bituminous tar sand deposits of economic significance are identified in Ondo State (Agbabu and Gbelejuloda). The deposits have an estimated extrapolated reserve of about 42.7 million barrels of bitumen and heavy oil (Olabisi 2003). Experts say the bitumen runs through Ondo, parts of Ogun, Edo and Lagos States.

2.5 Biomass: Fuel wood – about 80% of Nigeria population live in rural areas and depend mostly on wood for heating and cooking. Since Nigeria is going through rapid urbanization, the consumption of wood for domestic purposes (mainly cooking) has to be minimized and replaced with LPG and electricity.

2.6 Solar And Wind Energy: A very small number of solar units are in Nigeria presently. They are for water heating and drying of grains. Wind energy is being used to pump water from wells.

3.0 ENERGY CONSUMPTION

The world energy scene is dominated by two factors, the increasing requirement for energy and the increasing population growth. It is clear that the growth rates are high but the increase in energy has been slightly greater than the population growth resulting in an increase in energy/capita between 1976 and 1987. This has generally resulted in a high quality life as indicated in a variety of statistical indicators e.g. life expectancy at birth has increased, as the number of cars on the road. The trend therefore in developing countries is for the energy consumption per capital to increase but in the case of developed countries, e.g. Europe, USA, the trend is for the energy consumption to decrease per capita. This energy ratio has often been simply related to GDP per capita but in recent years this has been decoupled and has changed with time.

The major source of energy in the world is oil but coal and natural gas make very considerable contribution as shown in Table 2. The total contribution of nuclear power is still small and is only likely to grow slowly over the next couple of decades. Of the renewable energy resources, solar makes a large but rather unquantifiable contribution, hydropower is becoming of greater significance. The other major source is biomass but estimates of the quantities used must have considerable errors associated with them. In table 3, some regional energy statistics are shown, whilst oil and gas are major fuels in all region coal is more important in Europe and it must be noted that there are significant difference in the amount of energy consumed. The growth rates too are different especially population. The energy /capita decrease for Europe and North America whilst Africa show a slight increase. It must be noted that approximately half the energy used in the USA and Europe is used for heating. Since this is generally unnecessary in Africa it partly closes the gap between the developed and developing countries, but the difference is still large.

Table 4, shows the energy consumption in Nigeria in the context of the world and regional area consumption: Energy supply is dominated by oil and gas consumption with coal playing a very minor role (0.1Mt/yr). The fuel wood production is very significant being 67Mt/yr (1987) and is a quarter of the whole of Africa. The energy per capita is for fossil fuel, but if biomass is included the figure is markedly increased.

Table 2: World Energy Statistics

World	1976	1987	Growth (Pa) Over the period
Population (millions)	4076	4917	1.7%
Total primary Energy consumed (Mtoe)	6293	7788	1.9%
Energy/ Capital (toe) Excluding biomass	1.54	1.58	Slight Increase
Oil (Mtoe)	2948	0.2	
Coal	2342	2.4	
Gas	1558	2.3	
Nuclear	406	9.1	
Hydro	534	2.6	
Biomass (wood) (Mtoe	400		
(Other than wood)	1257		

Source: Williams (1990)

Table 3: Some Regional Energy Statistics

Area	1976	1987	Growth (Pa) over the period
EUROPE			
Population (millions)	474	493	0.4
Total primary energy consumed (mtoe)	1210	1299	0.07
Energy/Capita (toe)	2.9	2.3	decrease
NORTH AMERICA			
Population (millions)	347	406	1.4
Total Primary Energy Consumed (Mtoe)	2010	2099	0.4
Energy/Capita (toe)	5.8	5.4	decrease
AFRICA			
Population (Millions	413	572	3.0
Total Primary Energy Consumed (Mtoe)	118	202	4.0
Energy/Capita (toe)	0.28	0.29	Slight increase

Source: Williams (1990)

Table 4: Nigeria Energy Statistics (1986)

Production		Consumption (1986)
Oil	72.2 Mto	9.5 Mto (13% Production)
Coal	53, 546 t	53, 546t
Gas	3.7 ($109m^3$)	3.7 Mtoe
Nuclear	0	0
Hydro	2210 GWh electricity	1.2 Mtoe
Fire wood	Mt 67.1	25
Population = 100 Million Growth rate 3.5% Pa		
Energy Consumption (fossil fuel + nuclear)/capita = 0.13 toe Energy Consumption (including biomass)/capita = 0.4		

Source: Williams (1990)

4.0 PERFORMANCE ASSESSMENT OF POWER GENERATION TECHNOLOGIES

Current power generation occurs mainly in power plants using fossil fuel, nuclear energy and hydropower. Modern coal-fired steam power plants feature:

- Steam generators with efficiencies up to 92%
- Steam turbines with efficiencies up to 93%
- Main steam pressures up to 250 bars and temperatures up to 560°C
- Low condenser pressure (around 0.04 bars)
- Single steam reheat (up to 580°C) and
- Regenerative feedwater preheating up to 320°C
- Air preheating up to 270 – 350°C
- Efficient particulate emissions control by electrostatic precipitators or fabrics filters
- Efficient SO_2 and NO_X emissions control
- Reduced auxiliary energy consumption

Such steam power plants are capable of attaining efficiency up to 38 – 42% on lignite and hard coal and 42 – 44% on natural gas and fuel oil. The peak –load can be covered by means of simple cycle gas turbine plants or pumped hydro – power storage (PHPS) or compressed air energy storage (CAES).

From the Carnot thermal efficiency,

$$\eta_c = 1 - \frac{T_2}{T_1}$$

it follows that the thermal efficiency of any power generation cycle increases when the mean temperature T_1 of heat addition is increased and the mean temperature T_2 of heat rejection decreased.

Table 5: Performance and Economic Data of the State – of – The -Art Power Plant

Technology	Capacity (MWe)	Efficiency %	Capital Cost $/kWh	CO_2 kg/kWh
Pulverized coal fired steam plant	< 1000	37 – 40	1100 – 1700	0.97 – 0.93
Gas turbine power plant	50 – 240	35 – 39	350 – 550	0.48 – 0.45
Combine cycle power plant	50 – 400	50 – 58	600 – 700	0.43 – 0.37

Source: Khartchenko (1998)

Table 5 represents performance data, capita cost and CO_2 emission of the state of the art power plants (Khartehenko 1998).

The near – term advanced coal- fired power plant with efficiencies up to 47% will feature the following (Khartehenko 1998)

- Main steam pressure up to 300 – 350 bars
- Main steam temperature up to 600 – 700^{0}C
- Condenser pressure of 0.025 – 0.03 bars
- Double steam reheat to the main steam temperature level, and
- 8 to 9 stages of regenerative feed water preheating up to 350^{0}C.

Increasing the conversion efficiency translates into reductions in specific fuel consumption and pollutant and green house gas emissions.

3. Gas Turbine Power Plant

In an ecologically minded world, modern-day power plant technology is expected to satisfy very high standards, and produce power in a way that does minimum harm to the environment as it makes maximum use of available resources. Against this background gas turbine, particularly those installed in combined cycle plants are gaining steadily importance. Gas turbine development engineer have two main goals: a significant reduction in pollutants, particularly of the nitrogen oxides (No_x) at their source and the optimisation of the gross efficiency of the combined cycle power plants in order to improve the utilization of the primary energy and lower the CO_2 emissions.

Besides these ecologically- orientated aspects, research and development work on advanced gas turbines also seek to secure the turbine and the overall plants reliability and availability, and so allow them to be operated economically.

The turbine inlet temperature has been raised from 1070^{0}C to 1100^{0}C and the compression pressure ratio from 13.9:1 to 15:1. This results in a high specific power output for a single- cycle application as well as a high combined cycle thermal efficiency. With a turbine inlet temperature of

1100°C and a pressure ratio of 15:1, it is capable in single –cycle applications of a power output of 164.3 MW and a thermal efficiency of 35.7%. Combined cycle gross efficiencies of up to 55% can be achieved. (Vierak 1993).

5.0 Combined – Cycle Power Generation and Cogeneration

For a combined cycle power plant comprising a gas turbine, heat recovery steam generator (HRSG) and steam turbine, the total power output and overall efficiency are given by the followings:

$$P_{cc} = P_{GT} + P_{ST} \tag{1}$$

$$\eta_{cc} = \frac{P_{cc}}{Q_f} = \eta_{GT} + \eta_{ST}(1 - \eta_{GT}) \tag{2}$$

Where P_{GT}, P_{ST} are the power outputs of the gas turbine and steam turbine respectively, Q is the fuel heat input, η_{GT} and η_{ST} are the gas turbine and steam turbine efficiencies.

In addition to gas turbines, fuel cell stacks or MHD generator can be used as topping plant. Steam turbines are normally used as a bottom plant. The best current gas turbine- based combine cycle plants show efficiencies up to 58%. It can be increased to 60% with more advanced materials and cooling technology. However, near-term fuel cell-based combined cycle power plants are expected to attain efficiencies between 65 and 70% (Khartchenko 1998). Cogeneration of electricity and useful heat can greatly improve the utilization of fuel energy compared to separate production of power and heat. The performance of a cogeneration plant with an electric power output P_{el} and useful heat production rate Q_u is characterized by the energy utilization factor.

$$EUF = \frac{P_{el} + Q_{u}}{Q_{f}} \quad (3)$$

EUF values up to 90% and fuel saving up to 40% can be achieved in advanced cogeneration plants based on gas turbines or diesel engines (Khartechenko 1981)

6.0 CO_2 Mitigation and Emissions control in Power Plants

High fuel-to-electricity efficiencies are currently the most cost – effective way to reduce CO_2 emissions. The CO_2 emission discharged to the atmosphere from coal fired furnace in a given period of time (hour, day or year) is given by

$$M_{CO2,f} = 3.67 f_{CO2} \quad M_f \, C_f$$

Where f_{CO2} is the average fraction of C of the fuel converted to CO_2 and M_f is the mass of coal burned in a given period of time, C_f is the carbon content of coal. For the plant using fuel gas desulfurization (FGD) or fluidized bed furnace with sorbent injection, the total CO_2 amount is given as the sum of CO_2 from fuel and sorbent.

$$M_{CO2} = M_{CO2,f} + M_{CO2,} \quad (5)$$

Thereby the sorbent related CO emissions can be estimated as follows

$$M_{CO2,\,sorb} = M_{CO2} / M_{sorb} \; m_{sorb} \; Ca/s \quad (6)$$

Where m_{sorb} is the sorbent mass, Ca/s is the calcium to sulphur mole ratio (1 to 4), M_{sorb} is the mole mass of the sorbent.

Table 6: **Emissions (in mg/m³) of advanced Power Plants**

Technology	SO_2	NO_x	Particulate Matter
Pulverized coal power plant	2450	800	50
Pulverized Coal plant + FGD+SCR	200	200	50
CFBC	200	170	50
IGCC	10	50	5

Source: Khartchenko (1998)

Sulphur oxides emissions can be effectively controlled by adding sorbent, e.g. lime, limestone, dolomite, calcium hydroxide etc into the furnace. Limestone is injected directly into the fluidized bed where the combustion occurs at 850 – 900°C to abate SO_2 emissions. At the temperature the thermal NO formation is negligible and therefore the fluidized bed combustion is one of low emissions combustion technologies. For the SO_2 removal from flue gas, flue gas desulphurization (FGD) units are used.

The in-furnace NO_x control is accomplished by using.

- Air staging i.e. division of combustion air into primary and secondary air.
- Fuel staging i.e. pulverized coal or gas reburning.
- Premixed lean combustion in low No_x burners (LNB), and
- Flame cooling by flue gas recirculation or water/steam injection (in gas turbine).

In a selective catalytic reduction (SCR) unit, the flue gas is treated by ammonia at temperature of 200 to 550°C and up to 80% of NO is converted to N_2 and H_2O and thus removed from the flue gas (Khartechenko 1998). Table 6 above compares emissions of various power plants including pulverized coal power plants with and without FGD and SCR, circulatory fluidized bed combustion (CFBC) and integrated gasification combined cycle (IGCC).

Table 7 below contains performance data of combined emissions control techniques (Khartchenko (1998).

Table 7: SO₂ and NOx Removal Efficiencies of Advanced Emmision Control Techniques.

Emissions Control Techniques	SO_2 Removed %	NO_x Removed %
NO_x SO dry regenerable gas clean up Process	97	70
SNOX catalytic gas cleanup process	96	94
Dry NO_x/SO_2 flue gas cleanup processes	70	80
Limestone injection + multistage burners	70	50

Source: Khartchenko (1998)

7.0 CLEAN COAL TECHNOLOGIES

7.1 Pressurized Fluidized Bed Combustion

The advantages of the fluidized bed combustion (FBC) over conventional combustion systems are the ability to burn different grades of fuel without recourse to major adjustment, and reduced pollutant ($S0_2$ and NO_x) emissions due to efficient combustion of coal of any sulphur content at relatively low temperature of 850^0C to 950^0C. The injected sorbent such as limestone or dolomite efficiently capture SO and NO so that their emissions are very low in the above temperature range.

$$CaO + SO_2 + \tfrac{1}{2} O_2 \rightleftharpoons CaSO_4 \qquad (7)$$

The Calcium sulphate (CaSO4) remains in the bed from which it can be withdrawn and disposed of.

A fluidized bed combustor is integrated with a steam generator of a steam power plant.

Currently in use are the following FBC technologies.

- Atmospheric bubbling fluidized bed combustion (AFBC)
- Atmospheric circulating fluidized bed combustion (CFBC)
- Pressurized fluidized bed combustion (PFBC) and

- Pressurized Circulating Fluidized bed Combustion (PCFBC)

Pressurized fluidized bed combustion (PFBC) systems are capable of achieving high efficiency and low emissions. A PFBC system produces a gas stream at 16 bars and 950 C that can drive a gas turbine, whereas steam generated in the fluidized bed can drive a steam turbine. Efficiencies up to 42% are typical for PFBC systems. For a closed cycle combine plant, at elevated temperature, the thermal efficiency η_{th}, of the combined cycle is given by

$$1 - \eta = (1 - \eta_{ST})(1 - \eta_{GT}) \qquad (8)$$

With the integration of hot gas clean-up (HGCU), advanced gas and steam turbines, combined cycle efficiencies exceeding 50% can be achieved. A hybrid system includes a PFB carbonizer that processes the coal into flue gas and char. Then PFBC burns the char to produce steam and to heat combustion air for the topping gas turbine combustor. Several large scale demonstration pressurized circulating fluidized bed combustion (PCFBC) projects are now underway. For advanced PCFBC plants the low emissions are predicted, in mg/m^3: $SO_2 < 100$, $NO_X < 120$, $CO < 50$, and particulate matter < 5mg/m^3 (Khartchenko 1998).

7.2 Integrated Gasification Combine Cycle

The integrated gasification combined cycle (IGCC) is expected to become one of the major clean, highly efficient coal based power generation mid-term technologies. Mature IGCC systems capable of processing low grades of coal and solid wastes are predicted to offer efficiencies up to 52% combined with environmental superiority that translate into 95-98% SO_2 removal, 70% NO_X emissions reduction, complete particulate removal by means of ceramic filter, and 30% CO_2 emissions reduction. Predicted emissions from advanced IGCC plants are in mg/m^3:

SO_2 < 25, NO_x <150, CO < 4 and particulate matter 5. The overall efficiency of an IGCC plant is the product of the coal gasification efficiency (up to 80%) and the combined cycle efficiency (50-58%).

In addition to the described system, several large-scale demonstration pressurized circulating fluidized bed combustion (PCFBC) projects are now being realized. For advanced PCFBC plants the following low emissions, in mg/m^3 are predicted; SO_2 <100, NO_x < 120, CO < 50, and particulate matter < 5.

7.0 FUEL CELL POWER GENERATION TECHNOLOGY

Faced with a steady depletion of the world's reserves of fossil fuels and growing opposition to nuclear power, there is an urgent need for energy generators which are both more efficient and add a minimum of pollution to an already deteriorating environment. One exciting development – the fuel cell – meets both criteria.

Fuel cells convert fuel energy directly into electric current by low voltage by means of electrochemical oxidation reactions. Hydrogen or hydrogen- rich gas is used as fuel. Demonstration fuel cell plants with power outputs up to 2 – 11MW , have been installed and operated in Japan and USA (Khartchenko 1998).

Table 8 Major Characteristics of Fuel Cells

Fuel Cell	Temperature (^0C)	Efficiency %	Ionic Conductor	Electrolyte
PAFC	160 – 220	37 – 42	O^{-2}	Phosphoric acid
MCFC	560 – 680	50 – 60	CO_3^{-2}	Molten Alkali-metal Carbonate mixture
SOFC	850 – 1000	60 – 65	H^+	Zirconium dioxide

Source: Khartchenko (1998)

The table 8 above shows operating temperature, efficiency, ionic conductor and electrolyte of fuel cells suitable for power generation (Khartchenko 1998).

The fuel cell types suitable for power generations are:

- Low temperature phosphoric acid fuel cells (PAFC)
- Intermediate temperature molten carbonate fuel cells (MCFC).
- High temperature solid oxide fuel cells (SOFC)

The principal advantages of fuel cell power generation systems are:

- High conversion efficiency (theoretically up to 83%, practically up to 60%)
- Efficiency independence on the plant size and on the Carnot cycle limitation.
- Extremely low environmental impact, quiet operation and load – following capability
- Modularity allowing the build up of large capacity plants.

PAFCs are highly developed, reliable but less efficient than two other types of fuel cells. The hydrogen-rich gas (H_2content 80% vol) is supplied to the anode and air to the cathode, PAFC stacks with capacities from some kW to 10MWe may be employed for distributed power production and heat supply.

Due to high efficiencies and high operating temperatures, MCFC and SOFC are most approximate fuel cell types for both power generation and cogeneration, additional benefits of fuel cell-based power and cogeneration plants are near zero emissions, quiet operation and load following capability (Khartchenko 1998).

Over 150 demonstration plants with a total electrical capacity of around 40M We have been installed worldwide: 75% in Japan, over 15% in North America and nearly 10% in Europe. These PAFC systems have proved their suitability for on-site cogeneration. The largest units which are installed in Japan include a 11MWe distributed power plant, a 5MWe plant, a 1MWe cogeneration plant and three 500kW plants; besides there are over 100 plants of 50 to 200kw.

The first ONSI unit is PC25, a 200KW PAFC cogeneratory plant. The PC 25's electrical efficiency P_{el} of 40% is favourable compared to small diesel engines with P_{el} of 36%. When the fuel cell waste heat is used for hot water or space heating and cooking fuel energy efficiency of 85% is attained. Operating costs of PC25 are by 25 to 40% lower than that of conventional cogeneration unit.

Table 9: **Performance of Advanced Fuel Cell Combined Cycle and Cogeneration Plants.**

Fuel Cell Type	Temperature 0C	Efficiency %	Combined Cycle Efficiency	Cogeneration EUF %
MCFC	600 – 650	50 – 60	60 – 65	85
SOFC	900 – 1050	60 – 65	65 – 70	90

Source: Khartchenko (1998)

The current world fuel cell production capacity totals about 60MWe per year. Estimate suggests that a competitive price of $1,000 to $1,500/kW can be achieved if about 100MWe of fuel cell stacks will be produced annually. The fuel cell service life must be increased to 40, 000 hours. Fuel cell-based plants in sizes up to 20MWe are predicted to become economically feasible by 2010. Table 9 shows the predicted data of advanced fuel cell combined cycle and cogeneration plants (Khartchenko 1998). Table 10 below also shows the comparison of the clean coal technologies with advanced gas fired power plants (Kharchenko 1998).

Table 10: Compaarison of Clean Coal Technologies with gas fired plants.

Technology	Efficiency (HHV) %	CO_2 Emissions Reduction, %
Clean Coal technologies		Reference: 0.97kg CO_2 /kwh
PFBC	45	27 – 35
IGCC	45 – 52	30 - 40
Gas fired power plants		Reference: 0.46kg CO_2/kWh
Gas turbine combined cycle	60 – 65	20
Fuel Cell Combined Cycle	65 – 70	30 - 35

Source: Khartchenko (1998)

9.0 INTEGRATION OF RENEWABLE ENERGY INTO POWER SUPPLY SYSTESM

The renewable energy resources stored are $9x10^{23}$kWh in geothermal energy and $4x10^{15}$kWh or $2x10^{12}$ tonnes in biomass. Annual recoverable renewable energy fluxes are $1000x10^{9}$kW solar energy, $10x10^{9}$kW in wind energy, 0.5 x 10^{9}kW in wave energy, $0.1x10^{9}$kW in tidal energy (Khartchenko 1998). Estimated world hydro-power resources are 50 x

10^{12}kWh per year, installed large hydro-power resources is 630GWe and annual world electricity production is 2.4×10^{12}kWh, i.e. over 20% of the total power generation. The Europe and USA shares are 32% and 26% respectively (Khartchenko (1998), Boyle (1996).

9.1 Solar Power Generation

Solar energy is the most promising of the renewable energy sources in view of its apparent limitless potential. The sun radiates its energy at the rate of about 3.8×10^{23}kW per second. Most of this energy is transmitted radially as electromagnetic radiation which comes to about 1.5kW/m^2 at the boundary of the atmosphere. After traversing the atmosphere, a square metre of the earth surface can receive as much as 1kW of solar power, averaging to about 0.5 over all hours of day light. Many authors have carried out studies relevant to the availability of solar energy resources in Nigeria.

Akinbode 1992, Sambo and Doyle 1986, Arinze and Obi 1983, Ojosu 1984, Fagbenle 1990 and Folayan 1988) have indicated its viability for practical use. Nigeria receives about 5.08×10^{12}kWh of energy per day from the sun and if solar energy appliances with just 5% efficiency are used to cover only 1% of the country's surface area then 2.54×10^{6}kWh of electrical energy can be obtained from solar energy. This amount of electrical energy is equivalent to 4.66 million barrels of oil per day (Sambo 1996).

Three technologies are suitable for solar thermal power generation: Parabolic Trough (PT) Central Receiver (CR) and Dish/Stirling (DS) engine technologies. Only PT technology has been commercially used for power generation. The electric power output of a solar power plant is given by

$$P_{el} = A I_b h_{el}$$

where A is the concentration aperture area, I_b is the intensity of beam solar radiation incident on the concentrator, and h is the electric overall efficiency of the power plant. The performance of parabolic trough collectors can be improved by using advanced materials so that mirror reflectivity and receiver absorptivity must be increased to 0.96 and 0.97, and receiver emissivity must be reduced to 0.15. However, the major performance and cost effectiveness ratio improvement is expected from application of direct steam generation (Khartchenko (1998)).

Photovoltaic (PV) plants can be used for remote power supply and particularly for home power systems in rural areas of developing countries. Current solar modules show efficiencies of around 10% at a standard insolation of $1kW/m^2$ and ambient temperature of 25^0C. Stand-alone PV systems need a storage battery and load controller, the grid-connected PV systems need an inverter for change from dc to ac. There is a pilot project of the Sokoto Research Centre providing electrical power to Kwakwalawa village. Annual electricity production of a PV plant, in kWh per year is given by

$$E_{el}, yr = E_{sol}, yr\, P_{rated} \quad QF \qquad (10)$$

Where E_{el}, yr is the annual solar radiation incident on $1m^2$ of the PV module area, P_{rated} is the rated power output of a PV module in kW at an insolation of $1 KW/m^2$, Q_f is the quality factor which depends on the PV plant type (QF is equal to 0.1 – 0.4 for stand alone PV plants without backup, 0.4 – 0.6 for PV plants with diesel generator, 0.6 – 0.75 for grid connected PV plants).

9.2 Wind Power Plants

In 1995, more than 78, 000 wind turbines operating worldwide generated more than 8×10^9 kwh of electricity per year. Power output of a wind power plant is given by;

$$P_{wind}, el = ½C_p \;\rho u^3 A_{wf} \eta_g \text{ in W}$$

(11)

Where C_p is the coefficient of power, ρ is the air density, u is the wind speed, $A_r = \pi d^2/4$ is the swept area of the wind turbine rotor with diameter d, and η_g is the efficiency of gear box and generator.

Annual power production of a wind power farm consisting of n wind turbine is

$$E_{wind,} \; n_{JJ} = CFu^3 A_r n \tag{12}$$

Modern wind turbines have rated outputs up to 2 MWe in the wind speed range of 5 to 25 m/s. The cost of electricity production depends on the wind energy potential and availability at a specific site. It is normally in the range of 0.05 to 0.11 $/kWh (Boyle 1996 and Euree Agenegy, London 1996).Major environmental concerns related to wind power plants are noise emissions, visual impact, impact on birds.

9.3 Small Hydro - Power

For 2000, the world technically and economically feasible potential of small hydro-power plants is estimated as 26 to 33 GWe of installed capacity including 11 to 15 GWe in Europe, 5 to 7 GWe in North America and 0.35 GWe in sub-Saharan Africa. At present there are more than 1000 plants with total capacity of about 5 GWe in operation in Western Europe (Boyle 1996).

Power output of a hydro-power plant is given by

$$P_{hydro} = g\rho HQ \; \eta_{el} \text{ in kW}$$

Where g is the acceleration due to gravity m/s^2 ρ is the density of water kg/m^3, H is the effective water head m, Q is the water flow rate m/s, η_{el} is the plant electric efficiency.

Initials cost of small – hydro power plants is in the range from 500 to 1700 $/kW at plant capacity of 2 to 8 MWe. Based on a 20 year lifetime, the electricity cost is about 0.06 $/kWh (Boyle 1996 and Eurel Aggeney, London, 1996).

9.4 Biomass Energy

Heat, electricity and liquid fuels can be produced using biomass. Basic heat production technologies include thermochemical process such as combustion, gasification, pyrolysis. For the electricity generation and cogeneration, conventional technologies including highly efficient combined cycles can be employed. Electricity can be generated at about 40 – 50% efficiency and at a 0.06 to 0.9 $/kWh cost.

Sugar and starch crops are subjected to anaerobic digestion, fermentation and distillation and oil crops are subjected to extraction and extravasations to produce liquid biofuels such as bioetharnol.

In developing countries like Nigeria biomass represents 45 to 80% of primary energy consumption. The biomass conversion efficiency is low and pollution is high. With technical and financial assistance of industrialized countries, more efficient and environmentally sound conversion technologies can be used.

9.5 Integrated And Hybrid Solar Power Systems

The continuation of renewable energy of global energy supply will grow and their integration in the sustainable energy sector will increase. Solar hybrid power systems use solar energy in combination with advanced fossil fuel technologies. Particularly advantageous are integrated solar combined cycle (ISCC) power systems using solar energy for air preheating in the gas turbine train and for steam superheating and reheating in the steam turbine train of a natural gas –fired combined cycle power plant. In this case, solar energy is converted to work with an efficiency of a combined cycle plant. Hence, concentrating collectors partially replace some of the components of fossil-fuel-fire power plants. Such solar hybrid power plants beneficially exploit the two energy sources with resulting significant fuel energy savings. They produce electricity at a lower cost than the solar- only plants described above and the commercialization of solar thermal power generation technology will thus be accelerated (Khartchenko 1998).

Based on solar radiation data for Nigeria (Nigeria receives

$5.08 x 10^{12}$ kWh of energy per day). The fuel savings that can be achieved in a hybrid solar power plant depend on the size and efficiency of solar concentrator absorber unit. For the total concentrator aperture area of 170,000 to 460,000m^2, the fuel savings in the range of 10 to 27% are predicted. Cost effectiveness ratios of hybrid solar plants depend on the initial cost and efficiency of solar collector plant. With improved solar components, the economics of hybrids power plants and their commercialization chances look rather optimistic. By using multiple energy resources, smaller generator can be used and an optimized systems is installed.

For remote power supply, photovoltaic (PV), wind power plant and diesel generator can be combined in a hybrid energy system. Such systems take advantage of two or even three different sources of energy where they are available, store electricity in battery banks and then supply the electricity load as required. So in a PV-diesel generator hybrid system, the PV modules are sized to cover the base-load and the diesel generator is designed as back up. The batteries can also be used to supply AC electricity to the users via an inverter. Batteries can meet the peak load of short duration so that the total capacity of all the generating plants may be smaller than the peak – load. Thus, the main advantage of hybrid power systems is production of electricity at a lower cost and with reduced environment impact.

10.0 MODEST CONTRIBUTIONS THROUGH RESEARCH AND DEVELOPMENT.

Mr. Vice-Chancellor Sir, I now want to delve a bit into my contribution to the sustainable energy technologies that will minimize problems associated with finite fossil- fuel resources and environmental deterioration due to emissions from fossil fuel based energy system.

10.1 Combustion Of Solid Fuels In Fluidized Bed Combustors

Fluidized bed technologies are important element toward achievement of the objective to develop more economic system for utilization of coal for electricity generation and for industrial boilers, particularly for the poorer qualities of coal, and low grade fuels. These are in abundance in Nigeria, very cheap, but are difficult to burn by other means particularly when clean, non-polluting combustion is essential.

However, the technology has not been confined to combustion of coal; liquid fuels and gases can be burned and the technology exploited for incineration, drying, metallurgical furnaces and heat recovery. The burning of coal within fluidized beds of inert particles is outlined, the factors which control combustion and some of the consideration which have to be made by the coal combustion system designer and development engineer in order to produce a reliable, efficient and economically fluidized bed combustor.

Akinbode (1984, 1990) reported that during the experimental investigation study on the mechanism of combustion of coal and wood fuels in a fluidized bed combustor, feeding secondary air into the above bed region did not enhance combustion when burning coal but feeding the same amount of air into the bed did when burning wood, the reverse was discovered. The heat release rate was found to be more in bed when burning coal but more in free board region when burning wood. The experimental results obtained are sufficient to estimate the important design requirements for a wood/coal combustion system.

Akinbode (1995) Adeyinka (1997), Adeyinka and Akinbode (1998, 2000, 2001, 2002) experimented with bituminous and sub bituminous coals and lignite. Their results show that fluidized bed technology has the ability to burn different types of fuels without recourse to major adjustment.

10.2 Solar Energy For Drying Applications

The preservation of agricultural production through drying is as old as the origin of man. Through the advancement of man, many crop drying equipment have been produced that are being fueled by many as the origin of man. Through the advancement of man, many crop drying equipment have been produced that are being fueled by many sources of energy. But it is pertinent to mention here that the early man used an open-air solar powered drying technique to dry the skin of animal that formed his first clothing. Of all the available sources of renewable energy to human race, solar energy is the most abundant and non-polluting sources of energy.

Solar energy find application in such areas as food and general agricultural drying processes, residential heating in cold climate areas, water heating processes etc. In the field of food drying, solar energy food dryer are gradually replacing the traditional method of drying food on mats and plat-forms exposed to direct rays of the sun. Akinbode and Abifarin (1995) modelled a multi-purpose solar drier for agro-allied industries. They found out that the design of a solar drier is a function of the place the dryer is to be used, the type of product to be dried and its moisture content, the weather condition of the place and the quantity of products involved.

Akinbode and Ogwuagwu (1995) developed a solar assist air heater. A prototype was constructed and tested in June. The maximum temperature obtained was 59°C and the fact that this was obtained during the rainy season justifies its efficiency.

However, the temperature attained with this prototype is suitable for drying most foods and agricultural products like fish and grains. Most of these products like fish require moderate drying temperature to retain their quality.

11.0 Wood As Energy Sources

About 80% of the population in Africa and Asia depends on wood as energy source. In rural areas, wood and charcoal are used for cooking and heating and some families used them as the source of light. Wood provides about 80% of all domestic energy (Timberlake 1980). Therefore in considering wood as an energy resource in the energy area, it is useful to define its true value and position within the family of combustible fuels. Akinbode (1993) tested for gross heating value and moisture content of some Nigeria wood species and found that among the wood species tested, gross heating value ranges from 12.04 to 18.8MJ/kg and moisture content ranges from 0.6 to 4.9%. Comparing wood with other solid finds, it was seen that wood is the transition fuel between the waste materials (13.6MJ/kg) and coal (36.4MJ/kg) considering the availability of these biomass fuels and high calorific values of fuels tested it can be concluded that Nigeria biomass could be a dependable alternative source of fuel to the already depleting oil and gas resources for thermal power generation.

11.1 Tes g Of Wood Stove

D c wood stoves are designed to perform heating tasks such as cooking and water heating. Many design, styles and sizes are commercially available in Nigeria. Increasing domestic energy prices for electricity, gas and kerosene coupled with the fact that these commodities are not readily available, have led to a very significant increase in the use of wood fuel in many areas. This in turn has led to much research interest in the wood burning stoves. The traditional designs are now being improved upon with increased efficiency, less pollution and more fool-proof operation. Apart from the function of the stove, what the user is after is how safe and convenient the stove is. Therefore what the researcher in this field needs is to be able to compare performance characteristics of different wood stores.

Akinbode (1991) tested four different types of stoves under two operating conditions (in-door and out-door cooking) which are the condition being practiced in rural and urban areas. The four different types of stoves are three stove wood stove, metal cylindrical shaped wood stove, condition being practiced in rural and urban areas. The four different types of stoves are three stove wood stove, metal cylindrical shaped wood stove, metal tripod wood stove and clay type wood stove. The best type of wood stove tested was the clay type. It is more superior to other types tested. Lagging could reduce the major heat loss to the stove wall.

11.2 Development Of Sawdust Stove

Of the renewable energy resources available in Nigeria, wood wastes from sawmills and crop residues from grinding mills are especially attractive as potential substitutes for domestic and industrial fuels.

Of course, the interest in sawdust and crop residue energy both for home owners and for business is rooted in other fossil fuels rapidly rising prices and sometimes uncertain availability. Depending on plant siting, sawdust and crop residues are cheaper in many cases than coal, oil or gas, and at least abundant. The fuels' merits go past price. Like coal, these fuels can be burned directly, gasified to produce a low-to-medium fuel gas or liquefied to make a fuel oil. Unlike coal and oil, these fuels contain virtually no pollution producing sulphur.

Akinbode (1996) developed a sawdust stove burning sawdust and rice residues from grinding mills. He concluded that the development of this stove would alleviate the sufferings of rural and urban dwellers in the quest for energy. It will also reduce the solid waste found in our big cities and leads to less dependence of rural and urban dwellers on kerosene and liquid petroleum gas that are very scarce, continuously increasing in price and not readily available all the time. It will also reduce deforestation. With well-compacted fuel bed, the heat output is increased thereby reducing the specific fuel consumption.

12.0 CONCLUSION AND RECOMMENDATION

12.1 Conclusion

Nigeria is blessed with abundant resources of fossil fuels as well as renewable energy resources. Whilst solar and other renewable energy sources look attractive, their low energy density makes them not very cost effective except in high oil price scenarios.

Only highly efficient power plants can provide sustainable utilization of these primary energy resources, mitigate CO_2 emission and reduce environmentally impact of power generation systems. Environmentally sound, highly efficient, economically viable power generation technologies such as combined cycle power generation and cogeneration plants present the dominant technology of the next decade. Their excellent performance is primarily attributed to utilization of advanced gas turbines. Pressurized fluidized bed combustion (PFBC) and integrated gasification combined cycle (IGCC) have been successfully demonstrated in large scale system and the near – term goal, is their full commercialization to provide the most clean and efficient coal fired power plants. Hybrid power generation systems combining PFBC and IGCC will further improve the efficiency and environmental characteristic of coal based power generation. However the emerging fuel cell technology is to revolutionize the power generation, as it is promising to covert up to 65-70% of the fuel energy to electricity with very low environmental impact. Still higher efficiencies (up to 85 – 90%) are predicted when the fuel cell based cogeneration of power and heat would be fully commercialized before the year 2010. Integration of renewable energy sources into global energy supply system will greatly promote the development of sustainable energy sector.

12.2 Recommendations

In addition to providing sustainable utilization of the nation's fossil fuel resources the following recommendation are made;

1. Maximize oil and natural gas output and particularly enhances natural

gas using locally for environmental and efficiency reason.

2. Establish energy management team as follows:
   i. Energy Management System to be established in industry. This will need technical back up. There is also a need to extend a secure electricity system for control purposes.
   ii. In transportation a number of energy economy measures can be introduced, namely (a) more efficient cars, (b) good maintenance (c) Lower speeds (d) good traffic movement and (e) good roads.

   Energy efficiency reduces pollution and this seems to be the best environmental pollution control measure to undertake.

3. In firewood usage, development of improved efficiency wood stove and good forest management are essential.
4. Utilization of combustible waste materials. All energy sources need to be used and waste materials can be a good source of energy.
5. There is the urgent need for more support for research, development and demonstration activities in the existing research centres as well as identified groups in the universities and other institutions. Also industries, ministries and parastatals should be encouraged to fund energy research and development.

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