Historical review and recent trends in non-conventional energy source: Fuel Cell

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Abstract: There are three national energy policy drivers of any country of the world, Energy security, Economy growth and Environment protection. Fuel cells are important future sources of electrical power and could contribute to a reduction in the amount of petroleum. They are electrochemical devices similar to a battery and consist of an anode, a cathode, catalysts, an intervening electrolyte, and an attached electrical circuit. The principal characteristic of a fuel cell is its ability to convert chemical energy directly into electrical energy giving much higher conversion efficiencies than any conventional thermo mechanical system thus extracting more electricity from the same amount of fuel. In operation they are nearly silent, are relatively safe, and generally do not pollute the environment. This paper reviews the existing or emerging fuel cell technology, their design, operation, limitation and benefits in connection with energy, environment and sustainable development relationship.

Keywords – Fuel Cell, Energy security, Chemical Energy, Electrical Energy.

I. INTRODUCTION

We explore the use of fuel cell for powering data centre based on benefits in reliability, capital and operational costs, and reduced environmental emission. It is well known fact that there is limited amount of crude oil, natural gas and coal reserves. The global warming situation is worsened by the fact that power generation is continuously increasing throughout the world using such a fossil fuel. Additionally, the world population keeps increasing at 1.2 – 2% per year and it is expected to double by middle of 21^{st} century, while primary energy demands are expected to increase by 1.4 – 3 times. It is well known fact global warming is due to effluent gases emission particular in CO_2 because of which temperature of environment is goes on increasing. From the US National Oceanic and Atmospheric Administration and the Scripps Institute of Oceanography in San Francisco the average temperature of the Atlantic, Pacific and Indian oceans (covering 72% of earth surface) has risen by 0.06^0 C since 1995. Worldwide, over one billion people living in urban area suffer from severe air pollution and according to World Bank over 7000000 deaths result each year [1]. These observation and other [2] demonstrate that there is critical need of a cleaner energy transfer. Which generate the energy Environmental friendly. The cleanest FC fuel is hydrogen. Even with natural gas as the most practical fuel option, FC emission are cleaner than those from combustion carbon dioxide emission may be reduce up to 49%, nitrogen oxide by 91%, carbon monoxide by 68% and volatile organic compounds by 93%. [3]

II. HISTORICAL NOTES

Fuel cells are an old technology. Alessandro Volta (1745-1827) was the first scientist to place the observation of electrical phenomena on a scientific footing. J. W. Ritter (1775-1810) also knows as founder of the electrochemistry, has continued to develop the understanding of electricity. Sir Humphrey Davy created in 1802, a simple fuel cell based upon compound (C/H_2O, $NH_3/O_2/C$) delivering a feeble electrical shock. Charles Langer and Ludwig Mond first used the term "Fuel cell" in 1889 while attempting to create a practical fuel cell using coal gas in 1839 Sir William Grove created the first cell type based on reversing the electrolysis of wafer.[4] ceramic fuel cell discovered in 1899 based on solid oxide electrolytes [5]. Francis Bacon developed usable hydrogen. Oxygen cell containing an alkaline electrolyte and nickel electrodes in 1932. However a practical system was not demonstrated by Bacon and his associate until 1959. In the same year Harry Karl Ihrig presented a tractor of 20 horsepower that was powered by fuel cell (Society of Automotive Engineers, 2001). In connection with the space program Apollo in 1960, NASA spent ten Millions of dollars in a successful program that used hydrogen based fuel cells to power the on bourd electrical system on the Apollo journey to the moon. The first small bus rolled out for the media in 1993, in the late 1960s, six Ballard-built fuel cell transit buses were put on to the street of Chicago and Vancouver. Today, fuel cells are common in space flight transportation and make sense for use as portable power, home power generation and large power generation. [6]

III. FUEL CELL

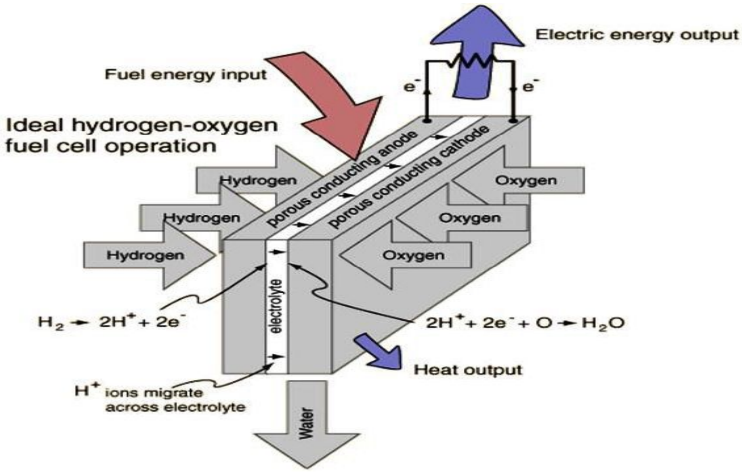
A fuel cell by definition is an electrical cell which unlike storage cell can be continuously fed with afuel so that the electrical power output is sustained indefinitely [7]. They convert hydrogen or hydrogen containing fuels directly into electrical energy plus heat through the electrochemical reaction of hydrogen and oxygen into water. The process is that of electrolysis in reverse.

Overall Reaction: $2H_2$ (gas) + O_2 (gas) ---- $2H_2O$ + energy.

Because hydrogen and oxygen gases are electrochemically converted in to water, fuel cells have many advantages over heat engines. The principal characteristics of fuel cell is its ability to convert chemical energy directly into the electrical energy giving much higher conversion efficiencies than any conventional thermo-mechanical system thus extracting more electricity from same amount of fuel . Since hydrogen is the fuel, there is no pollutant emission. If hydrogen is produced from renewable energy sources, then the electrical power is produced can be truly sustainable.

A. WORKING PRINCIPAL

Fuel cell mainly composed of two electrodes, anode cathode, catalyst, and an electrolyte. Hydrogen atom enters a fuel cell at anode. The anode, disperse the hydrogen gas equal over whole surface of catalyst and conduct the electrons, that are freed from hydrogen molecules to be used as useful power in an external circuit. Oxygen enter the fuel cell of cathode it recombine with electron returning from the electrical circuit and hydrogen ions that have traveled through the electrolyte from anode, to form water. The catalyst is a special material that is used in order to facilitate the reaction of oxygen and hydrogen. That can be platinum coating as in proton exchange membrane or nickel and oxide for solid oxide fuel cell.



The reaction of the electrodes

Anode reaction: $2H_2 \rightarrow 4H^+ + 4e^-$

↓ Electrolyte ↓ External Circuit ↓ ↓

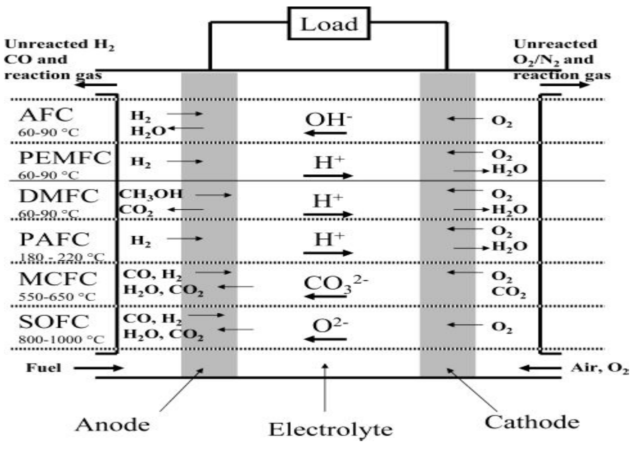
Cathode reaction: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

Overall cell reaction: $2H_2 + O_2 \rightarrow 2H_2O$

Fuel cell can either be an oxygen ion conductor or a hydrogen ion conductor, the major difference between two types is the side in the fuel in which water is produced.

B. TYPE OF FUEL CELL

The fuel cells are classified by nature of electrolyte material used and operating temperature. There are several type of fuel cell technologies being developed for different applications as small as a cellular phone (0.5 Watt) to as large as small power plants. For an industrial facility or small town (10 MW). Each using different chemistry.



Type of fuel cell	Electrode composition	Electrolyte composition	Operating temperature	Fuel	Electrical output	Portability of fuel cell	Potential problems	Potential uses
Phosphoric acid	Platinum on carbon paper	Phosphoric acid	150–200°C	Hydrogen	As much as 200 kilowatts	Not portable	Too heavy for many uses	Stationary installations
Alkaline solution	Insufficient information	Alkaline solution potassium hydroxide in water	150–200°C	Hydrogen	300 watts to 5 Kilowatts	Portable	Containers of liquids can leak	Vehicles
Molten carbonate	Anode: nickel-Chromium. Cathode: nickel oxide (lithium doped)	Molten carbonate salt- sodium, potassium, lithium, or magnesium carbonate	About 650°C	Methane	As much as 2 megawatts	Not portable	Too heavy for many uses; salts are highly corrosive	Stationary Installations- power stations and industrial uses
Solid metal Oxide	Anode: nickel zirconium. Cathode: lanthanum manganese	Solid metal oxide— calcium or zirconium oxide	Nearly 1,000°C	Methane	As much as 100 kilowatts	Not portable	Too heavy for many uses; leakage and sealing problems	Stationary installations— power stations and industrial uses
PEM (proton-exchange membrane)	Unknown	Solid, fluorocarbon–polymer film (a thin, flexible, permeable sheet)	About 80°C	Hydrogen	Unknown	Portable	Unknown	Homes and vehicles
Direct methanol	Unknown	Polymer membrane	50–100°C	Methanol	Unknown	Portable	Unknown	Vehicles
Reversible-unitized regenerative	Unknown	PEM (proton-exchange membrane) in water	Unknown	Hydrogen	Unknown	Portable	Unknown	Vehicles

Table 1. Types of fuel cell their components and characteristics

C. FUEL CELL APPLICATIONS

As a result of the inherent size flexibility of fuel cells, the technology may be used in applications with abroad range of power needs. This is a unique feature of fuel cells and their potential application ranges from systems of a few watts to megawatts. Fuel cell applications may be classified as being either mobile or stationary applications. The mobile applications primarily include transportation systems and portable electronic equipment while stationary applications primarily include combined heat and power systems for both residential and commercial needs. Fuel cells are currently being developed for the following application.

- Power for portable electronics devices 5-50 W [9]
- Power for remote telecommunications applications 100W-1KW
- Power for construction and outdoor recreational uses 1-3 KW
- Auxiliary Power units for Cars and trucks and motive for scooters 3-5 KW
- Stationary power generation 1KW-50MW
- Electric passenger car, utility vehicle and bus power systems 20-250 KW[8]

IV.FUEL CELL ADVANTAGES AND DISADVANTAGES

A. ADVANTAGES

The main advantages of fuel cells are:

Efficiency - Fuel cells are generally more efficient than combustion an engine as they are not limited by temperature as is the heat engine, convert up to 50-70% of available fuel to electricity (90% with heat recovery [10]) and reduces fuel cost and conserve natural resources.

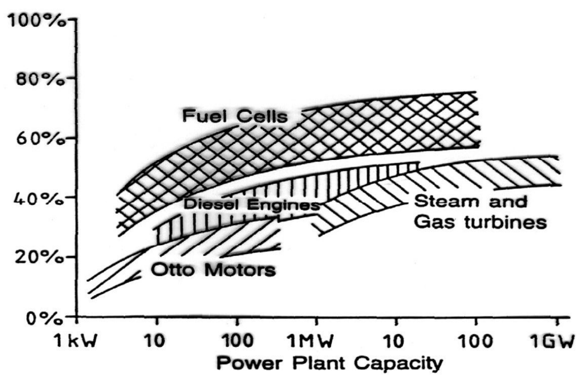


Figure 2: Comparison of power plant efficiency (Kordesch and Simader, 1996)

Simplicity - Fuel cells are essentially simple with few or no moving parts. High reliability may be attained with operational lifetimes exceeding 40,000 hours (the operational life is formally over when the rated power of the fuel cell is no longer satisfied) [11-12].

Low emissions - Fuel cells running on direct hydrogen and air produce only water as the byproduct. 100-1000 times cleaner than the 1998 American Clean bus standards (15 ppmv of CO_2) [13] and compared with traditional combustion power plants [10] Stop NOx and SO_2 from being released into environment therefore eliminates 20,000 Kg of acid rain and smog- causing pollutants from the environments and reduce CO_2 emissions by more than two million kg per year.

Silence - The operation of fuel cell systems are very quiet with only a few moving parts if any. This is in strong contrast with present combustion engines.

Flexibility - Modular installations can be used to match the load and increase reliability of the system.

B. DISADVATAGES

The principal disadvantages of fuel cells, however, are the relatively high cost of the fuel cell, and to a lesser extent the source of fuel. For automotive applications a cost of US$10 to $50 per kW and an operation life of 4000 hours is required in order to compete with current internal combustion engine technology. For stationary combined heat and power systems a cost of US$1000 per kW and an operation life of 40,000 hours is required [12,14]. The current cost of a fuel cell system is around US$3000 per kW for large systems with additional costs required for the heat exchanger in the combined heat and power systems. The cost of fuel cells will be brought down with mass manufacture and costs of US$100 per kW have been predicted as the production of fuel cells expand over the following few year [12].

V. STATUS OF FUEL CELL DEVELOPMENT AND COMMERSALATION

Currently, there are at least six different fuel cell types in varying stages of development. Four of these are receiving the most development attention. Proton exchange membrane fuel cell (PEMFC)—175°F (80°C) ,Phosphoric acid fuel cell (PAFC)—400°C (200°C), Molten carbonate fuel cell (MCFC)—1250°F (650°C), Solid oxide fuel cell (SOFC)—1800°F (1000°C)

A.PROTON EXCHANG MEMBRAN FUEL CELL (PEMFC)—175℉ (80℃)

Among the many applications of PEMFCs, transportation is the most competitive and promising. In addition, people could easily see the potential of this promising alternative technology through the development of environment-friendly vehicles. Therefore, the success of PEMFC in this field might be the most important factor to provide an incentive for expanding their applications to the other fields. Daimler-Chrysler and Ford Motor Company have committed $750 million for research in PEMFC development and cost reduction. With this infusion of capital, PEMFCs are expected to overcome technical and economic hurdles within the next five years. Both companies have announced plans to offer commercial fuel cell powered vehicles in 2003. This is expected to accelerate stationary power development as well. To date, several PEMFC power plants have been developed for both transportation and stationary applications. The most visible plants are those developed for transportation. Ballard Power Systems has PEMFCs in several demonstration transit buses in the Chicago Transit Authority and British Columbia transit systems and in Daimler-Chrysler NECARs I-IV. Ballard Power Systems also has demonstrated prototypes of 10 and 30 kW stationary systems. Now they are developing a 250 kW onsite generation unit for market entry in 2000.Plug Power is developing PEMFCs from 5–50 kW. Their first product is a 7 kW residential power unit to be offered commercially in 2000. H-Power has developed 10 kW PEMFCs for Ford and is currently working on three-kilowatt residential units which they expect to sell for about $5,000 in moderate volume (New York Times, June 17, 1998). Additionally, H-Power has developed the first wholly unsubsidized, fully commercial fuel cell unit for a trailer-mounted, electric-powered highway construction sign (New York Times, June 17, 1998). Northwest Power Systems is developing 7–10 kW residential power generators. To be successful in the transportation sector, it is widely believed that PEMFCs will have to cost $150/kW or less. In fact, automakers believe that in light duty applications they will need to cost around $25–50/kW. This means that the current cost of $500/kW will have to be reduced by another order of magnitude. To accomplish this, production volumes on the order of one million units per year are necessary. It is believe that stationary onsite fuel cell systems will have to cost $1500/kW to be competitive. Because PEMFCs have lower system efficiencies than other fuel cell types, utility experts believe they will need to cost less or will have to offer other benefits to potential customers in order to compete against phosphoric acid fuel cells in commercial markets [15].

B. PHOSHPORIC ACID FUEL CELL (PAFC)—400℃ (200℃)

PAFCs utilized an electrolyte and phosphoric acid solution. They operate at very high temperature approximately 180^{o}C and are well suited for co-generation system. PAFC systems were the first commercial stationary fuel cell systems and have demonstrated the greatest durability for commercial systems with lifetimes in excess of 60,000 hours. The phosphoric acid stationary fuel cell system operating on natural gas has 40% fewer greenhouse gas emissions when compared to the average coal-fired power plant in the United States. ONSI claims that in over two million hours of total operation, their PAFCs have demonstrated better than 95 percent reliability and a mean time between forced outage of 2200 hours a figure that bests onsite, diesel-powered generators [16].However, costs are still two to three times higher ($3000/kW or $4000/kW installed) than the commercial market will sustain. Thus, the only hurdle to the complete commercialization of PAFCs is cost reduction. To achieve 50–65 percent cost reductions, developers need higher sales volumes and design improvements in the power plant itself. Costs associated with every element of the power plant must be reduced—including fuel processor, cell-stack design, power conditioning and control, and ancillary components [17].

C. MOLTEN CARBONATE FUEL CELL (MCFC)—1250□F (650□C)

MCFCs are poised to enter the commercial market as early as 2000. Both ERC and MC-Power have several demonstration plants planned for 2000. In order to penetrate the commercial markets they've targeted, developers need to address the following issues:
1. High power density. This is a must for commercialization. Developers have set power density goals of 0.18 to 0.225 W/cm$_2$ to reduce cost and plant footprint [17].
2. Cell life. Nickel oxide (cathode) dissolution in the electrolyte, electrolyte management, and hardware corrosion protection are the three major factors in establishing long life characteristics in MCFCs.
3. Cost reduction. Developers need to achieve production volumes of 200–400 MW/year to drive manufacturing costs down to $200–400/kW.
4. Systems integration and thermal management
5. Reliability and durability of stacks

D. SOLID OXIDE FUEL CELL (SOFC)—1800□F (1000□C)

Current state-of-the art SOFC technology has demonstrated satisfactory efficiency and life performance. To date, Siemens Westinghouse has demonstrated 1 kW, 25 kW, 100 kW, and 250 kW tubular SOFCs and plans on releasing commercial 1–5 MW plants by 2002.Relative to the other fuel cell types, however, SOFC development is especially dependent on materials research and manufacturing processes. The development of suitable low-cost materials and fabrication techniques represents a significant challenge for SOFCs [18]. For example, sintering is a high temperature process that adds production complexity and cost. The materials may cost $7–$15/kW, but manufacturing can drive this to $700/kW for the stack [19, 21, 22].
Development issues common to tubular and planar SOFCs include:
1. Developing lower cost, reliable manufacturing techniques for cell components
2. Establishing quality assurance criteria (non-destructive evaluation techniques to detect manufacturing flaws in cell and stack components)
3. Refining the thermal management of stack heat flows (air cooling, internal reforming, etc.)
4. Studying systems applications to best integrate and take advantage of the new technology
5. Developing new and/or improved materials, including
A) Contaminant tolerant fuel electrodes
B) Improved interconnect materials (stability and conductivity over range of O_2 partial pressures)
C) Establishment of physical and mechanical properties of the cell and stack components versus Temperature for design and modeling of stack performance.

VI. CONCLUSION

Already it was predicted that fuel cells would be common for producing electricity and motive power within a few year. This system has several disadvantages such as transmission losses, and long lead times for plant Construction and large and long term financing requirements. Distributed generation is an alternative that is gathering momentum, and modern technologies, such as fuel cells are likely to play an increasing role in meeting ever-increasing power demands. Fuel cells have many advantages over conventional power generating equipment: high efficiency, low emissions, sitting flexibility, high reliability, low maintenance, excellent part-load performance, modularity, and multi-fuel capability. Because of their efficiency and environmental advantages, fuel cell technologies are viewed as an attractive 21^{st} century solution to energy problems. It is difficult to predict the success of one fuel cell type versus another given their immature development and commercialization, high cost and uncertainties in cell performance. If the technological and infrastructure barriers can be remedied, fuel cells provide enormous environmental, economic, and political benefits. If these benefits are to be realized we must commit to the technological and infrastructure developments that are required for fuel cell advancement. Despite this, fuel cells have a wide range of applications that can allow them to succeed in several.

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