Fuel Cell Technology as a Clean Energy Resource

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Abstract:

This study aims to give a clear view of fuel cells as a clean technology. Its history paths, basic operation principles and types are demonstrated. Fuel cells as a sustainable clean technology and its barriers are also discussed. The potential of fuel cells in Arabic countries, UAE has been taken as a case study.

Fuel cells offer great economic, environmental and social benefits. Economically, it offers zero CO_2 emissions by using absolute hydrogen produced from renewable resources. Even by using hydrogen derived from *non renewable resources like fossil fuel reforming, significant reductions of CO_2 emissions and pollution can be achieved compared to other conventional power generation means like internal combustion engines. Economically, huge financial savings could be obtained by implementing fuel cells in such important sectors such as transportation and stationary power generation units. Fuel cells can also offer societies a cleaner and less polluted environment. Moreover, lots of job opportunities for engineers and scientists could be provided by expanding fuel cells in a commercial sense and developing its field. For fuel cells to be clean and sustainable technology, hydrogen must be produced from renewable energy resources.*

Introduction:

Energy has been one of the most important priorities to mankind even since the early beginning of human civilization. In addition, energy consumption and its resources have played an important role in the development of human life style. Since almost a half century ago, the demand on energy resources in general and crude oil in particular has been significantly increased due to the incredible development in industry world and social life style. As a result of that dramatic demand on energy resources (crude oil in particular), the availability of those energy resources would be limited and might be degraded as the world population is increasing. Moreover, serious impacts on environment already exist and the greatest example is the global warming which is considered as the biggest threat to human life. Therefore, urgent actions have already started to decline as much as possible fossil fuel consumption and even trying to decrease carbon dioxide CO_2 levels to zero if that is possible. One of the challenging and promising and environmentally friendly technologies is fuel cells technology. Fuel cell can potentially play an important role to provide clean technology based on hydrogen consumption, and releasing water instead of CO_2.

Fuel cell are becoming widely accepted as a preferred means of generating electricity for distributed electrical power generation because of their high fuel conversion efficiency, environmental compatibility and reliable quiet operation [1].

Owing of their high energy efficiency , low noise, and minimal pollution, fuel cells are widely regarded as a 21st century energy-conversion devices for automotive, stationary and portable applications [2].

This study, however, is trying to give a clear view on its history and mechanism. Potential of fuel cells technology, its challenges and drawbacks are also discussed. United Arab of Emirates (UAE) has been taken as a case study of fuel cells implementation in Arabic countries.

3. Fuel Cell Energy:

A Fuel cell is an energy conversion device which converts chemical energy into electrical energy through electrochemical reactions take place in the electrolyte. Unlike traditional generating of electricity, fuel cells do not involve thermal and mechanical steps to produce electricity and generating electricity is achieved only in a single process (electrochemical reactions). In addition, fuel cells are not similar to conventional batteries because they do not run down and recharging is not needed as hydrogen and oxygen are supplied to them[3, 23].

According to D. Hart [8], “The Fuel cell is an energy conversion technology, not an energy resource”. Fuel cells technology is being considered as a part of future energy solutions and an important candidate for utilising hydrogen economy [12].

There are many benefits of fuel cell technology. For instance, technically, direct combustion of the fuel and mechanical processes are not existed during fuel cells operations to generate electricity so this makes it a quite technology compared with other traditional power generators[4, 5 and 23].

Environmentally, fuel cells produce water and heat as they are supplied by oxygen and pure hydrogen so they have been considered as a clean technology from environmental point of view because it does not release pollutant gases. In addition, for transportation applications, fuel cells provide significant CO_2 emissions and pollution reductions [14, 28].

High efficiency, low pollutants emissions, higher power generation are required for recent energy generation technologies. The above criteria can be achieved by fuel cell technology. Moreover, fuel cells are considered as a capable alternative to internal combustion engines because it is more efficient, much cleaner and quitter [10].

3.1 History of Fuel Cells:

Fuel cells have had a long history almost two centuries since its discovery in 1839. There has been a controversial debate about who discovered the concept of fuel cells technology. The Department of Energy of the United States [2] claimed that it was the German chemist Christian Friedrich Schonbein who in 1839 conducted the first concept of fuel cell technology. On the other hand, According to the IEEE Aerospace and Electronic System Magazine 2000, it was Sir William Robert Grove, in

January 1839 described the first Hydrogen-oxygen fuel cell, in which he immersed two platinum electrodes in a very dilute electrolyte of sulphuric acid and separate pairs of platinum electrodes in containers of oxygen and hydrogen as it is shown in figure 1 [17, 37]. However, Farady [15] proved that Grove was the first inventor of fuel cells.

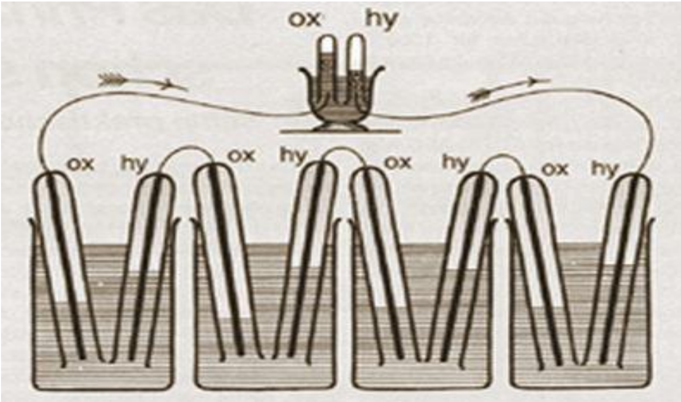

Figure (1) Four cells of Grove`s battery to drive an electrolytic cell, 1842 [38]

In 1800, Sir Anthony Carlise and William Nicholson invented an inverse process to fuel cell`s operation principle cells called Hydrolyses by applying electricity to the water results decomposition of water into hydrogen and oxygen [15].

The first practical application of fuel cells was developed by William W. Jacques in 1896. Walther Nernst was the first who used zirconium as solid electrolyte [1].

In the early start of the 20th century, William W. Jacques and Emil Baur designed and built in 1921the first molten carbonate fuel cells. High power systems (1.5 kW fuel cells with a stack of 100 tubular units and fuel cells with 30 kW) were built by W. Jacques [31]. In 1933, Thomas Francis Bacon was the first developer of Alkaline fuel cells by using potassium hydroxide instead of acids as electrolyte. In 1961, a new phosphoric acid fuel cell was made by G.V. Elmore and H.A. Tanner, the new electrolyte was a mixture of 35% phosphoric acid and 65% of silicon dust immersed into the Teflon [20]. Since 1970, Fuel cells technologies have had positive aspects: an increased performance, longer life time, reasonable prices of its catalyst due to using non noble metals, using reformed petroleum to generate hydrogen. In addition, nowadays, fuel cells have huge variety applications in which fuel cells are used in transport sector like aircrafts, ships, trains, cars, trucks, and motorcycles. Also in Stationary application and communication applications such as using it in mobile phones, laptops, etc [40].

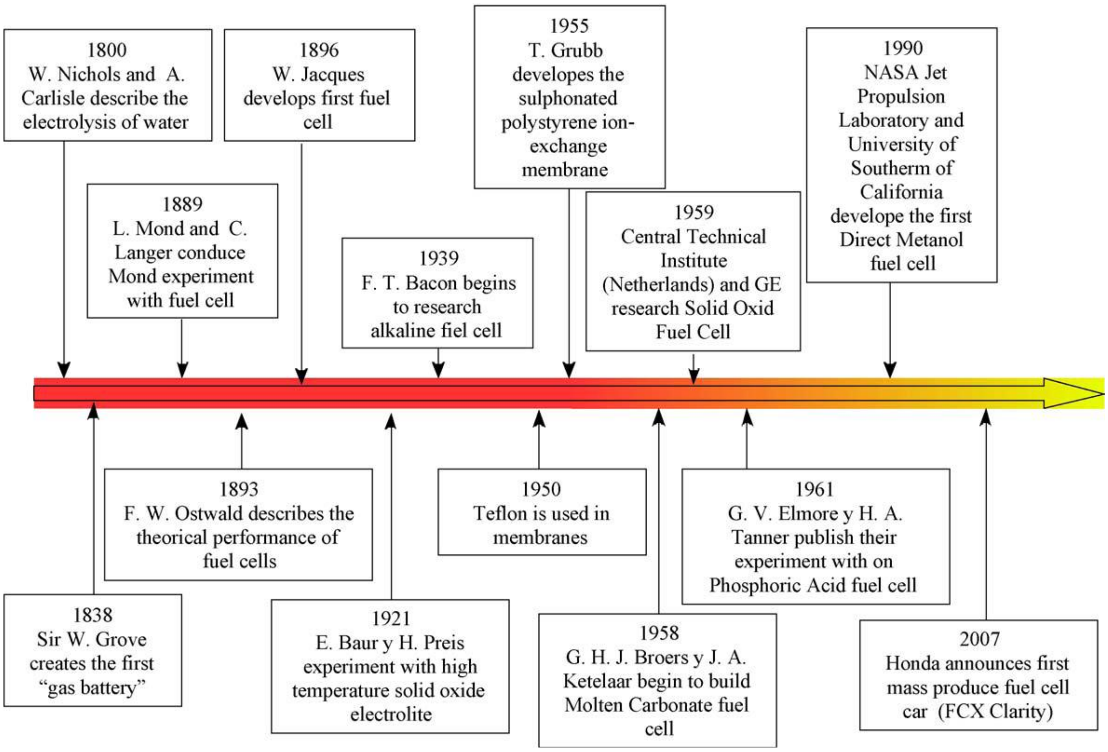

Figure (2) development of fuel cells technology [20]

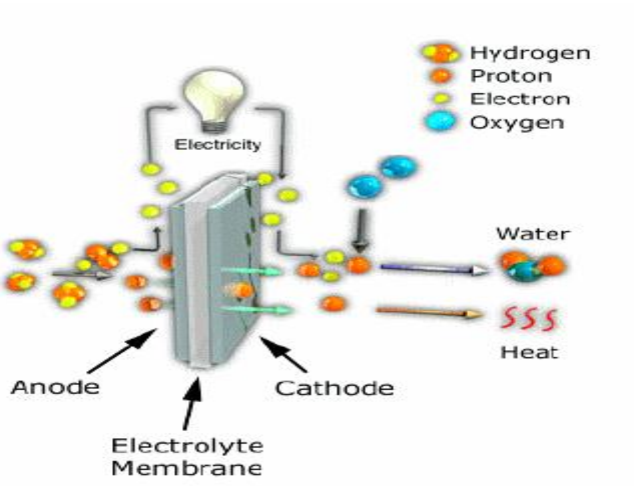

Figure (3) a schematic diagram of fuel cell components [4]

3.2 fuelcell`s Components and Concepts:

Figure (3) shows the main primary components of any kind of fuel cells which are: a cathode, an anode and an electrolyte. The above components often are called membrane electrolyte assembly (MEA). The electrolyte must be made of an ionic conductive material [33]. Hydrogen and oxygen are fed continuously in the presence of a catalyst to produce water and electricity [24]. The anode is fed continuously with a fuel (mostly Hydrogen). Meanwhile, cathode is fed with an oxidant (oxygen). In other words, oxidation reactions, which involve loss of electrons from the hydrogen resulting releasing hydrogen anions H^+, take place on the anode surface. Conversely, reduction reactions (gaining of electrons) occur on the cathode surface in which oxygen reacts with the hydrogen anions coming from the anode. However, the negative charges (electrons, e-) must pass through an external circuit to the anode to generate electricity. While, positive ions (H+) pass through the electrolyte to the cathode. The following reactions explain the cathodic and anodic reactions occurring on the cathode and anode respectively:

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

Cathodic reaction: $½ O_2 + 2H^+ + 2e^- \rightarrow H_2O$

Overall reaction: $H_2 + ½ O_2 \rightarrow H_2O$

Figure (4) illustrates the basic concept of fuel cells operation

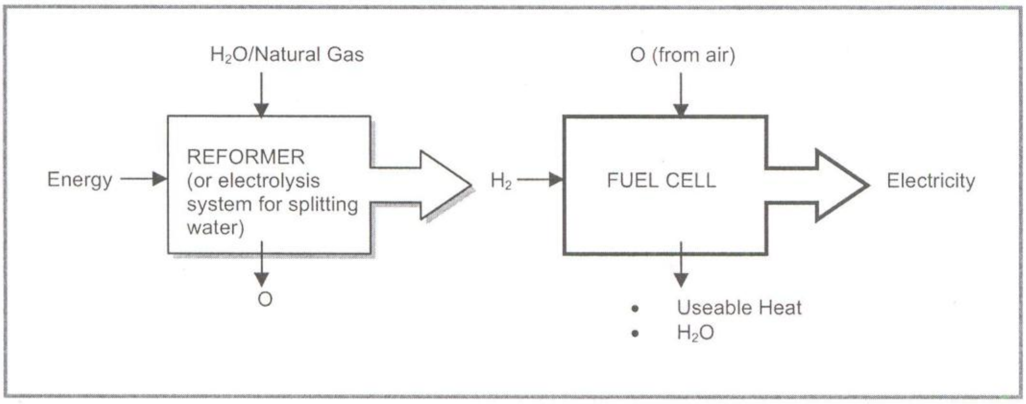

Figure (4): Simplified diagram showing the basic working of a fuel cell [36]

However, the electrolyte, which can be a liquid, solid or polymer plays significant roles in the fuel cell: firstly, it prevents the direct combustion of the fuel (Hydrogen) with the oxygen. Another duty is working as a barrier of gases diffusion and allows just positive ions (H+) to penetrate through it to the cathode. In addition, it prevents a short electric circuit between the cathode and anode [5, 33]

3.4 Fuel Cells Types:

Since the invention of fuel cells by William Grove in 1839, there have been various classifications of fuel cells types in the literature regarding to the electrolyte, operating temperature and the kind of fuel used [21,25,34 and 35]. The most common classification is by the type of the used electrolyte in the fuel cells as following [20]:

Alkaline Fuel Cells (AFC):

The electrolyte in this fuel is alkaline solution of Potassium hydroxide (KOH). However, operating temperature of the fuel cell depends on KOH concentration. When KOH concentration is 85%, the operating temperature is 250°C. Lower temperatures less than 120°C are used when using KOH concentration between 30 – 50 %. Various electro catalysts are used in AFC such as Ni, Ag, metal oxides and noble metals. Since 1960`s AFC has been used in space programs [3].

Proton Exchange Membrane Fuel Cells (PEMFC):

It is called also Polymer electrolyte fuel cells. A very thin layer ≤ 50µm of a polymeric membrane (such as Perfluorosulfonated acid polymer) is used as an electrolyte. Operating temperatures are between 60 – 80°C. Platinum loaded on carbon about 0.3 mg/cm^2 is used as catalysts. PEMFC has been widely used in automotive, portable and small scale stationary power applications [3].

Phosphoric Acid Fuel Cells (PAFC):

As it has been mentioned in the section of fuel cell`s history, PAFC was the first FC ever built and discovered by William Grove in 1839. However, 100% concentration of Phosphoric acid (H_3PO_4) is used as electrolyte. Platinum is used on both of the anode and cathode as an electro catalyst. Operating temperatures are between 150 – 220^{o}C [3].

Molten Carbonate Fuel Cells (MCFC):

A mixture of (Li, Na, K) carbonates is composed with a ceramic matrix of (LiAlO2) to form the electrolyte of MCFC. However, Due to high operating temperatures (600 –700), using noble metal catalysts are not required. In addition, using carbon salts in high temperatures conditions provide a good ionic conductivity [3].

Solid Oxide Fuel Cells (SOFC):

Unlike other kinds of fuel cells, oxide ions (O^{2-}) are conducted from the cathode to the anode. However, a solid oxide zirconium usually Y_2O_3-stabilized ZrO_2 is used as an electrolyte in SOFC`s. However, SOFC is considered having the highest operating temperature between 800–1000^{o}C [3, 20]

Table (1) explains briefly all kinds of fuel cells with its operating temperatures, electrolytes, and fuels.

Table (1) Fuel cells types and selected features [19, 27]

Type	Temperature °C	Fuel	Electrolyte	Mobile Ion
PEM: Proton Exchang Membrane	70 -110	H_2, CH_3OH	Sulfunated Polymers (Nafion™)	$(H_2O)_nH^+$
AFC: Alkaline Fuel Cell	100 – 250	H_2	Aqueous KOH	OH-
PAFC: Phosphoric Acid Fuel Cell	150 – 250	H_2	H_3PO_4	H+
MCFC: Molten carbonate fuel cell	500 – 700	Hydrocarbons, CO	$(Na,K)_2CO_3$	$CO3^{-2}$
SOFC: Solid oxide fuel cell	700 – 1000	Hydrocarbons, CO	$(Zr,Y)O_{2\delta}$	O^{2-}

4. Energy Resources in Arabic Countries

The main energy resources of Arabic countries are represented significantly with oil and natural gas. Wind, solar, hydro, geothermal and biomass represent renewable resources shares in those countries [28].

4.1 Oil and Natural gas

According to Organization of Arab Petroleum Exporting Countries [28], proved Arabic oil reserves represent 62% of the worldwide proved oil reserves. Table (2) shows the expected oil-production capacities in the Arabic countries between 2000 and 2015.

Table (2) Expected oil-production in the Arab countries (million barrels /day) [7]

Country	2000	2005	2010	2015
Algeria	0.8	1.2	1.0	0.8
Bahrain	0.181			
Egypt	0.93	0.85	0.71	0.56
Iraq	0.6	2.6	6.7	6.1
Kuwait	2.6	3.0	3.5	4.0
Libya	1.4	1.6	1.9	2.3
Oman	0.87	1.00	1.00	0.93
Qatar	0.5	0.7	0.6	0.5
Saudi Arabia	10.0	10.5	11.0	12.0
Syria	0.61	0.61	0.60	0.52
Tunisia	0.087			
UAE	2.6	2.8	3.0	3.5
Yemen	0.34	0.48	0.75	0.50
Total	21.518	25.34	30.76	31.71

Arabic countries constitute around 21.7% of the world natural gas reserves [28]. Table (3) shows the distribution of natural gas resources in the Arabic countries.

Table (3) Natural gas resources in the Arab countries, 1980 – 2006 (Billion cubic meters) [13]

Country	1980	2000	2006		Total
			Assoc.	Non-Assoc	
Algeria	3993	3300	141	3579	3720
Bahrain	142	173	3	144	147
Egypt	142	399	52	579	631
Iraq	524	3107	1586	1755	3341
Kuwait	1189	1518	1366	132	1498
Libya	849	1208	637	660	1297
Oman	253	204	73	7786	849
Qatar	227	4615	64	8921	8985
Saudi Arabia	1515	5223	3702	1653	5355

Country	1980	2000	2006		Total
			Assoc.	Non-Assoc	
Syria	23	156	35	465	500
Tunisia	28	85	4	66	70
UAE	290	5623	1385	4417	5802
Yemen	-	198	57	422	479
Total Arabic countries	9175	25,809	9105	23,569	32,674
Total World	39,443	130,258	14,667	135,537	150,241
Arab Countries/World	23.3%	19.8%	62.1%	17.4%	21.7%

4.2 Coal

Coal as an energy resource is located only in three Arabic countries: Morocco, Egypt and Algeria. Annual production of coal in Morocco has been estimated of more than 500,000 tons. In 1995Egyptian coal production was 125,000 tons. On the other hand, Algerian`s coal annual production was estimated as 40 million tons [28].

4.3 Hydropower:

Hydropower generation worldwide constitutes 18.5% of the world electricity consumption. However, due the scarcity of water in some of Arabic countries, there is a limited Arabic countries that use hydropower as a resource to produce energy. In 1995, the total Arabic hydropower capacity was 6224 MW. However, Egypt represents 45% of the total Arabic hydropower generation. Followed by Iraq and Syria constitute 14% each and 11% of Morocco [28].

4.4 Wind energy

Using wind as a resource to produce electricity is not encouraging in Arabic countries due to the expensive average electricity cost by wind turbines (5-6 US cents/kWh) compared with traditional electricity costs. Egypt, Jordan and Morocco are the Arabic countries that invest in wind energy technology and they are planning to expand their energy production capacity to 120 MW [28].

4.5 Biomass:

Biomass as an energy resource plays an important role to provide energies in some Arabic countries. For example, 50% and 70% are the total energy consumption shares in Sudan and Mauritania respectively. Moreover, the total annual consumption of biomass in Arabic countries is 17 Mton [28].

5. Case Study: Fuel Cell in the United Arab of Emirates (UAE):

Due to that fuel cells technology is still in the early stage of utilization in the Arabic countries, There is a lack of information about the implementation of fuel cells in Arabic countries. This section is going to demonstrate and apply assessment model [26] that has explained the economic and environmental benefits of introducing Proton Exchange Membrane Fuel Cells (PEMFC) to power and replace internal combustion vehicles in the United Arab Emirates (UAE). Assessment model aimed to reduce internal combustion vehicles (ICV) gradually starting from 2005 and to replace it totally by powered fuel cells vehicles by 2025. Table (4) presents a comparison between FC vehicles and IC vehicles.

Table (4) PEMFC vs. ICV [22]

Parameter	FC vehicle	IC vehicle
Gasoline-equivalent fuel economy, 1/100 km	3.06	9.08
Capital cost, $	30,400	17,300
Average vehicle life, km	289,000	193,000
Annual maintenance cost, $/year	401	516

Assessment mathematical equations [26] is used to estimate the number of IC and FC powered vehicles between 2005 and 2025. In addition, other mathematical equations were used by to the amount of air pollution caused by IC vehicles between 2005 and 2025 and also the calculated financial savings of introducing FC powered vehicles in the same period. By using the above mentioned equation and other local information relative to the UAE, the results presented in Figures (5) and (6). Figure (5) presents the expected FC vehicles in the transportation sector

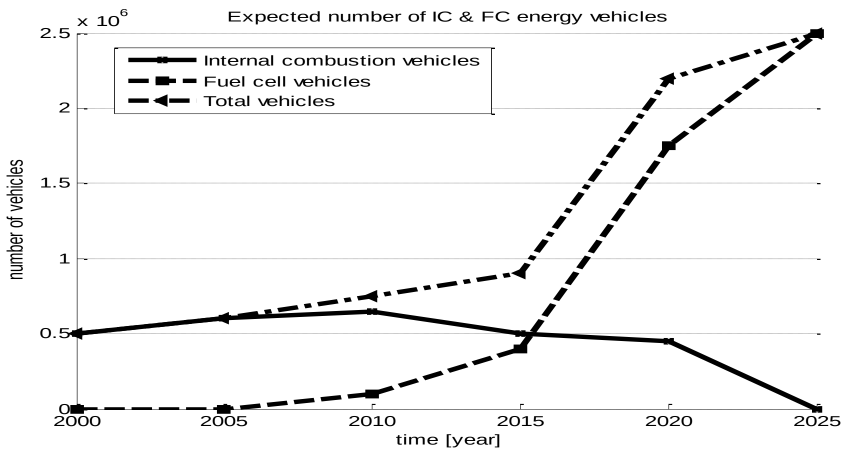

Figure (5) Expected PEMFC vehicles in the transportation sector

An annual growth for FC vehicles must be 3 folds the annual growth of IC vehicles in order to entirely substitute the IC vehicles with PEMF vehicles by the year of 2025. A percentage of 10% of the total number of vehicles (780,000) in 2005 is the initial number of FC vehicles in 2005.

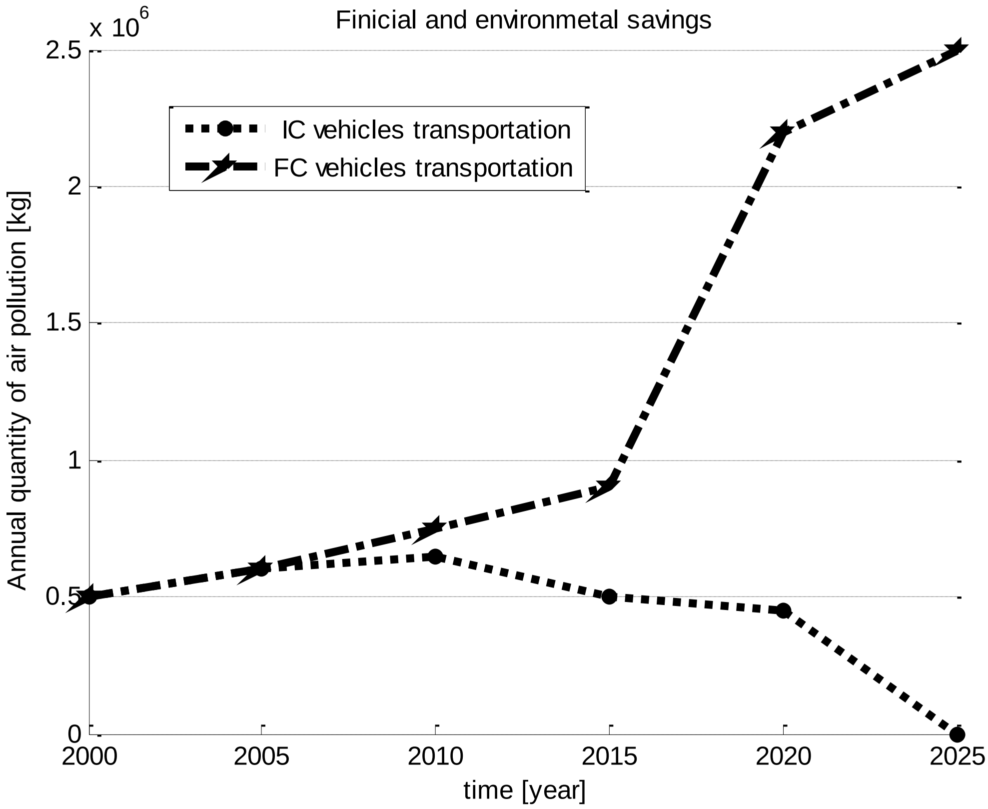

Figure (6) Financial and environmental saving of introducing PEMFC [26]

Figure (6) shows the financial and environmental costs associated with and without the introduction of FC vehicles. The environmental pollution quantities without the introduction of PEMFC in the period from

2005 to 2025 will increase 5 times to around 2.4×10^8kg. On the other hand, 14.4×10^8 kg would be the environmental pollution savings with introducing FC vehicles for the same above period. Moreover, the total financial savings would be about $\$23 \times 10^8$ [26]

Therefore, statically according to the above obtained economic and environmental benefit results, the implementation of this technology would bring sustainable energy saving solutions in Arabic countries if such these proposals turned into practical schemes to replace internal combustion vehicles (ICV).

6. Discussion :

Firstly, what is a clean technology? Makower [23] defined it as a technology that utilizes a variety of products, services and processes by using renewable materials. In addition, it aims to reduce the usage of fossil fuel resources and improve the life standards in Arabic countries.

According to Haile [11], in order for a technology to be sustainable, three basic principles must be fulfilled: high economic growth and providing stable levels of employment, using less fossil fuel resources, and effective environmental protection.

Regarding the case study in the UAE, huge financial savings and environmental CO_2 emissions cuts would be gained $\$23 \times 10^8$ and 14.4×10^8 kg respectively for the period between 2005 and 2025. As it has been mentioned in section 3, fuel cells produce electrical power with high efficiency and zero emissions. These features make fuel cells environmentally friendly.

Socially, although fuel cells is expensive technology recently, the expansion and development of this technology will offer lots of job chances for engineers, companies so it will improve the quality life standards.

Therefore, due to meeting the economic, environmental and social needs, it can be said that fuel cell is a clean and sustainable technology.

7. Future Remarks :

7.1 Environmental:

Although fuel cells technology is considered as clean technology providing clean electricity by using renewable hydrogen resources, recently one of the major hydrogen resources is the fossil fuel reforming which also release CO_2 emissions to the atmosphere. Therefore, relying on reforming fossil fuels to produce hydrogen would limit the environmental benefits of fuel cells technology as a clean technology [30].

Hydrogen naturally is not available in large quantities so there is necessity to produce and manufacture hydrogen as a fuel to the mentioned technology from renewable resources. However, there has been a controversial question which is: is it better using renewable resources directly to generate energy rather than of using them to produce hydrogen?[29].

Huge scale of hydrogen reliance to power variety of applications in the future could lead to hold huge quantities of hydrogen in the polar ozone layer which could lead to depletions in these layers [31].

Therefore, to overcome these environmental barriers, fuel cell technology must be only dependent on hydrogen renewable resources. In addition, further scientific researches should prove a bigger value of using hydrogen from renewable resources to feed fuel cells instead of the direct use of renewable resources to produce energy.

7.2 Economic and Social :

One of the biggest barriers for the implementation and commerciality of fuel cell technology is its high and expensive capital cost. Currently, installation fuel cells prices are between $ 7,000 and $35,000 per kW which are prohibitive compared with other conventional energy power generators due to that fuel cells technology is still in the early stage of development and also due to some kinds of fuel cells use expensive and complex catalysts such as platinum. These expensive prices have lead to customer reluctance to install such these new power technologies. Recently, scientific researchers are aiming to set a target to reduce the installation costs limits to $500 – $700 per kW for stationary application and $ 35 –$ 40 per kW for transportation applications [18].

Another social barrier for accepting the implementation of fuel cells is the public fear of dealing with hydrogen (dangerous volatile gas) so there have been many arising safety concerns. Moreover, a lack of hydrogen infrastructures would also be a drawback for the fuel cells implementation[18]

Therefore, in order to defeat these economic and social drawbacks, customers should be informed with the economic advantages and the high efficiency performance of adapting fuel cell technology. In addition, Local governments and bankers should also support this technology by providing loans, mortgages to those customers who cannot afford its capital cost.

Hydrogen supplying infrastructures are also widely required in the long term to raise fuel cells markets.

8. Conclusions:

This study has aimed to give a clear view about fuel cell`s technology, principles, history, components, types and drawbacks. Another target was to present the economic, environmental and social benefits of fuel cell implementation and its sustainability in one of the Arabic countries (United Arab Emirates) has been taken as a case study.

In conclusion, for fuel cells to be considered as a clean and sustainable technology: Hydrogen as a fuel in fuel cells should be produced as much as possible from renewable resources in the short term and must be produced totally from renewable resources in the long term.

The suggesting recommendations that could help to widely increase the commerciality of fuel cells in power generation markets are: stock holders should be informed with the economic advantages and the high efficiency performance of adapting fuel cell technology. In addition, governments and bankers support is also required to ease economic difficulty for who cannot afford it by providing loans, mortgages, etc. Hydrogen supplying infrastructures are also widely required in the long term to raise fuel cells markets. Finally, developed countries which have scientific and practical experience of this technology should help and provide some scientific and technical support to developing countries that do not have ability to commercialise this technology.

9. Nomenclature:

PEMFC: Proton Exchange Membrane Fuel Cells
AFC: Alkaline Fuel Cells
PAFC: Phosphoric Acid Fuel Cells
MCFC: Molten Carbonate Fuel Cells
SOFC: Solid Oxide Fuel Cells
UAE: United Arab of Emirates
IC: Internal Combustion
ICV: Internal Combustion Vehicles
PEMFCV: Proton Exchange Membrane Fuel Cells Vehicles

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