Journal of Power Sources 186 (2009) 455–463

Contents lists available at ScienceDirect

Journal of Power Sources

journal homepage: www.elsevier.com/locate/jpowsour

Market survey of fuel cells in Mexico: Niche for low power portable systems

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ARTICLE INFO

Article history:
Received 29 September 2008
Accepted 1 October 2008
Available online 21 October 2008

Keywords:
Portable electronics
Direct methanol fuel cells
Market survey
Mexico

ABSTRACT

This work provides an overview of the potential market in Mexico for portable electronic devices to be potentially powered by direct methanol fuel cells. An extrapolation method based on data published in Mexico and abroad served to complete this market survey. A review of electronics consumption set the basis for the future forecast and technology assimilation. The potential market for fuel cells for mobile phones in Mexico will be around 5.5 billion USD by 2013, considering a cost of 41 USD per cell in a market of 135 million mobile phones. Likewise, the market for notebook computers, PDAs and other electronic devices will likely grow in the future, with a combined consumption of fuel cell technology equivalent to 1.6 billion USD by 2014.

1. Introduction

Microfuel cells (FCs) for low power portable systems may be defined as any cell that provides small-scale power (≤50 W) to an electronic mobile system [1]. Portable systems include mobile phones (0.1–3 W), notebook computers (5–50 W), PDAs (1–2 W), digital cameras (5–20 W), and other relatively small electronic devices (3–50 W). The benefits offered by FC technology are derived from the electrochemical conversion, which silently transforms the chemical energy of a fuel into electrical energy with high efficiency and very low gas emissions. This technology may become an alternative to non-renewable energy sources and aid in the reduction of green house gas production. Mexico releases about 360 MM tons year^{-1} of carbon dioxide into the atmosphere, ranking it first among Latin American countries, with a contribution of 1% of the total world emissions [2]. The introduction of fuel cells in low power portable electronics will not considerably reduce the energy demand for emerging countries like Mexico. However, the ability to reduce the pollution released from batteries and internal combustion engines would prove highly beneficial. There are several reasons to consider microfuel cell technology; among these reasons is the fact that the development of lithium batteries seems to be too slow to meet the growing energy demands of 3G cellular handsets. Insufficient battery run time appears as one of the main considerations in the adoption of handheld devices with rich multimedia functionality. An additional factor to be considered is battery degradation, which is not commonly accomplished in Mexico and results in severe water and soil pollution by metals [3]. Energy savings and pollution control are some of the goals of the Kyoto protocol, which came into force on the 16th of February 2005. Another example of international support to employ clean technologies is the 'Implementing agreement for a program of research, development and demonstration on advanced fuel cells,' which was sponsored by the International Energy Agency. Although international efforts are moving to accelerate FC implementation and resource optimization, there are still several challenges to overcome. These include a high cost per kW, power policies, and technology development for hydrogen and methanol fuels based on hydrocarbons and renewable sources. Furthermore, FCs will have a relatively tough competitor in lithium batteries for several years, because of technological development of FC is still in progress and has proven high output power capabilities. The conversion from lithium batteries to FC technology does not appear to be straightforward. An analysis made by Demirdöven and Deutch indicates [4] that fuel cell vehicles using hydrogen from fossil fuels offer no significant energy efficiency advantage over hybrid vehicles operating in an urban drive cycle. This may suggest that the change from lithium battery to methanol FC would require a combined technology step, such as the fluidic chamber. However, this topic remains to be studied in detail. Despite these issues, industrialized countries are betting strongly on FC technology, as can be seen in the amounts invested in 2003, which are remarkably high for the United States and Japan (Fig. 1) [5].

The national plan for the development of Mexico (PND) 2007–2012 emphasizes investment in applied science and technology of alternative energies [6]. This research is focused not only on clean technologies and renewable energy sources, but also on the oil industry to improve oil and gas infrastructure and utilize envi-

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doi:10.1016/j.jpowsour.2008.10.038

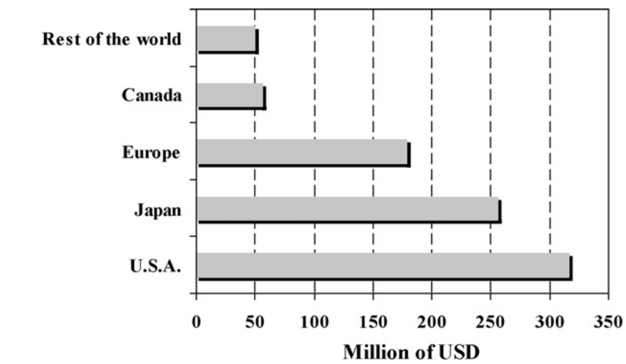

Fig. 1. Investment in fuel cell technology worldwide in 2003.

ronmentally friendly processes. By 2012, investment in the energy sector will reach 0.65% of the annual revenues of combined oil and gas production [7]. These actions driven by the Council of Science and Technology (CONACYT) will reinforce the research on fuel cells.

In Mexico, the commercialization of low power FCs for use in portable equipment will not depend on governmental power policies, as will be the case with motor vehicles; rather, it will depend on the swiftness with which these devices can reach a competitive cost and performance compared to alkaline batteries. This means that the application of FC technology in Mexico will be determined by international markets. Therefore, the market forecast of low power portable devices is key information for niche investment and country development. In this work, the potential market of portable electronics powered by fuel cells is analyzed.

2. Survey of worldwide activity of portable fuel cell development

Fuel cell markets are commonly divided into three groups: portable (electronic devices), stationary (generators) and vehicle propulsion. For portable devices, the most promising cell is the direct methanol fuel cell (DMFC) with a proton exchange membrane (PEM) as the electrolyte. In the DMFC, methanol fuel is fed into the anode of the fuel cell and encouraged by a catalyst; the methanol is split into a proton, CO_2 and an electron, which take different paths. The proton passes through the electrolyte to the anode. Sometimes, methanol crossover through the electrolyte membrane is hindered as a result of diffusion and electro-osmotic drag [8]. This results in a mixed cathode potential along with a reduction in power output and fuel utilization [9]. However, the low operating temperature of the DMFC allows for an easy start up and rapid response to changes in load and operating conditions.

A large number of portable electronic devices have been manufactured on the DMFC concept. It has been reported that around 6000 new portable systems were installed in 2006 [10]. The general consensus among electronic manufacturers is that they will be commercially available by 2007. However, the technology is not expected to become a mainstream product in industrialized countries until 2010 or later. Microfuel cells are likely to become a mass-marketed product, though they first need to become ordinary, which will happen when the user cannot distinguish between electronic devices powered by fuel cells and those powered by batteries, with the exception of the different amounts of energy supplied [11]. In September 2003, the company Allied Business Intelligence published a report that predicted that microfuel cells would enter the commercial market after 2004. Although the number of portable systems produced did not reach 4000 units, a worldwide market of 200 million units after 2011 was forecasted [12]. The report also highlighted the increase in the importance of direct methanol fuel cells in portable applications, which has expanded to over 40% of the total market this year.

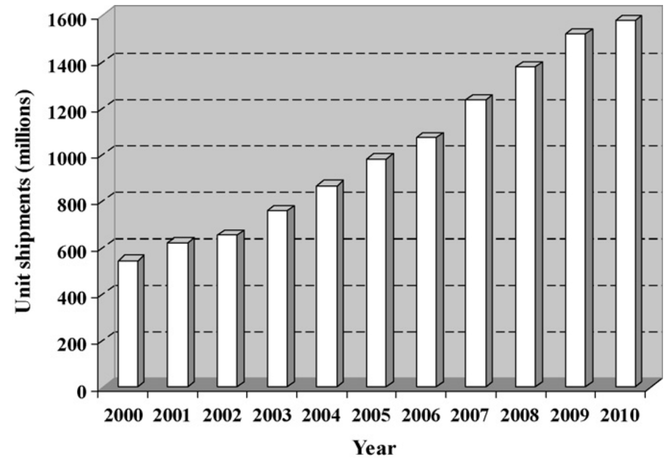

Fig. 2. Worldwide portable power market forecast.

Europe as a whole is pushing to reach for commercialization of a more efficient consumer handset with a longer battery lifetime. In Japan, numerous organizations continue the development and testing of fuel cells for use in portable applications, including Sony, Casio, Fujitsu, Hitachi, NEC and Toshiba. The development of portable fuel cells in Japan has primarily been undertaken by companies making and selling their own electronic devices (e.g., mobile phones, notebook PCs, etc.). It is interesting to note, however, that nationwide maintenance capabilities for fuel cell powered products in Japan are not expected to be ready in the short term, despite many companies claims that mobile phones will be available as early as 2007 [13].

Demand for the mobile handset has increased worldwide; for instance, an increase occurred in electronic units from 482.5 million in 2003 to 561 million in 2004. This growth rate is expected to gradually slow down over a period of 5 years. The estimated growth figures for these 5 years are 10% in 2005, 7.7% in 2006, 6.4% in 2007, 4.8% in 2008 and 2.6% in 2009. Despite the gradual decline in the growth figures, annual handset sales are predicted to reach 767 million by 2009. A survey performed by Frost & Sullivan [14] shows a retailing trend of 1400 million by 2009, and 16 million units sold by 2010, with a growth rate of 12.5% under an optimistic scenario (Fig. 2).

Mobile handsets with innovative features have gained large popularity in developed countries. However, the markets for which development is not yet saturated, namely, China, India, Russia, Brazil and Mexico, will carry on with the global handset acquisition phase [14]. The market for rechargeable batteries is expanding and is experiencing sales of several hundred million per year [15].

In Central & Latin America (CALA), the handset forecast exceeded 100 million units in 2006. A growth of 15% in 2006 pushed total handset volumes to 104 million units. Replacement sales become a primary sales driver in 2005 and in 2006, which accounted for 73% of the total CALA region sales. More than three quarters of the sales volume was through entry tier price points, but intense pricing pressure for low cost units has driven the entry tier to account for only 61% of regional handset revenues. Brazil and Mexico will continue to account for more than 50% of sales through 2010 [16].

According to a new report by Innovative Research and Products (iRAP) [17], microfuel cells are expected to constitute a 12 million USD market in 2006 and are predicted to reach 112 million USD in 2011. iRAP also predicts that microfuel cell use in PDAs will show the highest average annual growth of 89.8% by 2011, followed by cam-

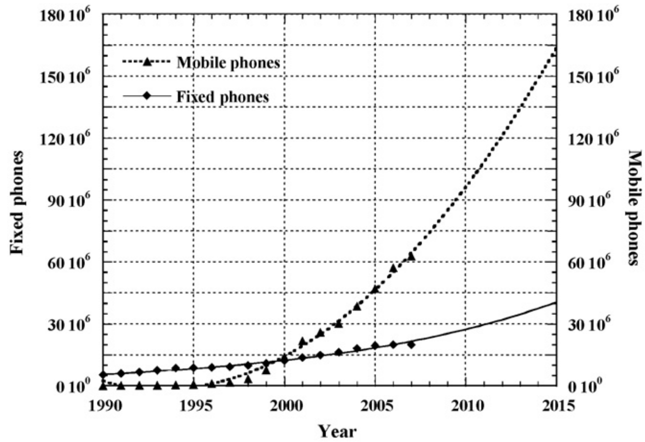

Fig. 3. The actual and projected growth of mobile and fixed phones in Mexico.

corders, chargers and other consumer electronics with a growth rate of 83.7% and mobile phone applications with a rate of 50.7%.

3. Portable electronic devices in Mexico

Portable electronics are becoming more essential to daily life and are increasingly suitable to meet new capabilities for client satisfaction. Nokia notes that there are nearly 2 billion mobile phones in the global market and forecasts that number will rise to 3 billion units by 2008.

3.1. Mobile phones

In Mexico, the federal commission of telecommunications (Cofetel) reported 69 million cellular phones in operation by 2007 [18]. According to the IDC firm, 34.3 million cellular phones were sold during 2006, and only 250,000 units were classified as convergent technology users. Namely, convergent technology includes devices which are capable of sending email and using office software; consequently, technology introduction in Mexico is feasible to be maintained for several years. In less than 18 years since the introduction of the first cell phone in Mexico, the number of mobile communication devices has already exceeded the total amount of conventional telephones installed in the country, as observed in Fig. 3.

In 2004, the cellular telephone in Mexico set a growth record in the number of users; this even surpassed the increment registered in 2000. The main increase (∼100%) was derived from client benefits, and this increase was observed at the end of the previous year with 37.354 million subscribers. Nevertheless, 7.8 million new subscribers were added to the cellular telephone service marker in 2004. Such a number is comparable with the accumulated amount in the previous record in 2000 of 6.344 million new clients, which led to a total of 14.74 million clients at the end of 2000 compared to the 7.730 million users in 1999.

Telefónica Móviles México was the company that registered the highest increase with a 63.25% increase in new users. This resulted in 2.185 million clients during 2004, and the year closed with a total subscriber base of 5.639 million compared to 3.454 million at the end of 2003 [19]. On the other hand, the number of cell phone users in April 2000 was 8.9 million, with an increase between March and April of 3.628 million. The Mexican potential market of FCs for cell phones, considering a cost of 41 USD per cell, would be almost 1.23 billion USD in 2003. At present, mobile phone accounts for 69 million people are projected to reach 2.8 billion USD by 2007. In agreement with these figures, the market of cell phones may constitute a great percentage in Mexico with 135 million mobile phones to reach 5.3 billion USD by 2013.

In Mexico, the market for batteries for cell phones reached 15.4 million USD in 2003 [20]. As seen in Fig. 2, the number of mobile users doubled in the 2003–2007 period, as well as the number of mobile phones units. Based on this trend, sales forecasts for cell phone batteries would be approximately 31 million USD in 2007. In agreement with Table 1, the market introduction of FC handsets is expected to be 3% by 2010. The acceptance of FC batteries is related to cost; therefore, when the FCs cost equals that of lithium battery FCs, sales would be 2.5 million USD, and this is expected to occur by 2013.

Motorola is one of the world's leading producers of energy products for portable applications and one of the world's leading battery consumers. Motorola researchers have focused on technologies that will reduce power drain and also on potential alternative energy sources. One major field in alternative energy is developing miniature direct methanol fuel cells, which could serve to continuously charge portable electronic devices. Research on this is current focusing on fuel cell materials, components and technologies, such as the mixing of small volumes of liquid in microfluidic-link-chambers and system design. In addition to internal research, Motorola works closely with outside partners and potential suppliers on the development of components and sub-systems that will eventually be needed for manufacturing [21]. In contrast, the Finnish cell phone manufacturer Nokia has shelved plans to commercialize fuel-cell technology, citing a number of problems including the current immaturity of technology [22]. In June 2004, Nokia demonstrated a prototype wireless headset powered by a DMFC, and commercialization was planned by 2006. However, an announcement suggests that Nokia will continue to monitor the technology [23]. In contrast, Samsung has announced the development of a microfuel cell capable of powering cell phones for 10 h with nothing more than a shot of water. In comparison, the fuel cell with hydrogen cartridges needed to be charged every 4 days when the phone was used for 4 h per day. This small water-powered fuel cell does not require methanol. However, this technology will not be put into production until 2010 [24].

3.2. Notebook computers, PDAs and other electronic devices

The number of transistors on a chip doubles every 18–24 months, which means that the computing power of the chips doubles as well. It seems that as chips become more complex, their need for power increases. When it comes to mobile devices like laptops, wireless phones, PDAs and other handheld gadgetry, batteries

Table 1
Sales forecast of FC batteries in mobile phones (USD millions).

Year/advance of FC technology	2003	2007	2010	2011	2012	2013
Portable batteries	15.4	30.8	50	54	62	69.3
Portable batteries (3% actuated by FCs)	–	–	1	1.62	1.86	2
Cell phones with a FC battery	–	–*	0.25	0.15	0.45	0.45
FCs in total	–	–	1.25	1.77	2.31	2.45

*163,393 batteries for fuel cell phones. An estimation of batteries for fuel cell phones used in 2007 was obtained from reference [11].

apparently cannot keep up with development. MTI MicroFuel Cells has announced plans to push a fuel-cell called Mobion, which can be used in handheld electronic devices like PDAs and smart phones. The result is to extend the operation lifespan of such devices and allow them to run on a single charge for three to ten times longer than a normal battery of equivalent size.

3.2.1. Notebook computers

In 2003, a moderate growth of 6% was forecasted for the global market of portable systems. The market of some applications has been slower to grow in the decay of the global economy. As a result of becoming "mobile," more people are buying laptops instead of desktop computers. The most recent trends in the industry of portable equipment are the new models with convergent accessories that combine two or more functions on a cell phone: calendar, hands-free technology, music player and digital camera, as well as Web applications, such as e-mail, Internet and electronic message service. Laptops and wireless equipment seem to drive the next generation design of computer equipment. The change in design and functionality of portable systems appears to have dramatically increased power consumption; it appears that battery operation time has diminished as a result of the energy consumption of peripheral accessories. For this reason, improved battery performance with a smaller required space is more and more important for the user. A few years ago, the prismatic lithium batteries, laminated lithium-aluminium and polymeric lithium had a wide acceptance in the cell phone market, electronic agendas and laptops. However, it is still unknown whether they will become powerful enough to reach the equipment requirements of multi-accessories technologies of the third generation.

Samsung has developed a new notebook with a high capacity of fuel cell storage; the power sent by the FCs could last nearly a month with use 5 days a week and 8 h a day without recharging. The DMFC offers an energy density of 650 Wh L^{-1} and total energy storage of 12,000 Wh. The Sense Q-35 FC laptop is in the process of undergoing further safety tests, and availability is predicted by the end of 2008 [25]. New Casio technology is capable of powering a laptop with twice the energy density of a lithium battery by using a micro-reformer to generate hydrogen from concentrated methanol [26]. The Taiwanese company Antig Technology has developed a compact prototype fuel cell integrated into a notebook PC. The prototype, which is the size of a CD, was demonstrated at the CeBit trade show. The company showed a prototype 12 W fuel cell for notebook PCs and a prototype fuel cell charger for mobile phones. A commercial version of the prototypes for notebooks and mobile handheld devices was expected to be available by late 2005 [27]. Smart Fuel Cell has developed a system for 25 W and 12 V laptops, with a fuel cartridge (methanol) as large as a small box of cigarettes. This system weighs only 150 g, and its methanol capacity is 125 ml. It provides 7 h of continuous autonomy with an average power of 20 W for a computer. In a digital camera, electronic calendar or cellular telephone, the working operation time would be much longer.

Samsung, NEC, and several other companies have recently announced breakthroughs in DMFC technology and discussed plans for commercialization. Toshiba is planning a DMFC charger for devices as an initial step before the commercialization of DMFCs that are small enough to replace batteries in portable products; meanwhile, Hitachi is developing a DMFC-based PDA. NEC has demonstrated a prototype unit for use with laptops. This prototype can deliver enough power for approximately 5 h, and the company goal was to develop and sell a 40-h unit by the end of 2005. Hitachi has co-developed a prototype direct methanol fuel cell to be used in mobile electronics products, and they planned to launch the product with a compatible PDA in 2005 [28]. Matsushita, a division of Panasonic, has unveiled a new direct methanol fuel cell designed to power portable electronics (Fig. 4). The DMFC, similar to that shown below, is smaller and more powerful than comparable models developed to date. It is about the size of a soda can (24 $in.^3$) and about half the size of the previous models made by Toshiba and Fujitsu. The DMFC provides an average output of 13 W with a peak output of 20 W; it weighs about a pound when empty, and it is able to achieve up to 20 h of laptop runtime. A system showcasing the fuel cell abilities was demonstrated at the 2006 International Consumer Electronics Show (ICES) [29].

Fig. 4. Panasonic laptop with a DMFC powered by a methanol cartridge capable of a 20-h operation [29].

Mexico has a population of about 120 million spread across an area of approximately two million square kilometres. In early 2008, the number of personal computers surpassed 21 million [30], whereas the number of Internet users reached 23 million; this figure also includes the 1.5 million people who navigate via cell phone and PDA [31]. Fig. 5 and Table 2 summarize the results of a survey performed by governmental organizations on these items. In this survey, personal computer acquisition showed a continuous but moderate growth, with projections indicating that, by 2015, Mexico will consume approximately 43 million units. According to Etforecasts [32], Mexico is ranked 14th worldwide in the number of PCs in use. In Mexico, each personal computer tends to have approximately 1.1 Internet users, which will result in approximately 50 million Internet users by 2015. It was noted that, of the 26 million Mexican homes, only 14.4% have a computer. Of this percentage, roughly 25% have a laptop. This means that, by the year 2008, a

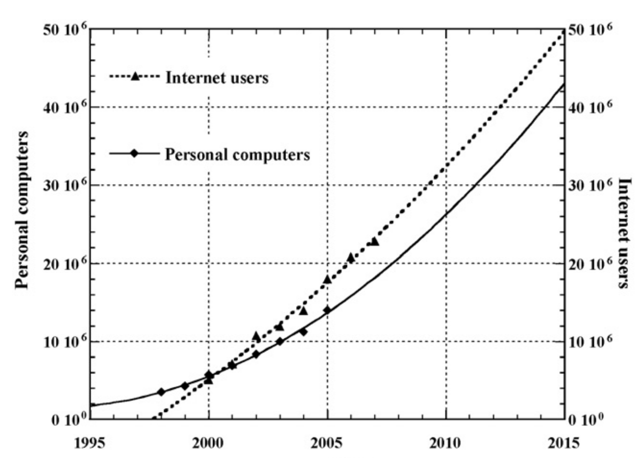

Fig. 5. The actual and projected growth of personal computers and Internet users in Mexico.

Table 2
Personal computer and Internet users in Mexico (millions).

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Personal computers	3.5	4.3	5.7	6.9	8.353	10.0	11.21	14.0	17.9	21.2
Internet users	–	–	5.06	7.1	10.72	11.88	13.94	17.97	20.85	22.81
PC users	3.5	–	–	14.8	–	–	–	–	26.60	30.5

potential market of 5.3 million units would be available to receive the fuel cell technology. It is important to note that laptop batteries accounted for 1.6 million USD in 2003, while it is expected that sales of this item will reach 15 million USD in 2010 [30].

3.2.2. PDAs and other electronic devices

The three biggest personal digital assistant manufacturers are the companies PalmOne, Hewlett-Packard and Research in Motion, which occupy 30, 21 and 17% in the worldwide market, respectively. The sales of PDAs in the world increased 6.6% in 2004, whereas the manufacturer income of those devices increased almost 17% [33]. In the first quarter of 2005, worldwide PDA shipments increased 25% to 3.4 million compared with 2004. The market was led by western European PDA shipments with a growth of 84.3%, whereas the U.S. market fell to 39.1% of worldwide shipments. The worldwide market has been projected to grow from 620 million units in 2002 to 830 million units in 2007.

Gartner reported [34] that the worldwide sales of PDAs totalled 3.6 million units in the second quarter of 2005, which meant an increase of 32% over the previous year. Market commercialization reached 15 million units sold in 2005 to surpass the 13.1 million units sold in 2001. PDAs may be seen as a substitute for the notebook computer, which seems quite useful for technology users. Despite portability and technological features, PDA sales were depressed in 2002–2004. However, the Blackberry model from Research in Motion rose to occupy 64.7% of the market to reach first place in retail PDAs. In 2005, the market for PDAs in central Europe grew to 94% with 1.3 million units; in this way, central Europe reached 37% of the worldwide retail share. Retail PDAs in the US totalled 1.4 million units, representing an increase of 1.3%. The American market stability is a result of sales decay for the PDA operating system of Palm in comparison to Microsoft.

The PDA was the largest segment in development until 2003, when the Smartphone segment became the leader in 2004. It seems that Smartphones may decimate the PDA market unless PDAs can add new functionality to keep growing. PDA manufacturers thus added functionality such as turn-by-turn navigation, mobile TV and communication via Bluetooth, Wi–Fi and soon WiMax (Worldwide Interoperability for Microwave Access). PDA sales for the main regions of the world are shown in Fig. 6 [35]. The US market is the leader in PDA consumption, accounting for 46% of the total PDA sales in 2005, which is forecasted to drop by 2011 to 42%.

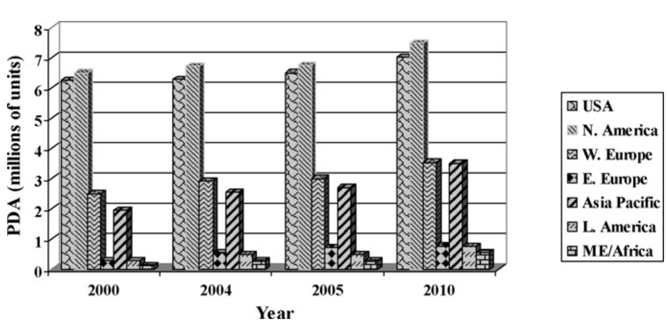

Fig. 6. Sales of PDAs for the main regions of the world.

Latin American mobile terminal sales combined to account for more than 38.4 million units in 2003. It is expected that by 2008, annual sales will reach approximately 71.1 million units, with a fixed annual growth rate of 3.9%. An increase in the average PDA sales price helped the worldwide income reach 4300 million dollars in 2004, which means a record increase of 16.7% in comparison to that of 2003, while the worldwide sales were increased by 6.6%. The biggest incomes from this concept were obtained in 2004 by Hewlett-Packard with 1132 million USD, followed by PalmOne (838 million USD) and Research in Motion (806 million USD) [36]. A consultant in the technology information market reported that during the first semester of 2001, 160,000 portable devices were sold in Mexico, from which PalmOne obtained a participation of 80% and 130,000 handhelds commercialized [37].

Growth of 27.5% in the Mexican handheld market was expected in 2005, an opposite trend to what is happening in the rest of the world. According to an IDC consultant, handhelds in Mexico generated a market of 93.6 million dollars in 2004. Regarding the convergent technology of PDAs with capability for voice, audio, video and Internet connection, this niche invoiced 13 million USD in sales in 2004; this corresponded to a jump of 90.2% in comparison to 2003 [38]. In Mexico, 600,000 units were sold to clients in 2003 with a market value of 162 million USD [39]. Furthermore, 85% of the market was dominated by PDAs manufactured by PalmOne [40,41].

It is important to note that the aforementioned data are related to the portable battery market and not to the FC itself, since the marketing forecast for small FCs may have begun by 2005. Table 3 shows a projection for the use of fuel cells in PDAs as a function of the portable FC introduction worldwide forecast [11].

3.2.3. Other electronic devices

In Mexico, sales of photographic cameras reached 66.2 million dollars in 2003, from which 76% (50.3 million dollars) was derived from automatic cameras and the rest from manual ones [42]. Fig. 7a and b display the data registered for manual and automatic cameras, respectively. The trends of manual cameras showed different plateaus before reaching a higher sales level; even so, the sales of manual cameras tended to decrease. This tendency may be the result of digital camera introduction. Despite this, a small group of users find manual camera flexibility attractive for professional work. In contrast, automatic cameras appear to show an increase every year as prices tend to decrease. Market trends seemed to be constant until the year 2000, when the curve flattens, probably due to an increase in mobile phones with a built-in camera. In the same year, video cameras reached 36.3 million dollars, whereas battery replacement was 14 million dollars. Data related to the sales of portable electronic devices in Mexico are summarized for the year 2004 in Table 4 [43].

Table 3
Growth projection of fuel cell PDAs in Mexico (thousands of units).

Year	2010	2011	2012	2013
PDA	816	840	864	888
% FC	20	31	50	50

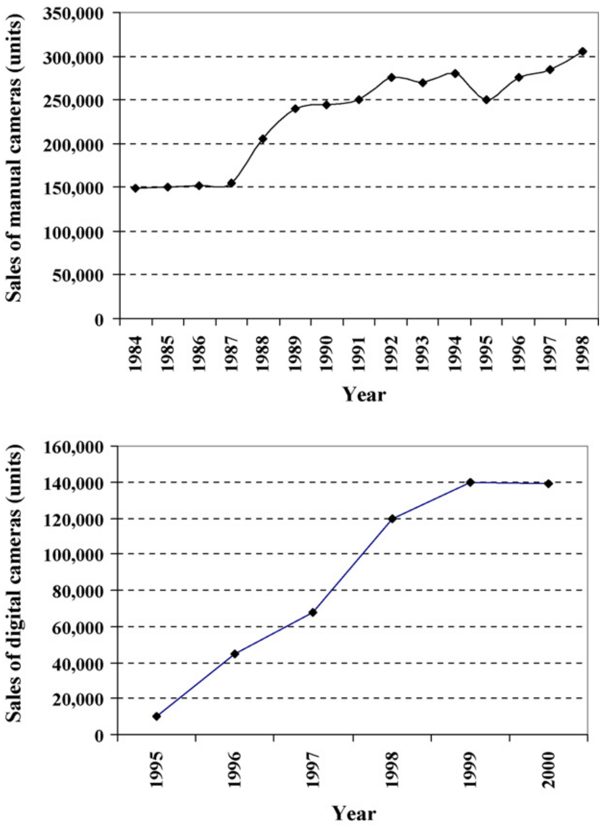

Fig. 7. Sales of manual and digital photographic cameras in Mexico.

Table 4
Economic survey in 2004 of the market for small handhelds.

Portable electronic devices	Sales (USD millions)
Radios	20.2
Tape recorders	30.5
Walkman, Discman, MP3	11
Video cameras	36.3
Scientific calculators	9.3
Total	107.3

4. The potential market of DMFC in Mexico for portable electronic devices

Although several kinds of fuels can be used in a fuel cell, the most active of these is hydrogen. Hydrogen is a flammable, explosive gas and is typically pressurized, which causes practical concerns for transportation and storage. Methanol has been considered as an alternative fuel because it is easier to handle and has a higher energy density than hydrogen, that is, it has more energy for a given volume and weight compared to hydrogen. Microfuel cells deliver “better than battery” performance by combining high energy density, long run-times and small form factors, along with clean, safe fuel to power portable devices. Microfuel cells can power cell phones, PDAs, sensors, lighting, two-way radios and other products. The rising demand for more functionality in mobile phones, including voice, data, music and video, together with the increasing demands for smaller size and longer run-times, has created a global opportunity for new power sources such as microfuel cells.

Methanol, as well as hydrogen, is perceived as the most useful fuel for portable systems. Methanol is a toxic and flammable substance. Hydrogen, on the other hand, is non-toxic but highly explosive when highly concentrated, which is difficult because it is more volatile than other gases. Despite these concerns, methanol and hydrogen are perceived as the more useful fuels for portable systems. Recently, the International Civil Aviation Organization's Dangerous Goods Panel (ICAO-DGP) action has allowed passengers to carry microfuel cells in the cabin of planes only, and not stowed in checked baggage, along with up to two separate methanol cartridges per person; the passenger allowance covers different types of methanol microfuel cell systems [44]. Lithium, a fundamental part of batteries, is used in cell phones, portable computers, cameras and other electronic devices and is highly explosive when exposed to oxygen or heat. This is why the acceptance of lithium batteries in planes took many years; moreover, a similar approval process is under way for hydrogen. Angstrom technology argued that in November 2007, the ICAO created new regulations that permitted the company's hydrogen devices to be transported globally in the passenger cabin of a commercial aircraft. Final approval of hydrogen fuel cells is expected before the regulations take effect in January 2009.

Badwal [45] predicts that microfuel cells, ranging from 0.5 to 50 W in output, will revolutionize the microelectronics industry by providing operating and standby times six to seven times longer than the current generation of lithium-ion batteries. They will be used in laptop computers, mobile phones, video cameras, portable TVs, DVD and audio devices, games consoles and power packs for soldiers in the field. They could also power autonomous remote-sensing devices or small silent robotic aircrafts that will monitor the terrestrial environment, collect weather data in remote areas or over the oceans; furthermore, these devices could carry video cameras and other surveillance devices for homeland security. The aim is to achieve a working life of at least 15,000 h, or nearly 2 years of continuous operation. The cells can be readily shut down and restarted, and when the compact cartridge of hydrogen or methanol runs out, another can be slotted into place to reactivate the cell within seconds.

Although direct methanol fuel cell electronic devices have been commercially available since 2003, the use of portable methanol cartridges was only approved in January 2007. In contrast, the use of a hydrogen proton exchange membrane fuel cell (PEMFC) for portable devices is limited by two unsolved problems, concerning hydrogen storage safety and the lack of established infrastructure for hydrogen distribution. As such, the DMFC appears to be the most promising technology due to factors such as high energy density and safety, since it is at ambient condition in its liquid phase [46]. The DGP did not act on proposals to include the use of hydrogen in metal hydrides and boron-hydride compounds. The available specification IEC 62282-6-1 [44] was developed by an international panel of industry and safety experts to ensure the safe design of microfuel cells and cartridges.

Ansgtrom Power Inc. reported [47] the manufacture of fuel cells that provide twice the run-time of lithium batteries with recharging times on the order of 10 min. The fuel cell is comprised of a novel architecture, innovative micro-fluidics and a revolutionary refillable hydrogen storage tank, which make it suitable for portable devices like cell phones. It is said that the company has successfully built prototype devices and is currently in the process of developing products for industrial and consumer markets. The family of products includes end-user devices as well as products for refuelling, which can either be portable by cartridges or fixed by hydrogen facilities.

5. Disposal of batteries and fuel cells

Batteries are safe for human handling and for feeding electric supplies, but when the useful life ends, it is very important to safely dispose of the construction materials. When batteries are discarded in aqueous environments, the interaction with either environmental elements or synthetic media degrades coverage, and toxic materials are released. For instance, an alkaline battery can contaminate 167,000 L of water, whereas a battery of mercury oxide can contaminate 600,000 L of water. Mercury is a carcinogenic element, which accumulates in humans until death; on the other hand, lithium is a neurotoxic agent that affects the human liver. Furthermore, cadmium is carcinogenic, and nickel may produce dermatitis. Batteries account for 93% of Hg, 47% Zn, 48% Cd and 22% Ni. Depending on the technology and length of time in service, batteries are classified as disposable or rechargeable. A rechargeable battery can substitute for 300 disposable batteries, so its lifespan is longer and it is disposed of over longer periods of time; however, it has a higher amount of toxic elements than disposable batteries. Ni–Cd and Ni–MH can be recharged more than 200 times and last more than 900 h in use. Ion-lithium batteries are used in mobile phones, MP3 players, GPS navigators and iPods. These batteries have a useful life of 300–500 cycles of charge/discharge to complete 2–3 years in life. At the current projected rate of use, this will account for 60 million lithium batteries in Mexico derived from disposable mobile phones, making a total weight of 900 tons, considering a weight of 15 g per battery.

In Mexico, 600 million units of disposable batteries are sold every year; from these, 50% come from illegal importation. This leads to an excessive generation of waste residues as a result of short life, low cost and low quality of the disposable batteries. This quantity of batteries indicates an annual average consumption of 6–10 units per habitant, without considering the ones included in new electronic devices or those illegally imported. Every year, Mexico disposes of 35,000 tons of batteries, while the US generates 200,000 tons. The National Institute of Ecology indicated that 635,000 tons of batteries were disposed between 1960 and 2003, and 30% of the materials were determined to be harmful to human health, such as MnO_2, Hg, Ni, Cd, and lithium compounds. During this period, there were more than 189,000 tons of toxic material liberated, distributed as follows: 145,918 tons of MnO_2; 1232 tons of Hg; 22,063 tons of Ni; 77 tons of Li compounds; and finally, 20,169 tons of Cd. In addition to the raw materials for battery construction, bromide fire retardants are added to disposable batteries, lithium batteries, laptops and other electronic devices. For example, in 2004, 1000 tons of flame retardants were added in the manufacture of 674 million units of mobile phones. This chemical compound, when accumulated in humans, deteriorates the learning functions and memory; it also interferes with thyroid and estrogen hormones. Moreover, exposure during the gestation period may result in behavioural problems. Studies have demonstrated that 35% of mercury pollution is due to domestic waste burning. A battery requires 50 times more energy to make than it is able to produce, and the current generated is 450 times more expensive than the one generated by the electric network. The average cost for confinement is 6.5 USD; meanwhile, recycling costs 1 USD kg^{-1}, except for the lithium battery whose average recycling cost is roughly 8.7 USD kg^{-1} [48–51].

Cost is likely to be the major barrier to the widespread deployment of fuel cells; although costs in volume manufacture are predicted to be competitive with conventional technologies, early products will be more expensive. To illustrate this, it can be pointed out that the assemblage cost of the electrode–electrolyte is around 1/3 of the real cost of a FC, and the other components make up the remaining cost. The development of technologies in the direct current/direct current converters will probably help to cover the expectations of FC longer lifetimes. Other potential barriers include the provision of raw material, safety and regulatory issues. At the moment, one DMFC requires 0.2 g platinum kW^{-1} and 0.032 g ruthenium kW^{-1}; nevertheless, this quantity could be reduced by optimizing the electrochemical system. At this time, the worldwide production of platinum is 178 tons, and 70 tons are recycled; this means that only 40% of the worldwide production could be used in the transport sector for Mexico. The annual production of ruthenium is 12 tons, which would be insufficient for a future supply, according to the growth projections [52]. Most of the regulatory issues for mobile systems are still being addressed, and specific safety concerns remain to be legislated. Problems of public perception with hydrogen or methanol portable systems also have to be taken into account. At the end of its useful life, the FC will have to be disposed of safely and most of its components recycled. The parts made of steel and aluminium can be recycled through well-known processes, but the electrode–membrane ensembles and the bipolar plates (the latter working to collect the electrical current generated) will require special recycling processes. One option is to dissolve the assemblies and recover the membrane, remove the carbon layers, and recycle the metals (platinum and ruthenium) by solvent extraction. The components of the bipolar plates can be recovered by a fluidized bed process to be recycled and reused [53]. Another problem is the water used in the process, which must take a circuitous route in order to cool the power cell where it is mixed with methanol. The recirculation of water requires a pump that increases the overall size of the power cell and decreases its overall efficiency; therefore, when the DMFC runs out of power, instead of plugging it in to recharge, it will be replaced like conventional batteries, but less often.

The present cost of a FC for a laptop, which is around €200–400, is not comparable with that of a lithium battery. However, the methanol cartridges for the FC replacement, once produced in mass, would be less than €1 and the price could be €2–3 per cartridge with a weight of 125 g (equivalent to 140 Wh of electrical energy) [54]. It appears that cartridge technology for low power portable devices has been available since 2005 [55]. Table 5 shows an estimate of the FC cartridge cost depending on the electronic device to be actuated and energy demand. This forecast was derived from a market study in which several low power portable device manufacturers agreed [1]. A standard battery for a cell phone or electronic calendar can be replaced by a zinc-air FC at a cost of 39 USD, which may provide energy for 20–40 h in continuous use. Although its cost is higher, the cell durability is much longer than that of common batteries. The market for rechargeable batteries is a difficult market in which to compete [56].

Table 5
Assessment of energy demand and cost of fuel cell and cartridge.

Application	Fuel cell power (W)	Battery power (W)	Total WH	Runtime (h)	System size (cc)	Retail fuel cartridge cost (USD)	Fuel cell system selling price (USD)	
Cell phone	1	2	12	12	10–5	<1	10	7
PDA	1	None	20	20	20	<1.50	10	7
Digital camera	2	3	10–15	5–7	20	3	25	20
Laptop	15	30	120	8	300	5-10	75	50

6. Production facilities of methanol in Mexico

Methanol is one of the main candidates to provide the hydrogen necessary to power portable electronics and fuel cell vehicles. In Mexico, methanol is produced by the Lurgi process at Pemex facilities in the Complejo Petroquimico Independencia, located in Puebla.[1] An installed plant capacity of 260,000 tons has been in operation since 1969. Methanol is produced primarily by the synthesis of a mixture of carbon and hydrogen [57]. The main feed stock for methanol production is natural gas, although other light petroleum distillates and coal can also be used. The production of methanol from natural gas is based on three fundamental steps: production of synthesis gas (syngas), conversion of syngas into crude methanol, and distillation of the crude methanol into methanol of desired purity. Syngas is a gas composed of hydrogen and carbon oxides, which is reacted over suitable catalysts to produce crude methanol. Syngas may be produced from many hydrocarbon sources; currently, more than 75% of methanol is produced from natural gas. An essential step in methanol production, which is not directly related to the process, is the natural gas desulphurization before it enters the steam reforming process to be transformed into syngas. Sulphur in the natural gas can damage the catalysts used in hydrogen production and in fuel cells, so it must be removed. At present, PEMEX produces 110,000 tons of methanol per year; however, this volume does not satisfy the national demand, and therefore, 650,000 tons are imported from Chile [58]. At this time, the imported methanol costs 599 USD ton^{-1}, while in January 2006, it was 325 USD ton^{-1}. The world production of methanol is 38 MM tons $year^{-1}$, which does not surpass the actual demand of 39 MM tons $year^{-1}$. As a result, a continuous rise in price is expected in the following years [59].

7. Conclusions

Mexico has a large potential for fuel cell consumption in portable electronic devices. The market size is about 2 billion units with a tendency to be increased periodically because several electronic devices are still in the expansion stage. It is thought that as the FC technology is introduced in the US, it will be extended to Mexico within a relatively short time period.

Market commercialization of the DMFC has slowed due to its size, weight and fuel cell cost. However, this technology is worth pursuing since environmental cleanliness counterbalances battery pollution and fuel consumption dependence. The use of platinum as a catalyst in the DMFC has a significant effect on cost, but this can be mitigated through materials recycling and the unit ability to function without a reforming unit. Another advantage is that the DMFC is made completely of a solid composition that allows miniaturization, which promises a significant increase in power availability and mobility, not regarding the long recharging periods.

Market introduction of new technologies is commonly slow and expensive; for instance, when Li-ion batteries were commercially introduced in 1995 as a substitute for Ni-MH batteries, the price of Li-ion batteries was twice that of Ni–MH. This tendency seems to be similar in Ni–Cd, Li–ion and Li–polymer; it appears that most companies who invested in Li–polymer batteries applications and related technologies are waiting to recover their investment before launching the new FC prototypes for portable devices.

[1] Public information.

Acknowledgments

The authors would like to thank the Instituto Mexicano del Petróleo for the facilities provided during this study and also to CONACYT for SNI grants given.

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