Utilizing Fuel Cell Technology for Dubai Roads and Transport Authority (RTA)

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Abstract—**The need for developing environmentally friendly and sustainable energy sources is globally evident. This is due to two main reasons: Fossil fuels will continue to supply energy demands for only a few more decades and the amount of pollution generated due to fossil fuels is exceeding acceptable limits. One very promising clean energy converter is the fuel cell (FC). Fuel cells have the ability to convert the chemical energy of their feed fuel to electricity through a chemical process without involving combustion, which significantly reduces harmful emissions such as NOx. Fuel cells generate absolutely no harmful emissions when their fuel supply is pure hydrogen and they are more efficient than internal combustion engines. This research will investigate the feasibility of utilizing fuel cells in the public transportation system of Dubai operated by the Roads & Transportation Authority (RTA), in order to gradually replace transportation fleets running on fossil fuel engines to engines running on pure hydrogen. The Proton Exchange Membrane (PEM) fuel cell is one of the leading technologies which has started to replace internal combustion engines. However, technology development, cost, durability and lack of relevant infrastructures are the biggest challenges to the implementation of FC.**

Keywords—Fuel Cells (FC); Dubai Roads and Transport Authority (RTA); Proton Exchange Membrane (PEM); Dubai Transportation

I. Introduction

Environmentally friendly transportation is an objective that many countries are trying to achieve. However, almost a billion tons of CO2 and other gases are still being emitted per annum worldwide. In Dubai, there is an increasing demand for both personal and public transportation and hence pollution is expected to increase unless an alternate clean fuel is utilized. Investigations have been carried out for many decades to find affordable alternate fuels and clean energy converters such as fuel cells to overcome pollution and to avoid crises caused by instability of oil prices and supplies.

Internal combustion engines, are severely criticized for their nasty effect on the environment, added to this is the fact that they are dependent on fossil resources of energy, which are rapidly depleting and are not being utilized properly due to the poor efficiency of heat engines. The low temperature direct conversion process, in which hydrogen is chemically oxidized, is the best alternative to heat engines. In this process, the heat emitted to the surroundings, or in driving the reaction, is kept to a minimum. This method would meet the pressing need of humanity to find alternatives for power generation and its best utilization, that can both reduce the amount of energy needed per unit time, i.e. power in terms of KWh, so as to conserve energy resources, and at the same time, protect the environment by reducing the amount of harmful emissions, and thermal loading i.e. greenhouse effects. In fact, the fuel cell technology can overcome these difficulties; and pave the way for utilizing different sources of energy [1].

There have been many demonstration projects and proof of concept for using public transport buses powered by hydrogen in various countries around the world. The hydrogen bus demonstration projects CUTE and its successor HyFLEET – CUTE were two projects supported by the European commission within the interest of mobility and transport. Major advances in proving fuel cell and hydrogen propulsion technologies have been achieved through these projects. A comparative study between internal combustion and fuel cell busses was performed in the HyFLEET:CUTE project where 33 fuel cell buses and 14 internal combustion engine buses have operated in daily public service. The busses were run for over 2,5 million kilometers in total and carried more than 8,5 million passengers. It was proven that busses running on Fuel Cell technology were highly reliable. Issues pertaining to hydrogen production, distribution and refueling infrastructure were demonstrated in the project, together with safety, training and public acceptance, which are important elements in hydrogen technology [2].

Another project was The Hydrogen Mobility Europe (H2ME) project announced in 2015, which was planned to extend over six years supported by the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) with funding from the EU's Horizon 2020 research program. The initiative aims to expand the European hydrogen vehicles fleet and to confirm the technical and commercial readiness of vehicles, fueling stations and hydrogen production techniques.

The first phase of the project planned for the deployment of 300 fuel cell electric vehicles (FCEVs) and 29 hydrogen refueling stations (HRS), mostly in Germany at a cost of €68 million. The second phase, which was announced in June 2016, included the operation of 1,230 FCEVs and the addition of 20 extra HRSs, as well as testing the ability of electrolyser-hydrogen refueling stations to help balance the electrical grid [3]. It is worth noting that commercialization of FCEVs has actually started by many car manufacturers and demands for FCEVs, HRS and other elements of the hydrogen transport economy are spreading in many parts of the world at a significant rate.

This research aims among its objectives to boost general awareness of the fuel cell technology, which can be considered, in the short run, as a supplement to heat engines. However, in the long term, fuel cells are expected to replace heat engines as a more efficient and environmentally friendly energy converter. Hydrogen as fuel is expected to replace fossil fuels in everyday utilization, while the remaining fossil fuels, which are basically hydrocarbons, will be treated to separate carbon from hydrogen under controlled conditions in order to utilize hydrogen in fuel cells for zero carbon generation of energy. On the other hand, captured carbon can be directed for use in other industrial processes, thus reducing the amounts of carbon emitted to the atmosphere.

II. RTA Motivations to Utilize FC Technology

This research investigates the current FC technologies and then presents recommendations to gradually utilize them in RTA public transportation systems. Fuel cell technology has been tested and practically validated to be one of the main energy converters that can be utilized due to their efficiency, compactness, low noise and pollution free.

The need for RTA to consider FC technology becomes clearer by examining the rapid growth of their transportation fleets as shown in Fig. 1, [4]. It is obvious that Dubai transportation sector is continuing to increase rapidly in the coming few years which will require new strategies and considerations of clean energy alternatives. Currently only small percentage of Dubai population is utilizing the public transportation. The roads and transport authority (RTA) is aware of the current situation and has established a strategic plan which guarantees expansion of public transportation with a world class services [5]. RTA integrated public transport system is comprised of bus, taxi, rail, ferries and recently air-taxis.

Fuel cells produce zero emissions when fueled by hydrogen and their efficiency is twice higher than the efficiency of conventional internal combustion engines. Therefore, there should be sufficient effort to introduce FC technology into all RTA transportation systems. In this paper, however, more focus will be given to buses since they run on diesel engines, which have greater impact on urban environment. It should be noted that although trams and trains run on electricity which is being generated using fossil fuels such as diesel and heavy oil, that generate huge amounts of pollutants; but their direct impact is less severe due to the location of power generation plants away from urbanized areas.

Fig.1. Growth of RTA transportation fleets [4].

III. Fuel Cell Technology

Fuel cells have been investigated for more than a century. Currently, researchers, manufactures and authorities are engaged in many FC's investigations to develop their fuel, materials, manufacturing processes, and control and optimization systems.

A. Fuel Cell Operation

A fuel cell is a device that generates electricity by a chemical reaction. Every fuel cell has an anode, a cathode and an electrolyte, which carries electrically charged particles from one electrode to the other. It also has a catalyst that speeds the reactions at the electrodes. Multiple fuel cells are usually assembled into a stack and generate direct current (DC). Hydrogen is the basic fuel for FC, but they also require oxygen. As shown in Fig. 2, hydrogen atoms enter a fuel cell at the anode where a chemical reaction strips them of their electrons and they become positively ionized. The Negatively charged electrons provide the electrical current needed to do work. Oxygen enters the fuel cell at the cathode and combines with hydrogen ions and electrons returning from the electrical circuit forming water as reaction byproduct. The electrolyte permits only the appropriate ions to pass between the anode and cathode [6].

Almost all types of fuel cells run on hydrogen as a fuel, but other types of ions can also be used in some fuel cells. Hydrogen is produced from various energy sources including: renewable energy, fossil fuel, coal, gas and many others. Its production and use give near zero greenhouse emissions. Hydrogen can be utilized for all sectors including transportation.

B. Fuel Cell Types

A fuel cell operates like a battery and produces energy continuously in the form of electricity and heat as long as fuel is supplied. There are five main fuel cell types available on the market. First type is alkaline fuel cells (AFCs) which have been

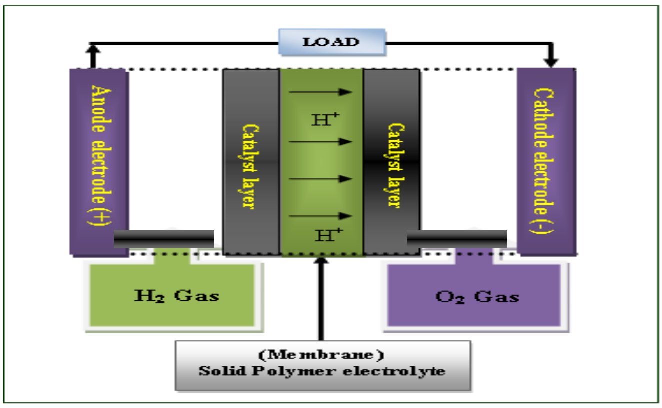

Fig. 2. Schematic representation of a PEMFC [7].

used by NASA for more than 50 years for space missions. They operate at temperatures of about 95 degrees C with an efficiency around 65%. They are vulnerable to carbon contamination and hence they need pure hydrogen and oxygen [8].

Secondly, phosphoric acid fuel cells (PAFCs) which use liquid phosphoric acid as the electrolyte with about 40% efficiency and they operate at temperatures of over 200 degree C. This type can use impure hydrogen which make them operate with various types of fuel. They are commercially available and used for wide range of applications.

Thirdly, solid oxide fuel cells (SOFCs) use hard ceramics compound as the electrolyte and hence they are high-temperature fuel cells, operating typically between 650°C and 1000°C. SOFCs can have an efficiency of about 60%. They are fit for stationary applications and vehicles auxiliary power units.

Fourthly, molten-carbonate fuel cells (MCFCs) which operate at temperatures of up to 650 degrees C with about 60% efficiency. MCFCs have been operated using hydrogen, propane, natural gas and carbon monoxide. They are potentially used for utility applications.

The fifth type is proton exchange membrane fuel cells (PEM) as shown in Fig. 2, with operating temperature of about 80 degrees C and around 60% efficiency. They are the most suitable for transportation because of: small size, lightweight, use thin permeable polymer sheet as electrolyte, the electrolyte dose not leak and their outputs range from 50 to 250 kW. But their fuels must be purified, and a platinum catalyst should be used on both sides of the membrane which is relatively expensive.

All Fuel cell types have the potential to provide high efficiency at wide range of load conditions without negatively impacting the environment. With the current FCs development, reasonable cost reductions are expected which will make FC's an appealing energy alternative. The different types of fuel cells are classified according to the type of electrolyte used in them, fuel type, temperature of operation and physical nature of the electrolyte whether solid or liquid. Table I represents the major types of fuel cells.

Table I. Characteristics of FC Types [8].

Fuel Cell Type	***Operating Temperature***	***System Output***	***Efficiency***
Alkaline (AFC)	90–100ºC 194–212ºF	10kW–100kW	60–70% electric
Phosphoric Acid (PAFC)	150–200ºC 302–392ºF	50kW–1MW (250kW module typical)	80–85% overall with combined heat and power (CHP)
Molten Carbonate (MCFC)	600–700ºC 1112–1292ºF	< 1MW (250kW module typical)	85% overall with CHP (60% electric)
Solid Oxide (SOFC)	650–1000ºC 1202–1832ºF	5kW–3 MW	85% overall with CHP (60% electric)
Polymer Electrolyte Membrane or Proton Exchange Membrane (PEM)*	50–100ºC 122–212ºF	< 250kW	50–60% electric

IV. Advantages And Limitations of Fuel Cells

Fuel cells rely mainly on hydrogen, which is an abundant and renewable element that reacts with oxygen releasing energy to generate electricity. The reaction happens without burning and hence no carbon dioxide or any other harmful substances are produced. The only by-product of this reaction is water. Therefore, hydrogen is considered one of the most powerful and efficient types of fuel. Hydrogen FC's have more than double the efficiency of diesel or any other traditional combustion engines. For example, a conventional combustion power plant usually generates electricity between 33 to 35 percent efficiency while hydrogen fuel cells are capable of generating electricity with up to 65% efficiency. Furthermore, FC vehicles have more than 50% reduction in fuel consumption. While traditional power plants are mostly large in order to obtain better efficiency, FC can achieve higher efficiencies at any scale, hence, they are good for small movable applications [9], [10].

FC transportation has the advantages of greater range, quicker charging, less downtime, steadier voltages, cleaner, and more compact when compare with internal combustion and electric vehicles. Fuel cells satisfy another vital environmental requirement which is operating silently because they have fewer moving parts. While batteries degrade and must be disposed, FCs do not degrade and they are easier to recycle. In addition, they can theoretically provide continuous electricity. Therefore, FC's are very suitable to be adapted in dense urban areas for the various applications including transportation [11].

While the initial costs of FC are high, once they are installed, hydrogen fuel cells and FC vehicles are very affordable to maintain. Existing vehicles can be refitted in order to accommodate hydrogen as fuel. Fuel cell is currently more expensive compared to fossil fuel. However, as time goes by, fossil fuel is becoming scarcer, while FC technology becomes more easily available and hence less expensive.

V. Running Cost of Diesel Buses

RTA has large transportation fleets including buses and the number is expected to increase rapidly [5], [12]. Therefore, it is essential to indicate the high cost associated with the running the diesel buses in order to show the usefulness of adapting FC technology for transportation.

A diesel bus normally consumes 24 liters per 100 km (for the average speed of 60 km/h); hence, it consumes about 15 liters per hour of operation. Considering the RTA bus fleet, it can be estimated that diesel consumption is11520 liters for 100 buses operating for 8 hours per day. Fig. 3, and Fig. 4, show the annual (365 days) diesel consumption & cost respectively for different RTA scenarios. Cost was estimated based on 1.9 AED per liter. However, cost associated with running the fleet includes many more items other than paying for the bus original price and its fuel; RTA has to pay to operate these buses for wages (drivers, mechanics, admins, supervisors, and other staff), maintenance, insurance, licensing, infrastructure, etc.

It can be estimated that the cost to drive a bus for one hour is about 600 AED. Considering the number of buses and operation hours, RTA would need to pay around 400 million AED annually (365 days) to operate 150 buses for 12 hours per day [13], [14]. Fig. 5, shows running cost associated with different RTA operation scenarios.

Therefore, for such a big investment, it is worthy to investigate the utilization of FC to run this fleet even with FC higher cost since it has significant positive environmental impacts as will be discussed next.

VI. ENVIRONMENTAL IMPACTS OF DIESEL BUSES

Transportation is responsible for more than 25% of the global greenhouse gas emission (GHG) which negatively affect air quality, water resources and all environmental aspects. In Dubai, vehicles run on petrol are responsible for 42% of the total pollution [15].

At the same time, transportation is vital for modern society development and rapid advancement. In the UAE, to achieve the planned sustainable development, transportation should be enhanced even further, which requires business development, and utilization of new technologies. At the same time, transportation is vital for modern society development and rapid advancement.

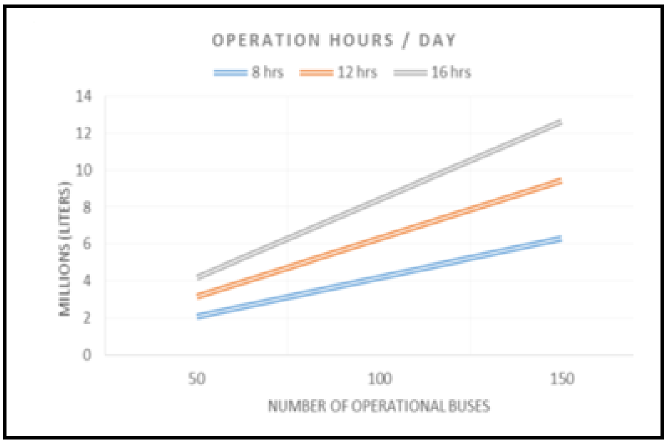

Fig. 3. Diesel consumption for RTA buses.

Fig. 4. Diesel cost (AED) for RTA buses.

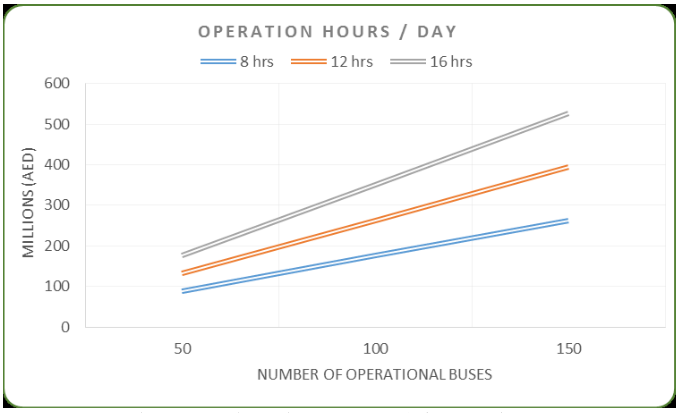

Fig. 5. Annul running cost (AED) for RTA buses.

In the UAE, to achieve the planned sustainable development, transportation should be enhanced even further, which requires business development, and utilization of new technologies. These facts are in line with UAE Government vision to ensure sustainable development while preserving the environment. “The UAE Vision 2021 National Agenda focuses on improving the quality of air, preserving water resources, increasing the contribution of clean energy and implementing green growth plans” [16]. One important technology that can support this vision is fuel cells.

Despite the fact the RTA buses are running with Euro 4 & 5 Diesel but yet it has significant negative impacts on the environment. As pointed out previously in this paper, diesel is a hydrocarbon, and diesel engines are internal combustion engines, therefore, it is inevitable to inhibit the production of carbon dioxide and Nitrogen oxides as well as particulate matter and unburnt hydrocarbon as a result of the combustion process. The EU standards for emissions are shown in Table II. However, these limits are sometimes exceeded based on vehicle life and prevailing conditions.

TABLE II. EU EMISSION STANDARDS (DIESEL) [17].

	Pollutants (g/Km)			
	CO	**HC+NOx**	**NOx**	**PM**
Euro 1	2.72	0.97	-	0.14 (0.18)
Euro 2	1	0.7	-	0.08
Euro 2	1	0.9	-	0.1
Euro 3	0.64	0.56	0.5	0.05
Euro 4	0.5	0.3	0.25	0.025
Euro 5	0.5	0.23	0.18	0.005
Euro 6	0.5	0.17	0.08	0.005

Considering the size of RTA fleet of buses and the number of operation hours, the amount of pollution caused is significant and should be eliminated if the aforementioned UAE vision is to be achieved. Number of investigations have indicated that the UAE suffer from significant pollution [18]. For example, CO2 emissions per capita (metric tons) in the UAE is 19.9 compared to world average of 4.9 and 3.9 for Middle East and North Africa respectively [19]. Hence, these findings require taking a number of measures to lessen pollution including considering clean fuel for transportation systems.

The benefits and need for utilization of fuel cells and hydrogen fuel are also justified based on costs. Current investigations indicate that fuel cell vehicles are costlier than the equivalent fossil fuel vehicles in the order of about 7000 AED per vehicle [20]. However, ongoing enhancements in fuel cell technology and large-scale production could potentially reduce the FC vehicles lifetime cost below that of comparable fossil foil vehicles.

Pollution has massive diverse effects on economy since it impacts tourism, property values, recreational businesses, infrastructures, machine maintenance and lifespan, etc. Unhealthy environment causes increase of spending for cleaning, hospitalization, medication, and loss of work man-hours. If both environmental impacts and costs are considered, then fuel cell vehicles are becoming both technologically and economically viable option compared with other conventional fuel vehicles, and ensure deep reductions in harmful emissions from transportation.

VII. CURRENT FC TRANSPORTATION SYSTEMS

Over the last two decades, fuel cell world market expanded largely to include thousands of telecoms and stationary units and vehicles. The vehicle applications included forklifts, electric bikes, scooters, aircraft, ships, cars and buses [21].

Since 1995 fuel cell bus projects have been propagated around the world. In 2003, ten European cities (like London, Paris and Madrid), have started running 3 public buses in each city which were built by Mercedes-Benz using a 250 kW PEM. These fuel cell are running on 44 kg pure hydrogen stored under 350 bar pressure in cylinders positioned on the bus roofs. Each city deployed a hydrogen refueling station to support FC applications. Considering the current growing interest in fuel cell vehicles, and the plans and strategies declared by many countries around the globe to gradually switch to zero carbon hydrogen economy, it is anticipated that FC hydrogen vehicles will become the biggest sector compared to hydrocarbon and electrical battery vehicles by 2050 as shown in Fig. 6, [11].

From the results of other proof of concept studies, and particularly the Clean Hydrogen in European Cities (CHIC) project, it has been proven that fuel cell buses are capable of meeting the daily needs of big cities like Dubai. The (CHIC) project, introduced 56 FC buses with the required infrastructure in eight European cities in 2010-2016. The project provided solutions for public transportation free of air pollution and with reduced noise. Furthermore, these FC buses provided a range of more than 350km, short refueling downtime and 26% higher efficiency than diesel buses [22].

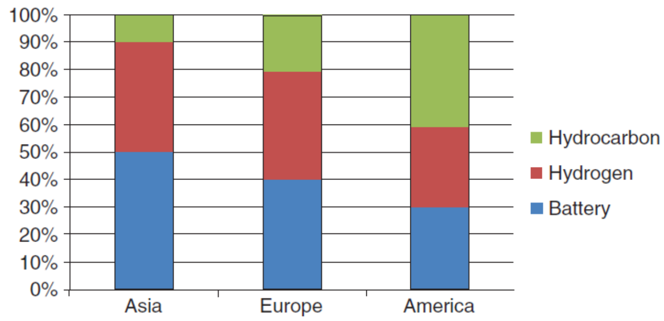

Fig. 6. Prediction of hydrogen fuel cells vehicles by 2050.

In North America, FC industry has been progressively growing including transportation applications over the last decade [21]. In Scotland, there are ten hydrogen buses in Aberdeen city alone [23]. Recently, Germany has tendered the procurement of 63 fuel cell buses which is a part of an EU funded project for deploying 139 new zero emission fuel cell busses. The project goal is to test FC buses performance and consumer response. Seven hydrogen cylinders on the bus roof allowed 35 kg of hydrogen gas at 700 bar pressure to give a vehicle range of more than 250 km [24].

VIII. SUMMARY AND RECOMMENDATIONS

FC's are used for many applications including transportation. FC vehicles include: buses, taxis, fork lift trucks, airport vehicles and many other specialized applications. However, it is recognized that penetration of the huge vehicles market will be achieved more slowly, due to the long life of internal combustion engine vehicles and the need to reduce costs of FC vehicles. The need for appropriate FC infrastructure is also a major request.

Ongoing research is focused on identifying and developing new materials that will reduce the cost and extend the life of FC components. Low cost, high volume manufacturing processes will also help to make fuel cell systems competitive with traditional technologies. This paper has discussed many important aspects of FC and their use for many applications including transportation. The research is done in relation to RTA needs to adapt FC technology starting with buses since they are main contributor to transportation and major source of pollution. The research leads to the following recommendations:

- Dubai Roads & Transport Authority (RTA) and Higher Colleges of Technology (HCT) may collaborate to establish FC research laboratory.
- RTA may introduce few FC buses and taxies for a trial period until RTA fully prepare for adaptation of FC technology and once infrastructure is ready to support full scale of FC fleets.
- Revision of energy related laws and policies to ensure readiness to adapt FC technology.
- Launching in-depth study of the future of FC technology in the UAE.
- Continuing the local and world-wide FC research to bring the technology into more appealing levels.

IX. CONCLUSION

Fuel cells are currently utilized worldwide for many applications and this trend will continue with new advancements. There are many FC technology concerns and the most important ones are cost reduction and durability. Hence, FC research will continue in order to fulfil the current and future demands of clean energy. Dubai is developing fast and requires rapid transportation enhancements to cope with these changes. Considering the economical and environmental impacts of Dubai's growth, RTA should work toward utilization of FC technology to meet, in a timely manner, Dubai needs and achieve the UAE vision of sustainable development while preserving environment.

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