A GEOGRAPHIC MARKET VALUATION FOR MICRO FUEL CELL TECHNOLOGY IN PORTABLE POWER APPLICATIONS

by

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ABSTRACT

Increasing demand for portable power has created a run-time gap with conventional batteries opening the door for leading edge technologies such as micro fuel cells. Emerging companies like Tekion attempting to enter the market face psychological and economical adoption barriers to commercialization. Examining innovation adoptive characteristics allows Tekion to identify niche markets.

Fuel cell technology has capacity to displace current battery applications where more power and mobility are desired. Penetration into mainstream portable power market requires the ability to meet consumer power needs and establish standardized technologies. Firms that establish themselves as leaders in the target market and provide product integration will flourish.

New markets have the highest potential for micro fuel cell adoption when targeting consumers with no access to power grids. The potential for dominance and availability of non-consumers makes Country X attractive. However, the presence of adoption deterrents and lack of augmenters make acceptance low. Tekion should benchmark Country X's valuation with other regions before developing a marketing plan.

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TABLE OF CONTENTS

GLOSSARY

BFC	Bio-fuel Cell
DGP	Dangerous Goods Panel
DMFC	Direct Methanol Fuel Cell
GSM	Global System for Mobile Communications
ICAO	International Civil Aviation Organization
IEC	International Electrotechnical Commission
NTT	Nippon Telegraph and Telephone Corporation
OEM	Original Equipment Manufacturers
PEM	Proton Exchange Membrane
RHFC	Reformed Methanol to Hydrogen Fuel Cell

1 INTRODUCTION

1.1 Scope and Plan

Tekion is an upstart company focusing on the commercialization of micro fuel cells. Its patent pending formic acid fuel cell targets portable consumer electronics. Tekion, along with other industry competitors, are looking for viable strategies to penetrate the mainstream portable consumer market. The adoption issues that have prevented the micro fuel cell technology from commercialization, including Tekion's formic acid fuel cell, will be discussed. As Tekion is in its early stages of developing a marketing program, the analysis will focus on the evaluation of potential geographical regions for micro fuel cell commercialization. Key valuation criteria will be identified to broadly determine the level of opportunities in different markets. An evaluation and recommendation will be presented for the Country X[1] market segment. The methodology used to evaluate Country X will be designed so that it is applicable to other potential geographical markets.

This analysis will not provide a marketing plan. Instead, it will provide a set of criteria to determine attractiveness of geographical areas to commercialize Tekion's formic acid fuel cell. The technical details of the technology will be discussed only so far as to describe the factors that will affect the evaluation criteria. The primary focus of the analysis will be on general technology adoption factors. These factors are independent of the company's ability to commercialize; therefore, an internal analysis of the company will not be performed at this stage. The valuation of geographical markets for micro fuel cell application is a starting point for a

[1] The country/region name has been disguised throughout this paper to preserve anonymity.

commercialization strategy. A detailed marketing plan should be developed once a target market is chosen based on the specific needs of that market.

1.2 Innovation Frameworks

Challenges for firms introducing new products and services for their customers always exist. Firms must perform careful research on their customers' needs, manage product development and costs, and choose the right channels for sales, marketing, and distribution. As long as they provide improvements to existing products that meet the demands of their customers, it will be accepted. Most firms today are able to manage this effectively. It is unclear what lies ahead for micro fuel cells as they try to enter the portable power market. Being new innovations and not improvements to existing products, firms face unique challenges to bring micro fuel cells to market and take uncertain risks. For truly innovative products, adoption and diffusion will be one of the greatest hurtles to overcome as there is no existing market. The knowledge surrounding adoption and diffusion of innovative technologies can be taken and applied to fuel cell technology.

Originally developed by Rogers, and later revised by Moore (2002), the Technology Adoption Life Cycle model describes the progressive stages of acceptance that all new innovative products experience. This adoption life cycle provides insight into choosing specific target markets based on the predictable characteristics of the various segments that make the adoption life cycle (Moore, 2002). Moving from one stage of the adoption life cycle to the next requires careful consideration of the differences in marketing strategy required to penetrate the next stage. Failure to do so may result in a company falling into an unpleasant chasm where profit is minimal (Moore, 2002).

Innovations that have the potential to disrupt established technologies require understanding the unique principles of disruptive innovation described by Christensen (2003) to be successful. This second framework postulates that certain types of innovations, namely disruptive ones, can completely change the playing field. Therefore strategies for disruptive innovations will be entirely different than those for typical innovations. It is however premature to deem an innovation disruptive until it has displaced an incumbent technology. Christensen (2003) suggests identifying the most valued attributes of the mainstream and beachhead markets. The performance trajectories of the most critical attributes required for adoption by a mainstream market reveal the current product life cycle of the technology and thus the appropriate target market (Christensen, 2003).

These innovation frameworks by Moore (2002) and Christensen (2003) will be used to understand the adoption and diffusion of micro fuel cell technology. Furthermore, if micro fuel cells exhibit characteristics of a disruptive technology it will have major implications on firms trying to develop and market products based on this technology. The lessons learned will offer insight on the industry's struggling effort to commercialize fuel cell technology. Based on these guidelines, a strategy to determine the attractiveness of geographical markets for micro fuel cell commercialization will be provided to increase its likelihood of success. The rewards of successful discontinuous and disruptive innovation are dominant market share and profit; however, the risks can be even greater if adoption fails.

1.3 An Explanation on Fuel Cell Technology

A fuel cell is a device similar to a battery which generates electricity through a chemical reaction. Unlike batteries that are self-contained with all the necessary chemicals that eventually run out and/or must be recharged, fuel cells produce electricity from an external fuel supply which can generate electricity as long as there is a flow of chemicals into the cell. While conventional batteries employ reactions between metals and electrolytes whose chemical nature changes over time (usually wearing out after a certain number of recharges), the fuel cell consumes its fuel leaving an empty reservoir or cartridge. The typical architecture for a fuel cell is a proton exchange membrane (PEM) where a proton conducting polymer membrane (or electrolyte) separates the anode from the cathode (Davis, 2005). Formed at the anode, protons pass through electrolyte, and electrons pass through an external circuit to the cathode to produce electricity. The most common chemicals used in fuel cells are hydrogen and oxygen (Wikipedia, 2006). Other hydrogen carrying fuels include diesel, methanol, butane, and chemical hydrides. The byproducts of the electrochemical process are usually heat, water and carbon dioxide (Donovan, 2006).

Fuel cells are categorized according to their chemistry and the type of electrolyte they use (Wikipedia, 2006). The type of fuel cell usually determines the type of application such as for power plants, automobiles, or portable devices. PEM fuel cells are usually good candidates for portable devices while fuel cells that use phosphoric acid, molten carbonate, or solid oxide are more appropriate for stationary applications because of their complexity and high operating temperatures (Pak & Heydorn, 2002). Micro fuel cells are scaled-down fuel cells that have been developed for use with small devices such as cameras, portable radios, mobile phones, and laptop computers. Micro fuel cells use fuels other than hydrogen, most notably methanol, a form of alcohol. Storage problems associated with pure hydrogen prevent its use in micro fuel cells (Pak & Heydorn, 2002). Common fuel cell design issues include material costs, water management, flow control, temperature management, and durability (Dorheim, 2006).

1.4 Company Background

Tekion Inc. is a North American based company with operations in Champaign, Illionois and Burnaby, British Columbia. It was founded in early 2003 by a small group of executives looking to commercialize an early-stage fuel cell technology with goals to realize revenue by 2007. The technology was developed by researchers at the University of Illinois and is being commercialized by Tekion. The technology uses formic acid that is used directly on one side of a proton exchange membrane, and oxygen on the other. This technology has been branded as Formira™, a purified and modified formic acid which is abundantly produced in nature by red ants. The advantage of this type of fuel is that it is non-flammable compared to the competing methanol fuel technology (Tekion, 2006). Tekion has a pending patent and has obtained exclusive licensing for the Formira™ fuel cell technology from the University of Illinois. The company's strategy is to establish relationships with key manufacturers. Currently, Tekion has formed a strategic alliance with Motorola through an investment by Motorola Ventures. The firm has also secured a collaboration agreement with BASF, the world's largest producer of formic acid. To date Tekion has successfully developed a prototype for integration with a portable electronic application. They hope to commercialize the product in the near future.

1.5 Evolution of the Battery

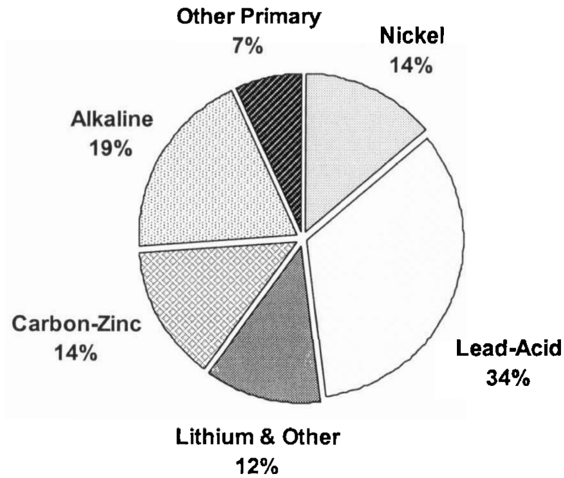
Benjamin Franklin first coined the term "battery" to describe an array of charged glass plates in 1748. Later in 1800, the Volta Battery was invented using a copper-zinc base. It was a primitive device that became the building blocks of battery operation but could not operate for extended periods (Buchmann, 2001). The first development of the carbon-zinc battery in the 1860s was crude and non-rechargeable but was easily manufactured and had an adequate shelf life. Also in the 1860s, the lead-acid battery was introduced which could be recharged or replenished many times but had a short shelf life. In 1899 the nickel-cadmium rechargeable battery, still in limited use today, came into existence. This battery had a better weight to energy ratio and longer lifetimes as compared to the previous lead based technologies. Alkaline batteries first appeared in 1959 with higher energy density and longer shelf-life than traditional batteries.

The next revolutionary developments in batteries were the nickel-metal hydride and lithium metal batteries. Commercialization of the nickel-metal hydride in the early 1990s sparked development of cordless and portable devices. This consequently boosted demand for batteries and brought down prices further reinforcing demand. The nickel-metal hydride battery provided two to three times the capacity over nickel-cadmium technology (Buchmann, 2001). The lithium-ion battery was first pioneered in 1912 but took almost 20 years of development prior to becoming commercially useable in 1991. It had great anticipation due to its light weight and long life. The battery's popularity as a power supply grew rapidly for mobile devices such as cellular phones and laptop computers. In 1996 the lithium-polymer battery was introduced using the same basic chemistry as previous battery technology but replaced the liquid electrolytic with a solid polymer. This reduced the size of the battery and eliminated the need for a metal casing, decreasing cost and weight. However the downsides of this technology that have prevented it from taking greater market share are lower energy density and higher manufacturing costs.

Since Alessandro Volta first drew electricity off a stack of cardboard sheets soaked in zinc and silver over 200 years ago, little has changed in the science behind the battery industry (Armstrong, 2005). Micro fuel cells have been touted as the next-generation power source for portable electronics. They have the potential to offer 10 times the energy density of current lithium batteries, which means longer run times and more power to satisfy function-rich devices (Buchmann, 2001). In addition, they generate electricity with very little pollution—much of the hydrogen and oxygen used in generating electricity combine to form a harmless by-product, namely water. Although first discovered in 1838, commercialization of fuel cell technology has yet to materialize due to deficiencies in performance and cost among other things.

1.6 Battery Industry Opportunities

Figure 1.1 Global Battery Market Share by Type.



Source: Advanced Technology Program, 2005

Battery sales are a lucrative $48 billion worldwide (Armstrong, 2005). The breakdown of sales by battery type is presented in Figure 1.1. Lithium batteries are the likeliest candidate for replacement by micro fuel cells of the different battery technologies. Applications of batteries include stationary, automotive, and portable. Portable applications are powered predominately by lithium-ion batteries and are the best target for micro fuel cells (The Economist, 2001). The global market for the portable power segment powered by lithium-ion batteries is forecasted to increase to $6.3 billion by 2009 (Portable Design, 2004). Predictions of fuel cell market share in the portable power segment range from $411 million by 2009 (Portable Design, 2004) to $2.6 billion by 2012 (Armstrong, 2005). Regardless of the variances in estimates by different analysts, the market is expected to see exponential growth. Forecasts of fuel cell penetration into the portable consumer electronics market in the past have incorrectly estimated fuel cell technology capturing market share from as early as 2004 (Evangelista, 2003). What is more predictable and evident is the increase in power demand for portable devices over the capacity of current power technology. This disparity has opened opportunities for scientists to experiment with exotic materials to increase battery run times (Armstrong, 2005). Although predictions for the portable fuel cell market vary from expert to expert and year to year, the mature battery industry is still seeing modest growth in the portable power sector. Even a small penetration by fuel cell technology can bring large revenues and even greater revenue from potential sales of replacement cartridges by a factor of 10 (Pillot, 2004). The current gap between supply and demand in portable power permits a leading technology to capture this unfulfilled market. The opportunities for companies in micro fuel cell technology to make significant profits are present if they can bring it to commercialization.

2 PORTABLE POWER MARKET APPLICATIONS

Micro fuel cells are scaled-down fuel cells that have been developed for use with small devices thus has been widely seen as a replacement for lithium technologies. Lithium technology has been extremely popular with mobile devices capturing 97% of the premium portable market (Portable Design, 2004) and will be the main competition for micro fuel cell technology. The portable power market is defined as units up to 1.5kW, making it clearly intended for small mobile devices and not for powering vehicles or other large machinery (Jollie, 2004). Industry analysts have commonly divided portable power market segments based on its application. Further segmentation is then applied by geography, pricing categories, etc. At this stage, however, only the high level segmentation will be discussed in order to better understand the industry and segments' overall needs.

2.1 Military

This segment is generally referred to as the pioneer market as they have been early adopters of the fuel cell technology. Devices such as sensors, electronic weapons, and communication gear are vital to soldiers in the field. These necessities have power requirements that are becoming more difficult to meet with existing battery technology. Military applications tend to be larger, more costly and highly critical (Red Herring, 2005). Due to the critical nature of power, military organizations are willing to pay more for reliable, long-lasting fuel cells than average cell phone users (Red Herring, 2005). Acting as a testing ground for many new technologies, they are more tolerant of the trials and tribulations associated with new technologies (Red Herring, 2005). In the field, power sources for charging batteries are scarce to nonexistent. To carry out increasingly longer missions (from 12 to 72 hours) soldiers are required to carry extra battery packs while performing their duties (Gerber, 2005). Given this, long battery run times and reduced weight are highly desired by the military. Even if a power source is available, waiting hours to recharge a battery during service is usually not available making instant recharging ideal. As military equipment become more sophisticated with intelligent functionality, power is essential in enabling these features. There has been a strong focus by North America in this market segment, particularly in the US (Jollie, 2004) as an unprecedented demand for batteries was created by the Operation Iraqi Freedom US armed forces (Lopez, 2006). The US Department of Defence has provided significant funding for the development of fuel cell technology and as a result created a small industry for fuel cells. The companies involved in the military, however, are able to survive solely on prototype projects without ever having to create commercially viable products (Jollie, 2004). Market size of this segment is relatively small generating less than $1 billion (Conner, 2006).

2.2 Mobile Computing

Improvements to wireless network infrastructure during the past few years have given mobile computing a new life. This has been enhanced by business factors such as an increase in remote workers and telecommuters, availability of inexpensive hardware, and growing adoption of internet-based applications such as wireless email. Laptop computers are the second largest potential market for micro fuel cells after mobile phones (Darnell Group, 2003). Market share is expected to increase in Europe, Asia, and North America (Darnell Group, 2003). North America holds the largest market share with predicted increases to 14% by 2007 (Darnell Group, 2003). In developing countries, market share of laptop computers are negligible as they are still too costly. Reductions in laptop computer prices will continue to fuel significant increases in demand as consumers in this market segment generally have medium to high price sensitivity (D'Onofrio, 2006).

The main drivers for mobile computing adoption are better communication and collaboration, and increase response to consumers (Vizard, 2006). The decision for consumers to purchase laptops over desktop computers is whether or not they have the need for computing mobility. The degree of mobility is a combination of the notebook size, weight, and battery life. Currently laptops use lithium-ion batteries that can operate between one to six hours on a single charge with the average being four hours. The trend for high power processors, RAM, and faster disk drives will consume additional battery power (D'Onofrio, 2006). Consumers now want a 10 hour battery life with power demands predicted to increase approximately 30% per year (Senmajumdar, 2004). Early adopters within this segment are deemed the "road warriors" as they are frequent travellers and will be most concerned with battery life, size, and weight (PC World, 2005).

2.3 Mobile Communications

The mobile phone industry is the largest potential market for micro fuel cells with 86% of application in Europe, 85% in Asia, and 76% in North America in 2002 (Darnell Group, 2003). Unlike the growing mobile computing segment, mobile phones' market share is expected to slightly decline over five years by 3% to 11% in these regions (Darnell Group, 2003). On the other hand, emerging regions such as China, India, Latin America and Africa are seeing exponential growth in mobile phone use. The greatest barrier to adoption in developing countries is the cost of the handset. Some of the near-term market drivers for mobile phones are cultural acceptance of technology and increased focus on design (Greengart & Akyuz, 2006). Japanese consumers, for example, are highly drawn to innovative features such as Bluetooth, video, music, TV, 3D games, GPS, etc. on their handsets (Greengart & Akyuz, 2006). US consumers also follow this trend although not quite at the extent of Japan (Greengart & Akyuz, 2006). Extra features on mobile phones significantly drain battery life and limit the number of features that can go on a handset. Sleek designs such as the Razor, is a good example where consumers are willing to pay premium prices for uniqueness (Greengart & Akyuz, 2006).

Over the long-term, superior voice communication will come first and price second (Greengart & Akyuz, 2006). The primary use for mobile phones will be for communication; therefore, availability, voice quality and reliability will be essential and auxiliary features will come second. In a highly competitive mobile communication environment where substitutes are abundant, consumers have become highly price sensitive (Greengart & Akyuz, 2006). Battery life will be important as improvements in networks, processors, storage capacity, and VGA screens will impact power consumption. The usability of these new features will continue to be constrained by the lack of progress in battery size, weight, and life (Greengart & Akyuz, 2006). Early adopters in this segment are expected to be the 3G phones (Sundgot, 2006). 3G is the third generation of mobile network resources. It has increased download speed improvements six times over existing technology and is expected to hit the mainstream by 2007 (Sundgot, 2006). These phones are packed with enhanced functionality and more gadgets which make them a good candidate for early adoption of fuel cell technology because of their high power requirements. Adoption of 3G phones in some regions are still lagging due to its higher cost (Wikipedia, 2006).

2.4 Other Consumer Electronics

Mobile devices in this market segment include camcorders, digital cameras, PDAs, handheld gaming devices, portable DVD players, battery chargers, and other types of portable devices not covered in other segments. An array of battery technologies that include lithium-ion, nickel-metal hydride, and alkaline batteries are used by the applications in this segment. This segment has the smallest market share in the portable consumer electronics market but is seeing substantial growth (Darnell Group, 2003). PDAs represent the most attractive application with the largest market share in this segment (Darnell Group, 2003). Devices targeted in this area will need to be on an individual basis and thus will be deemed niche markets due to their smaller market size and varying needs (Darnell Group, 2003). Only the high end premium portable applications will likely be candidates for micro fuel cells since less expensive consumer models such as disposable cameras will be powered by cheaper sources such as alkaline batteries (Darnell Group, 2003). North America and Europe dominate the market share for most of these premium portable devices (Darnell Group, 2003).

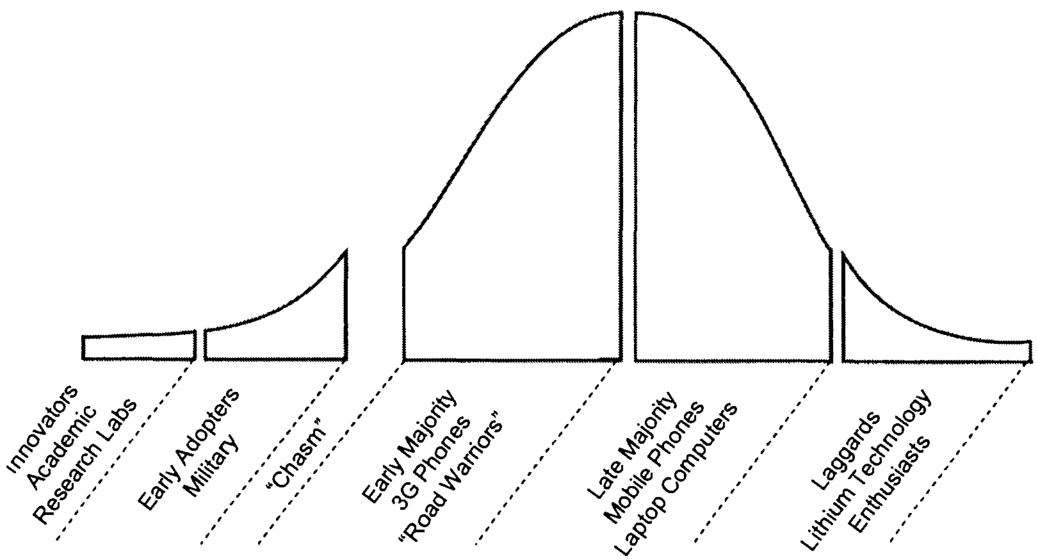
3 MICRO FUEL CELL ADOPTION AND ATTRIBUTES

Fuel cell technology is considered a discontinuous innovation because its success is sensitive to consumer perceptions of change. That is, consumers must alter their way of recharging a battery to take advantage of the improvements offered by micro fuel cells. The use of micro fuel cells also requires hardware infrastructure changes as it is incompatible with current devices. In contrast, the standard upgrading of a product that does not require consumers to change behaviour or hardware infrastructure is a continuous innovation (Moore, 2002). Examining the characteristic stages of a Technology Adoption Life Cycle for a discontinuous innovation such as micro fuel cells can help uncover risks and barriers in penetrating the mainstream portable market. Furthermore, a discontinuous innovation can be disruptive in nature, that is, it can eventually overturn the existing dominant technology in the market place (Christensen, 2003). As micro fuel cells have the potential to displace the lithium ion battery in the portable power market segment, it displays disruptive characteristics. These disruptive qualities will be explored by identifying the most valued attributes of the mainstream portable power market and beachhead markets of micro fuel cells. The performance trajectory of the most critical adoption attributes needed to penetrate mainstream consumers will uncover the technology's true disruptive power (Christensen, 2003).

3.1 Technology Adoption Life Cycle

When discontinuous innovations are introduced into a market they go through progressive stages of acceptance (Moore, 2002). Within these stages there are common psychological and social profiles that can be used to guide marketing programs aimed at adoption of new technologies (Moore, 2002). Many new technologies have failed to commercialize because they were unsuccessful in moving from one stage of the adoption life cycle to the next, falling into what is known as the chasm or deep gorge (Moore, 2002). By understanding the psychographic segmentation of potential markets, Tekion can focus on those which enable micro fuel cells to complete the adoption life cycle shown in the figure below.

Figure 3.1 Technology Adoption Life Cycle for Micro Fuel Cells.



Source: Moore, 2002

Initial acceptance of any new technology starts with innovators and early adopters (Moore, 2002). Innovators of micro fuel cells are likely academic research labs such as the University of Illinois where formic acid was first developed in conjunction with fuel cell technology. Other examples of micro fuel cell innovators include St. Louis University and Princeton which eventually formed Akermin Inc. and PowerZyme Inc. respectively (Davis, 2005). As technology enthusiasts known for being gatekeepers of new technologies, Academia exhibits many innovator characteristics (Moore, 2002). Characteristics such as an appreciation for technology, constant search for the truth, and a belief that knowledge should be free make Academia innovators for micro fuel cell technology. The proliferation of companies working with academic research labs to develop micro fuel cells indicates its approval by the innovator segment. Support from this segment is critical because it allows a smooth transition to the next segment in the adoption life cycle, the early adopters or visionaries (Moore, 2002).

Early adopters of micro fuel cells have been frequently identified as the military (Bradford, 2005). The military has been credited with seeing the potential micro fuel cell technology would provide in the field. With the military's seemingly limitless budget and their willingness to take great economic risks, they have promoted the development of micro fuel cells through its early stages. The industry has gained much visibility on the backs of the military via trade magazines and the internet. Companies have been able to obtain a steady flow of revenue catering to the military's specific needs. However as Moore's model (2002) suggests, companies servicing military specific needs are usually at odds with trying to create a universally applicable product for the masses (Jollie, 2004). Micro fuel cells have not been able to take off and break high-volume opportunities in the mainstream market but it will continue to feed off military demand. Timelines for introducing commercially viable micro fuel cell products have continually lapsed as a result of the same issues being unresolved for the last five years (Red Herring, 2005).

The early majority and late majority make up the mainstream market. The mainstream market is by far the largest portion of the market and where the largest potential for profits lie (Moore, 2002). For micro fuel cells, this mainstream adoption segment includes consumers of portable electronics. The early majority drives adoption for the mainstream market and gaining their support is crucial to long-term dominance (Moore, 2002). Some experts predict that adoption of micro fuel cells will occur in laptop computers before mobile phones (Bradford, 2005). Both products display early and late majority adoption characteristics suggesting that the early majority can consist of both laptop computer and mobile phone market segments. Early majority are coined pragmatists who want to purchase productivity improvements for existing operations (Moore, 2002). These productivity improvements should be established and appropriately integrated with existing technologies (Moore, 2002). Pragmatists are reasonably price-sensitive and want competition to assure that they have chosen the best alternatives (Moore, 2002). Consumers with 3G phones and "road warriors" fit the profile of an early majority as they value enhanced functionality and longer battery run-times. They would also be willing to pay modest premiums for these distinct services. The growing number of mobile devices has created many hardware and software incompatibilities which conflict with pragmatists' desire for simplified productivity solutions (Moore, 2002). Standardizing the auxiliary components of mobile devices would simplify and lower overall costs and will be essential to winning over pragmatists. Early adopters do not prefer one distribution channel but want to maximize their buying leverage by having a central point of control (Moore, 2002). The path into the pragmatist segment will be smoother if alliances can be developed with already established vendors (Moore, 2002).

The late majority are conservatives that moderately fear high-tech products therefore invest at end of the Technology Adoption Life Cycle when it is mature or completely commoditized (Moore, 2002). The key to a smooth transition from early majority to late majority is to maintain strong relationships with the early majority (Moore, 2002). Late majorities are extremely price sensitive and require discounts incentives to become motivated (Moore, 2002). The sheer volume from this segment can offer great rewards to companies that serve them properly (Moore, 2002). These conservatives are likely to buy preassembled low maintenance products, thus companies serving this market need to consider the "whole product" (Moore, 2002). The whole product concept pertains to satisfying all the needs of the end user from purchasing to consumption to maintenance (Moore, 2002). Conservatives include 2G mobile phone and laptop computer users.

Finally, laggards are known as skeptics that make up the remaining segment of the adoption life cycle. Their primary function is to block purchases of new technologies (Moore, 2002). Skeptics are those that believe the millions of dollars invested in developing micro fuel cells were wasteful and would have been better spent improving lithium technologies (Armstrong, 2005). To prevent skeptics from blocking sales, firms should ensure they are providing the whole product solution and heed their criticisms (Moore, 2002).

Micro fuel cells have penetrated innovators and early adopters through academic research labs and the military. Making the transition from early adopters to the early majority in the Technology Adoption Life Cycle, however, has presented difficult challenges for the micro fuel cell industry. These challenges stem from the negative perception of technology ideology among the two groups. Pragmatists feel early adopters' value new innovations simply as "must have" products whereas they take on a long term perspective (Moore, 2002). As a result, early adopters make poor references for early majority pragmatists who are highly reference and support oriented (Moore, 2002). The adoption of this technology now sits in a chasm that has few new customers, hungry investors, and formidable competitors (Moore, 2002). Successful transition through this chasm requires targeting a very specific niche market where micro fuel cells can dominate from the outset. Achieving market leadership is critical to dominating the early majority (Moore, 2002). The niche market should have a pragmatist consumer base that can be referenced by other pragmatists. Ensuring that this target market's buying objectives are completely satisfied to obtain access to other mainstream prospects requires identifying the attributes of portable power that they value most.

3.2 Portable Power Valued Attributes

The buying decision of the mainstream market is dependent on whether a technology product can satisfy their buying need. Not all attributes of a product are valued by a mainstream market. The unattractive attributes in the mainstream market are those that disruptive technologies possess great strengths in while they perform poorly on the mainstream valued attributes (Christensen, 2003). The unattractive attributes often are valued in emerging or beachhead markets (Christensen, 2003). The mainstream and beachhead markets will determine which attributes will open doorways for micro fuel cell technology. These attributes are described in the following subsections.

3.2.1 Mainstream Attributes

The most valued mainstream attributes in the portable power market from a consumer perspective include battery run-time, size, weight, cost, and longevity. Safety, reliability, and operating temperatures have become the minimum criteria for entering the mainstream market. These attributes are called enabling because they allow a company to compete in the market once these conditions have been met. The lithium-ion rechargeable battery's leadership in the portable power industry is a result of having strengths in all valued and enabling attributes. Micro fuel cell technology will need to work hard on closing the gap to meet these demands before it can enter the mainstream market.

3.2.1.1 Run-time

The run-time of a battery is the duration it can be used before recharging is required. More power is increasingly consumed by devices rich with functionality, reducing run-time of a battery. Market trends have put much greater value on added functionality of mobile devices. Consumers now demand versatile devices for functions such as web browsing and entertainment. This will require consumers using current battery technologies to recharge more frequently ultimately affecting mobility and productivity. Furthermore, travel has increased worldwide with global level outbound trips rising by 5% in 2005 (Travel Daily News, 2006). Developing countries such as Africa had the largest growth of 10% followed by Asia with 7% (Travel Daily

News, 2006). Frequent commuters will value longer battery run-time for productivity or entertainment on long commutes.

3.2.1.2 Size

The need for mobility has made this attribute highly valued. The benefit of a smaller size battery is that manufacturers can fit more functionality and gadgets onto a device without adding bulk to it. Consumers want to fit mobile handsets in their purse or pockets. Laptops need to fit into regular size backpacks or in the plane overhead compartments. Trend has also played an important role in making this attribute highly valued. A byproduct of reducing battery size is an increase in product aesthetics. Current market trends in some geographical locations often deem smaller and sleeker products to be more desirable (Greengart & Akyuz, 2006). A smaller battery will allow more flexibility on design.

3.2.1.3 Weight

Intuitively size and weight go hand in hand, although this distinction is not always the case. Generally, a relatively smaller size battery will have a smaller mass. The distinction between size and weight lies in the battery's density. Similar to the size attribute, a reduced weight product becomes much more versatile and mobile. Where the difference is more distinct is when considering battery run-time. Consumers can prolong the run-time of a device by carrying extra batteries. The weight of the battery can have a profound effect as given in the earlier example with military soldiers. It will also be valued by consumers with larger devices that require more power and thus larger batteries.

3.2.1.4 Cost

Mainstream consumers are highly sensitive to price as demand is greatly stimulated by it. Price sensitivity will be higher in developing countries than developed countries since it is closely tied to disposable income. In developed countries, price sensitivity has been fuelled by highly competitive telecommunication service providers offering aggressive price incentives on handsets to lure customers (Greengart & Akyuz, 2006). Electricity used to replenish rechargeable batteries is not considered in the cost of maintaining mobile devices for consumers as they generally view electricity from an outlet as "free" due to its low cost. Besides getting the cost of the handset itself down to current lithium-ion costs, manufacturers will need to bring cost of refilling cartridges down to a price point that is palatable to consumers. This price point will depend on how much they value the conveniences micro fuel cells bring.

3.2.1.5 Longevity

Current battery life is highly sensitive to many factors such as storage conditions, charge and discharge control and the depth of discharge. Ideally consumers want a rechargeable battery to last the life of its host product. Today most rechargeable lithium-ion batteries wear out well before the portable devices they are embedded in. When the battery capacity is depleted, it can no longer store energy and the device must be continually connected to an electrical power source to be usable. Once this occurs, the mobility of the device is terminated. For the device to become mobile again, the consumer must invest in a new battery. Given this, battery longevity is highly valued as replacement batteries can be expensive and increases the cost of maintenance. Battery replacement also becomes more expensive as the device gets larger such as in laptop computers. Micro fuel cells have unlimited battery life contrary to existing battery technology. Its capacity will never deteriorate, so long as fuel is supplied to the cell, run-time will not degrade over time.

3.2.1.6 Safety

This attribute is an enabling competency that is required by battery vendors to compete in the mainstream market. Most batteries contain heavy metals that are toxic and thus harmful to the public and environment. Regulations surrounding battery manufacturing have been heavily enforced to ensure public safety on the use of batteries. It is critical that batteries do not suffer from leakage, gassing, fire, or explosions. Safeguards against misuse of batteries must be put in place which requires more complex management techniques that may negatively affect cost, size and weight. The highly reactive lithium metal has been one of the lithium battery's major barrier to entry in the market but has since been managed at a level acceptable for consumer use. For micro fuel cells, safety considerations primarily include flammability as well as the volatile nature of the types of fuels used.

3.2.1.7 Reliability

One of the most important expectation consumers have when purchasing batteries is its reliability. Reliability describes the operation of the battery under changing or hazardous conditions. It is the ability of the power system to operate consistently and maintain efficiency when environmental conditions change and/or the system output power is varied. Portable devices usually have varied power usages depending on the tasks at hand. Batteries need to be able to meet the power demands in these different operating conditions. Since micro fuel cells are power generators, they output constant power; therefore the ability to handle varied system power requirements will be a big challenge. When power source is critical as in emergency devices, reliability is paramount.

3.2.1.8 Operating Temperatures

Extreme temperature conditions can greatly reduce battery capacity. Consistency of battery capacity in variable temperatures is highly desired as it increases its reliability. Batteries that cannot operate under variable temperatures will not likely be purchased by consumers making it an enabling attribute. The trend to run multiple gadgets with enhanced functionality on a mobile device can increase the operating temperature for a battery. A wider range of operating temperatures enables more uses for the battery and more mobility and flexibility to the consumer.

3.2.2 Beachhead Attributes

The strategy employed by many companies in micro fuel cell industry is to first approach a beachhead market such as the military. This particular segment has characteristics that enable the company to gain a foothold in the portable power market. The military generally sees power as "mission critical". In the field, electrical power sources are not readily available to recharge batteries and as a result, micro fuel cells are very attractive for this market segment. The most valued attributes of the beachhead market, unlike the mainstream market, include instant recharge, uninterruptible power supply, power grid independence, and low environmental impact. Targeting these attributes will enable traction in the market for micro fuel cell technology as the lithium-ion battery and other industry incumbents will be weak along these attributes.

3.2.2.1 Instantaneous Recharge

During charging, a device is limited in mobility as it must be plugged into an electrical outlet. Depending on the size and type of battery, charging times may vary and can take up to several hours. Micro fuel cells, on the other hand, provide instant recharging. When fuel is replenished or replaced, it is immediately at full capacity. Consumers can acquire additional battery packs to increase the battery run-time and provide a means to instantly recharge; however, this requires carrying extra weight. This attribute will be highly valued when mobility and time are critical. In addition, productivity can be increased as the wait time during recharging is eliminated.

3.2.2.2 Uninterruptible Power Supply

To increase the usability of a mobile device, many consumers purchase additional batteries to give them longer run-times. When the battery is depleted, another fully charged battery can be used to replace the depleted battery to enable continued use of the device. This requires the device to be powered off before the battery can be replaced. The application of micro fuel cell technology allows an uninterruptible power supply. Fuel can be replenished into the device without the need to power off. The use of cartridges as a refill technique does not require the device to be turned off, a method known as "hot swapping". This can be a valuable attribute with monitoring applications or other devices that require high system availability.

3.2.2.3 Power Grid Independent

Conventional rechargeable batteries require electrical power sources to replenish batteries once they are depleted of energy. This assumes the availability of electrical power. Use of rechargeable batteries is limited to areas with electrical outlets. Micro fuel cells eliminate this need to be dependent on an electrical power grid and thus increase the mobility of a device. Although most consumers in developed countries are connected to power grids, many parts of developing countries still do not have access to electrical power. These consumers are currently unable to use mobile devices as the batteries that power them cannot be replenished. Even in developed nations, mobile users are limited in finding sources for recharging which can decrease their productivity. This is particularly a problem during long commutes where electrical sources are not available such as on airplanes or when travelling to remote areas. Where productivity is important and/or electrical power is not available, this attribute is highly valued.

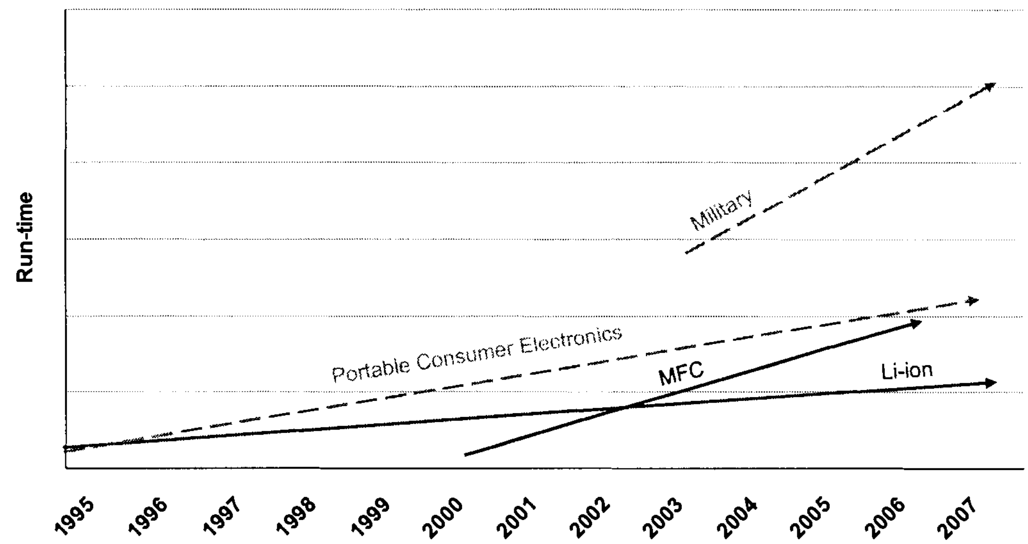
3.2.2.4 Environmental Impact

The concern for more environmentally friendly power sources to mitigate environmental impact is an increasing trend around the world. Higher quality of life is desired and as a result energy sources that do not deteriorate the environment are sought out. This world prevailing view has fuelled the development of alternative power sources such as fuel cell, hydro, solar, and wind. As the growth of developing countries rise so do their power consumption. These countries have need to find environmentally friendly power sources because they tend use traditional sources such as burning biomass and coal that highly degrade air quality. Ultimately these sources of energy are unsustainable. In developed countries, power consumption needs are more constant, they are concerned with using alternative energy sources to replace current demand with smaller environmental footprints.

3.3 Critical Performance Trajectories

Unlike other markets, batteries and fuel cells do not have much synergy in the portable power market. In portable power applications, micro fuel cells must compete on price, weight, size, and performance. They must also out perform batteries in these areas as they improve in the future. The critical performance trajectories describe the rates at which the most relevant performance attributes have improved and are expected to improve for micro fuel cells (Christensen, 2003). These improvements will make micro fuel cells acceptable to portions of the mainstream market, allowing it to displace the incumbent lithium ion technology. The performance trajectories can be used to understand the current stage of the fuel cell's product life cycle and target an appropriate market. The most critical attributes are run-time, size, weight, and cost.

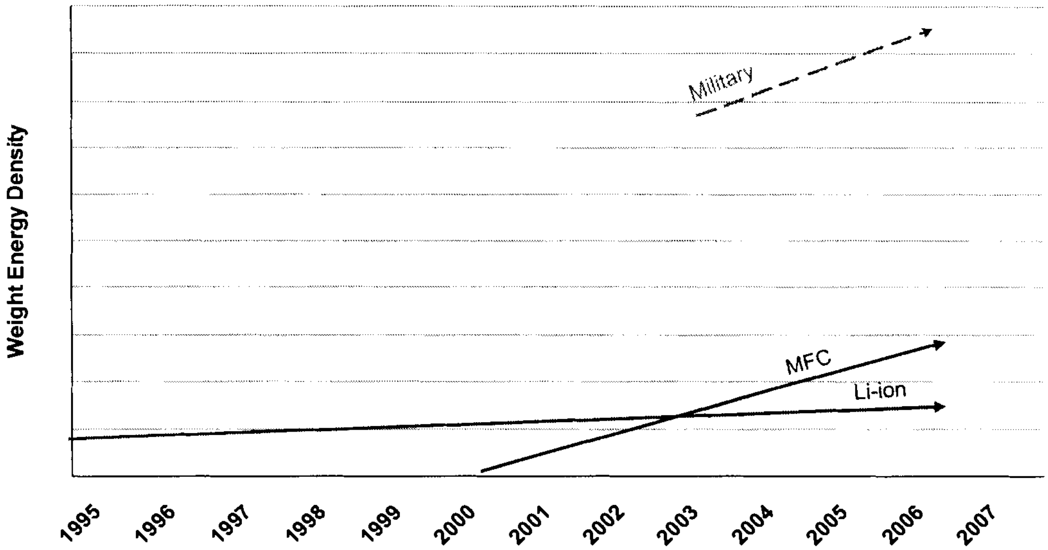
Figure 3.2 Battery Run-Time Performance Trajectory.



For the last ten years, lithium ion batteries have been able to bridge the burdening power demands of mobile users (Senmajumdar, 2004). The broadening gap is a result of laptop users requiring double the battery run-time of what existing technologies can provide. A chart of run-time versus a chronological timeline is depicted in the figure above. Currently, laptop users want eight to ten hours of run-time (Senmajumdar, 2004) of which the average lithium ion battery can only provide four to five. Similar circumstances of shortfall exist for mobile communications. Talk time is limited to 60 minutes for 3G phones with lithium ion batteries (Mobile Tech News, 2005). Expected consumer demand for mobile power rising 26% per year will further widen the gap between supply and demand (Armstrong, 2005). Although the lithium ion technology has continued to show improvements over the last decade increasing at approximately 8% to 10% a year, it is expected to have only eight years left before it reaches maximum capacity (Crawley, 2006). This means lithium ion batteries have only the potential to improve by 50% from today's performance (Mobile Tech News, 2005). Micro fuel cells can theoretically generate 10 times longer run-times than lithium ion batteries giving laptop computers more than 40 hours before refuelling is needed (Evangelista, 2003). Micro fuel cell run-times have come a long way from its first commercial development for portable devices in 2000. Today run-times for laptops using micro fuel cells have demonstrated to last eight to ten hours (Armstrong, 2005). Mobile phones using fuel cells have also demonstrated to run 2.5 times longer than lithium ion batteries (Donovan, 2006). Today's advancements in micro fuel cells have surpassed lithium-ion technology and are quickly intersecting the demands of the mainstream.

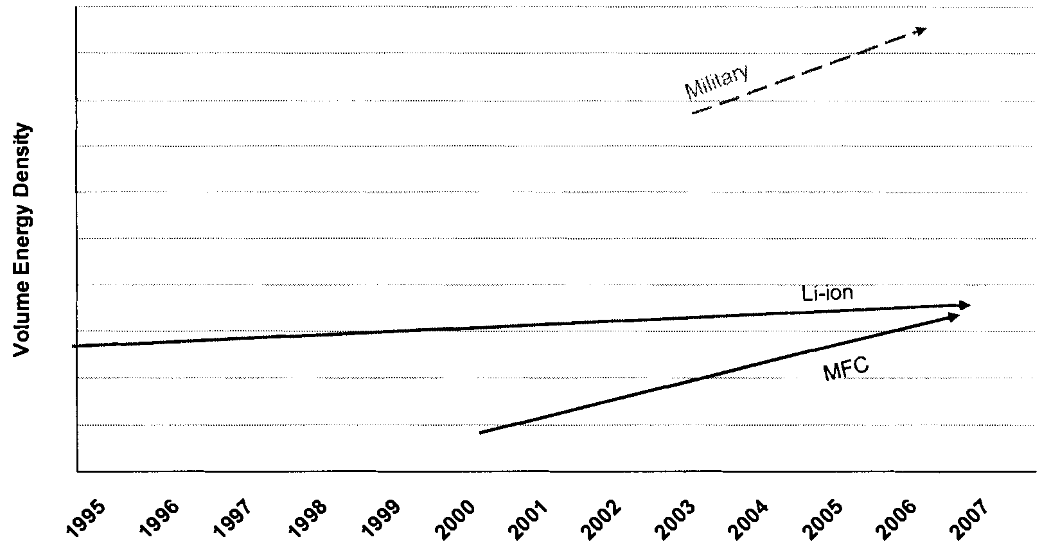
To compare weight and size attributes of batteries in a meaningful way requires plotting weight or volume against run-time. Powering a laptop computer with a lithium ion battery versus a micro fuel cell for four hours will show a higher energy density for the lithium ion battery and thus have less weight and smaller size. However, when the timeframe is increased, it will require additional batteries and this would cause the micro fuel cell's density to be greater than the lithium ion battery since the weight of the additional fuel is far less than the weight of additional batteries. Creating performance trajectories for battery weight and size requires plotting weight energy density (Wh/kg) and volume energy density (Wh/L) respectively.

Figure 3.3 Battery Weight Energy Density Performance Trajectory.



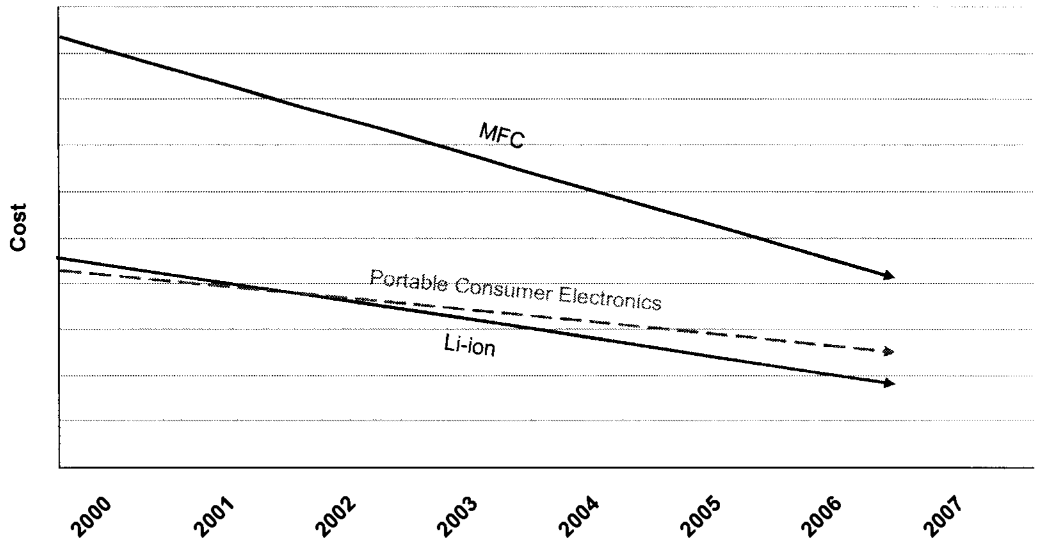
When Sony first announced the launch of lithium ion battery in 1992, these early batteries exhibited 90 Wh/kg (Marsacq, 2005). Since then they have seen gradual improvements to 160 Wh/kg (Marsacq, 2005). Future improvements of the lithium technologies can theoretically achieve a maximum of 300 Wh/kg (The Economist, 2001). Currently micro fuel cells are able to deliver twice the weight energy density of lithium ion technology. At 340 Wh/kg some micro fuel cell companies are already surpassing lithium ion's maximum theoretical density output (Armstrong, 2005). The Pentagon wants to deploy portable equipment with 1,000 Wh/kg requirements and is looking at 3,100 Wh/kg in the near future (The Economist, 2001). From Figure 3.3 it can be seen that the weight energy density performance of micro fuel cells have exceeded that of lithium ion technology. Theoretically micro fuel cells can only reach a maximum of 1,500 Wh/kg therefore its trajectory may not intersect the military's demand. Consumer demand was not plotted because there was no sufficient data to indicate the projection of the demand curve. However, the current performance of micro fuel cells is likely sufficient to meet the consumer demand given lack of evidence of a demand gap.

Figure 3.4 Battery Volume Energy Density Performance Trajectory.



Battery size measured by volume follows the same improvement projections as weight for lithium ion technology (Pillot, 2004). The growth in energy density is steady at 10% per year (Morrison, 2002). Micro fuel cells have had a real challenge in getting the volume energy density to the equivalent of lithium ion; however, the potential can be higher than 1900 Wh/L depending on the type of fuel cell (Pak & Heydom, 2002). This attribute has been more critical in entering the mainstream market than weight density because it must fit into current portable devices. Although advancements in volume energy densities have not been as rapid as weight energy densities, it has caught up and likely to surpass lithium ion volume densities. The Department of Energy's growing expectations for micro fuel cells of 1,000 Wh/L by 2010 (NanoMarkets, 2005) may not be likely intersected by micro fuel cells as consumer expectations. Consumer demand could not be plotted for the same reason as weight energy density. The graph is still useful in showing the rate at which micro fuel cell improvement will surpass that of lithium ion technology and likely meet consumer demand if consumer demand for size it is similar to run-time.

Figure 3.5 Battery Cost Performance Trajectory.



Battery cost can be divided into three categories, the cost of the battery cell itself, the cost to recharge the battery, and the cost to maintain the battery. Mobile phone lithium ion battery prices have declined at an average rate of 13% per year. The average lithium ion battery for mobile phones sold for $13.59 in 1999 and was reduced to approximately $8.00 in 2004 (Darnell Group, 2003). Prices for laptop batteries followed a similar trend (Darnell Group, 2003). Consumer price expectation will be $8.68 at the beginning of 2006 and down to $8.15 by the end of the year (Darnell Group, 2003) resulting in a declining rate of 6% per year. As Figure 3.5 shows above, consumers are willing to pay a price premium over current battery technologies because they want greater performance and functionality. Evidence from the past has shown that this trend is not uncommon. Even after economies of scale from high volume production of lithium batteries were achieved, it was able to remain a higher ticket item than nickel metal hydride batteries because of its greater performance and functionality (Darnell Group, 2003). The cost of micro fuel cells were slightly less than double lithium ion batteries in 2001 (Buchmann, 2001). Cost is predicted to drop 30% from $10.75/W in 2004 to $2.96/W by 2009 (Darnell Group, 2003) from economies of scale due to expected higher volumes. This puts micro fuel cells above consumer price demand tolerance. However the trajectory line for micro fuel cell is steeper than that of the consumer; therefore, it will likely intersect in a few years.

Fuel cartridge costs will need to be comparable to the cost of electricity. The availability and cost of fuels such as methanol and formic acid will be a fraction of the significant costs for packaging, logistics, and marketing (Gaertner, 2002). Consumers in industrialized countries pay between $0.05 and $0.15 US per kWh (Buchmann, 2001). Power obtained through the electrical utility grid is the most cost effective; therefore, it is not expected that fuel cartridges can come down to the same level (Buchmann, 2001). Methanol fuel cartridge cost to consumers is projected at $3 to $5 US. However prices are expected to drop as a result of manufacturing learning curves and economies of scale (Senmajumdar, 2004).

Micro fuel cells have unlimited battery life. Its maintenance costs in terms of cell care are negligible. On the other hand, the lithium ion battery cell has a limited life that usually does not last as long as its host device. Therefore maintenance of lithium ion batteries is substantial and usually requires replacement batteries every few years. Consumers may not factor in maintenance cost with their buying decision. It is easier to base buying decisions on a product's purchase price because it is simpler to calculate and plan for (Kriegh, 2006). This factor may also be a deterrent for consumers to purchase micro fuel cells because of the complexity in calculating and planning for fuel cartridge replacement costs. This barrier to adoption is better addressed in a marketing program after the target market is known.

The following table summarizes the average performances of the competing technologies, lithium and micro fuel cells, for the valued attributes previously described.

Table 3.1 Portable Power Mainstream and Beachhead Market Valued Attributes' Performance for Lithium and Micro Fuel Cell Technologies

Attribute	Li-ion	Polymer	Methanol	Formic Acid
Run-time – Laptops (hrs)	4-6	n/a	8-10	n/a
Size (Wh/L)	250-350	270	250	300-400
Weight (Wh/kg)	160	300	n/a	250-333
Cost (US$/Wh)	1.09	1.60	n/a	n/a
Longevity (cycles to 80%)	500-1000	300-500	Unlimited	Unlimited
Charge Time (hrs)	2-4	2-4	0	0
Continuous Power	No	No	Yes	Yes
Power Grid Required	Yes	Yes	No	No
Environmental Impact	High	High	Low	Low
Safety Issues	Yes	Yes	Yes	No
Reliability	High	High	Medium	High
Operating Range (°C)	0 to 60	0 to 60	n/a	25 to 30
Thermal Efficiency	95%	95%	>20%	40%

Cycles to 80% refers to the number of recharges before the battery hold only 80% of the original battery capacity; Data Sources: Buchmann, 2001, Armstrong, 2005, Millennium Cell, 2006

Micro fuel cell development has been closing the gap on meeting the demands of the mainstream market because of its steeper performance trajectory than lithium ion batteries. Its performance today has surpassed that of lithium ion batteries in run-time, size, weight and longevity. The technical hurdles to meet the industry standards on safety, reliability, operating temperatures, and thermal efficiency have been overcome, enabling it to compete in the mainstream market. Furthermore, micro fuel cells possess a unique set of attributes that cannot be fulfilled by established technologies. These attributes give micro fuel cells disruptive potential. Its main hurdle now is to meet the price demands of a pragmatist mainstream group. High volume can help bring down the cost; however, high volume can only be obtained by penetrating the early majority. Targeting a market in the mainstream that is able to appreciate the current stage in the micro fuel cell's product life cycle will be the key to wider penetration.

4 COMPETITIVE ENVIRONMENT

The competitive challenges for micro fuel cells begin with its choice of fuel. There are various companies working with different fuel designs each with their own technical challenges. Adoption by a mainstream market will require standardizing a few designs. Superior technologies that can overcome the technical hurdles quickly will likely become the standard. Moreover, understanding the competitive landscape will help to determine where Tekion is likely to succeed as a market leader. Technology standardization and market leadership will be the key to gaining an early majority market in portable applications (Moore, 2002).

4.1 Micro Fuel Cell Technologies

One of the main challenges in the micro fuel cell industry is identifying the appropriate technology for portable power applications. Not only do micro fuel cells compete with incumbent battery technologies, it must vie for opportunities among the different types of configurations. Current fuel cell technologies for portable application include borohydride, direct methanol, reformed methanol, formic acid, and bio-fuel (Davis, 2005). Borohydride fuel cells apply the PEM technology with sodium borohydride as fuel (Davis, 2005). Boron hydrides have large energy potentials. However, harnessing its energy has been problematic requiring complex micro-pumps to control the release of hydrogen to the fuel cell (Davis, 2005).

Direct methanol fuel cells (DMFC) are similar to PEM fuel cells in that they both use a polymer membrane as the electrolyte. However, in the DMFC, the anode catalyst itself draws the hydrogen from the liquid methanol, eliminating the need for a complicated fuel reformer (Gangi, 2005). There are two types of DMFC technologies that include active-based DMFC and passive-based DMFC. Indicative of its name, water is actively pumped or passively back-diffused through osmosis to the anode side for subsequent reaction with methanol (Davis, 2005). DMFCs suffer from low efficiency and safety issues since methanol is toxic and flammable (Tekion, 2005).

Reformed methanol to hydrogen fuel cells (RHFC) disassociates hydrogen from methanol to generate electricity. This technology gives higher power densities than DMFCs but requires a complex fuel processor and operates at high temperatures (Davis, 2005). Formic acid fuel cells supply formic acid to the anode and oxygen to the cathode. Formed at the anode, the protons pass through the electrolyte and the electrons pass through an external circuit to the cathode, thereby producing electricity (Davis, 2005). Like RHFCs, formic acid fuel cells have higher power densities than DMFCs, but have advantages of performing at lower operating temperatures and requiring less complex components (Tekion, 2005).

Bio-fuel cells (BFC) convert chemical energy to electrical energy through biocatalysts such as acid or glucose rather than inorganic catalysts like platinum. BFCs can extract fuel such as glucose from living organisms to generate electricity (Davis, 2005). Power output of bio-fuel cells are usually small and thus limit their applications to small medical devices such as pace makers and insulin production generators (Davis, 2005). The following table is a summary of the major players, cost components, and safety concerns for the various micro fuel cell technologies.

Table 4.1 Competing Micro Fuel Cell Technologies & Attributes.

Technology	Major Players	Cost	Safety
Borohydride Fuel Cells	Millennium Cell, Medis Technologies, Protonex, Materials & Energy Research Institute Tokyo Ltd (MERIT)	No need for expensive platinum catalysts	Flammable, highly corrosive
DMFCs	Toshiba, Hitachi, Fujitsu, NEC Corporation, MTI Microfuel Cells, Neah Power Systems, Smart Fuel Cell, Polyfuel	Expensive platinum catalyst	Flammable
RHFCs	Motorola, Casio Computer Co, UltraCell	Expensive platinum catalyst and palladium membrane required	Flammable
Formic Acid Fuel Cells	Tekion	Less expensive palladium catalyst	Non flammable
BFCs	n/a	Inexpensive biocatalyst	Non flammable

Data Sources: Davis, 2005, Wikipedia, 2006

Some research suggests that DMFCs are leading the market by the sheer number of developers (Jollie, 2004). DMFCs, however, still have many hurdles to overcome. With its pending patent in place, formic acid fuel cells see little competition in terms of developers. Formic acid fuel cell technology has become a formidable competitor as it has many advantages over the pervasive DMFC technology including a cheaper catalyst, safe nature, higher power densities, and lower performing operating temperatures. With the numerous micro fuel cell technologies still vying for portable power market share, commercialization will be contingent on standardizing a select few. Those micro fuel cell technologies that can overcome the technical hurdles to satisfy the mainstream market first will likely become the standard in micro fuel cell technology.

4.2 Competitor Positioning

The environment for commercialization of micro fuel cells in portable power applications is highly competitive which is characteristic of a discontinuous technology in a chasm. Market competition consists of battery manufacturer conglomerates along with over 50 smaller firms all working on micro fuel cells (Armstrong, 2005). Conglomerates of portable electronics such as Motorola, Toshiba, NEC, Fujitsu, Hitachi, Samsung, Sanyo, and LG all have active fuel cell programs. They have demonstrated prototypes and are considering commercial viability of their products (Red Herring, 2005). Toshiba has gone farther than most to demonstrate DMFC portable applications (Red Herring, 2005). Larger manufacturers will look at commercializing consumer electronics such as laptop computers, mobile phones, PDAs etc. (Gangi, 2005). The smaller firms primarily focus on niche markets such as disposable cell phone chargers, handheld radios, power tools, etc. (Gangi, 2005).

In terms of regional development of micro fuel cells, Japan and China are leading the way for consumer electronics segment as most of the major manufacturers are located in these areas (Jollie, 2004). In North America, development is fuelled primary by the military. However, the Pacific Northwest is seeing increased development of fuel cells for consumer electronics (Jollie, 2004). Europe is also seeing investment in micro fuel cell development with Germany being one of the notable countries (Jollie, 2004). Smaller firms have taken on strategies similar to Tekion, establishing alliances with major manufacturers, distributors, and network providers. Table 4.2 displays the major alliances formed by different technology developers, manufacturers, distributors, and network providers.

Table 4.2 Major Competitor Alliances.

Developer	Manufacturer	Distributor	Network Provider
Tekion	Motorola, BASF		
Medis Technologies	General Dynamics, Eastman Kodak's Global Manufacturing Services	Superior Communications	
MTI Microfuel Cells	Harris RF Communication Division, Duracell		
Nanosys	Sharp		
	Toshiba		KDDI
	Hitachi		KDDI
	Fujitsu		NTT DoCoMo
Millennium Cell	Samsung, Dow Chemical		
PolyFuel	NEC, Sanyo		

Data Sources: Gangi, 2005, Chau, 2005, Mobile Tech News, 2005

Firms that have secured alliances with established vendors will have a competitive advantage as they will be viewed more favourably by the early majority. Gaining wider acceptance by providing the whole product solution requires technology developers, manufacturers, distributors, and network providers working collectively. Companies are deploying these strategies, as evident from the number of alliances formed, making it more difficult to have a competitive advantage. With fierce competitors covering the entire spectrum of micro fuel cell technologies and portable power applications, the question arises whether these competitors will have a viable commercial product and what regions they will target first. Avoiding regions with greater competition will increase the chance to gain dominance.

5 COMMERICALIZATION CHALLENGES

Unlike other technology products, micro fuel cells require cross-organizational coordination of safety and regulation, network infrastructure, manufacturing, and distribution channels. These factors can inhibit the adoption of micro fuel cell technology if they are not addressed early. Firms should not focus on factors that out of their control. Rather, firms should lobby the right stakeholders and time those markets when they see barriers being lifted. Alternatively they can focus on markets that do not have these barriers to adoption. The current major challenges facing micro fuel cells' commercialization are discussed as follows.

5.1 Policy and Regulation

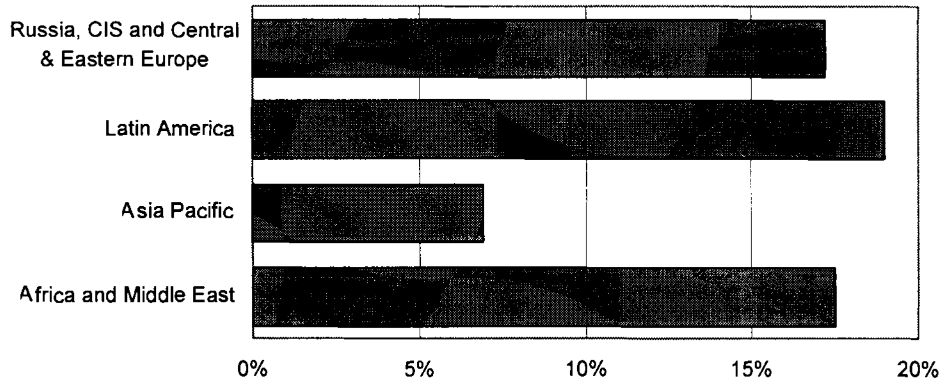
5.1.1 Safety

The lack of safety regulations for fuel cells will be a critical delaying factor in their commercialization. Current drafts by the International Civil Aviation Organization's Dangerous Goods Panel (ICAO DGP) will allow the transportation and use of fuel cells and fuel cartridges on passenger airliners. The vote on November 7, 2005 to allow the carry and use of micro fuel cells on aircrafts was a critical milestone in the global commercialization of micro fuel cells. The amendment allows the transport and use of four types of micro fuel cell systems that include butane, formic acid, direct methanol, and reformed methanol (Millennium Cell, 2006). The DGP did not include the use of hydrogen in metal hydrides and borohydride compounds. This has serious implications for competitors as it will delay their commercialization. Compliance is required with the International Electrotechnical Commission (IEC) Specification for Micro Fuel Cell Safety which places limits on the size and number of fuel cartridges (up to 2 spare fuel cartridges per person) to be in carry-on baggage only (Millennium Cell, 2006). The publicly available IEC 62282-6-1 specification also requires that fuel cell devices and fuel cartridges pass rigorous testing, and include external markings notifying consumers of IEC certification. Prohibitions on battery chargers and refillable systems will limit the options for firms seeking to use micro fuel cells as battery chargers and refuelling. These conditions are expected to be ratified on January 1, 2007. After such, each ICAO contracting State is expected to implement the Standards within its own territory. As aviation technology continues to rapidly develop, the Standards are kept under constant review and amended as necessary. These events bode well for Tekion and the micro fuel cell industry as it brings the adoption of this new technology closer to acceptance by a conservative mainstream market that is fixed on safety and standards. Furthermore, Tekion's position in the market place is enhanced as the number of micro fuel cell systems and competitors has been limited to a select few.

5.1.2 Taxation

Taxes are an additional component in the total cost structure for mobile products and services. In developed countries, taxes have minimal effect on the consumption of mobile products as disposable income is relatively greater than that in developing countries. For the poorest countries, however, this can have a significant impact on the affordability of mobile products. The GSM Association (GSMA) commissioned an independent study across 50 developing countries found that taxation acts as a significant barrier for consumers, preventing potentially millions of people from being able to afford mobile communications (GSM Association, 2005). For instance, the Indian government saw mobile penetration increase from less than 1% to more than 5% when it reduced handset import duty over the past three years (GSM Association, 2005). Taxes were found to be disproportionately high in many developing countries, at times representing more than 20% of the total cost of ownership on mobile phones and services. Africa and the Middle East had the lowest penetration (10%) and highest tax burdens (15% - 20%) on mobile subscription. The highest share of taxes in the total cost of ownership belong to Africa, specifically Uganda, Syria, Zambia, Tanzania, and Kenya and has been one of the biggest obstacles to deeper telephone penetration.

Figure 5.1 Taxation as a Percentage of Total Cost of Mobile Ownership by Region.



Source: GSM Association, 2005

Besides taxes paid directly by end-consumers, business taxes also have a significant impact on penetration of mobile subscription. High corporate taxes reduce return on investment, limiting investors' interest in expanding capital-intensive mobile networks to reach the 1.4 billion people currently living in areas without signal. Overall, high taxes will negatively affect the adoption and penetration of micro fuel cell technology in regions where income is low. With significant price reductions in micro fuel cell technology yet to be realized, it will further increase the existing cost barriers of mobile communications for developing countries. Policy changes on taxes can be a slow iterative process and requires collaboration from government agencies and mobile operators. Tekion should take on a longer term strategy for regions where higher taxes act as barriers for users in adoption of mobile phones.

5.2 Network Infrastructure

The use of mobile communications requires the existence of a mobile network. Without this essential infrastructure in place, mobile phones would be of little value. Approximately 77%

of the world's population reside in regions covered by mobile communications networks. However, only 25% actually use the services (GSM Association, 2005). For those 4 billion people living with access to network services, cost is the major barrier for not using mobile phones. The remainder of the population without mobile phones are living in areas without any access to network signals. These regions are primarily rural areas in developing countries with low population densities that make mobile and conventional communication infrastructure investments unattractive. Development of new mobile networks in these areas will be more desirable than new fixed lines because of its longer development time and significantly higher costs (We have the power, 2006).

Capturing the high-end consumer market for mobile communications requires updating current infrastructure. Enormous capital investments are needed to build 3G networks. Japan and South Korea have been at the forefront of 3G adoption with over 40% of subscribers using 3G networks (Poropudas, 2006). Popularity of 3G network has also been found in Western Europe. However, coverage around the rest of the world continues to lag. Slow penetration has been mainly due to a lack of perceived value and higher costs. For developing countries, leapfrogging directly to 3G infrastructure is inhibited by its high upfront cost (Nikkei Business Publications, 2006). 3G technology is not expected to reach critical mass until the end of this decade (Forrester, 2006). Development of network infrastructures can take years due to massive capital costs of which Tekion is not able to contribute. Instead, Tekion should adopt a long term strategy to target potential consumers in areas lacking network infrastructure. When updates to existing networks and coverage to rural areas begin to materialize, Tekion should use these signals as opportunistic entry points.

5.3 Distribution Channels

With the market lacking uniform standards in terms of cartridge design and fuel cell composition, commercialization could be hindered by the numerous competing designs vying for market share. Numerous fuel cell designs cause incompatibilities with original equipment manufacturers (OEMs) and poses distribution challenges. Commercialization that lack standards on cartridge design and fuel cell composition will require retailers and distributors to carry multiple fuel cartridge types and sizes increasing logistical effort. As a result, retailers and distributors may be hesitant to commit to selling fuel cells until they have consolidated to a few standards (Red Herring, 2005). Fuel cartridge accessibility should maintain current convenience consumers are use to. For consumers with access to power grids, fuel cartridges must attempt to be as convenient as plugging into an electrical outlet. This requires having extensive distribution networks that reach electronics stores, department stores, grocery stores, and gas stations. This creates a problem for companies trying to gain a foothold in the mainstream market as retailers and distributors are less likely to carry fuel cartridges until there is broad penetration in the market (NEAH Power Systems, 2004). Until there is convenient access to fuel cartridges, mainstream consumers will unlikely adopt micro fuel cell products (Red Herring, 2005).

A straightforward distribution option available to firms trying to commercialize micro fuel cells is to work with existing distribution channels already in place for similar products such as batteries and lighters. Other options include creating new or using unconventional distribution channels as many disruptive technologies have done (Christensen, 2003) or select specialized distribution channels to start and expand over time for mainstream consumers. Global standardization of micro fuel cells have already begun with the IEC Working Group 10, a special task force aimed at providing specification guidelines for micro fuel cell power units and their fuel cartridges by 2007 (PhysOrg, 2004). In addition, some of the major distributors including BIC, Tokai, and Duracell are attempting to tackle the cartridge and distribution issues (PhysOrg, 2004). Although these events are positive for the industry as it brings micro fuel cells closer to acceptance by the mainstream, it is still in its early stages. Tekion should ensure that there are accessible channels established and acceptable by the target market. Furthermore, as convenience will be compared to the status quo, a target market that does not have wide access to battery recharging will be more likely to tolerate limited distribution channels for fuel cartridges.

6 TARGET MARKET ALTERNATIVES

There are two distinct market options for firms exploring opportunities in different geographical regions for micro fuel cells. These choices stem from the fact that disruptive innovations can create new markets (Christensen, 2003). Micro fuel cells have shown to exhibit characteristics of disruptive innovation offering firms the option to pursue new markets or existing markets. Theses options have been labelled as non-consumers and consumers, respectively. Each alternative targets different market segments and requires completely different strategies. Common barriers among both alternatives are satisfying early majority acceptance criteria and overcoming the current commercialization hurdles. Each alternative will display some unique considerations and these will be discussed below.

6.1 Non-consumers

Customers that cannot use currently available products are coined non-consumers (Christensen, 2003). The barriers to consume these products include not being able to afford them or being too inexperienced to use them (Christensen, 2003). Targeting non-consumers effectively requires removing the barriers that prevent consumption. Strategies such as providing lower prices and simpler products can be beneficial. Arguably this market has the highest potential for adoption because these consumers will compare the new technology with having nothing at all (Christensen, 2003). Dominating this market requires looking for beachhead attributes that can meet these criteria. This will guarantee that existing technologies cannot compete with these particular attributes. For micro fuel cells the beachhead attributes include instant recharge, continuous power supply, power grid independence, and low environmental impact. The unavailability of an electrical power grid will prevent consumers from using portable rechargeable devices therefore power grid independence is a contender for non-consumption. The remaining attributes are not candidates for non-consumption as they only provide enhancements over existing technologies and do not act as barriers. Mainstream attributes can also be candidates for non-consumption, although not as attractive. Cost is the only attribute that would be a barrier to adoption of portable devices. Users that need more run-time or increased mobility can still consume current available portable products with limitations. Since micro fuel cells cannot currently compete with existing technologies on cost, the only viable market segment for non-consumers are those without access to power grids. Power grid access will primarily be a problem in developing countries (World Energy Council, 2005). The second largest barrier will be affordability in these regions, therefore segments that are less price-sensitive will be more likely to adopt.

6.2 Consumers

Consumers are those that are able to use current available portable products. The disruptive model suggests that when non-consumers are not available firms should seek low-end disruption because these markets will look unattractive to established competitors (Christensen, 2003). Low-end consumers are those that will accept mediocre performance at a lower price because they cannot use all the functionality they have to pay for (Christensen, 2003). Micro fuel cells cannot currently offer lower prices and therefore cannot take on this strategy. However, the principles can still be applied to find segments in this market that will be most likely to adopt micro fuel cells. Penetration of the mainstream market requires winning over the early majority and in the portable power market; this segment includes 3G phone users and "road warriors". Micro fuel cell's improvement in run-time, weight, and size ensures that the buying objectives of these customers will be satisfied. This precursor to building a loyal pragmatist consumer base will make price premiums acceptable to this group. Adoption will be more likely in segments that have a greater need for enhanced run-time, reduced weight, longevity (as micro fuel cells have exceeded the performance of the incumbent technology) and/or value the beachhead attributes. Dominating the market will require identifying regions and applications of fuel cells that do not see many strong competitors.

7 MARKET VALUATION & RECOMMENDATIONS

Country X is one of many emerging regions seeing exponential growth in mobile phone subscribers making it a possible target market for Tekion. Growth has been a result of policy reforms and declining handset prices. Total penetration is still extremely low. Of the 100's of million people living in Country X, less than 10% of the population subscribes to voice telephony. This provides great potential for new market growth. However, there are equally great economic risks to firms trying to penetrate this area. Mobile communications is the only attractive portable application in this region because of its affordability relative to the other portable applications. Adoption of fuel cell powered mobile phones will depend on a number of factors already discussed. The evaluation of Country X's market for micro fuel cell commercialization consists of determining the target market and its potential size, the likeliness of adoption by the target market, and the potential for Tekion to be the market leader[2].

7.1 Target Market Potential Size

The availability of non-consumers is widespread in Country X. Access to electric power grids continues to be a major challenge for many parts of this country. It has poorly developed infrastructures to deliver energy. Rural access to electricity is less than 50% in some areas (Appendix A). This market's incentive to buy fuel cell powered mobile phones will be high because they cannot communicate otherwise. However, existing consumers of mobile phones in Country X will be less compelled to adopt micro fuel cells especially if it is more costly because they are able to use existing products to satisfy their communication needs. Given that non-

[2] Some of the relevant details for the market evaluation have been omitted in this section to preserve anonymity.

consumers have a more compelling reason to adopt micro fuel cell products, they are the preferred target market in this geographical area.

There are a number of factors affecting the potential size of the non-consumer target market including network coverage, tax policies and regulations, and affordability of mobile communications. Infrastructure for communication networks is a challenge in Country X. Network infrastructure is a necessity for mobile communications; therefore, the target market should include consumers without electric power but with network coverage. As network coverage will be lacking in more rural areas, it will be highly correlated with a limited access to electrical power. Although most Country X has some network infrastructure with the majority being based on GSM standard, coverage to rural areas can still be improved. This will greatly reduce the potential size of the original non-consumer target market.

With one of the lowest income per capita in the world, cost is a major barrier to consumption for mobile products in Country X (see Appendix B for GDP per capita comparison). The target market must be narrowed to include those that can afford mobile phones and services. Tax policies will greatly affect the affordability in these emerging areas. Unfortunately, Country X sees some of the most disproportionately high taxes on mobile products and services. Policy and regulation reforms are having a large impact on growth of voice telephony subscribers and will continue to do so. In addition, Country X's consumers are deploying a number of techniques to overcome the hurdles of affordable communications. These techniques include the use of airtime vouchers, rental services, pay per use, and communal sharing. By applying these techniques, Country X's users save on costs of handset ownership, time and money used to travel to a landline town. This provides opportunities to target a niche market, resellers of mobile services that will be sufficiently well funded to pay the prices of mobile handsets. These informal resellers will be good references (as they belong to the same segment group) and thus will be able to provide access to the larger mainstream market of non-consumers.

7.2 Likelihood of Adoption

The potential for the target market to adopt the technology makes a particular region attractive. There are two main opposing forces driving the likelihood of adoption. Factors affecting consumption either deter and/or augment the adoption of the technology. Deterrents include network coverage and quality, policy and regulations, affordability, and availability and accessibility of distribution channels. Regions scoring low on these factors will deter adoption. Augmenting factors include environmental sensitivity, usefulness of instant recharging, productivity concerns, and device power demand. Regions scoring high on augmenting factors will enhance the likeliness to adopt. These factors help determine to what extent the whole product is being provided to target market.

Network coverage and quality is low in Country X. Subscribers are not able to roam seamlessly when travelling to different areas in Country X. Policy regulations on network operation in Country X are not as liberal as in developed countries although it is seeing great reform. Active competitiveness in network operators has yet to be pervasive. Policy and regulations is the key to fostering this type of environment and will provide better quality and more affordable services. In rural areas, distribution will be a great challenge. Channel distributors and retailers will be few and far in between and likely have a small coverage area. Fuels such as formic acid can be stored for up to five years therefore consumers can bulk up on supply to reduce the number of trips to restock. However bulk fuel affordability may be an issue.

Environmental issues have been at the forefront of world concern. Deforestation is one of the most pressing environmental problems faced by Country X. Wood in these regions is primarily used for fuel and affects health due to smoke inhalation. Alternative energy sources are sought out to decrease the impact to health and the environment. The target markets' motivation to adopt fuel cell powered mobile phones because they are more environmentally friendly will only be at most mediocre. There is also no foreseen usefulness for instant recharging by this target market however productivity is a high concern. Communication provides a point of contact for information and enables users to participate more actively in the economic system. Since this segment needs basic telephony, they will not have a large requirement for increased power output to fuel function-rich devices.

7.3 Market Leadership Potential

Early majority adopters will only purchase from established and proven market leaders (Moore, 2002). Therefore the attractiveness of a region will be greatly enhanced if Tekion can become the market leader. The potential for market dominance depends on the threat of other competing micro fuel cell technologies and competitors vying for the same market. Tekion's formic acid fuel cell has been able to perform at the same level or greater than lithium-ion and other micro fuel cell technologies except on price. Formic acid fuel cells possess less safety issues, greater energy density, and lower catalyst cost than its counterpart DMFC technology. There are a lack of firms developing micro fuel applications in Country X. Given this, Tekion's position is enhanced in Country X to be a market leader.

Table 7.1 **Summary of Market Potential Evaluation for Country X.**

	Rating	Subtotal	Total
Potential size of market:			Med
Non consumers	High		
Network Access	Med		
Potential to adopt technology:			Low-Med
Deterrents		High	
Network coverage and quality	Low		
Distribution channels	Low		
Affordability	Low		
Policies & Regulations	Low		
Augmenters		Low-Med	
Environmental sensitivity	Low-Med		
Instant recharge usefulness	Low		
Productivity concern	High		
Device power demand	Low		
Potential to be market leader:			High
Technology threat	Low		
Competitor threat	Low		

Country X does not score high on all the three criteria that make up the market's attractiveness for micro fuel cell commercialization shown in Table 7.1, therefore it should be considered with caution. The table also highlights the weaknesses of this potential market. Tekion should look for other similar developing regions that do not have the same barriers before committing to a marketing plan. This evaluation can be performed for other geographical regions of interest. Adding scores to the rating will enhance the comparison of the attractiveness of this target market relative to other target markets.

8 CONCLUSION

Fuel cell technology has the capacity to displace current battery applications where more power and mobility are desired. Early military adopters' value for the unique attributes of fuel cells has allowed it limited success. Penetration into the mainstream portable power market requires the ability to meet consumers' power needs and establish standards related to the technology. Firms that can assert themselves as leaders in the target market and provide seamless product integration will gain access to larger markets.

New markets have the highest potential for micro fuel cell adoption when targeting consumers that have no access to power grids. Otherwise, in existing markets pursuing the high-end consumers is required. The potential market of non-consumers and the likelihood of dominance by Tekion make Country X attractive. However the presence of adoption deterrents and lack of augmenters makes acceptance low. Tekion should benchmark Country X's valuation with other geographical regions before developing a marketing plan.

APPENDICES

Appendix A: Rural Access to Electricity by Region

Region	Population (Millions)	Access	Increase in population with access to since 1970 (Millions)
North Africa & Middle East	108	35%	27
Latin America	125	40%	32
Sub-Saharan Africa	340	8%	18
South Asia	836	25%	140
China	794	80%	365
East Asia & Pacific	1072	45%	249

Data Source: World Energy Council, 2005

Appendix B: GDP per Capita by Region

Region	GDP (Billions)	Population (Millions)	GDP per Capita
Africa	$592.8	803.7	$738
China	$1,038.9	1,267.3	$820
FSU / Eastern Europe	$821.8	415.8	$1,976
Japan	$4,278.7	126.2	$33,904
Middle East	$627.3	177.6	$3,532
North America	$10,060.5	401.8	$25,039
Other Asia	$1,876.6	1,946.3	$964
South America	$1,172.0	405.7	$20,123
Western Europe	$9,095.8	452.0	$4,919

Source: DOE EIA, 1999

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