International Journal of Recent Engineering Research and Development
Volume No. 01 – Issue No. 01
www.ijrerd.com

Diversification of the Nigeria Energy Portfolio: Fuel Cells Power System Perspective

Luqman Muhammed Audu[1], Asor Levi Mathew[2], Friday Chukwuyem Igbesi[3], Braimah Dirisu[4]

[1]*Mechanical Engineering Department, Auchi Polytechnic, KM 118, Benin – Okene Express Road, Auchi Edo State, Nigeria.*
[2]*Mechanical Engineering Department, Auchi Polytechnic, KM 118, Benin – Okene Express Road, Auchi Edo State, Nigeria.*
[3]*Mechanical Engineering Department, Auchi Polytechnic, KM 118, Benin – Okene Express Road, Auchi Edo State, Nigeria.*
[4]*Mechanical Engineering Department, Delta State Polytechnic, Otefe - Oghara Delta State.*

Abstract: Fuel Cells Power System (FCPS) are highly efficient and simple direct energy converter from chemical input to electrical output. They are efficient, clean and reliable means of producing electric power for primary, combined heat and power (CHP) applications, and limiting the producing of green house gases. This study critically examined the viability of the application of Fuel Cells Power Systems (FCPS) in the diversification of the Nigeria energy portfolio to enhance power generation and mitigation of global warming effects. Findings of research work on FCPS energy generation and applications were used to analyze its operations taking into cognizance its fuel flexibility, high energy efficiency, environmental compatibility and economy of application. The practical performance and new technological breakthrough in FCPS in the Developed Countries were equally assessed in line with their technical requirement and the social – economic implication of their application in the Nigerian economy. The findings include that FCPS have the capability to considerably improve on power generation in Nigeria and mitigate the Nigeria's protracted energy crisis by meeting the energy requirement of the country given its fuel flexibility, availability, reliability, high efficiency and their successful application in the Developed and Developing counties; although the prices of the FCPS presently imposes a constrain in their utilization without government backing. The paper concluded that the Federal Government of Nigeria(FGN) should initiate programs on FCPS utilization since the price of FCPS are falling considerably with time through improved technology and large scale production.
Key word: Diversification, Energy Portfolio, Fuel Cells, Nigeria, Power

1. Introduction

A review of the trends in industrial and economic development shows that economic growth is inextricably linked to energy consumption. Economic versatility is tied to energy availability, equitable access to energy and energy mix. Various forms of energy are required to drive services, machineries and processes to produce goods for national consumption and export. Thus there is a close relationship between the energy consumption of a country and its level of industrialization.

The energy portfolio of Nigeria consist mostly of petroleum products that are used for the generation of electric power for industrial and domestic consumption, powering transportation systems, private generators and for cooking purposes. Firewood is used extensively in the rural areas for cooking and heating purposes.

The average generating power capacity for 2004 by PHCN was 2,763.6 MW [1], this fluctuated and dwindled to 1500MW by early 2007 [2]. By December 2012 it was 5,517MW but plummeted to 3,443MW by April, 2013 [3], making power generation and supply from PHCN very epileptic and unreliable. The worsening electric situation had led to the near collapse of the nation's manufacturing sector. Owing to frequent power outages, manufactures use oil base generation to meet 70 per cent of their power need at a cost of ₦ 47.74 per kWh has against the normal average PHCN tariff of 12.20/kWh [4]. The net effects are low industrial capacity utilization, high industrial mortality and rising unemployment which made the Nigeria economy unattractive to foreign investors [2].

This narrow energy mix does not confer on the Nigerian economy any measure of energy efficiency and security. This makes it easy for labor unions in the oil industries and militants in the Niger Delta region of Nigeria to easily hold the economy hostage. In case Nigeria faces any form of external aggression the Nigeria economy can easily be paralyzed. Also since access to sustainable modern energy services contributes to poverty eradication, saves lives, improves health and helps provide for basic human needs, there arises the need for the exploitation of a prospective economically viable and versatile power technology to provide the needed energy for the rapid industrialization of the Nigerian economy. This could be achieved by the use of Fuel Cells Power Systems (FCPS).

A FCPS are highly efficient and simple direct energy converter from chemical input to electrical output. The fuel cell power plants using hydrogen are pollution free, modular and available in a range of sizes from 5kW to 100MW. They are convenient source of electric power for residential, commercial, transport, agricultural, industrial, military and rural applications. A type of fuel cell -Microbial Fuel Cells (MFC), is an emerging technology that uses biofilms as catalysts to convert chemical energy in organic (and some inorganic) matter directly into electricity [5]. It creates renewable, clean, portable power source, while simultaneously making use of and efficiently disposing of unwanted organic waste. MFC has found application in the area of waste treatment as a variety of waste water can be oxidized to produce electricity [6].

The initial problem of high cost of FCPS has been greatly reduced by improved material technology in platinum and membrane reduction in fuel cells and high volume production [7]. US Department of Energy estimated that the cost status of fuel cell technology had fallen by about 82.90% by 2012 [8]. The status of the technology will continue to fall with advance in technology and higher volume production. Therefore, the stage has now been reached to introduce the FCPS into the Nigeria energy mix for many power applications in Nigeria to enhance the Nigeria energy portfolio.

In Nigeria, FCPS will make energy available for residential, industrial, transportation utilization and accelerates rural development. MFC could be deplored in Nigeria in sufficient quantity to assist in the management and accelerated disposal of organic waste in the production of electricity.

Their use is in consonance with the implementation of the Kyoto Protocols by reducing or eliminating the production of green house gases and implementation of Nigeria Energy Policy of promoting the accelerated development of solar energy and introduction of new and renewable energy technologies into the nation energy end use patterns [9].

This paper analysis the fuel cell power systems (FCPS), their features and application in relation to the suitability of their application in Nigeria to diversify the Nigeria energy portfolio for increased energy security and power utilization.

2 Fuel Cell Technologies

2.1 Principles and Operations of Fuel Cells

A fuel cell is a device that converts chemical energy into electricity. Electric energy, water and heat are produced in a continuous manner. The cell consists of two porous electrodes sandwiched around an electrolyte which conduct ions between the electrodes. Hydrogen fuel is fed to the anode while oxygen (or air) is supplied to the cathode

By the action of a catalyst, the hydrogen ion splits into a proton and an electron. The proton migrate through the electrolyte while the electron flow to the cathode through a different part thereby creating a separate current that can be utilized before reaching the cathode where it interacts with the hydrogen and oxygen to form water. The difference between the respective energy levels of the electrodes is the voltage output per unit cell. The chemical activity of a cell and the amount of fuel supplied to it determine the amount of current available at the external circuit [10].

The operation of a fuel cell is affected by temperature. The chemical activity of the fuel and catalyst are reduced by low temperature. High temperature improves the activity factor but may reduce the functioning life of the cell components. Hydrogen can be made from diverse primary resources such natural gas, coal, biomass, wind and solar energy, reducing petroleum dependence [11].

A Fuel Cell Power System (FCPS) generates DC power which is converted to AC power by power inverters. Individual cells are stacked to achieve higher voltage and power.

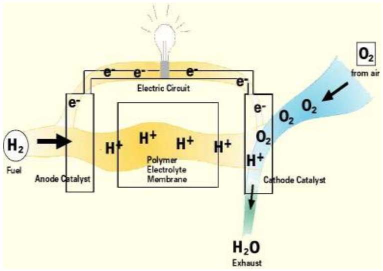

Fig1: Schematic of a H_2-O_2 Fuel Cell

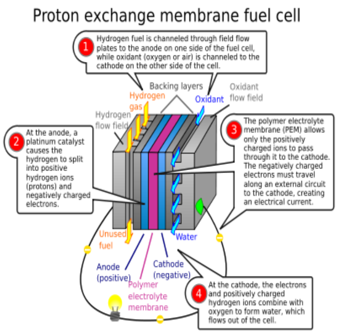

Fig 2: Construction of a Proton Exchange Membrane Fuel Cell

3 Prospects of Fuel Cell Power Systems in Nigeria

3.1 Availability of Fuel

Fuel Cell Power Systems (FCPS) operates on a wide variety of fuels. Hydrogen is the most favored and beneficial fuel because it produces zero emission. For small power systems hydrogen can be generated at home using electrolyzers that make hydrogen from water using electricity. Hydrogen can also be produced from renewable energy technology with solar and wind power and from natural gas through catalytic reforming.

Fuel cell technology in a compact system converts natural gas, propane, and eventually biofuels into both electricity and heat, producing carbon dioxide (and small amounts of NOx) as exhaust. Nigeria LNG deposit is estimated in excess of 160 trillion cubic feet. It is ranked amongst the 10th largest in terms of proven natural gas reserves in the world, and its natural gas reserves and production is estimated at 109 years [12].

Coal gasification, may be one of the most flexible technologies to produce clean-burning hydrogen for tomorrow's automobiles and power-generating fuel cells. The Office of Fossil Energy of US DOE concentrates its fuel cell research, development, and deployment on Solid Oxide Fuel Cells (SOFC) to be fueled with gasified solid hydrocarbons [13]. The proven Coal reserves so far in Nigeria total about 639 million metric tons while the inferred reserves sum up to 2.75 billion metric tons [14].

Waste management in Nigeria poses a social challenge in environmental sanitation management [15]. The total tonnage of biowaste generated in Nigeria per annum was estimated at about 542.5 million tons per year [16]. MFC could be deplored in Nigeria in sufficient quantity to assist in the management and accelerated disposal of organic waste with the production of electricity.

3.2 Cost Competitiveness of Hydrogen fuel

The findings of the study carried out by the U.S National Academy of Science (NAS) and the National Research Council (NRC) show that the cost competitiveness of hydrogen per mile driven in a Fuel Cell Vehicle (FCV) ought to be 27% to 52% lower than the cost of gasoline (petrol) per mile in an Internal Combustion Engine Vehicle (ICEV) and between 3% to 32% less than the cost of gasoline used in an hybrid electric vehicle for the same distance [17]. The project found that these vehicles achieved more than twice the efficiency of today's gasoline vehicles with refueling times of five minutes for four kilograms of hydrogen.

3.3 Safety of Hydrogen Fuel Power System

Experience has shown that hydrogen can be safely produced, transported and used to produce energy. A study by Ford Motors judged the safety of a hydrogen fuel systems to be potentially better than the demonstrated safety record of gasoline or propane and equal to or better than, that of natural gas [17].

3.4 Environmental Benefit of Fuel Power Systems

Pure hydrogen generates zero emissions in FCPS, but due to shortage of hydrogen FCPS run on fossil fuels, methanol, ethanol and gasified coal which produce low greenhouse gas emissions. The result of the study by Argonne National Laboratory shows that fuel cell vehicles running on natural gas emits 60% less greenhouse gases than a conventional ICEV vehicle. The DOE estimated that fuel cell electric vehicles using hydrogen produced from natural gas would result in emissions of approximately 55% of the CO_2 per mile of internal combustion engine vehicles and have approximately 25% fewer emissions than hybrid vehicles [18].

3.5 Fuel Cell Vehicle.

In 1990 the cost of fuel cell vehicle was $3,000/KW but due to improved technology and mass production the cost was reduced to $225/kW by 2004[7], while in 2012 DOE study fixed the cost at $47/kW [8]. This high cost is attributed to platinum and membrane components. Industry goal is the reduction of platinum content to further achieve cost reduction. Similarly advancements in fuel cell technology have reduced the size, weight and cost of fuel cell electric vehicles.

Fuel cell electric vehicles have been produced with a driving range of more than 250 miles between refueling. Deployed fuel cell buses have a 40% higher fuel economy than diesel buses. EERE's Fuel Cell Technologies Program claims that, as of 2011, fuel cells vehicles achieved a 42 to 53% efficiency at full power, and a durability of over 75,000 miles with less than 10% voltage degradation, which double that achieved in 2006 [18](Wikipedia, 2013). Although the cost difference between FCVs and gasoline vehicles is initially very large, FCVs eventually become lifetime cost competitive with gasoline vehicles as their production volume increases, even without accounting for externalities. High valuation of externalities and high oil prices could reduce hydrogen transition costs by more than $10 billion and make hydrogen FCVs achieve cost competitiveness [11].

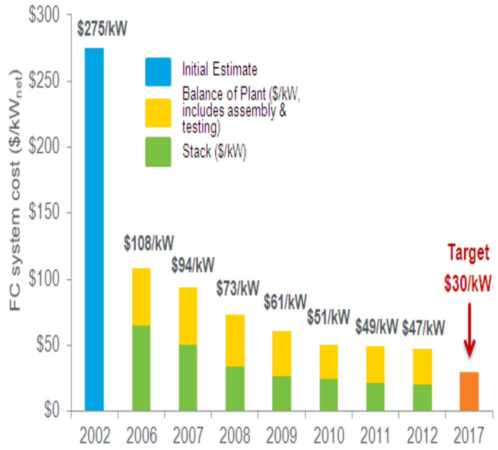

Fig 3: Cost Profile of Fuel Cell Power Systems with Time

3.6 Home Fuel Cell

A home fuel cell is a residential-scaled energy system available for micro combined heat and power (microCHP) generation. This allows a residence to reduce overall fossil fuel consumption, reduce carbon emissions and reduce overall utility costs, while being able to operate 24 hours a day. This results to higher efficiency because of the simultaneous generation of electricity and heat for home use. Some of the newer home fuel cells can generate between 1 to 5 kilowatts (1.3 to 6.7 hp). A 5 kW home fuel cell produces about 80 MWh of annual combined electricity and heat. Operating costs for home fuel cells can be as low as 6.0¢ per kWh based on $1.20 per therm for natural gas, assuming full electrical and heat load utilization. [19].

4.0 Field Application and Updates on Fuel Cell Power System

4.1 FCPS at Goi Power Station, Japan.

A 11MW fuel cell power plant with Phosphorous Acid Fuel Cell (PAFC) technology has been in operation in Japan since 1991. The plant built by Toshiba Electric Company (TOEC), was installed at Goi Power Station [20]. Several other plants with ratings 500KW to 5MW are under execution in Japan.

4.2 Sierra Nevada Brewing CHP Application

FuelCell Energy, Inc., announced the upgrade of its 1 megawatt (MW) Direct Fuel Cell® (DFC®) power plant at Sierra Nevada Brewing Co. to use fuel created from a waste by-product of the brewing process. With this enhancement, Sierra Nevada furthers its sustainability and energy efficiency goals, while realizing substantial cost savings by offsetting its purchase of natural gas. The fuel cells operate in co-generation mode, so their 650 degree thermal output is utilized to create steam that further offsets the natural gas needs of their existing boilers providing an additional reduction in operating costs by 25 to 40% and increase in system efficiency [21].

4.3 Telecommunications, Residential, and Small Commercial Buildings

As the need for reliable cell phone and critical communication networks grows, fuel cell manufacturers ReliOn, Altergy Systems and IdaTech have found success selling fuel cell systems that provide long-running, primary or backup power for telecom switch nodes, cell towers, and other electronic systems that require reliable, on-site, direct DC power supply. The fuel cells are quiet, rugged and durable, generating reliable, long-running power at hard-to-access locations, or sites that are subject to harsh or inclement weather. They are typically in the range of 1 to 5 kW [22].

4.4 Electricity and Portable Water in Indonesia

AFC has entered into Memorandum of Understanding (MOU) with the Indonesia Government to provide 32 million households with the ability to produce electricity and portable drinking water in the Nabire- Papua region. The MOU contains an initial order of three thousand 3.5 KW system [23].

4.5 Large Stationary

U.S. fuel cell manufacturers Bloom Energy, FuelCell Energy, and UTC Power are selling fuel cell systems to corporations, municipalities, and state and local governments, for primary power or for combined heat and power (CHP) applications. These systems range from 100 kW to more than 5 MW in capacity. Because stationary fuel cells can be installed as part of the electric grid, or in parallel with it, they can provide reliable power to a site without interruption in the event of a grid failure or blackout. This allows these business or government sites to continue their operations and helps grocers and warehouses to keep refrigerators and freezers running to prevent the expensive spoilage of goods [22].

4.6 Power Cost Savings

20 companies have installed Bloom Energy fuel cells in their buildings, including Google, eBay, FedEx. The eBay have saved $100,000 in electricity bills in the 9 months they have been installed [18].

4.7 Reliable Backup Power

Outages to the U.S. power grid caused by storms and other natural disasters cost an average of $150 billion in economic losses each year. Recognizing the vulnerability of critical infrastructure, companies in a variety of industries. From telecommunications firms and banks to hospitals are turning to fuel cells to provide an efficient, clean, and most importantly, reliable source of backup power [24].

4.8 The Technology Validation project at DOE

A six-year program that joined automakers with fuel providers to test FCEVs and hydrogen fueling in real-world settings, recently came to a close. DOE collected data from more than 180 vehicles that collectively made more than 500,000 trips, traveled 3.6 million miles, fueled up more than 33,000 times at 25 hydrogen stations, all while achieving more than twice the efficiency of today's gasoline vehicles. Most of the major automakers whether involved in the Technology Validation project or not, have confirmed the 2014-2015 timeframe as the target for small-scale fuel cell vehicle commercialization [22].

5 Advantages of Fuel Cell Power Systems

i. Fuel cell power systems are versatile and modular and can be designed to the power of the system for residential, commercial, industrial and transport applications.
ii. Fuel cell system using hydrogen generates zero emission, with natural gas low level emission. They are noiseless, have good availability and long service life.
iii. Have the tendency to improve the energy security of any nation.
iv. Suited to power automotive systems with the advantage of elimination of auto noise, pollution and fire outbreak during auto crash.
v. The systems do not required extensive grid system to supply power to remote communities
vi. Have the capability to supply steady power to GSM Base Station Transceivers (BST), reducing their reliance on 24-hours diesel generators power supply, thereby improving the quality and cost of operation of GSM out fits.
vii. They run on a wide variety of fuel.
viii. As a renewable energy source, it can check the deforestation and degradation of forest in rural communities.
ix. Assist in the cutting of emissions responsible for global warming.
x. They have high operational flexibility with fast response to changes in power demand. They operate efficiently from 50% rated power to 100% rated power.
xi. They are ideally suited for peak shaving, dispersed stand alone and remote power plants.
xii. They are effective back up power systems

6 Analysis and Discussion of Findings

In recognition of the potentials of fuel cell power systems to provide alternative energy for residential, commercial, transport and industrial Consumption, the leading World Industrialized Nations, Research Institutions and Auto Makers have been providing funds to support Research and Development (R&D) efforts in the area of fuel cell Technology applications. This R&D effort is gradually leading to the emergence and use of FCPS for home, public, military and industrial applications. The ultimate focus of the Developed Countries is to shift focus to the development of renewable energy and rely less on fossil fuel combustion technologies in order to mitigate the effect of global warming and to achieve energy efficiency and security.

With the current economic reforms, Nigeria is at the verge of an aggressive industrialization process and the present energy mix is grossly inadequate to provide the required energy for the process. Fuel cell power systems offers great opportunity for the new power generation capacity the Nigeria economy needs as well as outstanding business opportunities and potential to create jobs in many sectors of the economy.

In Nigeria, FCPS will reduce the reliance of the economy on fossil fuel technology, improve the nation energy security as availability of energy would not solely rely on the volatile Niger Delta Region making the energy sector to achieve higher energy security, bring about increase and enhanced capacity utilization in the manufacturing sector which will make made in Nigeria goods competitive in the world market and make the Nigerian economy attractive for foreign investments. It also has the potentials to provide steady power supply to our homes, eliminate the use of private generators with their dangerous emissions which cause respiratory complications and indoor pollution and improve the quality of GSM services.

The initial constrains in the use of fuel cell power systems was the high cost of the cells. But from historical and economic trends, Research and Development efforts have significantly reduce the cost of the technology through improved cell technology and high volume productions resulting to more than tenfold reduction in the price of the fuel cells systems. The cost of fuel cell power system was reduced from $3000/kW in 1990 to $225/kW in 2004 and presently to $47/kW representing about 98.43% price reduction. Further price reduction is foreseen in 2015 from the present cost level. The price profile of fuel cell technology is shown in figure 3.

For transportation, FCV are cheaper to run as the cost of hydrogen per mile driven on FCV ought to be between 27% to 52% lower than the cost of gasoline in an ICEV [17], and is environmentally friendly as it emits 60% less green house gas than an ICEV when it runs on natural gas. FCPS have the capability to remove the automobile from the pollution list and save the lives of many Nigerians that are lost to auto fire during auto accidents.

Nigeria coal deposit have been largely neglected, large scale use of FCPS in Nigeria will bring about optimum harnessing of the vital coal sector of the economy through the production of gasified coal as fuel for FCPS. This will create jobs in that sector and usher in unlimited development.

FCPS will help create demand for Nigeria gas which will minimize the flaring of associated gas in crude oil production in the Niger Delta where it is estimated that about 0.3 billion cubic feet of gas is flared per day [25]. This will promote the development of a comprehensive and flexible gas infrastructure, save potentially valuable sources of energy and minimize the production of greenhouse gases. Also MFC could be deplored in Nigeria in sufficient quantity to assist in the management and accelerated disposal of organic waste.

Electric power and portable water are two essential and scarce commodities in the average Nigeria home with worsening cases in the rural areas. As the Indonesian experience has shown FCPS can be used to produce portable water apart from the production of electricity. This double advantage if explored will provide the vital elements water and electricity in the Nigeria home that are prerequisite for social development, promotion of quality health and alleviation of stress and poverty in the rural areas. FCPS can also be used for CHP generation in the Nigerian home, making hot water available for utility purpose and increasing energy efficiency.

Thus fuel cell technology is a viable tool for the diversification and mitigation of our energy crisis and has the potentials to usher the economy into an era of flourishing industrialization. Its utilization will diversify our energy portfolio and enhance the Nigeria energy security.

7 Conclusions

As a renewable source with high efficiency, good availability and reliability, fuel cell power systems is a viable energy source for the rapid social, economic and industrial development of Nigeria. This viability is further enhance by the fact that FCPS do not require extensive grid – system, has long service life, modular and is environmentally friendly.

Since FCPS run on hydrogen fuel that can be generated at home and a wide range of other fuels and simple in operation, they are conducive for application in Nigeria technically and socially. The versatility of their applications, their noiseless operation, availability and reliability far outweighs their initial cost and make them preferable to other power systems in Nigeria.

Therefore, the adaptation and application of FCPS in Nigeria will not only mitigate our energy crisis but also enhance our energy security and provide an impetus for the social-economic transformation of Nigeria making the country attractable to foreign investors. Thus Nigeria energy portfolio will be diversified and its energy security enhanced.

8 Recommendations

1. The Federal Government should provide funds to sponsor Research and Development (R & D) activities in fuel cell Technology adaptation and application in Nigeria.
2. Strategic locations should be identified for use for pilot plants and demonstration project of fuel cell power systems application in the country.
3. The neglected coal sector should be revived with the establishment of coal gasification plant to provide fuel for FCPS.
4. In partnership with the private sector the Federal Government should set up a National Hydrogen infrastructure to provide hydrogen fuel for FCPS.

References

[1]. Central Bank of Nigeria. "Annual Report and Statement of Account." 2004, Central Bank of Nigeria.
[2]. A. Arowolo, "Energy Sector’s Dismal Scorecard." The Punch. Pp. 15, February 19.
[3]. D. Oketola, "Power generation drops by 1,074MW." The Punch, August 11, 2013. [Online] Available: http: www.punchng.com/news/. (Accessed: August 12, 2013).
[4]. H. U. Ugwu, B.N. Nwankwojike,.E. A. Ogbonnaya, and E. J. Ekoi, "Energy and Economic Losses Due to Constant Power Outages in Nigeria." Nigerian Journal of Technology. 31(2), pp. 181 - 188. 2012.

[5]. M. Zhou, H. Wang, D. J. Hasset and T. Gu. "Recent Advances in Microbial Fuel Cells (Mfcs) and Microbial Electrolysis Cells (Mecs) for Wastewater Treatment, Bioenergy And Bioproducts." wileyonlinelibrary, [Online]. Available: wileyonlinelibrary.com. [Acccessed August 15, 2013).
[6]. C. Oji, C. Opara and M.K. Odunola. "Fundamentals and Field Application of Microbial Fuel cells (MFCs)." European Journal of Applied Engineering and Scientific Research, 1(4), pp. 185-189, 2012.
[7]. B. Rose, "Fuel Cells and Hydrogen: Ultimate Energy." fuelcells.org, 2005. [Online]. Available: www.fuelcells.org/info/confr.html. [Accessed: February 25, 2010).
[8]. Department of Energy (Hydrogen Program). "Record 12020: Fuel Cell System Cost – 2012." hydrogen.energy.gov, 2012. Available: www.hydrogen.energy.gov/program_records.html. [Accessed:August 12, 2013).
[9]. O. G. Iwu, "Energy Options in the Industrialization and Development Process of the Nation, What Role for Coal." National Association of Petroleum Engineers News, Pp. 30-38, March 1998.
[10]. Encyclopedia Britannica. Direct energy conversion device: Fuel Cells. Encyclopedia Britannica Inc, London.Vol. 18, pp 398 – 399. 2005.
[11]. Y. Sun. "Societal Lifetime Cost Comparison of Hydrogen Fuel Cell Vehicles and Gasoline Vehicles." udini.proquest.com, 2013. Available: :www.udini.proquest.com/view/societal-lifetime-cost-comparison-goid:857637505/. [Accessed: August 13, 2013).
[12]. Nigeria LNG Limited. "NLNG and Gas Reserves." 2013. [Online]. Available: http://nlng.com/PageEngine.aspx?&id=87. [Accessed: August 16, 2013).
[13]. Office of Fossil Energy. "Solid Oxide Fuel Cells."energy.gov, 2013. [Online]. Available: http:// energy.gov/fe/science-innovation/clean-coal-research/solid-oxide-fuel-cells. [Accessed: October 11, 2013).
[14]. S. J. Mallo. "The Nigerian Mining Sector: An Overview." Continental Journal of Applied Sciences, 7 (1): pp. 34 - 45, 2012.
[15]. Institute of Waste Management- Nigeria. "Brief History of the Institute. 2012". instituteofwastemanagement.com, 2012. [Online]. Available: http: //www.instituteofwastemanagement.com.ng/About%20IWMN.html. [Accessed:September 10, 2013)
[16]. C. Ngumah, J. Ogbulie, J. Orji and E. Amadi. "Potential of Organic Waste for Biogas and Biofertilizer Production in Nigeria." Journal of Environmental Research, Engineering and Management,1(63), pp. 60-66, 2013.
[17]. R. Robert, "Question and answers about Hydrogen and Fuel Cells." fuelcells.org, 2005. [Online]. Available: http://fuelcells.org/info/library/questions.answers. pdf [Accessed: January, 27 2007)
[18]. Wikipedia. "Fuel Cells Vehicle." en.wikipedia.org, 2013. [Online]. Available: http://en.wikipedia.org/wiki/Fuel_cell_vehicle. [Accessed: August 30 2013).
[19]. Wikipedia. "Home Fuel Cells." en.wikipedia.org, 2013. [Online]. Available: http://en.wikipedia.org/wiki/Home_fue_cell. [Accessed: August 30, 2013).
[20]. S. Rao and B. B. Parulekar, Energy Technology: Non conventional, Renewable and Conventional. Khana Publishers, Delhi, 2005.
[21]. Energy Vortex. "Fuel Cell Helps Sierra Nevada Harness Beer Power to Reduce Its Energy Cost by 25 to 40%." .energyvortex.com, 2013. Energy Newsletter. [Online] Available: www.energyvortex.com/pages/headlinedetails.cfm?id=2477&archive=1. [Accessed: October 10, 2013)
[22]. Fuel Cells 2000. "Markets." fuelcells.org, 2013. [Online]. Available: www.fuelcells.org/base.cgim?template=markets. [Accesses: October 10, 2013).
[23]. AFC Energy. "MOU signed with the government of Indonesia." afcenergy.com, 2007. [Online] Available: http: http://www.afcenergy.com/news/2007/6/11/1192/mou_signed_with_the_government_of_indonesia_including_us135_million_initial_order. [Accessed: September 29, 2013).
[24]. Fuel Cells 2000. "When the Grid Fails: Fuel cells power critical infrastructure in disasters." fuelcells.org. April 2013. Available: www.fuelcells.org/uploads/Fuel-Cells-in Storms.pdf. [Accessed: October 10, 2013)
[25]. Shell Nigeria Gas Limited. "Shell In Nigeria Gas Flaring". static.shell.com, April 2011 [Online]. Availble: wwwstatic.shell.com/content/dam/shell. [Accessed: September 12, 2014).

Authors' profile

Engr Audu Muhammed Luqman is a senior lecturer at the Mechanical Engineering Department of Auchi Polytechnic, Auchi, Edo State, Nigeria. He holds an M. Eng (Thermal Power Engineering) from University of Benin – Benin City, B. Eng (Mechanical Engineering) from the Federal University of Technology, Minna, Niger state and a National Diploma in Civil/Building Engineering from Auchi Polytechnic, Auchi. He is currently running a PhD program in Manufacturing Engineering in the Production Engineering Department, University of Benin, Benin City. He is a member of various professional bodies which includes the Council for the Regulation of Engineering in Nigeria (COREN), Nigeria Society of Engineers (NSE), and Nigeria Institution of Mechanical Engineers (NIMECHE). He has published papers in reputable national and international journals.

Engr Igbesi Friday Chukwuyem is a lecturer in the Department of Mechanical Engineering, Delta State Polytechnic, Otefe – Oghara, Delta Sate, Nigeria. He holds an M. Eng (Production Engineering) from Nnamdi Azikiwe University, Awka, Anambra State, Nigeria and a B. ENG (Mechanical/ Production Engineering) from the same school. He is a member of the Nigeria Society of Engineers (NSE) and the Council for the Regulation of Engineering in Nigeria (COREN).

Mr Asor Matthew L. is currently in charge of Autotronics laboratory and Automotive workshop of the Mechanical Engineering Technology Department, Auchi Polytechnic, Auchi, Edo State, Nigeria. He is undergoing a master's degree program in the Federal University of Technology Akure (FUTA) with specialization in energy studies. He is a member of various professional bodies which includes the International Association of Engineers (IAE), Nigeria Institution of Mechanical Engineers (NIMECHE), Nigeria Institution of Automombile Engineers (NIAE) and Nigeria Institute of Management (NIM).

Mr Dirisu Braimah holds a Higher National Diploma (HND) in Mechanical Engineering Technology, Auchi Polytechnic, Auchi, Edo, State, Nigeria and a Postgraduate Diploma (PGD) in Mechanical Engineering, Federal University of Technology Akure (FUTA). He is doing his Master's Degree Programme in the same University. (FUTA). He is presently a Technologist and the Assistant Head of Welding and Fabrication Unit of the Department of Mechanical Engineering Technology, Auchi Polytechnic, Auchi. He holds memberships of various Professional bodies like Nigerian Institute of Mechanical Engineering (MNIMECHE), Nigeria Institute of Welding (NIW), Nigeria Institute of Management (NIM) and Proficiency Certificate in Management (PCM).