Fuel Cells for Portable Power:
Markets, Manufacture and Cost

Revised Final Report (4) for
Breakthrough Technologies &
U.S. Fuel Cell Council
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Section I:

1.1 Introduction

This project analyzes the potential markets, manufacture and cost of fuel cells for portable power applications. The Revised Final Report provides:

(1) Updates and changes to the First Phase report, based on feedback from the Fuel Cell Council;
(2) Updates and changes to the Second Phase report, based on feedback from the Fuel Cell Council; and
(3) Updates and changes to the Final Phase report, based on feedback from the Fuel Cell Council.

All three of these phases have been incorporated into one Final Report, with redundant information eliminated.

With the above structure in mind, this Final Report presents:

(1) An analysis of fuel cell development for portable power, including a competitive overview of major fuel cell developers and suppliers; a look at batteries versus fuel cells; technology assessment; and cost reduction opportunities. The competitive section breaks down the major fuel cell developers by (1) those companies focused on portable fuel cell applications; and (2) companies focused on developing fuel cell materials, components and fuels.

    Fuel cells are assessed relative to the battery (or battery charger) technologies they are expected to replace, specifically Li-on and Li-polymer. Since pricing is a critical factor in whether fuel cells can displace current battery technologies or wall-plug chargers, an historical perspective is given for both Li-ion and Li-polymer batteries. Polymer, in particular, is a recent example of a new technology expected to replace Li-ion, as well, so particular attention is given to this chemistry.

    System technologies and electronics are also discussed, since advanced systems with "power-hungry" features are expected to drive the need for advanced energy storage solutions. Materials availability and cost, system needs, and applications are discussed. An assessment of fuel cell system architectures is presented – in particular, looking at "hybrid" systems such as ultracapacitors and fuel cells, along with fuel considerations.

    Cost reduction opportunities are examined from two perspectives: (1) by stack (materials-based, design-based and manufacturing-based); and (2) by system (design-based, manufacturing-based, and fuel packaging/distribution-based). In addition, the relevance of these cost reductions to larger fuel cell systems is also discussed.

(2) A detailed and quantitative analysis of potential markets and applications for fuel cell portable power products. Forecasts for the worldwide Total Available Market (TAM) are broken down by applications: Portable Power Units/Battery Chargers, Camcorders, Digital Cameras, Mobile Phones, Notebook Computers and PDAs. Fuel Cell Adoption (potential Served Available Market) forecasts are broken out for each region (Worldwide, North America, Europe and Asia) and are provided for dollars, units and pricing, with an additional Portable Power Unit/Battery Charger forecast. Both “aggressive” and “conservative” forecasts are given for each application.

Estimates of adoption rates (penetration rates), price elasticity (including pricing assumptions), and the fuel cell “learning curve” are among the factors discussed in detail, including the resulting market share that can be expected at different price points. This discussion also focuses on the role of “early adopters,” timing/growth potential, parameter sensitivity, and other relevant factors.

(3) An analysis of product/application matches, technical approaches and consumer experiences that are pertinent to the commercial introduction of fuel cell systems for portable devices.

(4) Finally, implications of all the above findings are presented in the form of “Recommendations for Successful Commercial Introduction of Fuel Cells for Portable Devices.”

1.2 Purpose, Scope & Methodology

The fundamental purpose of this research study is to provide Breakthrough Technologies and the U.S. Fuel Cell Council with an evaluation of portable power markets for fuel cells. The study identifies and quantifies selected portable power markets for fuel cells under 1kW, evaluates the potential of fuel cells to compete in these markets, suggests high-priority market areas for fuel cell developers, evaluates market sensitivity to cost and identifies cost reduction pathways likely to result from successful pursuit of portable power markets. The ultimate goal of this independent project is to pinpoint the areas of greatest market potential and evaluate the impact of successful market penetration on fuel cell stack and system design, cost and consumer acceptance.

The first portion of this report presents an analysis of the status of Fuel Cell development for portable power and encompasses the major suppliers and developers, as well as the significant technology variations, strategies and fuels. Pricing and cost reduction opportunities are quantified for fuel cells from both an historical perspective, as well as future pricing targets. This includes an analysis of the potential worldwide market for fuel cells in selected portable application segments, including an analysis of pricing, demand, production estimates and market share.

The data presented in this report are for the Total Available Market (TAM) and the Potential Served Available Market (SAM). The data are derived from a comprehensive study of the Asia, North America, and Europe markets where premium battery packs would be used in portable devices, and the end users likely to initially adopt these technologies. The detailed forecasts are based on primary data gathered in discussions with system OEMs and manufacturers of portable, rechargeable battery packs in Asia, North America and Europe. All OEM consumption data were gathered on a confidential basis.

To this end, the following forecasts are provided:

(1) Worldwide historical pricing for Li-ion and Li-polymer battery packs, by application. Forecasts give Average Selling Prices (ASPs), Projected Price Declines, Projected Market Share and Price Elasticity.

(2) Estimates are also provided for Worldwide Pricing of Li-polymer and Fuel Cells, by both ASPs and $/W.

(3) The Total Available Market (TAM) for selected portable products, including Mobile Phones, Notebook Computers, PDAs, Camcorders and Digital Cameras. Forecasts are Worldwide and are broken out in units.

(4) Specific sub-segments of demand are identified as Fuel Cell Adoption Forecasts (potential Served Available Market/SAM). Each forecast is broken out regionally, by application and includes dollar sales, unit sales, and average selling prices. A discussion of the "target price" is included, which is the point at which fuel cells must "cross over" from a niche product to the "Early Majority" mainstream market.

Two forecasts are provided in this revised report: An "aggressive" forecast that provides the pricing needed, and the market share that will result, to achieve mainstream commercial production by 2009. These are not traditional forecasts in the sense of providing a projection of fuel cell adoption into these segments. They are the "path" fuel cell makers will have to take to achieve an aggressive penetration into the portable system market.

The "conservative" forecasts provide projections of fuel cell adoption based on current fuel cell development and projections by both OEMs and fuel cell manufacturers. This is not a "path to commercial production." It simply represents when development and initial product introductions are likely to take place, assuming no ultimate date as the "goal" of commercial profitability.

For the aggressive forecasts, our methodological premise assumed that an emerging technology/product (an economic "substitute") must break out of the "Early Adopter" segment and enter the broader market if it is to become a commercial success. This detailed methodology employs the concepts of the learning curve, the cross price elasticity of demand between the emerging/substitute and existing products, and the anticipated rate of price decline for the existing products as the basis for the development of sales forecasts for emerging technologies. This methodology is designed to identify critical pricing levels that must be achieved during the commercialization process and initial product introduction. These critical pricing levels must be achieved or the product will likely fail in the marketplace or, at best, be limited to the status of a "niche" technology. Based on the assumption that the critical pricing levels can be achieved, this methodology produces unit and dollar sales forecasts and a "technology adoption roadmap" for the emerging technology.

The *learning curve* is defined as the (constant) rate at which the production cost for a given product declines each time cumulative unit production volume doubles. The learning curve can be used to predict pricing levels for products based on a specific sales forecast.

The *cross price elasticity of demand* is defined as the percentage change in unit demand for a product in response to a change in relative prices between the emerging/substitute product being forecast and an existing product. In the case of emerging/substitute products, the cross price elasticity of demand states that consumption of the emerging/substitute product rises as its price premium versus the existing product declines. [Note: if the cross price of elasticity is zero or negative, the products are called "complements," and the emerging technology will not displace the existing technology in the market.]

The cross price elasticity of demand can be used to produce a "demand curve," which describes the sales volumes for an emerging product at a series of "relative" pricing levels compared with prices (or anticipated prices) for the existing substitute product. Cross price elasticity of demand provides a tool for estimating the market penetration rates of the emerging technology at prices higher than the general market price for the existing/substitute products.

Certain primary data were obtained from non-proprietary Darnell Group studies that used "open questionnaires" with telephone and in-person interviews. All interviews were conducted using a questionnaire, with detailed written notes. Interviews were also conducted at various trade shows. The interviews conducted at trade shows were typically performed in a more informal atmosphere and were generally very successful in gathering good quantities of hard data and insights from the individuals being interviewed. The data were used in combination with the responses from all other respondents.

For the "conservative" forecasts, a series of interviews was conducted of system OEMs and fuel cell makers. The interview process used was as follows:

(1) A selected group of individuals knowledgeable about fuel cells at various system manufacturing companies and fuel cell manufacturing companies was provided to Darnell Group by the Fuel Cell Council.

(2) After eliminating individuals who no longer worked at the companies, 11 people were contacted via e-mail and phone. All individuals were e-mailed the "assumptions matrix" (Exhibit 29, below) showing the assumptions to be used for the market survey.

(3) Of the 11 individuals contacted, three did not return either phone calls or e-mails. Of the remaining eight, two agreed to provide information but did not return the survey and/or have time for the interviews before this report was completed.

(4) One company asked for complete confidentiality, but represents a first-tier computer manufacturer. Another company was a mobile communications and computing battery packs, first-tier OEM. The remaining individuals did not want to be identified by name, but agreed to their companies being mentioned: Palm, IBM, Apple, and Smart Fuel Cell.

(5) Two companies (IBM and Apple) wished to complete the survey via e-mail. The remaining individuals were interviewed over the phone. Appendix C provides the survey questions and responses as completed by the interviewer.

The data gathering methodology included primary research and data collection for North America and other regions. Secondary research was performed using all available published sources including, but not limited to, all available trade journals, proceedings from related trade conferences, previous industry studies, annual reports, 10Ks, advertising, product literature, and so on.

By employing multiple primary and secondary information sources and using various forms of primary information-gathering techniques, all results were cross-correlated and tested for reasonableness. In addition, the thorough and appropriate use of statistical analysis techniques insured that the conclusions drawn from this report accurately represent the surveyed markets. The Darnell Group believes that this combination of thorough and detailed data gathering, together with the use of sophisticated statistical analysis, has yielded a high degree of accuracy.

Darnell Group forecasts are constructed from the "top down." Methodologically, top-level numbers are the most verifiable, consistent and least open to interpretation. Bottom-up "surveys" of key manufacturers have been used only for purposes of validation, not for developing specific forecasts. Using this methodology, regional breakdowns, product categories, power levels and end users can be predicted with a high degree of accuracy. As a result, Darnell Group forecasts are not based on the "self-report" of companies, which have a low rate accuracy and are considered the least reliable statistically. No forecast is meaningful without an accompanying analysis, which provides detailed insights into the trends behind the numbers.

These forecasts are a reflection of Darnell Group analysis of end-market product and technology trends and the effect those trends will have on sales of fuel cells. They are based on top-level sales forecasts, not regional production forecasts. Darnell Group is confident that this detailed methodology has produced the most accurate forecast possible for this analysis of the potential Worldwide market for fuel cells.

Section II: EXECUTIVE SUMMARY

2.1 Major Suppliers and Developers

- Most fuel cell companies are not true "manufacturers" in the sense of developing, manufacturing and selling commercial products. At this stage, companies have prototypes, limited manufacturing, or partnerships with the government or companies to provide fuel cells for their products. Other companies are larger OEMs who are already in the portable device or battery business.

- Materials, components and fuels represent a significant portion of fuel cell design and manufacturing costs, so companies who provide these products are critical to how the industry will unfold.

2.2 Batteries versus Fuel Cells

- Successful commercialization of fuel cells is often predicated on the assumption that current battery technologies are not "up to the task" of future portable electronic devices. But this assumption is not necessarily correct, because these systems may not necessarily need more batteries.

- Semiconductor companies are developing ICs that use existing battery technologies more intelligently. They are designing power management products that push the energy envelope, and their overall philosophy is, "Don't worry about the battery – we can find a way to deal with it." These developments in semiconductor electronics will help keep current battery technologies competitive, even with the increasing energy demands of portable electronic devices. Semiconductor companies see fuel cells as "pie in the sky." They believe that any problem with battery power management can be addressed by semiconductor technology.

- Because OEMs of consumer electronics products compete in a low margin business, they are particularly sensitive to component pricing. Therefore, fuel cell pricing vs. batteries will be an important penetration consideration. A useful scenario for comparison is the introduction of Li-polymer batteries, which were also promoted as an alternative to Li-ion batteries. Overall, Li-polymer has not offered lower pricing or enough value-added features to totally offset its high prices. Therefore, polymer has not taken significant market share away from Li-ion.

- In Darnell Group's 1999 report on the Worldwide Battery Pack market, the average selling price for a Li-ion battery pack for a mobile phone was $13.59; a Li-polymer pack was $16.39 – a price premium of about 21%. For notebook computers, the Li-ion battery pack ASP was $60.39, and the Li-polymer ASP was $79.77 – a slightly higher price premium of 32%. Three years ago, Li-polymer prices for these applications were expected to drop by about 14% per year, bringing their price premium over Li-ion to 11%-17% by 2004. This did not happen, and as a result, Li-polymer "failed" in the marketplace – at least as a serious competitor to Li-ion.

- Pricing of these batteries may be poised to drop considerably. In July, 2002, battery manufacturers Samsung SDI, LG Chemical and SKC (all in Korea) announced that they were planning to make "large investments" in lithium-polymer battery technology. This means lower prices for Li-polymer, which means even lower Li-ion prices and increased pricing pressure on fuel cells.

- For fuel cells to be successful, they will have to deliver meaningful value to OEMs and consumers vs. Li-ion and Li-polymer batteries. Also, fuel cell manufacturers cannot focus on the current price of Li-ion or Li-polymer; pricing is a moving target, and with commercialization a few years off, the pricing goals would have to meet projected lithium prices in the 2004-2005 time frame for an "aggressive" forecast. That means a Li-polymer battery for a mobile phone will have an ASP (OEM price) of $8.14-$10.20, while a notebook battery will be around $47.34-$73.02.

- Certain factors will come into play when considering the value of fuel cells vs. batteries, including how portable devices are used; new devices with increased battery needs; new battery chemistries; and determining the "functional equivalence" of batteries versus fuel cells.

- The adoption of 3G is a factor that could make fuel cells a more attractive alternative to batteries because it is generally believed that today's batteries will not provide the needed energy density for these devices. Currently, 3G is mired in the global telecommunications crash; but as a standard, it is expected to be adopted eventually. The date keeps getting pushed out (estimates are now being put at 2005), but this could coincide nicely with the widespread commercial introduction of fuel cells. Even though 3G-enabled phones have been used on a limited basis in some parts of the world (such as Japan), this is a future market opportunity for fuel cells.

- Materials availability and cost are critical to any discussion of fuel cell cost reductions. Present fuel cell prototypes often use materials that are in limited supply and therefore expensive. However, one of the drivers behind the recent emergence of fuel cells has been that platinum and ruthenium content has been reduced over the years of recent fuel cell technology development. But even if these materials are reduced, the cost of a fuel cell system will still be initially higher than batteries.

- Cost reductions are needed in all areas, not just membranes and catalysts, where many developers focus. For this reason, some researchers believe it may be difficult to attain sufficient market share to justify the investment for mass production while competing against established technology. For the portable market, going after "hybrid" systems that require higher energy densities and utilize fabricated techniques developed for the semiconductor industry could prove more successful.

- Fuel cell companies need to show a solution to current regulatory limitations. Safety standards and regulations currently exist that make fuel cells legal in the passenger compartment of planes, but 100% methanol fuel can only be loaded on planes as cargo, not checked baggage or in the cabin. The recent DOT ruling on Polyfuel's request that their fuel be allowed in cabins (<24% methanol and 50% water) is based on the percentage of fuel on board, and other percentages might find acceptance in the future. It is expected that weight and quantity limits will be established in the future.

- If fuel cells are positioned to compete with batteries, the best applications are those which are high-value, or those where the benefits of the fuel cell outweigh the costs. Lithium-ion has a stranglehold on the consumer electronics market, and semiconductor makers are actively finding ways to make batteries work more efficiently with consumer devices. Fuel cells could also target portable applications that are used in high-cost environments that are less price sensitive, such as auxiliary power units (APUs) used with commercial or residential photovoltaic systems.

2.3 Technology Assessment

- Platinum loading is necessary for power density, yet it represents a significant increase in cost. If platinum can be reduced with only a reduction in peak power, however, system architectures can be altered to make up the power loss. For example, Maxwell Technologies is collaborating with Avista Labs and several other companies to incorporate ultracapacitors into fuel cell system designs to augment the peak power requirements. T/J Technologies also announced a project in which they would design, assemble and test a power pack for portable electronics that integrates ultracapacitors with fuel cells.

- Methanol, possibly in aqueous solution, appears to be leading as the fuel of choice for development of portable fuel cells. Also, Japan's Ministry of Economy, Trade and Industry has chosen it as the "likeliest way of supplying hydrogen for small fuel cells." However, other fuels that may be safer, and therefore, avoid some of the regulatory pitfalls are in the race to fuel small fuel cell powered devices.

- When considering the potential commercial success of an emerging technology, it is useful to look at previous technology introductions and what made them successful. Industries tend to operate like the industry that came before, and in the case of fuel cells for portable applications, the lithium-ion battery industry is the best model. When portable, rechargeable Li-ion batteries were first introduced commercially, they were marketed as substitutes for NiMH batteries. Looking at the price differential between Li-ion and NiMH in 1995, Li-ion was twice as expensive as NiMH, but it was still successfully introduced because it delivered significantly higher energy density to meet the power demands of an increasingly power-hungry new generation of mobile computing devices.

- Fuel cells could enable the universal connectivity of wireless devices, such as notebook computers and 3G phones. Currently, these devices cannot be wirelessly connected to each other very well because of their limited battery life. Such connectivity requires a lot of power, which fuel cells could provide. The early adopters of these devices will, in essence, be the road warriors of "mobile connectivity." And that will raise one of the biggest challenges for fuel cell manufacturers: channels of distribution.

- Fuel has to be convenient and readily available – anywhere. The road warrior/early adopter could be in Europe, Asia or South America. Fuel cell companies will have to establish distribution channels (or team with companies who have them) to enable mobile connectivity.

- Because of their higher cost, fuel cells need to target markets where batteries cannot "do the job." 3G phones and other "convergence" devices may eventually need the energy density of fuel cells, but current mobile phones do not. Demand for 3G and similar phones is not expected to be significant for several years, at least. So the potential market for fuel cells in mobile phones and convergence devices is considered a longer-term opportunity.

- Total cost of ownership (TCO) could pose a hurdle for fuel cells, due to the value pricing of fuel. Consumers can basically recharge their batteries for portable devices for free. Refilling a fuel cell cartridge requires the extra expense of buying fuel. And fuel can go up in price. The long-term cost of using a fuel cell could, potentially, be higher.

2.4 Cost Reduction Opportunities

- Materials development is critical to the commercialization of fuel cells. The most promising materials are expected to be metal catalysts, carbon/graphite, polymers and ceramics.

- Membrane electrode assemblies (MEAs) are considered the largest single contributor to cost of a fuel cell. Materials costs account for about 50% of MEA cost.

- Fuel cells typically use platinum at both the anode and the cathode. The Department of Energy (DOE) indicates that platinum catalyst loadings for hydrogen fuel cells have been reduced by over a factor of ten, with only a 30% reduction in peak power. But demand for platinum is expected to increase dramatically over the next 10 years. The automotive industry accounts for about 80% of the industrial uses of platinum each year (mainly in catalytic converters), and the demand for platinum in fuel cell technology is projected to be three to four times greater than that for catalytic converters. Fuel cell vehicles, in particular, pose a particular threat to the world supplies of platinum, which will be reflected in other fuel cell applications.

- A long-term materials consideration is recycling. Although currently there are no requirements for recycling platinum, efforts will be initiated for platinum in the same way that lead-acid batteries need to be recycled. This will be more for economic and production reasons than for environmental reasons.

- Thermoplastics and high-temperature polymers can provide fuel cell system cost reductions in the same way that plastics have replaced metal over the years. But the increasing demand for these materials in fuel cells could result in cost increases. Competition from other high-growth industries for thermoplastics and high-temperature polymers could keep costs higher until production catches up with demand.

- Looking at fuel cell design, companies are considering different ways to reduce costs. Plug Power is looking at materials substitutions, component elimination and specification changes that result in lower-cost parts. Manhattan Scientifics believes that the distances between bulk conductors in a fuel cell need to be as short as possible to reduce costs. Motorola is trying to integrate the fuel processor into the stack, where microfluidics, mixing and pumping can all take place within the ceramic structure or stack itself. Protonex found that exploiting patented technology reduces stack costs.

- For Plug Power, volume increase is a combination of volume price breaks and changes in manufacturing methods that are driven by volume, such as molded versus machined parts. Protonex has found that using DuPont's Nafion™ PEM and available gas diffusion layer, catalyst and off-the-shelf sealants, production requires minimal labor.

- At 10W and above, fuel cell system manufacturing is particularly costly. Protonex's manufacturing process uses low-cost molds, and as they scale up, their process is injection-molding-compatible. Minimal tooling is a way to lower production capital.

- Using low-cost materials and keeping a fuel cell design as simple as possible is critical to keeping it as affordable. This means using low-cost manufacturing processes, off-the-shelf components, and already-existing materials that are likely to remain in strong supply.

- Initial cost is key to commercializing fuel cells, so having the lowest price will be key for any company wanting to be "first to market." Japanese companies like Toshiba, NEC, Sony, Casio, Samsung, Sanyo, Panasonic and Hitachi have announced technical achievements and prototypes and have projected fuel cell production, but not all of these companies make batteries. Panasonic, Sony, Sanyo and Samsung have Li-ion manufacturing and distribution systems in place; the remaining companies have Li-ion manufacturing capabilities. But Toshiba, Casio, NEC and Hitachi are not considered "players" in the Li-ion business. For those that are, Japanese companies could be very competitive on price.

- Commercialization experience in the product area fuel cells are expected to replace is important. Volume manufacturing is key to reducing costs, along with worldwide factory locations. Since many fuel cell companies do not have these capabilities, they need to consider partnerships with companies that do.

- A vertical business model is one way to reduce costs with an emerging technology. Panasonic's model includes: OEM relations; sales and distribution channels; relations to potential internal customers; mass production capability; commercialization experience; worldwide factory locations; brand name; and battery and/or capacitor production for fuel cell hybrids.

- Looking at the relevance of portable fuel cell system cost reductions to larger fuel cell systems, the latter must compete with battery products for stationary applications, such as industrial NiCd batteries. SunTrust Robinson Humphrey, a venture capital firm, believes that the value of back-up power is nearly high enough to support fuel cell systems.

- Fuel cell vehicles could pose a significant threat to the world supplies of platinum, with increased demand slowly raising platinum prices over the next century.

2.5 Portable Power Market Forecasts

- Our fuel cell market forecasts are built from the OEM markets for batteries in electronic devices. We feel that fuel cells have the greatest potential powering devices that are currently using "premium" rechargeable batteries – Li-ion and Li Polymer types.

- The largest potential market for fuel cells is Mobile Phones, representing 86% of applications in Europe, 85% in Asia, and 76% in North America in 2002. This dominant market share will persist over the five-year forecast period, although it will decline in all regions to 83% in Asia, 79% in Europe, and 65% in North America. This is due to a relatively slow, overall Worldwide compound annual growth rate (CAGR) of just 8.0%.

- Notebook Computers is the second-largest potential market for fuel cells, but its market share is significantly lower than Mobile Phones. Still, Notebook Computers is expected to gain market share over the forecast period in all three regions. North America is the largest market, with Notebook Computers holding 13% share of this region's premium battery market in 2002, increasing to 14% in 2007.

- Other important segments (Camcorders, Digital Cameras and PDAs) are small but fast-growing. Of these applications, PDAs present the best opportunity, with the largest market share of the three in 2002. North America, in particular, is expected to be a good market for PDAs, with 6% market share in 2002, increasing to 10% in 2007. PDAs will have the second-fastest growth rate of 24.8%, as well. In this region, PDAs will grow from 6.3 million to 19.1 million units between 2002 and 2007.

• Camcorders and Digital Cameras will remain smaller, “niche” markets for premium batteries. In 2002, about 50% of Digital Cameras are still expected to use NiMH batteries, so the penetration of premium batteries into this segment will lag behind Mobile Phones, Notebook Computers and PDAs. Only high-end Digital Cameras are expected to be good candidates for fuel cells.

• Camcorders are not expected to use Li-polymer batteries in significant numbers at all during the forecast period. Although the number of Camcorder units using Li-ion batteries is larger than Digital Cameras in 2002, many Camcorders still use NiMH and NiCd batteries. Like Digital Cameras, only higher-end, professional-level Camcorders are expected to be good candidates for fuel cells.

• Handheld gaming devices, portable DVD players and other consumer devices typically use nonrechargeable, alkaline batteries. These products are not good candidates for a premium battery, such as lithium-ion, since they are inexpensive and often replaced before the extra cost of a premium battery would pay for itself. As such, we do not believe they are good candidates for fuel cells, either, where the price premium is even higher.

• Consumer battery chargers are a “niche” product; the cheaper, mass-produced models use alkaline batteries. Consumer battery chargers are facing cost pressures, with prices for these chargers and adapters dropping the fastest in the <5W segment. Battery charger manufacturers are taking a “wait and see” approach to using fuel cells, and the companies we spoke to did not indicate any interest in them. Furthermore, retailers such as Ritz Camera have indicated they are not planning to offer Electric Fuel’s zinc-air fuel cell battery charger.

• Portable Power Units/Battery Chargers for industrial/military applications could be a good market entry opportunity to provide a “transition” to larger portable markets. This segment is expected to exhibit many of the characteristics of Early Adopters, in terms of its small size and relative price insensitivity. Even though the unit market is small, it is still a potentially large dollar market, growing from $346 million in 2004 to $501 million in 2009, a compound annual growth rate of 7.7%.

• Fuel cells are expected to penetrate all the application segments by 2005, with the exception of Camcorders, which fuel cells will penetrate by 2006. Notebook Computers and PDAs are projected to have the “highest” initial penetration rates of 0.8%, but this is relative. For all five application areas, the initial penetration rate is expected to be under 1%.

2.5.1 Aggressive Forecasts

• The Fuel Cell Adoption (potential SAM) forecasts are “aggressive” forecasts based on a number of important assumptions, including user adoption rates, the learning curve, first premium pricing, target price premium, production start quantity, medium-term price decline, long-term price decline, and key “demand suppressants.”

- The forecasting methodology is valid for “substitute products” only, i.e., fuel cells are a product expected to replace an existing product, with sales of fuel cells reducing sales of battery products. Battery chargers are not substitute products but rather are a “complementary” product to batteries. But since they are an added cost to a battery system, fuel cells can be introduced with a higher price premium for products that also need battery chargers.

- The “crossover” year for fuel cells in the SAM forecasts is 2006. This is the point at which fuel cells must cross over from Early Adopters to Early Majority in order to reach “significant market penetration” and enter the mainstream. At this point, the “target price” for each application area should be achieved.

- The demands of 3G are expected to push the power capacity of batteries enough to make fuel cells a desirable alternative for Mobile Phones. The price of these handsets is also expected to be high enough to “absorb” the price premium of fuel cells, at least initially.

- Mobile Phones represent the largest potential portable market for fuel cells between 2004 and 2009, in every geographical region. Europe is expected to hold the largest market share of potential fuel cell unit sales, at about 40% in 2004, declining slightly to 39% by 2009. Asia’s unit market share will increase slightly, from 32% to 33% between 2004 and 2009, while North America’s remains constant at 28% over the forecast period.

- Worldwide, fuel cells could account for 8.6 million unit sales for Mobile Phones in 2004, increasing to 463.8 million in 2009, a CAGR of 122.1% – if the right price points are achieved. Using this forecast model, fuel cells would potentially penetrate just under 89% of the total available worldwide unit market by 2009.

- Fuel cell pricing can actually start out relatively high for Mobile Phones ($21.49 per unit), which would produce worldwide revenue sales of $185 million. To successfully emerge out of its niche status, pricing will have to drop at a rate of 22.7% per year, reaching an average selling price of $8.68 in 2006. By the end of 2006, this price should be down to about $8.15. The “target price” for fuel cells in 2006 is $8.17.

- Fuel cells could enable “mobile connectivity” and “always-on” notebook computers. And because of the high pricing in the Notebook Computer segment, a higher-priced fuel cell is easier to justify. For these reasons, Notebook Computers will be the second-largest unit market for fuel cell adoption.

- North America is projected to hold the largest market share in Notebook Computers, growing from 40% to about 45% between 2004 and 2009. And due to higher ASPs, the overall revenue from these sales could potentially reach $687 million by 2009. Worldwide, dollar sales could grow from $80 million in 2004 to $1,547 million in 2009, a compound annual growth rate of 80.7%.

- The Notebook Computer segment potential forecasts and target pricing were based on only battery pricing, not on both battery and battery charger pricing, like the other segments. This is due to the way Notebook Computers are used: Unlike chargers for Mobile Phones and many other portable devices, the Notebook charger performs also as a power adaptor to power the computer from AC outlets. Therefore, we expect that even fuel-cell-compatible computers will ship with chargers/power adaptors. Pricing for fuel cells in Notebook Computers need to decline by about 22.8% per year, from $77.88 in 2004 to $21.41 in 2009, with the target price of $31.30 being achieved in 2006 in order to win the Early Majority.

- The PDA unit and dollar markets are the largest in North America and the smallest in Asia. North America will increase in unit market share from 40% to 55% between 2004 and 2009, while Asia shrinks from 20% to 8%. This is partly due to the larger Mobile Phone market in Asia, relative to North America. Mobile Phones in Asia are expected to have many of the features currently used in PDAs, while the latter are still expected to be a separate product in North America throughout the forecast period.

- The target price for PDAs in 2006 is $15.79, which is somewhat higher than the battery competition price of $13.16. This is because fuel cells will help enable the increased functions of handheld computerized devices, making their higher price somewhat justified. Fuel cell pricing for PDAs will need to decline 21.8% per year, from $39.42 in 2004 to $11.54 in 2009.

- North America and Europe represent the largest markets for Digital Cameras, with both being somewhat equal in size in terms of dollars and units. North America's unit market will grow from 0.1 million to 16.1 million between 2004 and 2009, a CAGR of 165.5%, while Europe's unit market grows from 0.1 million to 16.0 million during the same period. These units are professional-level digital cameras, not consumer models.

- Looking at potential revenue, North America will increase 105.7% per year, from $4 million to $137 million between 2004 and 2009. In Europe, this market will grow from $3 million to $133 million during the forecast period, a CAGR of 115.1%. To achieve these sales, pricing must decline at 22.4% per year, from $30.28 in 2004 to $8.52 in 2009. The target price in 2006 is $12.06, which is slightly above the competitive battery technology price of $10.05.

- Camcorders is the smallest portable market for fuel cells of the five application segments. Like Digital Cameras, these units are professional-level camcorders, not the less-expensive consumer models. As such, the total Worldwide unit market for fuel cells is only expected to increase from 0.3 million to 23.7 million, which is a very high growth rate of 134.8% because of the very small starting base. Although regional market share will start out equal due to this small base, most of the sales will occur in North America. By the end of the forecast period, about 51% of the unit sales will be in this region.

2.5.2 *Conservative Forecasts*

- The Targeted Fuel Cell Adoption forecasts are "conservative" forecasts, based on later introduction dates, slower price declines, and smaller market penetration than the previous "aggressive" forecasts. These forecasts are based on interviews with portable system OEMs and portable fuel cell manufacturers (the complete set of questions and assumptions matrix are given in Appendix C).

- Using the assumptions data presented in the matrix, the interview respondents felt that increasing the system size and volume of fuel was okay, but if they are much bigger, consumers will not buy the product. For laptops, 15W for fuel cell and battery power was a "bit light," particularly for peak power. A fuel cell charger was considered good for laptops.

- For PDAs, the runtime needs to be closer to 25-30 hours; Palm said they would need 50% more energy than a battery in the same size system. Physical size is very important for PDAs; 4-5mm is the limit for thickness.

- The amount of time OEMs put into product planning varies considerably. For new products and emerging technologies, the cycle can be anywhere from one to four years, with three years being the average. Cell phones and PDAs are typically 18 months.

- Batteries are putting hard limits on system technologies now. Runtime is one of the most important factors to consider. A laptop manufacturer said their research indicated that a 5x better runtime is important for customers to make a change to any new technology.

- For PDAs, worldwide availability and distribution of fuel is the most important issue. Palm said that there must be standardized cartridges, standardized fuel, and worldwide distribution of fuel.

- One computer manufacturer said that laptops were unlikely to put limits on batteries. Intel "would never design chips that push batteries beyond their limits, since they rely on batteries to run the products their chips go into. They would not assume that something new (like fuel cells) would replace batteries.

- Fuel cell chargers were generally viewed in a positive light. Pricing could be slightly higher for these, as well. Mobile chargers, not stationary chargers, were emphasized. Fuel cell chargers could also reduce risk for OEMs, since the system remains separate from the charger and any associated problems. On the other hand, portable chargers are considered an "extra" device, not a "necessary" device. Wall plugs are too accessible, and free. One interview respondent felt fuel cell chargers would only be used by "wilderness remote users," but this could include business users at remote field sites, such as construction, oil fields, and so on.

• The conservative forecasts assumed a later introductory date of 2006, with the forecasts extending to 2011. Most interview respondents felt that market introduction would occur around 2004, but wider acceptance would not occur until 2006-2007. Market penetration rates were projected to be between 0% and 20% in 2005; and 0% to 50% by 2008.

• Worldwide, unit sales of Portable Power Units/Battery Chargers will be small – about 100,000 units in 2006, growing to about 600,000 units in 2011, a CAGR of 43.5%. But pricing will be higher for these units than for other portable devices, producing a fairly good-sized dollar market of $103 million in 2006, increasing to $352 million in 2011, a CAGR of 27.9%.

• A mobile communications and computing battery packs, first-tier OEM felt that the percentage of cell phones using fuel cells would be 0% in 2005, but this is at a $10.00 fuel cell system price. Cell phones are not considered as good of a market for fuel cells as Portable Power Units, Notebooks, or PDAs. Worldwide, unit sales are likely to be just 8.1 million in 2006, increasing to 30.5 million in 2011, a CAGR of 30.4%.

• In terms of market penetration for Notebook computers, one system OEM said that 10% penetration by 2005 was a possibility, with no more than 30-40% by 2008. IBM, on the other hand, felt that batteries would maintain 100% of the laptop market up through 2008, with fuel cell chargers possibly capturing 2% of the market by 2008.

• In terms of pricing for Notebooks, all respondents felt that the $5.00-$10.00 pricing for a fuel cell cartridge was too high, except possibly for professional users. One respondent said that $3-$4 was probably the highest pricing could go. The $75.00 for the fuel cell system was considered okay. Because of the higher price of the fuel cell system, the dollar market for fuel cells used with Notebooks is the largest of any of the portable devices forecast. Between 2006 and 2011, fuel cells used in Notebooks could grow from $374 million to $1,316 million, a CAGR of 28.6%.

• Palm felt that by 2005, about 80% of PDAs would be battery-powered. “Assuming fuel availability,” by 2008, approximately 50% could be powered by fuel cells. They felt the percentage for fuel cell chargers would be smaller, about 5% fuel cell chargers in 2004, increasing to perhaps 30% by 2007. According to Palm, customers will pay for smaller sizes.

• In terms of unit sales, PDAs are potentially the largest market. The Worldwide PDA unit market is expected to grow from 5.8 million units to 40.9 million units between 2006 and 2011, a CAGR of 47.8%.

• Digital Cameras were not seen as a good market opportunity for fuel cells by the interview respondents. The main problem is that digital cameras can use primary batteries, which are much less expensive. Even $3.00 for a fuel cell cartridge was considered too steep for this market. For this reason, the introductory date for fuel cells used with Digital Cameras was pushed back to 2007. Worldwide, unit sales will only reach 1.5 million by 2011, with the dollar market reaching just $28 million that same year.

- The Camcorder market is expected to follow a similar pattern as Digital Cameras in the conservative forecasts, with a later introduction date and low market penetration. This segment will be the smallest of all the portable applications, both in terms of unit sales and dollar sales. Worldwide, unit sales will reach just 800,000 by 2011, while dollar sales are approximately $17 million the same year.

- The sizes of the served available markets for fuel cells were developed using the terminology of “Moore’s Product Life Cycle”: Innovators, Early Adopters, Early Majority, Late Majority, and Laggards. The Innovators group is small (about 5%) and has an inelastic demand for new technologies. The Early Adopters are a more demanding group but still have a relatively inelastic demand; they are also a much larger group, typically about 12% of the total market.

- The Early Majority has a more elastic demand than the Early Adopters, but typically accounts for over one-third of the overall market. One of the most critical events in the successful commercialization of an emerging technology is the expansion of the SAM from the Early Adopters to also include the Early Majority. If the SAM cannot be expanded to include the Early Majority segment, the technology will be trapped in a market niche, or could disappear from the market altogether.

- Setting an appropriate “target” price is necessary to ensure successful commercialization, and this price is different from the initial “introduction” price that gets the technology accepted by the Innovators and Early Adopters. Keeping the product target price at the same level that was successful with the Early Adopters may doom fuel cells to niche status or (if the price is much too high), the technology will fail in the marketplace.

- Once sales have started, the “learning curve effect” comes into play. The learning curve states that every time cumulative production doubles, pricing declines by a given percentage. This occurs only after the technology has reached “full manufacturing” status. It cannot be applied to units produced in the lab or to pilot production lines.

- Fuel cells will only reach full commercialization when both process control and manufacturing development are achieved. A fuel cell company can have batch production with relatively high yields, but such production is still not at levels efficient enough to bring prices down in the long run.

- Successful commercialization of fuel cells depends on multi-dimensional factors, starting with the initial, maximum price premium; the price elasticity for the product and the market share to be captured as the price premium comes down; manufacturing production and how pricing will decline relative to production yields; the point at which price declines open up new markets beyond the early adopters (so-called “price points); and the “critical market share percentage” that determines the product has successfully penetrated the market. Some of these factors occur sequentially and some occur simultaneously.

• Fuel cells do not have to be priced the same as lithium batteries. Even after volume production was achieved, lithium remained a higher-priced chemistry than nickel-metal hydride because they increased the performance and functionality of mobile computing devices. Fuel cells are expected to increase performance of 3G phones and "interconnectivity" devices, which gives them increased value and justifies prices that are higher than lithium batteries.

• The price reductions given in this report represent fairly significant fuel cell unit volume at a high price premium at the beginning of the forecast period. Also, these pricing numbers represent an aggressive forecast that must be achieved for successful commercial introduction of fuel cells by 2004. For example, in 2004, a 2W fuel cell for a Mobile Phone is expected to be $10.75/W or $10,750/kW. By 2009, the cost will come down to $2.96/W or $2,960/kW. A 16W fuel cell for a Notebook Computer is expected to be $4.87/W or $4,870/kW in 2004, declining to $1.33/W or $1,330/kW in 2009. Even though the costs are still high in 2009, the declines are significant, and this cost reduction path will be similar for fuel cells used in electric vehicles – perhaps even steeper declines. This is because a larger fuel cell is relatively less expensive, but the relative reduction in cost is greater at the kW level.

2.6 Summary of Findings

• Reducing materials costs is one of the critical challenges facing successful commercialization of fuel cells. This includes finding ways of lowering costs with existing materials, as well as developing new technologies that will reduce costs.

• Ultimately, platinum is not necessarily a showstopper for fuel cell commercialization. Platinum reduction is necessary, but it does not have to be eliminated. Researchers and companies are creating catalysts that could allow the production of cheaper and more efficient fuel cells, and reducing the amount of platinum present in the catalyst. New materials are being evaluated with low platinum content.

• Another approach to reducing fuel cell costs is nanostructured materials for advanced energy storage devices, including fuel cells. Carbon nanotubes, conductive plastics and catalyst layers are a few of the areas under investigation.

• With transportation as the DOE's long-term fuel cell goal, transfer of micro fuel cell technology to transportation fuel cell technology is important. Operating temperature is a critical characteristic for transportation fuel cells, as well as the need for quick start and thermal insulation requirements. Operating temperatures for portable fuel cells are lower than those required for transportation applications, so for portable fuel cells to provide a successful commercial path to fuel cells used in automobiles, inexpensive, durable and higher performance membranes will be needed that can operate at temperatures exceeding the 80°C.

- Currently, fuel cell cartridges are being considered in both replaceable and refillable forms. Consumer acceptance of fuel cells for portable devices such as cellular phones may depend on using refillable cartridges rather than replacement cartridges. Consumers might want to purchase the fuel separately, much as they buy butane fuel in canisters to refill cigarette lighters. Plus, costs will need to be the equivalent of just pennies per refill. Such fuels as methane will need to be available anywhere in the world, just as cigarette lighter fuels are.

- Rechargeable, refillable and reusable alkaline batteries have not successfully replaced NiCds, NiMH and lithium chemistries in notebook, cellular and other portable consumer devices. Alkaline batteries are best-suited for low-current applications, and they perform better in devices such as portable radios and MP3 players than in more demanding ones, such as handheld computers or digital cameras. This is because their purchase price is low, but cost per cycle is high when compared with some rechargeable batteries. However, fuel cells offer the instant energy replacement convenience of alkaline with a higher OEM cost but a much lower cost per watt-hour for fuel. Analyzing consumer response to this type of product vs. rechargeables is a key determinant of fuel cell penetration.

- An important consideration with fuel cells is that there is more than one factor driving adoption. High-value applications, new features of devices, less price-sensitive markets, and the ability to bring costs down will all play a part in whether this technology will be successful. At the same time, competing technologies, overcoming technical hurdles in the development of fuel cells, regulatory requirements for transport, small markets that would not produce economies of scale, and the business model of Japanese companies who already have a foothold in the market could pose threats sufficient enough to delay entries into this market.

- "First Tier" opportunities for fuel cells include: Portable Power Units/Battery Chargers; Convergence Devices/Mobile Phones; and Notebook Computers. "Second Tier" opportunities include: Mobile Phones, PDAs/Handheld Computers; Battery Chargers for Consumer Devices; Portable Power Units (generators); and Two-Way Radios (Military). "Third Tier" opportunities include: Digital Cameras; Camcorders; and Portable Audio Devices.

- Of the fuel cell technologies being seriously considered for portable applications, Darnell Group believes the direct methanol fuel cell holds the most promise. They operate in a relatively low temperature range, making them attractive for tiny to mid-sized applications. But issues related to cost and transport regulation need to be addressed.

Section III: MAJOR SUPPLIERS AND DEVELOPERS

3.1 Introduction

This section profiles the major developers and suppliers of fuel cells for portable products. Because there are many companies doing research and development, and so few actual "commercial" suppliers, most of the companies listed here are not true fuel cell "manufacturers," in the sense of developing, manufacturing and selling commercial products. Some companies have prototypes only, or limited manufacturing, or a partnership with the government or a company to develop a fuel cell for their product. Other companies manufacture portable devices and/or batteries, and have a department that is developing fuel cell products for an anticipated future market.

The Components, Fuels and Materials manufacturers include companies like 3M, Chevron/Texaco, Delphi, DuPont, GE Power Systems, and Teledyne Energy Systems, who are materials manufacturers for other industries and are also providing components and materials for fuel cell companies. Since materials and components represent a significant portion of the fuel cell design and manufacturing costs, these companies are key to how the industry will unfold.

Longer profiles are provided for companies that are more or less dedicated to fuel cell development and supply. Companies whose major focus is not fuel cells have shorter profiles, with information presented only on their fuel cell activities. Strategic relationships are a critical step toward profitability for many of these companies, so partnerships are highlighted where appropriate.

The longer profiles include background information on the company, management, partnerships, financial status, employees, manufacturing, products and technology, sales and distribution, research and development, and recent news about the company.

3.2 Portable Fuel Cell Companies

3.2.1 AVISTA LABS

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Background: Avista Labs is the distributed power affiliate of Avista Corporation, an energy, information and technology company whose utility and subsidiary operations focus on delivering products and providing solutions to business and residential customers in North America. Avista Labs is developing integrated, modular, PEM fuel cell products initially for applications in distributed power generation and industrial power backup systems and, on the basis of its intellectual property position, may pursue future applications in vehicle auxiliary power units (APUs) and industrial and consumer electronic devices.

Partnerships: In August, 1999, Avista Labs entered into an exclusive partnership with Chicago-based UOP LLC, an international supplier and licensor of fuel processing technology. The purpose of the partnership is to produce the first modular, integrated fuel cell power plant.

Avista Labs also works with Merrill Lynch to evaluate strategic options as it works to develop and commercialize its fuel cell power system. Additional partnerships include a joint marketing/installation agreement with Black & Veatch; and an agreement with Logan Industries, a Spokane-based contract manufacturing company, which has been manufacturing and assembling fuel cell units for field testing since early 1999.

In June, 2001, Avista Labs selected Maxwell Technologies' PowerCache ultracapacitors to optimize performance and reduce the cost of its unique, modular fuel cell systems and components.

In January 2001, Avista Labs formed a new company, H2fuel, LLC, to develop and commercialize technology for manufacturing hydrogen for fuel cells and other hydrogen applications. Avista Labs owns a 70 percent interest in H2fuel. The remaining interest is owned by Unitel Fuels Technologies, LLC. Avista Labs transferred its ongoing fuel processor development work to H2fuel. H2fuel has two patent applications pending directed to the use of certain catalysts for auto thermal reforming.

Management: J. Michael Davis, CEO; Peter Christensen**,** VP Technology/IP; William Fuglevand**,** VP Research & Development.

Financial Status: Revenue (2001) for Avista Corp's Information and Technology division, which includes Avista Labs and Avista Advantage, was $13.8 million.

Employees: Avista Labs employs 62 people.

Manufacturing: Logan Industries provides manufacturing services for Avista.

Products and Technology: Avista Labs offers the SR-12 PEM Fuel Cell and the SR-72 Fuel Cell System, which "can be shipped within two weeks of a site assessment." The SR-12 is a 500W unit that has air-cooled, low temperature operation; integrated control electronics monitoring; a simple design that eliminates the need for pumps and compressors; and advanced hydrogen sensors for safe start-up and operation. The unit includes hot-swappable cartridges. The SR-12 is designed for back-up power applications at the point of use.

Sales and Distribution: The company has 76 installations in 21 sites worldwide. Avista Labs completed commercial transactions for the sale or lease of 50 units during 2001.

Research and Development: Avista Labs has three patents issued covering over 260 claims, one Notice of Allowance covering more than 300 claims, and 25 patent applications pending covering Modular Cartridge Technology™ in fuel cells, hydrogen sensors, power electronics and fuel processing.

Recent Developments: In September, 2002, Avista Labs announced a strategic supply agreement in which Avista Labs will purchase membrane electrode assemblies (MEAs) exclusively from 3M Company (St. Paul, MN) for integration into its commercial fuel cell products. The agreement enables reduced and competitive product costs, which will immediately benefit Avista Labs customers. 3M will supply MEAs for use in Avista Labs' 250 and 650 Series fuel cell cartridges, which are integral components in the company's Independence™ product line. The terms of the agreement call for 3M to provide Avista Labs with all of its requirements for commercial MEAs through June 30, 2004.

In May, 2002, Avista Labs announced that it had been awarded a patent further protecting its claims of modularity in fuel cell system construction. The new patent is the fifth patent issued to Avista Labs and includes 300 claims covering certain basic control and balance-of-plant systems when used in a modular or multiple fuel cell system. "This new patent adds substantially to the value of our company," said Michael Davis, CEO of Avista Labs. "The key to reliability in fuel cell systems is in a modular approach. When other fuel cell developers build systems that use fuel cells or balance-of-plant components in modular configurations, this patent may require a licensing agreement with us."

In October, 2001, Avista Labs announced that its affiliate H2fuel LLC (Mt. Prospect, IL) was developing new technology that would greatly reduce the cost of producing hydrogen for use in fuel cells. The new membrane-based technology works by eliminating carbon dioxide and carbon monoxide from readily available fuels such as natural gas and propane, thus allowing the production of nearly pure hydrogen. According to H2Fuel President Serge Randhava, this membrane-based approach to the extraction and purification of hydrogen from natural gas or propane is a departure from other methods currently in use, and is expected to be less expensive than other methods. Avista Labs owns a 70 percent interest in H2fuel, with the remaining interest owned by Unitel Fuels Technologies LLC. Avista Labs transferred its ongoing fuel processor development work to H2fuel.

In August, 2001, Avista Labs launched a hydrogen sensor product for fuel cell developers and other hydrogen users. The Avista Labs hydrogen sensor component detects hydrogen in varied applications. Avista Labs believes it is a necessary component for any fuel cell system. "The highly advanced sensor was specifically designed by our team as a fuel cell component when Avista Labs unsuccessfully searched for a hydrogen sensor that would meet our safety, cost and performance specifications. This development, effort and product rollout represent another milestone in the execution of our component strategy and our progress to market," said Avista Labs CEO J. Michael Davis. Avista Labs' hydrogen sensor has received UL recognition under UL Standard 2075.

Also in August, 2001, Maxwell Technologies Inc. (San Diego, CA) announced that its PowerCache ultracapacitors had been selected by Avista Labs to optimize performance and reduce the cost of its modular fuel cell systems and components. Carl Eibl, Maxwell's president and CEO, and J. Michael Davis, Avista Lab's CEO, report that the companies have signed a multi-year agreement and are exploring areas of mutual interest for a broader strategic relationship.

3.2.2 BALL AEROSPACE & TECHNOLOGIES

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Background: Founded in 1956, Ball Aerospace & Technologies Corp. (BATC) is a subsidiary of Ball Corporation. BATC provides imaging, communications, and information systems, products, software, and services to government and commercial aerospace customers. Ball Aerospace develops portable fuel cell systems to offer an effective alternative to batteries or generators for sensors, scanners, video equipment, radio receivers, transmitters, or other electrical devices with power needs from 15W to 1,000W at varying voltages.

Management: Don W. Vanlandingham, President & CEO; David L. Taylor, Sr. VP and COO; Eugene P. Morgan, Sr. VP, Finance and Accounting and Compliance; Douglas C. Neam, VP, Engineering.

Financial Status: $363 million (2000).

Employees: 2,200.

Manufacturing: Along with corporate offices, Ball Aerospace's major development facilities are located in Broomfield and Boulder, Colorado. These facilities comprise resources required for the design, development, and production of state-of-the-art antennas, satellites, cryogenic devices, and electro-optic instruments for commercial, military, and space applications. They reportedly do not do fuel cell manufacturing.

Products and Technology: Ball Aerospace offers two portable fuel cell power systems: the 50 Watt Portable Power System and the 100 Watt Portable Power System. As a fuel option, hydrogen generator technology is available.

Ball's 50 Watt Portable System (PPS-50) is a small and lightweight portable fuel cell power system that supplies 50 watts of power at 12 volts as an alternative to batteries. The PPS-50 generates electricity to power sensors, scanners, video equipment, radio receivers, transmitters, or other electrical devices. The 100 Watt Portable System (PPS-100) supplies 100 watts of power at 24 volts. The PPS-100 is designed to furnish power to charge most rechargeable batteries in the military inventory, and to provide power for electrical systems requiring higher power than the PPS-50 can provide.

Sales and Distribution: Ball Aerospace has offices in North America, Australia and New Zealand, many of which support military/aerospace customers. The Ball Aerospace Pasadena office is a small marketing office used to support west coast customers.

Research and Development: Ball is developing technology to use methanol in fuel cells for commercial applications such as cell phones, personal digital assistants, laptop computers, and other portable or mobile electronic devices. Ball's expertise in the field of balance of plant development ensures that the fuel cells will be optimized for energy density. This means that the weight versus power output will be minimized and the systems will be rugged enough for use in all types of environments.

In September, 2001, a patent for a unique hydrogen generation technology developed by Ball Aerospace & Technologies was granted by the U.S. Patent and Trademark Office. Patent number 6,274,093 is entitled "Self-Regulating Hydrogen Generator." The invention encompasses a portable apparatus for generating hydrogen using a reactant having a positive vapor pressure when at ambient temperature. The apparatus automatically adjusts the amount of reactant that comes in contact with the hydride in proportion to the amount of hydrogen that is delivered from the apparatus, thus providing the unique self-regulating feature.

Recent Developments: In July, 2001, Ball Aerospace & Technologies was awarded a contract to develop a 20-watt fuel cell power system for the Defense Advanced Research Projects Agency (DARPA) Palm Power Program. The fuel cell power system provides a hand-held, direct current electricity power system using direct methanol fuel cell technology. The nominal output of the power system is 20 watts. This compact electrical power source offers power for warfighters, robotics and other emerging applications.

If this 1.5-pound device were used to power a laptop computer, it could run for three days continuously (more than 70 hours) without being recharged with methanol. Similar in size to three video cassette tapes, this compact power system can replace 22 pounds of batteries now required for a soldier power system to operate for three days. Under the three-year DARPA contract, Ball Aerospace will develop and field-test the power system.

In March, 2001, eight Portable Power Systems (PPS) were shipped to military customers by Ball Aerospace & Technologies Corp. These represented the first sales of the volume build of PPS units that were developed commercially to replace batteries and generator sets as a power source. The Maryland Procurement Office purchased four PPS units and Natick Soldier Systems purchased two. The Marine Corps also received two units. The build of several units to inventory has allowed Ball Aerospace to offer effective pricing to customers.

3.2.3 BALLARD POWER SYSTEMS INC.

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Background: Ballard Power Systems was founded in 1979 and is a leading company in developing, manufacturing and marketing zero-emission proton exchange membrane (PEM) fuel cells. Ballard is commercializing fuel cell engines for transportation applications and fuel cell systems for portable and stationary products. Ballard's proprietary technology is enabling automobile, bus, electrical equipment, portable power and stationary product manufacturers to develop environmentally clean products. Ballard is partnering with world-leading companies, including DaimlerChrysler, Ford, EBARA, ALSTOM and First Energy, to commercialize Ballard® fuel cells. They have supplied fuel cells to Honda, Nissan, Volkswagen, Yamaha, Cinergy and Coleman Powermate, among others.

Mergers & Acquisitions: In December, 2002, Ballard Power Systems announced that it had completed the acquisition of the interest of ALSTOM Canada Inc. in Ballard's stationary power subsidiary, Ballard Generation Systems Inc. (BGS). Ballard's relationship with the ALSTOM Group will continue through a member of the ALSTOM Group being granted a non-exclusive worldwide (except for Japan) distribution right for Ballard's stationary fuel cell systems in place of ALSTOM's prior exclusive rights to manufacture and distribute Ballard's stationary fuel cell systems in Europe only. Additionally, the jointly owned company ALSTOM BALLARD GmbH, based in Europe, will continue to oversee the existing European 250kW stationary field trial program.

In December 2001, Ballard announced that it had completed the acquisition of the interest of EBARA Corporation (Japan) in Ballard's stationary power subsidiary, Ballard Generation Systems Inc.

Again in December 2001, Ballard completed the acquisition of the interests of DaimlerChrysler and Ford in XCELLSIS (a venture among Ballard, DaimlerChrysler, and Ford) and Ecostar Electric Drive Systems (Dearborn, Michigan) to become the world leading supplier of complete vehicular fuel cell engines, and to offer an expanded range of products from components to power generators.

In addition, Ballard and Victrex plc (UK) have an alliance for Victrex's sulphonated polyetheretherketone (PEEK) thin film membrane for fuel cells. Victrex reportedly expects to invest as much as $25 million in the development of material systems and manufacturing facilities for fuel cell MEAs.

Management: Firoz Rasul, Chairman and Chief Executive Officer; Dennis Campbell, President and Chief Operating Officer; Lee Craft, Vice President, Operations; Noordin Nanji, Vice President, Corporate Strategy and Development; Dave Smith, Chief Financial

Officer; Fred Vasconcelos, Vice President and Chief Technology Officer; Ross Witschonke, Vice President, Sales and Marketing.

Financial Status: In 2001, total revenue was $36.2 million. Fuel cells and fuel cell systems accounted for over 81% of Ballard's sales. The company includes major investment from DaimlerChrysler and Ford.

Employees: Ballard has approximately 1,300 employees as of December, 2002.

Manufacturing: Ballard's research and development headquarters is located in Burnaby, British Columbia, Canada. This facility is used for fuel cell and fuel cell systems development, assembly and testing, and for heavy-duty fuel cell engine activities. Ballard's initial fuel cell manufacturing facility, Plant 1, is located adjacent to Ballard's research and development facility in Burnaby. The 110,000 square foot (10,219 square meter) facility was commissioned in December, 2000. Plant 1 will meet Ballard's initial commercial needs through 2004. Ballard's Power Generation Division, which develops fuel cell stationary and portable power products, is also headquartered in Plant 1. Ballard's facility in Nabern, Germany, near Stuttgart is used for fuel cell engine and fuel processing development, assembly and testing, and for PEM fuel cell module development. Ballard has additional manufacturing facilities in Lowell, Massachusetts, and Dearborn, Michigan.

Products and Technology: Ballard's lines of products build upon its proprietary fuel cell technology and include the following:

- The Nexa power module, the PEM fuel cell module designed for integration into a wide variety of stationary and portable power generation applications
- 250-kW stationary fuel cell power generator and one-kW co-generation fuel cell power generator designed specifically for the Japanese residential market
- XCELLSIS fuel cell engines used in sedans, jeeps, and buses
- AVCARB carbon fabrics and milled fibers for use in applications in the aerospace, automotive, electrical, and sports equipment industries

Sales and Distribution: Ballard develops and markets its products through strategic alliances with leading companies worldwide. The first of these alliances created a jointly owned venture known as XCELLSIS Fuel Cell Engines Inc. among Ballard, DaimlerChrysler and Ford. In 2001, Ballard acquired the interests of DaimlerChrysler and Ford in XCELLSIS and the interests of EBARA in Ballard Generation Systems. Ballard supplies fuel cells to Nissan, Honda, Volkswagen and General Motors.

Research and Development: Ballard has several research facilities in Canada, the United States, and Germany. Its associate company, EBARA Ballard, recently unveiled the second-generation of its engineering prototype 1kW PEM fuel cell stationary power generator for the Japanese residential market.

Recent Developments: In May, 2001, Ballard Power Systems and MicroCoating Technologies Inc. (MCT, Atlanta, GA) announced that they had signed an exclusive agreement to develop MCT's proprietary combustion chemical vapor deposition process (CCVD) for use in the manufacture of Ballard fuel cells. Under the joint development agreement, Ballard acquired the exclusive rights, for a defined period, to license MCT's proprietary CCVD technology for use in catalyst application for Ballard fuel cells. Ballard will also fund a portion of MCT's related development costs.

Also in May, 2001, Ballard announced that it had completed its acquisition of the carbon products business unit of Textron Systems (Wilmington, MA). The deal was closed for $12.8 million on May 25, 2001. The acquired business, known as Ballard Material Products Inc., is a wholly owned subsidiary of Ballard Power Systems. Ballard's new business unit develops and manufactures a variety of carbon materials for automotive and fuel cell applications, including a gas diffusion layer for use in PEM fuel cells.

In October, 2001, Ballard announced the commercial launch of its Nexa power module, the world's first volume-produced proton-exchange membrane (PEM) fuel cell system designed for integration by original equipment manufacturers (OEMs) into a wide variety of industrial and consumer end-product applications. The Nexa power module generates up to 1,200W of unregulated dc electrical power. Emitting only heat and water as byproducts of power generation, the Nexa power module allows OEM products to be used in indoor environments and other locations not possible with conventional power sources such as internal combustion engine generators. The power module's quiet operation and compact size make it ideal for integration into UPS systems and emergency power generators, as well as recreational and portable products.

In October, 2002, Ballard's management announced intentions to tighten its focus on its business plan and to "significantly decrease cash consumption." Ballard suspended the development of its 10kW and 60kW stationary generators, two products not expected to have a near-term impact on revenues. In addition, Ballard is looking to sell or license its fuel-processing-technology operations, in part, because fuel-cell users appear to be focusing on pure hydrogen as the best energy source for the cells.

In November, 2002, Ballard Power Systems and Millennium Cell Inc. successfully completed a joint development agreement. The two companies have moved into a new phase of their business relationship, with Ballard obtaining a licensing option for Millennium Cell's Hydrogen on Demand™ hydrogen fuel system and making a strategic investment in Millennium Cell. Ballard retains its licensing option for the non-exclusive right to manufacture and sell products with Hydrogen on Demand™ technology for specific portable fuel cell products and internal combustion engine generator sets.

In December, 2002, Coleman Powermate, a leading power equipment manufacturer, introduced the AirGen™ fuel cell generator. According to Ken Frank, senior research and development engineer, the AirGen fuel cell generator can be used as a portable power source or as an emergency backup power system. "It automatically senses when utility power fails and acts as an uninterruptible power supply, keeping mission-critical computer and phone systems online," said Frank. "It also acts as a surge protector, buffering expensive electronics from dangerous power spikes and regulating voltage."

The AirGen, powered by Ballard's Nexa™ power module, generates up to 1,000 watts of electricity as long as hydrogen gas is supplied. It is claimed to be the "world's first commercial proton exchange membrane fuel cell generator for end-users." The UL- and CSA-approved AirGen fuel cell generator has a built-in power inverter that can generate ac power. The power inverter, by SoftSwitching Technologies, converts the fuel cell's dc power into electricity that can power standard electronics, computers and appliances. The AirGen is available to industrial customers directly from Coleman Powermate. Hydrogen fuel is supplied through high-pressure cylinders and can be purchased from Praxair, Coleman's exclusive hydrogen supplier with hundreds of locations throughout the U.S. and Canada. To help encourage the use of this new technology, a $1,000 manufacturer's rebate is being offered in cooperation with the California Air Resources Board for the first 50 California industrial businesses that purchase the AirGen fuel cell generator.

A commercial/residential version of the AirGen fuel cell generator is in the works. Instead of high-pressure cylinders, the unit will draw hydrogen from three smaller fuel canisters that are inserted into the unit.

3.2.4 CASIO

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Japan
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Casio began research of fuel cells in 1998, developed them in 2000, and realized basic performance of fuel cells in the last two years. The special feature of Casio fuel cells – Casio's silicon wafer device with micro-reactor function – has been developed independently by the staff of Casio's research division. The catalyst used in the micro-reactor has been developed and made compact, showing high performance under the guidance of Professor Akira Igarashi of Kogakuin University in Japan. More than 100 inventions have been made using Casio's fuel cell, and patent applications have been filed with the Japanese Patent Office and in other countries. Casio aims to commercialize this fuel cell in 2004 and will advance R&D forward to improve their performance and to develop applications for various devices.

In March, 2002, Casio Computer Co. Ltd. (Tokyo, Japan) announced its newly developed fuel cells at a chemical engineering conference. The new fuel cell technology is suitable for use in laptop computers, digital cameras, PDAs and pocket television receivers. Within the reformate fuel cell, a reformer produces hydrogen from fuel or alcohol, and electric energy is generated from the hydrogen through a generating cell. The reformer, a micro-reactor formed on a silicon wafer, causes a chemical reaction to reform methanol to hydrogen gas in the presence of catalyst at a reforming rate of more than 98 percent.

The generating cell, which brings a chemical reaction between oxygen and the produced hydrogen, has a high-power-generation efficiency per area and provides energy.

Casio aims to commercialize the fuel cell in 2004 and will advance research and development to improve performance and develop applications to various devices.

3.2.5 DCH TECHNOLOGY

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ENABLE FUEL CELL

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Background: Diversified Commercial Hydrogen Technology (DCH) Inc. manufactures unique, state-of-the-art hydrogen sensors used for applications in food processing, semiconductor, petrochemical, metals processing, automotive, and nuclear power industries. DCH also manufactures hydrogen-based (PEM) fuel cells and is a global provider of hydrogen safety services. Enable Fuel Cells, a wholly owned subsidiary of DCH Technology, was created in March 2000 to commercialize portable and stationary fuel cell technology licensed from Los Alamos National Laboratory. DCH/Enable Fuel Cells is dedicated to developing portable, hydrogen-based fuel cells that are environmentally friendly, reliable and efficient.

Management: John Donohue, DCH President and CEO; Dr. Johan A. Friedericy, Chief Operating Officer; Ronald Ilsley, Treasurer; Robert S. Walker, Interim Chairman of the Board; Dr. Sanjiv Malhotra, VP, Business Development and Marketing for all DCH lines of business.

Financial Status: For the year ended December 31, 2001, DCH had sales of $1.1 million.

Employees: About 50 employees.

Manufacturing: DCH manufactures its products in Valencia, California; Enable Fuel Cell products are developed at Enable's facilities in Wisconsin and in cooperation with Los Alamos National Laboratory. DCH has entered into a joint venture with Diado, a Japanese manufacturer of precision parts, to significantly reduce the cost of both the parts and assembly of their fuel cells.

Products and Technology: DCH/Enable™ Portable Fuel Cells are designed for mini-generators; lighting; communications; power for scooters, bikes and wheelchairs;

emergency power; recreational vehicles; police and military applications; and entertainment. Key specifications:
- Power: Up to 100W.
- Voltage: 3, 6, 12, or 24V.
- Current: Up to 10A.
- Weight: As low as 2 ounces.
- Length: As short as 1 inch.
- Diameter: 2 inches or less.
- Efficiency: 50-57%.

Current prototypes include a 6-volt battery replacement fuel cell with integrated hydride; a three-cell prototype of a D-diameter battery replacement fuel cell; and a 12W/12V "soda can" fuel cell, weighing just over a pound and about 8 inches tall.

The company's latest product is a 15W power supply "robustly packaged" for field applications. Remote environmental sampling specialist IPS MeteoStar has selected the fuel cell to power field communications equipment. DCH and MeteoStar are working together to supply and power a remote data sampling and feedback system for the Texas Natural Resource Conservation Commission (TNRCC). The unit is 15W with regulated 12V output, using pure hydrogen or gas from a hydride.

The company indicates that they continue to make good headway in their "lower-power portable fuel cell systems, which are in the field today as 10W to 30W battery replacements." The company indicates that they were able to leverage their success in designing these units for the TNRCC to recently sell essentially the same type of units in Pennsylvania.

Sales and Distribution: DCH/Enable shipped the first of its family of portable fuel cells to the U.S. Army Communications-Electronics Command. The U.S. Army Tank, Automotive, and Armaments Command subsequently began featuring an Enable fuel cell in demonstrations to military and civilian audiences. Other PFC customers include the Texas Natural Resource Conservation Commission, and the State of Arkansas.

DCH's marketing strategy for their hydrogen sensors involves three components: establishing DCH in the "hydrogen community," comprised of trade groups such as the National Hydrogen Association, the California Hydrogen Business Council and the Congressional Hydrogen Technical Advisory Panel; establishing a coalition with the insurance industry to require use of hydrogen detection systems; and using commissioned independent sales representatives specializing in particular industries to sell their products.

DCH Technology customers include Allied Signal (Honeywell), Argonne National Laboratory, Ballard Power Systems, Boeing, Department of Energy, Duracell, Eaton Corp., Exxon, Ford Motor Co., General Motors, Hamilton Standard, Horiba Instruments, Lockheed Martin, Mobil Oil, Nissan, Panasonic, United Technologies, and Westinghouse.

Research and Development: In addition to current products, DCH plans to introduce:
- A low-cost, highly accurate, low-range hydrogen detector that will compete directly with the "inexpensive" product currently on the market.
- A highly sensitive, fiber-optic-based gas detector that is "intrinsically safe," i.e. no electricity at the sensing point.

DCH currently conducts research and development activities with strategic partners: sensor development in connection with federal research laboratories such as ORNL; applications development in conjunction with field representatives; and advanced systems designs for specialized industries with customers. To date, a significant portion of research and development has occurred through CRADAs with the U.S. Department of Energy: the ORNL CRADA, the LANL CRADA and the NREL CRADA.

A total of $2.5 million was spent on research and development during the year ended December 31, 2001, compared to expenditures of $1.8 million for the period ending December 31, 2000. The increase in R&D expenses during the period was due to a greater focus on commercialization and development of products.

Recent Developments: In September, 2001, DCH Technology announced that Daido Metal Ltd., (Nagoya, Japan) DCH's joint venture partner for the manufacture and sale of fuel cells in the Asian markets, had sold its first 12W/12V portable fuel cells to targeted customers in the Japanese automotive, electronics manufacturing and highway sign industries.

The fuel cells were sold through NeWave Fuel Cell Corp., the 50-50 joint venture between DCH and Daido. Daido said they sold nearly two dozen prototype units for specific applications. Daido anticipates strong long-term demand for the fuel cell and has invested approximately US$1.0 million to date in equipping a development and manufacturing facility to design and handle commercial volumes. They plan to announce a timetable for initial commercial introduction by the end of the year.

"Japan and the rest of Asia are going to be very important markets for fuel cells, and we are pleased to have such a well-respected partner as Daido, their reputation in the region as a responsive, high-quality manufacturer is second to none," said John Donohue, DCH president and CEO. "Since forming our joint venture last November, Daido has worked very aggressively to develop and demonstrate the NeWave fuel cell to their customer base. We are just beginning to see the results."

In May, 2002, DCH Technology announced that they had been granted a U.S. patent for significant improvements to their its passive fuel cell technology that increases the power of a portable DCH Enable™ fuel cell generator by up to 50 percent. while also making the unit more robust. DCH is currently shipping passive portable fuel cells for use as power packs serving field data collectors and telecommunications up-link equipment. "This patent protects breakthrough engineering targeted at this and other strategic market niches for DCH, such as personal mobility markets," said DCH President & CEO John Donohue.

DCH's passive fuel cell technology is based on, and licensed from, technology resulting from a significant investment in PEM fuel cells by the U.S. Department of Energy at its Los Alamos National Laboratory. The new DCH patent, and several trade secrets surrounding the patent, are viewed as critical to the company's commercialization plans. The improvement is an innovative passive water management system that increases both power density and operating stability.

DCH's passive technology is targeted at portable applications, where either the available envelope within a product for the power pack is often a given – like the sleeve for a six-volt battery or the battery on a electric wheelchair – or if the envelope is not yet defined, there's usually a strong desire to make it as small and light as possible. With this patent DCH now offers a power pack that, within existing design configurations, provides more power for more product features and functions, or alternatively, allows the OEM to downsize the product with the same features and functions.

In September, 2002, substantially all of the assets of DCH Sensors Inc., a wholly owned subsidiary of DCH Technology, were sold through an assignment for the benefit of creditors to H2SCAN. The principals of H2SCAN, which will be engaged in the business of licensing, developing and commercializing hydrogen-specific gas sensors, are Steven Huenemeier and Dennis Reid, former executive officers of DCH and Sensors.

In connection with the sale of Sensors' assets, DCH transferred certain intellectual property to H2SCAN for aggregate consideration of $100,000. The intellectual property consisted of DCH's rights under a license from Sandia Corporation, certain trademarks, and all other intellectual property owned by DCH and used in the business of licensing, developing and commercializing hydrogen-specific gas sensors.

3.2.6 DIRECT METHANOL FUEL CELL CORP.

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Background: The Direct Methanol Fuel Cell Corporation (DMFCC), founded in February, 2002, is an early-stage company formed to commercialize next-generation portable and premium power products using patented fuel cell technology developed at and licensed from the Caltech/NASA Jet Propulsion Laboratory and the University of Southern California.

DMFCC is a portfolio company of ViaSpace Technologies LLC. ViaSpace was formed in 1998 to commercialize technologies from Caltech, JPL and other university and government laboratories. ViaSpace currently has six companies in its portfolio.

Management: Dr. Carl Kukkonen, Chief Executive Officer; Rick Cooper, Interim President and Chief Operating Officer.

Financial Status: DMFCC is actively seeking strategic partners and investment.

Products and Technology: DMFCC intends to produce direct methanol fuel cells for OEMs and consumers, along with replacement fuel cartridges. DMFCs have been demonstrated at JPL in sizes ranging from 1 watt to 1.4 kilowatts.

Research and Development: The California Institute of Technology and the University of Southern California made a firm agreement with DMFCC in August, 2002, to provide DMFCC with rights to 26 issued and over 40 pending U.S. and foreign patents on the direct methanol fuel cell technology developed at the Caltech/NASA Jet Propulsion Laboratory and USC. These include the fundamental patent for using methanol dissolved in water as the fuel with a solid polymer membrance electrolyte, as well as patents on a new membrane, fuel cell designs and a methanol sensor. The agreement also provides for access to key JPL and USC scientists who developed the technology in order to assure its effective transfer to DMFCC.

According to DMFCC's CEO, these patents are crucial to the company's business model and are the result of over $10 million of R&D investment. Patents are pending in Europe, Japan, China and Korea. The company has stated, "If a product is found to infringe a patent, it cannot be made, sold or used in countries where the patent has issued. DMFCC's extensive intellectual property position is a significant barrier to entry for unlicensed competitors. However, companies can gain the benefit of our patent protection through a number of partnership mechanisms."

3.2.7 ELECTRIC FUEL

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Background: Electric Fuel is a world leader in primary and refuelable zinc-air fuel cell technology, pioneering advancements in battery technology for defense and security products and other military applications, electric vehicles, and consumer electronics. They recently discontinued their Instant Power line of portable, consumer zinc-air fuel cell products.

Management: Robert S. Ehrlich, President and CEO; Avihai Shen, Vice President - Finance.

Financial Status: For fiscal year ending December 31, 2001, revenues were approximately $4 million.

Employees: As of February 28, 2002, Electric Fuel had 112 full-time employees in their Israeli subsidiary. Of these employees, four hold doctoral degrees and 34 hold other advanced degrees. Of the total, 31 employees were engaged in product research and development, 60 were engaged in production and operations, and the remainder in general and administrative functions. The company also has five employees at their Auburn, Alabama research facility, one employee at their Georgia research facility and nine employees in their New York office.

Manufacturing: The company has manufacturing facilities in Israel and Auburn, Alabama. Electric Fuel's facilities include all of the physical plant and support functions necessary for carrying out zinc-air cell and technology development, including an analytical laboratory, testing laboratories with more than 100 discharge channels, a machine shop, and electrode fabrication equipment.

The company intends to explore the possibility of establishing strategic marketing and manufacturing partnerships. Potential strategic partners for batteries and chargers may include consumer electronic device manufacturers, major retailers, battery producers and assemblers, wireless accessory distributors, cellular phone service providers and consumer goods distributors. Although they currently manufacture zinc-air cells and assemble chargers and batteries for use in consumer electronic devices at their own facilities, they may later outsource part of this work as volume increases.

Products and Technology: In October, 2002, Electric Fuel announced that it would discontinue retail sales of its Instant Power consumer battery products because of the high costs associated with consumer marketing an dlow volume manufacturing. The company will instead focus on its defense- and security-related businesses. The Instant Power batteries and chargers had been built using Electric Fuel's 3300mAh, 1.4V zinc-air fuel cell technology. Products included PDA chargers, cell phone chargers, cell phone batteries, camcorder batteries, and digital camera batteries. The company indicated that they "remain committed to [their] zinc-air electric vehicle program and to [their] growing and profitable defense- and security-related businesses."

Sales and Distribution: Electric Fuel has corporate and sales offices in New York and London. Instant Power products are sold in retail stores throughout the United States, Canada, Europe and Israel, as well as through distributors in Australia, Croatia, Czech Republic, Greece, Hong Kong, Iceland, Indonesia, Malaysia, Nordic, Poland, Singapore, United States, and South & Central America. The company has marketing partners in Germany, Italy, Spain, and the U.K.

Research and Development: For the year ended December 31, 2001, Electric Fuel's gross research and product development expenditures, including costs of revenues, of prototype batteries and components of the Electric Fuel System, were $11.3 million.

The company has R&D facilities in Israel and Auburn, Alabama. In addition to zinc and air electrode development, the company's expertise includes configuration of cell elements to optimize performance for device-specific voltage and power requirements. Electric Fuel claims to have all the necessary research, engineering and production capabilities to develop and produce a myriad of OEM applications. The flexibility of their technology also allows them to design new cell configurations to meet the requirements of custom applications.

3.2.8 GINER ELECTROCHEMICAL SYSTEMS, LLC

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Giner Electrochemical Systems, LLC, was established in May, 2000, as a partnership between Giner Inc. and General Motors Corp. GES, a subsidiary of Giner Inc., specializes in the development of proton-exchange membrane (PEM) based electrochemical technologies. GES applies membrane technology to fuel cells for power generation, high-pressure electrolyzers for regenerative power, hydrogen fuel production, and oxygen production for life support. Giner, Inc. focuses PEM technology on electrochemical sensors and biomedical devices such as self-contained transdermal alcohol sensors and environmental gas sensors.

In July, 2002 Giner Electrochemical Systems announced that it had demonstrated a simplified direct methanol fuel cell (DMFC) system based on a novel method of supplying methanol to the fuel cell. The technology will be beneficial to DMFCs of all sizes, but is particularly beneficial for micro and low-power fuel cells of up to approximately 20W output for medical devices, cell phones, PDAs, laptops and other wireless devices.

In that same month, GES announced that it had delivered a complete liquid feed direct methanol fuel cell (LFDMFC) system providing a 50W/12V output to the U.S. Army Research Laboratory (ARL) in Adelphi, MD. This lightweight, compact, portable device was fabricated under a Small Business Innovation Research (SBIR) contract. It incorporates many of the inventions and technological advances made by GES on various LFDMFC programs funded by DARPA during the last ten years.

A LFDMFC stack utilizing a low-methanol crossover membrane developed by GES under SBIR/ARL funding supplied all system power. According to Jack Kosek, Director of Energy Conversion Programs at GES, "The innovative membrane, in addition to reducing methanol crossover by over 60% compared to previous membranes, has demonstrated a long shelf life and the ability to provide state of the art LFDMFC performance. Development of reduced methanol crossover membranes directly improves the overall system efficiency."

"This device is extremely lightweight and is poised to satisfy many of the military's portable power requirements. Portable auxiliary power requires a rapidly refuelable, reliable, and rugged system. We believe that the DMFC is uniquely suited to fill this need," said Tony Vaccaro, President of GES.

The DMFC system provides 50W during normal use, and has a maximum power output of 90W. The use of off-the-shelf components resulted in a package with dimensions of 45 x 33 x 17 cm (20 x 13 x 7 inches) and a weight of 6 kilograms (13 pounds). Optimization of system components is expected to result in a 50% reduction in size and weight. The system is entirely self-contained, with enough on-board methanol storage for 800W-hr of operation. The system is approximately one-third the weight of a 150W DMFC system GES delivered to ARL in October 2001. The heart of the system, a LFDMFC stack, is based on GES' proprietary molded graphite bipolar plate technology and uses membrane-electrode assemblies specifically developed by GES to exploit the advantages of the new membrane. The stack provided an average cell voltage of 464 +/- 12mV at 100mA/cm^2 during 60°C testing using low-pressure air, prior to insertion into the complete system.

3.2.9 H POWER/PLUG POWER

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Background: H Power Corp. is a leading fuel cell development company. Founded in 1989, H Power has developed, owns or has been granted exclusive rights to significant patents, proprietary technology and trade secrets covering fuel cells and ancillary systems – particularly fuel cell stacks and fuel processors. The company's PEM fuel cells are designed to provide electricity for a wide range of stationary, portable and mobile applications. In November, 2002, the company was acquired by Plug Power Inc.

Partnerships: H Power intends to aggressively pursue manufacturing, marketing and distribution alliances. The following have already been established: Mitsui & Co., Ball Aerospace & Technologies Corp., SGL Carbon LLC , Kurita Water Industries, Osaka Gas Co. Ltd., Air Products and Chemicals Inc., Gaz de France, Altair Energy LLC, and Naps System Oy.

Management: H. Frank Gibbard, CEO; Dudley Wass, COO; Arthur Kaufman, CTO; William L. Zang, CFO.

Financial Status: H Power's major investors have contributed approximately $46.5 million toward the funding of ongoing and future operations. H Power's major investors include ECO, DQE Enterprises Inc., Hydro-Quebec Capitech Inc., and Sofinov Societe Financiere d'Innovation Inc.

For FY ending May 31, 2001, revenues from products were approximately $1.5 million; and revenues from contracts were approximately $2.2 million.

Employees: As of May 31, 2001, the company employed 183 persons.

Manufacturing: In January, 2001, H Power entered into a lease for a 90,000 square foot manufacturing facility in Monroe, North Carolina. The facility was opened in July, 2001. The company hired key personnel and will continue the staffing process over the next several years. H Power also leases a total of approximately 27,000 square feet in two buildings in Belleville, New Jersey, and a total of 30,900 square feet in two buildings in Saint Laurent, a suburb near Montreal, Canada, where they have the capability for limited manufacturing. These facilities are expected to provide sufficient capacity through FY2003.

Products and Technology: H Power's business focus is to design, manufacture and sell Proton Exchange Membrane (PEM) fuel cell systems that address the needs of existing and near-term commercial markets. The company is currently focused on Stationary Power Units, Portable/Mobile Power Units, and Education/Demo Power Units.

H Power's portable fuel cell systems can power electronic equipment and personal portable electronic devices. Mobile fuel cell systems can replace or supplement batteries in small, specialty vehicles such as golf carts, and can provide auxiliary power for applications that operate the air conditioning and electronic systems of large vehicles. Current portable products include:

- PowerPEM VMS50 50-100W 12Vdc: A 50-100W, 12Vdc, hydrogen-fueled power supply for battery charging, for use as back-up power for solar variable-message road signs.

- PowerPEM-PS500 500Wdc: A 500W dc, hydrogen-fueled power supply for telecommunications back-up power, auxiliary power units (railroad/medical), electric wheelchairs, small electric vehicles, and remote power.

The company also has the PowerPEM-D35, a 35W, 12Vdc hydrogen-fueled power supply for educational, demonstration and scientific applications; and the PowerPEM-SSG50, a 50W, 12Vdc, hydrogen-fueled power supply for general purpose power, remote communications and instrumentation, and railroad and traffic equipment applications.

Sales and Distribution: H Power plans to market and sell their products globally through distribution channels that they consider to be appropriate for the particular product and geographical area. The company has a distribution arrangement with Mitsui & Co. Ltd. to sell products in Japan.

Research and Development: Research and development has been funded internally and from work performed under government contracts. For the fiscal years ended 2001, 2000 and 1999, total R&D expense was $13.5 million, $5.3 million and $3.1 million, respectively. During fiscal year 2001, the company continued developing DMFC technology, and also made advances in the fuel cell stack assembly design to increase output and allow the fuel cell units to function normally in adverse conditions.

The activities of H Power's development team are complemented by the multi-kilowatt system development team efforts at their subsidiary, H Power Enterprises of Canada, Inc. This team provides for the specification, procurement, evaluation and optimization of key subsystem hardware such as fuel processors and power conditioners, as well as overall system assembly.

The company has 22 patents issued or allowed in the U.S., and one patent issued or allowed in each of Europe, Taiwan and Singapore covering H Power's proprietary technology.

Recent Developments: In February, 2001, H Power announced that it had signed letters of intent with Air Products and Chemicals Inc. (Allentown, PA) to jointly investigate forming a business alliance to serve the emerging market for small portable and mobile hydrogen-based fuel cells. The letters also provided that the two companies would jointly conduct an analysis and development effort to pursue the market for hydrogen-based fuel cell power systems used in high-value, critical-service telecom back-up power applications. This analysis will include market size, growth, customer requirements, price volume targets, and maintenance and service requirements. In addition, both companies will participate in discussions with potential customers.

In June, 2001, H Power announced that it was working jointly with its partner, Energy Co-Opportunity Inc. (ECO, Herndon, VA), to market a residential fuel cell system for the rapidly growing California market. These units would be designed to meet the needs of California consumers.

In July, 2001, H Power announced a multi-tier distribution and development agreement with Naps Systems Oy (Finland), a subsidiary of Fortum Corp. (Finland). Under the agreement, H Power will deliver fuel cells for Naps Systems' solar-power products. Both companies will work toward the distribution of H Power's standard and customized off-grid fuel cell units throughout selected European and Asian countries. Additionally, both companies will jointly work toward the further development, marketing and sales of fuel-cell products for off-grid use.

In August, 2001, H Power announced it had formed a joint development agreement with DuPont Fluoroproducts (Wilmington, DE) aimed at developing direct methanol fuel cells (DMFC) for portable and mobile applications. Under the agreement, the two companies will work together to develop direct methanol fuel cell products in the range of 100W to 1,000W, initially targeted to mobile applications such as scooters, bicycles and golf carts. This technology could also be applied to consumer products such as power tools and other battery-replacement applications.

H Power will provide expertise in the area of designing, developing and manufacturing fuel cell stacks and systems where DMFCs can be used. DuPont Fluoroproducts will provide H Power with advanced DMFC materials based on its DuPont Nafion membrane technology, and will cooperate in the design of stacks and components. As part of the agreement, H Power has delivered a proof-of-concept product to a potential customer and intends to deliver an integrated system in the near term.

In September, 2001, H Power announced the formation of H Power Japan in partnership with Mitsui and Co. Ltd. (Tokyo) and Mitsui and Co. (USA) Inc. Both parties will have a 50 percent ownership in the newly created company, which will be a Japanese corporation headquartered in Tokyo. H Power Japan's initial activity will be to conduct a nine-month feasibility study relating to the sale and distribution of H Power's fuel cell products in Japan and potentially to other countries. The feasibility study will include evaluating marketing strategies and business plans, developing an operating plan, and building a maintenance and monitoring network. All of the gathered market research data will provide the basis for sales, distribution and servicing of H Power's products and other related activities in Japan. Concurrent with forming H Power Japan, Mitsui also disclosed that it had made an equity investment in H Power, purchasing an undisclosed number of shares in the open market.

In December, 2001, H Power announced that its products performed successfully in tests conducted by Concurrent Technologies Corp. (CTC, Johnstown, PA) on behalf of the US Air Force's (USAF) Air Expeditionary Force Battlelab (AEFB), Common Core Power Production (C2P2) Initiative. The US Air Force Battlelabs are chartered to demonstrate the military utility of existing technologies and accelerate emerging technologies to meet USAF needs and requirements. Using H Power's hydrogen-powered fuel cell systems, the USAF's Battlelab C2P2 Initiative successfully demonstrated that proton-exchange membrane fuel cells have the potential to provide the core of all AEFB power production, from powering an office in a tent city to aircraft ground support equipment on the flight line.

In February, 2002, H Power announced that it would continue the rollout of its new EPAC 500 fuel cell by introducing the first version specifically designed for the Japanese market. The new product was introduced at the invitation-only U.S. ECO-Energy 2002 Exhibition & Seminar on February 27 to February 28, 2002.

In April, 2002, H Power and Synergy Technologies Corp. (Calgary, Canada) announced that they had entered into a memorandum of understanding (MOU) to jointly pursue development of fuel cell systems utilizing H Power's proton-exchange membrane (PEM) fuel cell technology and Synergy's patented SynGen cold plasma process for reforming heavy fossil fuels to produce hydrogen. "We are extremely pleased with this understanding," said Barry Coffey, CEO of Synergy. "We look forward to the opportunity to work with H Power, a leader in the development and manufacturing of PEM fuel cell systems. We believe this agreement provides validation of the potential for commercial applications of Synergy's reforming technology."

In November, 2002, Plug Power Inc. (Latham, NY) and H Power Corp. announced that they had entered into a definitive merger agreement pursuant to which Plug Power would acquire H Power in a stock-for-stock exchange valued at approximately $50.7 million. The two companies believe that the combination of the two leaders in the PEM fuel cell industry will create a stronger company that is better positioned to achieve long-term commercial and financial success in this new industry.

"We believe that this transaction will create a stronger and better capitalized company that will immediately benefit from greater financial strength, intellectual property and technical resources," said Roger Saillant, president and CEO of Plug Power, who will continue to serve in both capacities. "The combined entity will have 83 issued patents and

168 pending patent applications worldwide. By pooling the resources of H Power with Plug Power, we are better positioned to maintain a clear leadership position in the market for stationary PEM fuel cells."

Plug Power plans to streamline the business and eliminate redundant operations, leading to an expected ongoing cash consumption rate of $40.0 to $45.0 million annually. It is anticipated that all operations will be consolidated into Plug Power's headquarters in Latham. Plug Power expects that it will have $90.0 million in cash at the closing date, which should be sufficient to fund operations into 2005. The transaction is expected to close no later than the first quarter of 2003.

3.2.10 HYDROGENICS CORP.

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Background: Hydrogenics Corporation is a designer and developer of commercial PEM fuel cell systems for transportation, stationary and portable power applications. The company is a leader in fuel cell balance-of-plant and operating system technology and is applying this extensive knowledge and expertise to the development and manufacture of fuel cell power modules and fully integrated power generators.

Partnerships: Hydrogenics is a member of the General Motors' Alliance of fuel cell commercialization companies. At the time of the signing of the corporate alliance agreement in October 2001, the two companies already had a long-standing working relationship in fuel cell development. A synergy had been established from teaming the strengths of GM's fuel cell expertise with Hydrogenics' operating system and system integration capabilities. Hydrogenics' FCATS products have been instrumental to GM's advanced fuel cell development, and the progressive product development of the fuel cell advanced testing systems (FCATS) has often been driven by the growing demands of GM's fuel cell program.

As of December, 2001, Hydrogenics has undertaken a significant engineering services contract for GM at their fuel cell research facility in New York state. Partnering with Hydrogenics and other alliance partners will create an environment for GM to continue an aggressive development plan to advance their stack technology. Hydrogenics, in parallel, will continue to optimize fully integrated fuel cell systems around GM's stack, accelerating the commercialization of Proton Exchange Membrane fuel cell technology.

Management: (As of December, 2001): Pierre Rivard, President and Chief Executive Officer; Gary Brandt, Chief Financial Officer; Boyd Taylor, Vice President, Sales &

Marketing; Joseph Cargnelli, Vice President, Technology; Dr. Ravi B. Gopal, Vice President, Systems & Applications Engineering.

Financial Status: Revenue for fiscal year ending December, 2001, was about $7.4 million. Asia accounted for 33% of sales, with North American and Europe accounting for 67% of sales.

Employees: 160 employees, as of December, 2001.

Manufacturing: The Company's headquarters are located in Mississauga, Ontario, Canada. They also have Asia-Pacific operations in Tokyo, Japan, a facility in upstate New York, and European operations based in Gelsenkirchen, Germany.

Products and Technology: For the portable market, Hydrogenics has introduced the HyPORT series of portable generators, which are fully automatic. These generators are capable of operating within 0 to 40 degrees C and are currently configured to offer 1 to 5kW of power.

The HyPORT™ C Power Generator is a portable fuel cell power generator and integrated hydrogen generation system, with a power configuration of 100W to 1kW. The generator has an advanced composite fuel cell stack and a high energy density chemical hydride hydrogen subsystem that eliminates the need for a hydrogen storage vessel. The product is particularly suited for battery recharging.

In addition, Hydrogenics has the HyPORT™ E auxiliary power unit, which was developed under contract by the U.S. Army for deployment and testing on army vehicle platforms. The APU is comprised of individual modules for the fuel cell system, electrolyzer and hydrogen storage, which are part of a single, space-efficient package. The PEM electrolyzer module will recharge the hydrogen supply while the vehicle engine is operating. This will supply the hydrogen storage subsystem with sufficient fuel to operate the fuel cell auxiliary power system for up to five hours with a load of 3kW average, and peak demand of 5kW.

Sales and Distribution: Hydrogenics' largest customers are General Motors, Johnson Matthey (a U.K. based specialty chemicals manufacturer and developer) and Minnesota Mining and Manufacturing (3M).

Research and Development: Hydrogenics' R&D facility is located in Mississauga, Ontario, Canada. Research and development expenses were $3.5 million in 2001. Resources are being aggressively applied to R&D advances in three main areas: Stack Development, System Integration toward working products, and PEM Electrolyzer development.

The company's R&D facility is fully outfitted with state-of-the-art FCATS systems to meet a wide array of testing and diagnostic requirements. These advanced capabilities are significantly accelerating progress in stack and system development. Intellectual property is an important outcome of the R&D group.

Recent Developments: In January, 2003, Hydrogenics announced that it had acquired Greenlight Power Technologies Inc. (Burnaby, BC) in a transaction valued at approximately $19 million. The acquisition will enable Hydrogenics to consolidate its industry-leading position in the fuel cell testing business, while creating additional capacity and aligning dedicated resources to its fast growing fuel cell power products business.

In November, 2002, Hydrogenics announced that the company had delivered a regenerative fuel cell auxiliary power unit (APU) developed under contract by the U.S. Army for deployment and testing on army vehicle platforms. This initiative with US Army Tank-automotive and Armaments Command (TACOM) in Warren, Michigan, was initiated in response to the military's desire to explore alternative power sources to meet the increasing demands for electrical power to support digital equipment and extended silent watch requirements. As an alternative to the battery systems and diesel generators currently being used by the military, power generated from hydrogen fuel cells offers longer and quieter operation, zero emissions, faster recharge, improved cycle-life, reduced deterioration and better performance in cold weather.

In August, 2002, Hydrogenics and Dow Corning (Midland, USA), a leading developer and manufacturer of silicon-based materials, announced the signing of an agreement to jointly commercialize an innovative manufacturing process that the two companies co-developed for sealing PEM fuel cell stacks, electrolyzers and membrane electrode assemblies (MEA). Fuel Cell "Seal-in-Place™" (FCSIP) technology is a robust and cost-effective automated sealing process that injects Dow Corning's proprietary silicone materials into an unsealed assembled stack. The development of this unique Seal-in-Place process capitalizes on the combined expertise of Hydrogenics and Dow Corning. Dow Corning brings extensive experience to the collaboration in the area of curable elastomeric seal materials and adhesive and process applications, while Hydrogenics contributes leading fuel cell design engineering and testing expertise. The Seal-in-Place process substantially reduces stack assembly time and labor costs by eliminating the need to individually seal each stack component.

3.2.11 IDATECH CORP.

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Background: Founded in 1996, IdaTech is developing advanced fuel cell solutions based on its proprietary mult-fuel processing technology and fuel cell system integration capabilities. With the support of strategic partners, the company's solutions are being deployed on a global scale for portable and stationary applications. The company has commercialized a family of methanol fuel processors and has processors that run on an array of hydrocarbon and alcohol fuels, including propane, natural gas and methanol. Based in Bend, Oregon, IdaTech is majority owned by the Idaho-based energy and technology holding company IDACORP Inc., which owns the regulated utility, Idaho Power Company.

Partnerships: IdaTech has worked with a number of domestic and international strategic partners, including Sandia National Laboratories, the Bonneville Power Administration, the U.S. Army CECOM, the University of Alaska, the Propane Education Resource Council, the French utility EDF and the Japanese trading company Tokyo Boeki, among others. IdaTech's solutions are being delivered to partners in Europe, Japan and North America. IdaTech strongly believes in working with Development Partners to shorten product development and accelerate the adoption of fuel processing technology and fuel cell systems for various markets. IdaTech's Development Partner Program is focused on the following areas: technology and system development; fuel reforming; market development; and application development. In 2000, IdaTech formed a strategic alliance with Tokyo Boeki to introduce its components and systems to markets in Japan and Asia. In addition to representing IdaTech's interest in Asia, Tokyo Boeki also made an equity investment in the company in anticipation of a long-term relationship.

Management: Claude H. Duss, President and Chief Executive Officer; David J. Edlund, Sr. Vice President and Chief Technology Officer; William A. Pledger, Sr. Vice President and Chief Engineer; Michael A. Otterbach, Vice President of Operations; Roger Laubacher, Vice President of Finance; Mark Fleiner, Vice President of Marketing; Eric L. Simpkins, Vice President of Business Development; Jerry Young, Director of Engineering.

Financial Status: No significant commercial sales yet.

Employees: IdaTech employs about 80 engineers, machinists, researchers, scientists and administrative professionals.

Manufacturing: IdaTech has a prototype manufacturing plant in Bend, Oregon. The company plans to ramp up its manufacturing capabilities over the next five years.

Products and Technology: IdaTech's first commercial products are comprised of three major subsystems: the proton-exchange membrane (PEM) fuel cell; a fuel cell processor; and the balance of plant components. IdaTech incorporates its patented fuel processor, capable of converting conventional fuels into 99.9%-plus pure hydrogen with less than 1 part per million carbon monoxide, with a variety of fuel cell stacks.

IdaTech's FPM™ family of fuel processors, including FPM 20™, are the fuel cell industry's first commercial fuel processor modules. The compact fuel processor modules are comprised of an integrated steam reformer and a hydrogen purifier. As a fully integrated hydrogen generation system, the FPM family was designed for simple integration into any application that requires high-purity hydrogen delivered from a compact package. The fuel processors are designed on a scalable platform and are capable of powering fuel cell modules ranging from 1 to 6 kW. Used as a stand-alone unit, the FPM systems provide hydrogen on-demand, eliminating the need for hydrogen storage.

Sales and Distribution: IdaTech is building strategic alliances with private industry, market leaders with established channels of distribution, and the electric utility industry. In 2000, IdaTech formed a strategic alliance with Tokyo Boeki to introduce their components and systems to markets in Japan and Asia. In addition to representing IdaTech's interest in Asia, Tokyo Boeki also made an equity investment in the company in anticipation of a long-term relationship with IdaTech. The company has also teamed with European partners for the development of fuel cell solutions for various markets.

In addition to using their fuel processor in their fuel cell systems, IdaTech sells the units to other fuel cell companies and to industries needing sources of pure hydrogen.

Research and Development: IdaTech has received 26 issued and allowed patents, both domestic and foreign, and has more than 100 others pending.

Recent Developments: In 2002, IdaTech announced the commercial launch of its FPM 20™ fuel processor module – the first commercial product of its kind incorporating a steam reformer and the company's patented, two-stage purification process into a compact package. The first of a family of fuel processors to be commercially released, the FPM 20 is designed for simple integration into fuel cell systems or for use as a stand-alone hydrogen generator producing high-purity hydrogen.

"Today's launch of a commercial fuel processor module is a significant milestone for IdaTech and the fuel cell industry," said IdaTech President and Chief Executive Officer Claude Duss. "We expect the FPM 20 to accelerate and support the introduction of commercially available fuel cell systems." This product marks the first commercial product introduction for IdaTech and the first commercially available fuel processor for fuel cell applications.

"Additionally, it displays our on-going commitment to the development of our multifuel reforming and system integration capabilities," he added. "As the technology advances, IdaTech will continue to develop fuel processors and fuel cell systems that will operate on a variety of common fuels for various applications based on market and application requirements."

IdaTech expects to commercially release its fully integrated methanol/water fueled FCS 1200 portable fuel cell system in early 2003.

3.2.12 LYNNTECH INDUSTRIES LTD.

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Lynntech Industries Ltd., an affiliate of Lynntech Inc., is the entity in which systems, subsystems, or components associated with technology originally developed and patented at Lynntech Inc. are manufactured/assembled, marketed and sold. As of January 2001, Lynntech Industries manufactures, markets and sells the family of modular fuel cell test systems originally assembled and sold by Lynntech Inc. These systems are capable of being integrated with fuel cells having power outputs of up to 1kW, 5kW, 10kW, 25kW, etc., and are compatible with all types of fuel cells including proton exchange membrane fuel cells (PEMFCs), solid oxide fuel cells (SOFCs), alkaline fuel cells (AFCs), and molten carbonate fuel cells (MCFCs).

A generation of new fuel cell test systems for direct methanol fuel cells (DMFCs) has been launched by the company. The first of these is a test kit for DMFCs having power outputs up to 100W. A larger fuel cell test system can accommodate a DMFC having a power output up to 300W. Larger test systems are in the design stage. In addition, the company manufactures and sells a family of single cell PEMFC test fixtures having active areas of $5cm^2$, $25cm^2$, $50cm^2$, and $100cm^2$ as well as the corresponding membrane/electrode assemblies (MEAs). These fixtures can be supplied with MEAs for either hydrogen gas (reformate) or methanol/water solutions as the fuel.

In September, 2001, Lynntech delivered four prototype, self-contained, direct methanol fuel cell (DMFC) power supply systems to the US Army Research Laboratory (ARL, Adelphi, MD) at the completion of a small business innovation research phase two contract. The fuel cell prototypes provide a fully regulated 15W/12V output and were developed for use as individual power systems. The power supply contains a fuel cell based on Lynntech's patented Monopolar proton-exchange membrane fuel cell technology. The Monopolar design allows for small fuel cells to be packaged into a small and lightweight unit, critical for a power supply for the soldiers of the future and for civilian applications such as cell phones and laptop computers. By using methanol as the fuel, the unit can be quickly and easily refueled.

"The Monopolar fuel cell technology will find many opportunities as a power source for small electronic devices such as cellular telephones and portable laptop computers," said Oliver Murphy, Lynntech's president. "The collaborative effort between Lynntech and ARL was very beneficial and greatly accelerated the development of this fuel cell technology."

3.2.13 MANHATTAN SCIENTIFICS INC.

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Background: Manhattan Scientifics Inc. (MHTX) is a technology developer that nurtures financially promising technologies with potential global commercial applications. The company's goal is to successfully commercialize these technologies through a cooperative effort of highly skilled scientific expertise, experienced management and aggressive marketing. The company is focusing on acquiring and commercializing technologies in the areas of Alternative Energy, Computer and Internet Technology, and Water Filtering.

In the Alternative Energy areas, MHTX is providing backing for former Los Alamos National Laboratory scientist Robert Hockaday, who is developing a flat printed fuel cell designed to provide an "always on" energy source to power micro-electronics such as cellular phones and pagers. MHTX also owns the global rights to the technology of NovArs GmbH Technologien, a German company developing hydrogen-powered fuel cells in the 3 to 3,000 watts range to provide high current, low voltage for applications such as laptop computers, cordless power tools, motor bicycles and home appliances.

Partnerships: MHTX entered into an agreement with Aprilia, S.p.A., Europe's largest manufacturer of motor scooters and motorcycles, to develop a fuel-cell-powered concept bicycle. Aprilia unveiled a version of MHTX's Hydrocycle at a motor show in Italy. The company also entered into a agreement with Electrolux LLC and Lunar Design Inc. to develop an evaluation prototype of a portable fuel-cell-powered vacuum cleaner. The company also announced a fuel cell cooperation with Japan's Mihama Corporation, demonstrating a power holster during a trade show in Japan.

Management: Marvin Maslow, President, Chairman and CEO; Jack Harrod, COO; Scott L. Bach, General Counsel, Secretary and Director; David A. Teich, CPA, Director, Comptroller; Robert G. Hockaday, Chief MicroFuel Cell Scientist; Arthur Koschany, Chief Mid-Range Fuel Cell Scientist.

Financial Status: No significant revenue or earnings yet.

Employees: As of March 1, 2001, the company had three full-time employees, including two unsalaried employees in general management, one compensated employee in research and development, and two part-time unsalaried employees. In addition, there are approximately 34 other people working on the company's behalf as employees of various research and development independent contractors. The company indirectly funds the salaries of these individuals through contract research and development payments to their employers.

Manufacturing: MHTX is "in discussions" with several potential joint venture partners about building a pilot production line for volume manufacturing of its proprietary NovArs fuel cells. The planned pilot line will use new processes, materials, machines and tools created in the past year to validate and fine-tune the final volume production line design.

Products and Technology: The MicroFuel Cell™ being developed by Manhattan Scientifics is the result of more than sixteen years of research by physicist and inventor, Robert Hockaday. It is in the working prototype stage, approaching a state of technical development that is sufficiently mature to interest potential manufacturing partners prepared to advance it to commercialization.

The Mid-Range Fuel Cell technology expands the scope and speed of fuel cell market positioning and dovetails with the MicroFuel Cell research efforts. The NovArs fuel cell research is directed toward high-current, low-voltage applications, while the MicroFuel Cell addresses low-current, high-voltage applications. As a working demonstration and proof of principle of its design, NovArs developed the Hydrocycle, a prototype electric bicycle powered by a fuel cell stack hat produces a power output of 170W.

The company has unveiled a portable 3kW fuel cell for scooters, emergency home generators and other recreational uses.

The company plans to introduce fuel cell battery chargers for cell phones by 2003.

Sales and Distribution: The company is engaged in an early marketing program intended to facilitate the transition from development to manufacturing and sales. This program consists of preliminary dialogues with potential strategic partners, investors, and manufacturers concerning the funding and implementation of potential manufacturing and distribution activities.

Research and Development: Manhattan Scientifics' research headquarters in the U.S. are located in Los Alamos, New Mexico. The company's European research headquarters are in Buchlberg, Germany. A significant portion of research and development is performed by independent contractors from whom the company acquired or licensed certain technologies, and their various employees. As of March 1, 2001, the company had three independent contractors conducting research and development. Robert Hockaday performs research and development under contract through his company, Energy Related Devices, Inc. Dr. Arthur Koschany also performs research and development under contract through his company, Novars Geselleschaft fur neue Technologien, GmbH. Independent contractors utilize a number of their own various employees to satisfy their research and development obligations to MHTX, and their employees are considered to be part of the company's research and development team. Research and development expenses were $3,093,000 for the year ended December 31, 2000.

In February, 2002, Manhattan Scientifics announced that it had used MicroFuel Cell technology to create a working prototype of the Power Holster, a portable charger/cell phone carrier. Fueled by disposable ampoules containing methanol, the fuel cells can also use cartridges that provide hydrogen gas generated by a sodium borohydride/water reaction. Generating approximately 1W of power, the MicroFuel Cell array in the unit consists of 10 cells in a 4.7 (L) x 1.8 (W) x 0.02 (H)-in. package. The cells are formed on paper-thin plastic sheets intended for roll-fed mass production.

Recent Developments: In March, 2001, Manhattan Scientifics announced that it had obtained a new US patent for a large non-bipolar fuel cell stack configuration covering further applications of its MicroFuel Cell for portable electronics devices, including household power generators and power tools. US patent number 6,194,095 was issued to Robert Hockaday and is assigned to and owned by Manhattan Scientifics, which owns exclusive rights to all of Hockaday's fuel cell patents.

The new patent extends the MicroFuel Cell principles established in earlier patents. It covers methods of stacking electrically parallel modules to obtain a high-current capacity and demonstrates how individual fuel cells may be configured into a stack to create higher capacity systems. The fuel cells are formed on large plastic sheets in arrays, which the company claims enables a low-cost manufacturing process suitable for large-volume applications.

“We're working towards an affordable and environmentally clean energy source for smaller, portable applications," stated Robert Hockaday, chief micro-fuel cell scientist for Manhattan Scientifics. This patent is the fourth one granted in connection with Hockaday's development of the MicroFuel Cell, which he also invented.

In June, 2001, Manhattan Scientifics announced that it had completed a one-year productization effort and was seeking to build a pilot production line leading to volume manufacturing of its NovArs fuel cells. The company is in discussions with several potential joint-venture partners in the US, Asia and Europe for this purpose.

The NovArs fuel cell is a medium-power fuel cell capable of providing power for personal transportation, portable electronics, power tools, emergency home generators, home and outdoor maintenance appliances, portable defense electronics, and portable power systems for home and recreation.

The anticipated pilot production line would use new processes, materials, machines and tools created during the last year to validate and fine-tune the company’s final-volume, production-line design. This would provide the capability to build and test-certify the fuel cell product. Its modular design could theoretically be replicated anywhere in the world, facilitating mass production.

CEO Marvin Maslow commented, “We have begun the process of identifying potential partners and/or contract-manufacturers and we are already in serious discussions with several of them. We are also exploring the opportunity to invest our own capital in the pilot alongside other participants. We intend that the line's initial output will be sufficient to support the early fuel cell needs of our current customers, in addition to a list of other possible volume customers.”

In October, 2001, Manhattan Scientifics announced that it was engaged in a cooperative effort with Mihama Corp. (Japan) to establish a Japanese industrial team to complete development and prepare its MicroFuel Cell technology for commercial production.

As part of this effort, Mihama presented a briefing during a trade show for portable information equipment held in Yokosuka, Japan. The briefing described Manhattan Scientifics’ recent progress with its methanol-powered fuel cell and showed examples of cell elements and a prototype cell-phone holster charger used to continuously charge a phone, which the company calls a Power Holster.

In January, 2002, Manhattan Scientifics announced that it had been issued a new patent covering the use and manufacturing of its MicroFuel Cell™ power devices (No. 6,326,097) for portable electronics. The patent issue coincides with the announcement by Department of Energy Secretary Spencer Abraham that detailed a new public and private partnership with the nation's auto manufacturers to promote the development of hydrogen as a primary fuel for cars and trucks. The Manhattan Scientifics' patent will facilitate the integration of the MicroFuel Cell™ into a variety of consumer and industrial applications that include a portable and wearable charger for cellular phones, laptop computers, camcorders and power tools. This will allow greater performance, workability and convenience to users of these devices. The patent presents and discusses specific features of the configurations. The patent also covers processes used to manufacture the MicroFuel Cell devices.

In May, 2002, Manhattan Scientifics announced that it had boosted the energy of its MicroFuel Cell by a factor of six to nine times beyond the capabilities of current lithium-ion batteries, with an estimated specific energy of 940Wh/kg. The energy boosts were achieved using a sodium borohydride $NaBH_4$ ampoule as a hydrogen-producing fuel source.

3.2.14 MECHANICAL TECHNOLOGY INC./MTI MICRO FUEL CELLS

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Background: Mechanical Technology was founded in 1961 by two entrepreneurial engineers dedicated to developing and commercializing micro fuel cells and in the design, manufacture and sale of non-contact precision test and measurement instrumentation. MTI has two operating companies, Precision Instrumentation and New Energy; and three affiliated companies, Plug Power Inc., SatCon Technology Corporation, and Beacon Power Corporation.

Under New Energy, MTI MicroFuel Cells was formed in 2001 as a majority-owned subsidiary developing direct methanol micro fuel cells (DMFCs) for mobile phones, PDAs, laptops, convergence devices and other portable electronics.

Plug Power designs and develops on-site electric power generation systems utilizing Proton Exchange Membrane fuel cells for stationary applications. (See separate profile.)

Partnerships: The company has formed relationships with DuPont and ATK (Alliant Techsystems) for the development of micro fuel cell applications in commercial and military markets.

Management: Dale W. Church, Chairman and Chief Executive Officer; Dr. William Acker, President and Chief Technology Officer; Dr. Judith Barnes, Vice President and Chief Marketing Officer; James Bunch, Vice President of Business Development; Dr. Shimshon Gottesfeld, Head of Technology Development.

Financial Status: Net revenue was $7.3 million for 2001, from sales generated by MTI Instruments. MTI MicroFuel Cells had no significant sales.

Employees: MTI MicroFuel Cells has about 45 employees.

Manufacturing: The company teams up with industry leaders in both the military and commercial markets in order to share resources, reduce costs, and accelerate both technical advancement and product development. The company has consolidated its growing operation in a new 15,000-square-foot facility.

Products and Technology: The company's goal is to enter the mass market in 2004 with a micro fuel cell power source for cell phone convergence devices. To move forward with commercialization, the company plans to spend approximately $1 million per month for fiscal 2002.

Mechanical Technology unveiled its micro fuel cell prototype in March, 2002, about two months earlier than expected. The device was originally scheduled to be unveiled in May, 2002. According to Dr. William Acker, MTI President, "Reduced size and increased performance are both very important in order to advance to mass commercialization. This prototype moves us closer to the milestone for our September (2002) prototype."

Sales and Distribution: The company expects to team with an OEM/distribution partner by the end of 2002.

Research and Development: Twenty-five patent applications have been filed for technological advancements critical to the company's 2004 mass-market entry with a micro fuel cell power source for cell phone convergence devices. The company also has received a $4.6 million government grant in conjunction with DuPont to develop advanced micro fuel cell systems, along with a series of technological advancements that led to a proof-of-concept micro fuel cell in June 2001 and an early stage prototype micro fuel cell system in October 2001.

Key technical advancements include doubling of energy density, size reduction, and the ability of the micro fuel cell system to operate in any orientation.

MTI MicroFuel Cells shares R&D facilities with leading universities, such as University of Albany's Center for Environmental Science and Technology Management, and Rensselaer Institute.

Recent Developments: In September, 2001, Mechanical Technology announced it had received an award of more than $4.6 million from the Advanced Technology Program (ATP) of the National Institute of Standards and Technology (NIST). The award is to carry out a two-and-one-half year, $9.3 million cost-shared program to research and develop a micro fuel cell for use in portable electronics.

The primary program goal is to combine a direct methanol micro fuel cell being developed by Mechanical Technology with other components to create an advanced micro fuel cell system. The proposed system, a portable power source the size of a current cell phone battery, would substantially extend the "on" or total use time of a mobile phone, be instantly refuelable and be more environmentally friendly than current battery technology.

In November, 2001, DuPont (Wilmington, DE) contributed an additional $5.0 million in a second round of funding for MTI MicroFuel Cells Inc., a subsidiary of Mechanical Technology. DuPont contributed additional cash to maintain its six-percent ownership position in MTI Micro. Mechanical Technology also reinvested during the round, maintaining the company's controlling position in its subsidiary. The partnership between Mechanical Technology and DuPont, announced in August 2001, also included an agreement to customize selected fuel cell components based on DuPont Nafion membrane technology, as well as a supply agreement for DuPont to provide MTI Micro with membranes and related fuel cell components.

"The continued support of DuPont and Mechanical Technology allows us to maintain momentum in both our technical achievements and our business development, such as the recently announced agreement to cooperate with Alliant Techsystems in developing the military market," said James Bunch, CFO for MTI Micro.

In April, 2002, Mechanical Technology demonstrated a new micro fuel cell prototype during its annual shareholders meeting in Albany, NY. The new prototype is approximately 20% smaller than the one it unveiled in October, 2001, and features integrated electronic controls and a power output that is more than double.

In August, 2002, MTI MicroFuel Cells demonstrated a breakthrough in micro fuel cell design and system architecture. The company unveiled a simple direct methanol micro fuel cell prototype system that can be scaled to applications ranging from chargers to battery replacements, for a wide range of portable devices. The prototype demonstrated 0.24Wh/cc of fuel consumed and is projected to yield up to 5Wh of energy content. The prototype includes a replaceable methanol fuel cartridge, requires no pumps and works in any orientation. MTI Micro completed the prototype two months ahead of schedule and met its stated milestone of a 50-percent reduction in size from that of its October 2001 prototype.

The prototype features a completely integrated system that combines the fuel cell, a dc/dc converter, a replaceable fuel cartridge, and controls for both the charging process and the fuel feed rate. The prototype includes a proprietary dc/dc converter that is running at greater than 90 percent efficiency with a size of less than 1.5cc. Because it was designed to function as an auxiliary charger or battery extension pack, the prototype does not contain a small hybridizing battery, which was included in past prototypes.

3.2.15 MEDIS TECHNOLOGIES

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Background: Medis Technologies was established in 1992 to enter a joint venture with Israel Aircraft Industries, Israel's largest aerospace company, in order to exploit new technologies for civilian application. Medis is applying the accumulated knowledge of leading Russian-Israeli scientists and cutting-edge technology developed for military use to create its products. The company's product pipeline, in varying stages of development, includes: small-scale fuel cells for portable electronics; a "super green" AA-sized battery; a new proprietary-shaped engine; and compressors for refrigeration and air conditioning units. Medis started trading as a U.S. Public company in June, 2000.

Mergers & Acquisitions: In late 2001, Medis acquired the remaining shares of More Energy, their fuel cell subsidiary. The company has entered into a non-exclusive cooperative agreement with France-based Sagem, SA, one of Europe's largest manufacturers of cell phone handsets and other electronic equipment with sales in year 2000 of approximately $4 billion.

The company also has an exclusive agreement with General Dynamics Government Systems Corporation, a unit of General Dynamics Corporation, to develop and market fuel cells and fuel cell-powered portable electronic devices for the United States Department of Defense. As part of the agreement, among other things, General Dynamics agrees to market the DLM fuel cells to the Department of Defense.

Management: Robert K. Lifton, Chairman and CEO and Secretary; Howard Weingrow, President, Treasurer and Director; Zvi Rehavi, Executive Vice President; Jacob S. Weiss, Senior Vice President, Business Development and Director; Israel Fisher, Vice President, Finance, Secretary.

Financial Status: No significant revenues.

Employees: As of February 1, 2001, the company had 33 full time employees, of which approximately 27 were engineers, scientists and other degreed professionals and 6 were professional, technical, administrative and manufacturing support personnel. The company also employs approximately 14 engineers, scientists and other degreed professionals as consultants who do research and development on a part time basis.

Manufacturing: Medis is planning to develop a pilot plant to demonstrate manufacturing capability and profitability. They intend to license, joint venture or merge with a company capable of worldwide mass production. The company also plans to manufacture the proprietary elements that form the core of their fuel cell technology – the highly electric conductive polymers (HECPs), the catalyst and the electrolyte. The company indicated in its Third Quarter 2001 report that it had invested $655,000 for the purchase of property and equipment primarily for fuel cell development.

The company has also commenced discussions with the State of Israel to build a pilot plant in Israel to manufacture the catalyst, electrolytes and the individual fuel cells. Capital costs for the construction of the pilot plant and equipping the Or-Yehuda facility is expected to be approximately US$10 million, with the construction beginning in 2002.

Products and Technology: Medis has successfully completed Phase I in the development of its direct liquid methanol (DLM) fuel cell module for portable electronic devices. The 1in X 1in X 3/8in DLM fuel cell module delivered .24 watts and .9 volts.

Medis' DLM fuel cell technology includes the DLM Fuel Cell Modules and the DLM Fuel Cell Power Pack. The company plans to package its fuel cells as individual modules ("chips") for manufacturers of portable electronic devices. The DLM Fuel Cell Power Pack is designed as a universally compatible secondary power source for existing cellular phones, PDAs, and laptop computers. Ultimately, the company plans to market its fuel cell as a primary battery, directly manufactured as part of an electronic device.
Medis expects to have its DLM product commercially available in 2002, with chargers/cell phone battery replacements in 2003.

Sales and Distribution: Medis intends to sell its DLM individual fuel cell to cell phone and portable electronics companies worldwide and work with them to develop a fuel cell assembly.

Research and Development: The company's products are developed through its wholly owned subsidiary Medis El, in Israel. The company's research laboratory and technology center and Israel-based executive offices and back office functions are located at a leased facility of approximately 11,500 square feet in Yehud, Israel.

Medis' research and development programs are generally pursued by scientists employed in Israel on a full-time basis or hired as per diem consultants. Most of the scientists working in the fuel cell field are emigres from the former Soviet Union where they worked on developing fuel cells for as many as fifteen years. Programs are also pursued in collaboration with multinational companies with interests in the company's fuel cell technologies.

Currently, Medis' major focus is on achieving a greater power output at smaller sizes and extending the length of use time and standby time for the DLM fuel cell. The development team is also working to lower the cost of the components of the fuel cell and lower the platinum content of the catalyst, which represents a significant expense in manufacturing a fuel cell. Another objective is to find new applications for the components that make up the fuel cells, including HECPs and catalysts.

In 2001, the company had six patents pending on their fuel cell technology in the United States.

Recent Developments: In October, 2001, Medis Technologies announced that it had achieved a major milestone in the development of its proprietary direct-liquid ethanol (DLEF) fuel cell technology, specifically, in the use of its fuel cells as the source of power to operate a working model of its Power Pack cell-phone charger. The Medis

Power Pack is capable of directly charging a cell phone as if the cell phone was connected by a charger to a wall socket. In its current stage of development, the Power Pack consists of two 1W DLEF fuel cells with a dc-to-dc converter. Each fuel cell is 3.40in x 1.65in x 0.70in and weighs 70g. The fuel cells use an internal concentration of ethanol as its fuel source.

There are no external fuel feeders, water-management systems or other external support systems. The Power Pack is capable of fully charging the cell phone in the regular time required by the phone for charging. It is not trickle charged in small increments. At present, the Power Pack is already capable of charging the phone twice on each fueling.

"We believe that this is a giant stride towards the commercialization of Medis' first fuel-cell-powered product," said Robert K. Lifton, chairman and CEO of Medis.

In January, 2002, Medis Technologies announced that it had received a $75,000 purchase order to define a specification and carry out the preliminary design of a direct liquid ethanol/methanol fuel cell for a new energy pack for infantry soldiers. "We are pleased to receive this initial purchase order for this important military program," said Robert Lifton, chairman and CEO of Medis Technologies. "The modern soldier carries with him into the field increasing amounts of sophisticated energy-driven equipment and we believe that fuel cells have the potential to offer a unique cost-effective solution, which provides the necessary power output while meeting the very restrictive program requirements of weight and space."

In March, 2002, Medis Technologies announced that its subsidiary, More Energy Ltd., had achieved an important breakthrough in developing a catalyst for use on the cathode in its direct liquid ethanol/methanol (DLE/M) fuel cell, which no longer requires platinum or other precious metals as a component, reducing the cost of the fuel cell.

"We are pleased with this valuable step forward in the development of a commercially viable fuel cell," said Robert Lifton, chairman and CEO of Medis Technologies. "Platinum is already a very expensive metal, costing over $500 an ounce, and if large fuel cells for cars or power generation reach the market, they can be expected to sharply increase the demand and hence further increase the price of platinum. We expect that eliminating the use of platinum as a component of the catalyst for the cathode would reduce the cost of making our fuel cell when it comes to market by an estimated 20 percent. More Energy's scientists are focusing on the elimination of platinum from the catalyst for the anode, as well. Our aim is to lower the cost of our fuel cells to a level that makes our product very attractive both in price and performance compared with rechargeable batteries presently used in portable electronic devices."

In July, 2002, Medis Technologies announced that it was working with General Dynamics C4 Systems (GDC4S) on the development of a highly mobile fuel cell (FC) battery charger system for the U.S. Army. Medis received a $75,000 purchase order from GDC4S to develop an initial prototype of the fuel cell charger. GDC4S is using Medis' proprietary direct liquid ethanol fuel cell technology to develop a system that will enable soldiers in the field to recharge the batteries for portable electronic Army equipment such as personal digital assistants, portable computers and certain weapons.

3.2.16 MOTOROLA LABS

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Motorola Inc. is a global company that provides integrated communications and embedded electronic solutions. Motorola Labs serves as the advanced research arm of the company, focusing on “future technologies” that will allow Motorola to offer smarter, simpler and more synchronized products to its customers. Motorola also actively licenses technologies developed at the Labs to external customers.

In October, 2001, Motorola Inc. announced that they had successfully demonstrated a methanol powered fuel cell, which could provide enough power between chargings for a month of cell phone calls. The fuel cell is essentially a miniature electrochemical plant that fits into a belt holster. Inside the cell, methanol is stored in an area the size of a ballpoint pen's ink holder. A chemical reaction releases oxygen, heat and electricity. The electricity then either powers the phone directly or charges another battery that can then power the phone. The company has managed to combine each of the working parts (guiding the methane's path and ensuring the electricity is sent to the phone) into a device that measures about 2in x 4in x 0.50in. Motorola did not predict when it would sell the fuel cells on a wide scale.

Also in October, 2001, Motorola Labs demonstrated a prototype of an integrated, ceramic-based miniature direct-methanol fuel cell (DMFC) system, and built several of the key components required for a miniature, ceramic-based reformed methanol-to-hydrogen fuel cell (RHFC).

Researchers have integrated many other components, including a methanol concentration sensor and liquid-gas separation for CO2 release, directly in the ceramic device. Miniature pumps and control and conversion electronics were also built into the device. The ceramic DMFC experimental assembly, measuring about 2in (5cm) x 4in (10cm) and less than one-half of an 1in (1cm) thick (without electronics or fuel) produces over 100mW net power continuously. In the lab, the fuel cell system has been operated continuously for a week at a time, with little degradation in performance.

Motorola Labs is also doing research on a related fuel cell technology in which methanol is converted to hydrogen as needed and supplied to a more conventional hydrogen fuel cell membrane electrode assembly (MEA). Using its multi-layer ceramic technology, Motorola researchers have demonstrated an integrated vaporizer and miniature methanol steam reformer, and separately a miniature chemical heater – three of the key components in the reformed methanol to hydrogen fuel cell system. Eventually, Motorola plans to integrate all of these components, along with a fuel cell, into a single device producing 1W or greater power.

Motorola has a DMFC prototype, measuring about 2 inches by 4 inches, that is powered by liquid methanol and could be integrated into numerous existing and future electronics devices. Use of the fuel cells could extend the power for a cellular phone to several weeks without refueling or charging.

Another DMFC prototype measures about 2 inches by 2 inches and powers a PDA. In the prototype, the electronics have been integrated directly onto a ceramic substrate. The highly simplified and miniaturized passive air design eliminates the need for condensers, heat exchangers and other complex devices. The fuel cell could directly power the device or operate as an onboard battery charger, extending the operating time to a month or longer without refueling or charging.

The company expects to have chargers/next generation cell phones with fuel cells by 2004-2006.

Motorola's Energy Systems Group evaluates strategic partners to license their advanced technologies, including lithium polymer, fuel cells and electrochemical supercapacitors. Research on their advanced methanol fuel cell technology is being partially funded by the U.S. Army Robert Morris Acquisition Center (RMAC), RTP Division. The program, under the Army Research Laboratory (ARL) Collaborative Technology Alliances (CTA) Program, is designed to stimulate scientific research.

3.2.17 NEC

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In September, 2001, NEC Corp., the Japan Science and Technology Corp. (JST, Japan), and the Institute of Research and Innovation (IRI) announced that they had developed a small-sized fuel cell for mobile terminals using nanotechnology. The fuel cells are solid polymer fuel cells with methanol used as the fuel. The cell generates electric energy by producing a chemical reaction between oxygen and the hydrogen contained in methanol. When the battery dies, it is necessary to inject methanol into the battery again. They can generate electrical energy of about 10 times that of a lithium-ion battery with the same cubic volume.

Yoshimi Kubo, senior manager of Nanotechnology Research Group at NEC's Fundamental Research Laboratories, stated, "By using this technology, NEC will start manufacturing a new cell by 2003-2005 that enables a notebook PC to operate for several days continuously, and a cell that enables a mobile phone to operate for a month without power down."

NEC has adopted for the electrode of the fuel cell a nanotechnology-based raw material named "carbon nanohorn," one kind of carbon nanotube. NEC says that cells with the carbon nanohorn electrode generate about 20 percent more electric power than conventional fuel cells with activated-carbon electrodes. The carbon nanohorn has a finer structure than activated carbon, and can disperse on the electrode the fine particles of platinum that are the catalyst for decomposing hydrogen. This enhances the efficiency of the decomposition of hydrogen, the company said.

NEC, the Japan Science and Technology Corporation and the Institute of Research and Innovation will aim to practically apply the small fuel cell from here onwards and more proactively promote research and development, including production conditions of carbon nanotubes and the catalyst support on them.

In April, 2002, NEC Corp. announced plans to re-enter the US mobile phone handset market in this year. The move hopes to strengthen its advanced Internet-capable phone operations. NEC pulled out of the US market in 2000 when it was unable to keep up with the market shift to 2G digital phones after being a strong player with their 1G analog phones. NEC is in talks with several US telecom carriers over the use of its 2.5G phones, though no official agreements have been reached yet.

3.2.18 NUVERA FUEL CELLS

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Background: Nuvera was formed in April, 2000, through the merger of De Nora Fuel Cells SpA, the fuel cell division of the Italian engineering concern, De Nora SpA and Epyx Corporation, the fuel processing division of the American business and technology consulting firm, Arthur D. Little Inc. Nuvera is a designer and developer of fuel processors, fuel cell stacks, power modules, and integrated fuel cell systems for stationary and transportation applications. Nuvera maintains corporate and operational facilities in both Cambridge, Massachusetts, and Milan, Italy.

Mergers & Acquisitions: Nuvera Fuel Cells is the result of a merger between Epyx Corp. (a division of A.D. Little Inc.) and De Nora Fuel Cells (Italy). The company is also partially owned by energy conglomerate Amerada Hess (16%). Epyx's technology enables the conversion of gasoline and other commonly available hydrocarbon fuels into hydrogen to produce electricity. Since 1992, Epyx, working with the U.S. Department of Energy, has demonstrated its expertise in creating novel fuel processors in power capacities ranging from 300 watts to 200 kilowatts. De Nora Fuel Cells, in combination with Gruppo De Nora, has delivered more than 310 fuel cell stacks to customers around the world in the stationary and transportation markets since 1993. The fuel cell stacks utilize the hydrogen created by the Epyx fuel processors.

Management: Roberto Cordaro, President and CEO.

Financial Status: Nuvera's major source of revenues is the sale and lease of fuel cell stacks and fuel processors to end-users. Given the early state of fuel cell technology, the sales practice in the company's initial years was to test the fuel cell stack prototypes by leasing them to customers. In 1999, they began offering prototype fuel cell stacks for sale to customers in addition to leasing them. Accordingly, fuel cell stack revenues are now primarily generated through sales and not through leases. In 2000, revenue through sales, contracts and leases was approximately $1.8 million.

Employees: As of March, 2001, Nuvera has about 200 staff members and independent contractors, of which approximately 150 are engineers, scientists and other degreed professionals.

Manufacturing: Has manufacturing facilities in South Windsor, Connecticut.

Products and Technology: Nuvera currently is developing a 1kW hydrogen fuel cell, a 1kW propane fuel cell and a 5kW natural gas fuel cell. The 1kW power modules offer an alternative choice for energy needs in places where there are no existing power grids and where reliability, fuel flexibility, and noise reduction are highly desirable. Such power modules are suitable for manufacturers of recreational products (RVs), yachts, power hand tools, telecom backup systems, remote power generation systems, industrial equipment, home backup systems, portable military field units, and remote sensing equipment.

Sales and Distribution: Nuvera plans to deliver their first commercial fuel cell power modules to distributors by the end of 2002. For the automotive market, the company's goal is to work with OEMs over the next several years to develop and promote the demonstration of fuel-flexible fuel cell vehicles by 2005.

Research and Development: Nuvera's offices, analytical research laboratories, and product development and testing facilities are located in Cambridge, Massachusetts and Milan, Italy. The company has more than 20,000 square feet of lab space dedicated to product development and testing.

Recent Developments: In February, 2001, Nuvera Fuel Cells and Air Liquide (France) announced their agreement to form a joint venture to be based in Sassenage, France, near Grenoble. The new company will develop and market, on a global scale, complete power production systems based on fuel cell and fuel processor technology. These systems will be used for portable, stationary and transportation applications.

The agreement stipulates that the joint venture will develop, make and market equipment systems using hydrogen as their main fuel source. The aim is to produce power with no harmful effects on the environment. The joint venture will also pursue its research in the area of fuel cells to develop, test and enhance its technology. The new company will be supported by a team of engineers from Nuvera's European office, who will be responsible for the fuel cell stack. Air Liquide will help Nuvera develop the stack and will be responsible for developing hydrogen production and storage technology and ancillary fuel cell equipment, and for the testing and qualifying of the integrated systems.

In July, 2001, The Department of Energy awarded Nuvera Fuel Cells $17.0 million over the next three years in cost-shared programs to fund new research and development of advanced transportation-based fuel cell systems. Program partners include Caterpillar Inc. (Peoria, IL) and De Nora (Italy), among others. The multiple awards will primarily focus on overcoming technical barriers to introducing fuel cells to the public, such as high component costs, size, weight, start-up time, power density and system efficiency.

In September, 2001, Nuvera Fuel Cells postponed its initial public offering (IPO) and withdrew its registration statement previously filed with the Securities and Exchange Commission. "During the past year, we made great progress toward commercializing our fuel cell technology, establishing partnerships with global organizations such as Mitsui & Co. Ltd. and RWE Plus AG, and forming a joint venture (Axane) with Air Liquide," said Mark Brodsky, the previous president and CEO of Nuvera Fuel Cells. "However, despite our successes, we recognize the difficulties of the IPO market at the present time. As such, we intend to review a number of funding opportunities to advance Nuvera's technology and maintain our industry leadership position as well as pursue additional strategic partnerships."

3.2.19 PANASONIC TECHNOLOGIES

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Panasonic Technologies is an affiliate of Matsushita Electric Industrial Co., Ltd., a worldwide leader in the development of technologies and the production of electronics and electric products for consumer, business and industrial use. Matsushita recorded sales of $61.45 billion for the fiscal year ended March 2001. Matsushita Electric and its affiliates have over 290,000 employees in 46 countries. In Europe, Panasonic has marketing, production, research and development and service operations that employ more than 13,000 people.

In 1997, Matsushita developed a PEMFC 26W fuel cell for notebook PC applications. The notebook runtime was 7 hours. More recently (December, 2001), Panasonic announced that it was developing a fuel-cell-driven energy generation system that can provide electricity and hot water for the home. Encouraged by test results and ongoing development efforts, the company plans to commercialize this co-generation system in Japan in 2004.

The polymer electrolyte fuel cell at the heart of the Panasonic co-generation system produces 1.3kW of electricity while supplying 70 °C hot water for supplementing household energy needs. The Panasonic fuel cell catalyst for fuel processing is designed to withstand repeated exposure to the air. This resilience enables the catalyst to be re-used frequently without needing replacement, which makes it highly suited to the daily start and stop operation and fluctuating power demands of the average home. In addition, as the Panasonic system has no need to purge nitrogen into a bulky gas cylinder, it is compact and convenient enough to fit easily into homes with limited space.

Panasonic is a leader in small rechargeable battery manufacturing and distribution. Its battery subsidiary alone, Matsushita Battery Industrial, generates sales of nearly $2.5 billion/year. It also has internal fuel cell technology and IP. As such, it is expected to be a strong competitor in the portable fuel cell market.

3.2.20 POLYFUEL

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A spin-off of SRI International (Menlo Park, CA), PolyFuel Inc. is developing a proprietary, direct methanol fuel cell that provides up to 10 times the energy of rechargeable batteries. PolyFuel's innovative micro-power system will dramatically improve the run time of wireless phones and laptop computers. The company's rich intellectual property portfolio includes more than a decade of know-how, patents and trade secrets relating to fuel cell components, systems and high-volume manufacturing processes. A working prototype of the fuel cell is ready for scale-up production in anticipation of commercializing the first micro fuel cell in the wireless device market in 2003. At this time, the company expects to have fuel cells as original equipment in next-generation electronics equipment.

In August, 2002, PolyFuel announced that it had secured $15.6 million in its second round of financing. The financing round, led by Ventures West Management Inc. (Vancouver, BC), included Chrysalix Energy LP, Intel Capital, Mayfield and Technology Partners. PolyFuel President and CEO Gregg Semler stated, “We had very clear objectives when we set out to raise this round of money and I am delighted to have achieved them with this group of investment and industry leaders. Together, we can build PolyFuel into a major player in next generation power systems for consumer electronic devices."

In October, 2002, the US Department of Transportation (DOT, Washington, DC) reportedly ruled that a direct methanol fuel cell (DMFC) developed by Polyfuel could be taken on airplanes, partly clearing the way for commercial acceptance of fuel cells as an alternative to standard laptop batteries. Onboard use of fuel cells, which will let notebook computers run 3 to 10 times longer without a recharge, has been questioned because they contain methanol, a flammable liquid. However, the DOT has stated that a PolyFuel DMFC can ride in airplane cabins when it emerges commercially because it contains a relatively low concentration of methanol, according to PolyFuel CEO Jim Balcom. Methanol makes up only 24 percent of PolyFuel's fuel cells; the rest is water. The fuel cells break down methanol molecules into protons, electrons and carbon dioxide. Protons pass through a specialized membrane, and electrons are shuffled into a wire that powers the device containing the cell. The byproducts from the chemical reaction come together as water molecules.

The PolyFuel DMFCs remain in the development stage, and notebook makers won't likely put them in notebooks until late 2004. "We've still got around a year and a half to go," said Balcom. "We're still in the technology development phase."

3.2.21 SAMSUNG ADVANCED INSTITUTE OF TECHNOLOGY

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Background: SAIT was established in 1987 to serve as the central research center to support Samsung's technology development and globalization efforts. Principal activities include researching "frontier" technology for creating new businesses, and developing leading and basic technology for enhancing competitiveness of existing products.
SAIT also provides Samsung affiliates with mid- and long-term technology strategies and technology consulting. Other functions include complex computer simulations as well as sample and process analysis for Samsung affiliates.

Partnerships: In January, 2002, Sanyo Electric, R&D Headquarters, and Samsung Advanced Institute of Technology (SAIT), entered into a memorandum agreement for technology collaboration in key technology fields. Initially, both companies will work together in development of Fuel Cell technology, with plans to further expand the range of joint cooperation in the future.

Management: Wook Sun, President and CEO; Hyuk Chang, Principal Researcher, Fuel Cells.

Products and Technology: SAIT is developing fuel cells for zero emission vehicles and stationary electric power plants. They are also developing the materials and processes for PEMFC (Proton Exchange Membrane Fuel Cell) and DMFC (Direct Methanol Fuel Cell). SAIT has developed a 40W PEMFC (12V-3.4A), which successfully operated a notebook PC for over 6 hours without charging. Core technologies for miniature DMFC cell packs are under development that will power cellular phones or PDAs.

Sanyo and Samsung will jointly develop fuel cells for small-scale home and commercial power generation. For Polymer Electrolyte Fuel Cell (PEFC) technology development, the companies are looking at integrating Sanyo's electrode technology, beginning with its high performance battery and system technologies, with Samsung's technologies for compact size and low-cost processes to develop a highly efficient, compact 1kW to 10kW class PEFC. Through this joint collaboration, the companies aim for early introduction to market of core generation systems for household use, dispersed power sources, and power resources for emergency use.

"What's most important is that by combining our technologies we can speed up commercial availability," stated Fusao Terada, director of Sanyo Electric's research and development center. "And by boosting efficiency, we can reduce the cost burden while improving the level (of technology)."

In April, 2002, SAIT announced that it had developed a fuel cell that can be built into a cellular phone, and which is to be commercialized sometime in 2004-2005. It is the size of a credit card and can be attached to the back of a cellular phone for use. It is a DMFC with output density of $32mW/cm^2$ (output is 2000mW), $50mW/cm^2$ at maximum (output is 2600mA). An electrolytic membrane, key to an increase of DMFC output, was developed by the institute. SAIT claims that methanol crossover is reduced by 30%, compared with DuPont's Nafion membrane.

Research and Development: Sanyo stated that collaboration between the two groups' research and development areas would expand to other technological areas as well.

SAIT is developing the materials and processes of PEMFC (Proton Exchange Membrane Fuel Cell) and DMFC (Direct Methanol Fuel Cell). Already SAIT has developed a 40W PEMFC (12V-3.4A), which successfully operated a Notebook PC for over 6 hours without charging. Core technologies for a miniature DMFC cell pack is under development, which will power cellular phones or PDAs in the near future.

To enhance research activities, SAIT maintains working relationships with leading research institutes in Canada, the U.S., Russia, China, Japan and Europe.

3.2.22 SANYO ELECTRIC CO. LTD.

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Background: The principal activities of Sanyo Electric Co. Ltd. are the manufacture and sale of electrical equipment. Operations are carried out through the following divisions: Audio-visual and Information (digital cameras, cellular phones, LCD projectors, televisions, video recorders and information systems); Home appliances (washing machines, vacuum cleaners, microwave ovens, air conditioners, refrigerators and compressors); Commercial Machinery (commercial air conditioners, show cases, vending machines, commercial kitchen equipment and heat pump air conditioners); Electronic Devices (electronic components for personal computers and cellular phones, LCDs and semiconductors); Batteries (nickel metal hybrid batteries for personal computers and digital cameras, lithium-ion batteries for cellular phones and nickel-cadmium batteries for power tools).

Partnerships: In January, 2002, Sanyo Electric, R&D Headquarters, and Samsung Advanced Institute of Technology (SAIT), entered into a memorandum agreement for technology collaboration in key technology fields. Initially, both companies will work together in development of Fuel Cell technology, with plans to further expand the range of joint cooperation in the future.

Management: Fusao Terada, Sanyo Representative to the agreement and Director of Sanyo's R&D Center; Wook Sun, Samsung Representative to the agreement.

Financial Status: Audio-visual equipment accounted for 37% of fiscal 2001 revenues; Electronic Devices, 21%; Home Appliances, 14% and Batteries & Other, 28%.

Employees: 22,542 worldwide.

Manufacturing: At present, the collaboration would be limited to research and development and would not extend to manufacturing or other operations.

Products and Technology: Sanyo and Samsung will jointly develop fuel cells for small-scale home and commercial power generation. For Polymer Electrolyte Fuel Cell (PEFC) technology development, the companies are looking at integrating Sanyo's electrode technology, beginning with its high performance battery and system technologies, with Samsung's technologies for compact size and low-cost processes to develop a highly efficient, compact 1kW to 10kW class PEFC. Through this joint collaboration, the companies aim for early introduction to market of core generation systems for household use, dispersed power sources, and power resources for emergency use.

"What's most important is that by combining our technologies we can speed up commercial availability," stated Fusao Terada, director of Sanyo Electric's research and development center. "And by boosting efficiency, we can reduce the cost burden while improving the level (of technology)."

Research and Development: Sanyo stated that collaboration with SAIT's research and development areas would expand to other technological areas as well.

SAIT is developing the materials and processes of PEMFC (Proton Exchange Membrane Fuel Cell) and DMFC (Direct Methanol Fuel Cell). Already SAIT has developed a 40W PEMFC (12V-3.4A), which successfully operated a Notebook PC for over 6 hours without charging. Core technologies for a miniature DMFC cell pack is under development, which will power cellular phones or PDAs in the near future.

3.2.23 SMART FUEL CELL GmbH

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Background: Founded in early 2000, Smart Fuel Cell (SFC) develops, produces and markets compact fuel cell systems to address the power needs of the portable power market, as well as the remote, off-grid power market in the range of 10W to 1000W. The SFC system enables reliable, long-term operation for a wide range of electronic appliances, such as notebooks, camcorders or power tools, as well as certain "mission critical" applications, such as off-grid telemetry, ITS and telecommunications, and in the mobile market such as for RVs. The company aims to supplement batteries and improve the output (longer run-time and operational flexibility) derived from storage battery technology their innovative DMFC-based fuel cell products.

Partnerships: Smart Fuel Cell has established a worldwide network of partners to guarantee the highest quality standards. The venture capital companies, PriCap Ventures Partner AG and 3i Group Ltd., have been associates from the start of the company.

Management: Manfred Stefener, Founder and Managing Director.

Financial Status: No significant sales yet.

Employees: About 33 full-time employees, expecting to grow to 50+ in the first part of 2003.

Manufacturing: Smart Fuel Cell has a pilot manufacturing facility near Munich and expects to produce up to 20,000 units per year. The company hopes to achieve higher production capacity by establishing collaborative manufacturing alliances with key strategic partners for various key target markets.

Products and Technology: SFC offers its direct methanol fuel cells as a "whole DMFC product solutioin." This includes a reliable fuel cell power system coupled with an energy delivery component in the form of a fuel cartridge (tank). SFC has patented technologies related to the fuel cell system and its components, as well as the proprietary technology for the interface between the cartridge and the fuel cell.

SFC's product strategy is to address a wide range of applicable markets with its two core products. The first product, SFC 25.2500R, based on a portable system powered by a replaceable methanol cartridge, can be deployed as a power supply operating as a stand-alone system, battery charger or a back-up system to the grid. The complete system is comprised of a fuel cell that can provide 25W continuous and up to 80W peak (~25 minutes) and is currently capable of operating from sub-zero temperatures up to 40 C. The methanol cartridge (2.5 lts tank) can provide 2500Whr of electrical energy. SFC 25.2500R serves the off-grid, as well as the battery charger, markets.

SFC's second core product line revolves around an engineering prototype introduced in April, 2002. This prototype is about 50% smaller and 30% lighter than the earlier version and offers 40W of power, thus making it appropriate as a power source for portable electronic devices such as laptops. A replaceable cartridge embedded into this fuel cell system offers 8-9 hours run-time for a laptop computer.

Sales and Distribution: SFC's strategy is to address a wide range of markets through relationships with established players from target markets. SFC is currently in advanced stages of discussion with key strategic partners for the marketing and distribution of its products. These partners have already started testing SFC's systems.

Research and Development: R&D targets have been: enhancing product reliability; improving component functionality in order to reduce overall system costs; and miniaturization and enhancement of complete system features to satisfy the critical needs of customers for new applications.

Recent Developments: In April 2002, Smart Fuel Cell presented the first prototype power supply for mobile office applications at the Hanover Fair. SFC claims it has miniaturized its products every six months by more than 50%. The recent progress was based on a new DMFC stack design. Every system component was made smaller, in close collaboration with the worldwide supplier network. SFC will market this product from the second quarter of 2003 on to strategic partners.

In August 2002, SFC Smart Fuel Cell launched its first series product: a portable stand-alone power supply powered by an exchangeable methanol cartridge. The system, called SFC 25.2500 R, is used by a large variety of business users in fields like traffic systems, environmental sensors, camping and outdoor equipment, and is now offered commercially to other industrial customers. The company has set up its own production facility, which it claims is yielding "excellent product quality." SFC is entering strategic partnerships to facilitate fast capturing of the most attractive markets.

In September 2002, SFC indicated that it had established a complete logistics chain for fuel cartridges for its fuel cell product – the Remote Power System SFC 25.2500 R. Since the middle of 2002, SFC had been shipping this product to customers in markets such as traffic systems, remote sensors, camping and outdoor equipment, among others. Through a hotline, customers can order new cartridges, which are delivered directly within two days. The question of how to supply the fuel has always been an uncertainty for marketing fuel cell products. By establishing a complete logistics chain, SFC is demonstrating that its fuel cartridges will be available almost everywhere – for example, at filling stations and supermarkets.

Also in late 2002, SFC obtained the required regulatory approvals for transport of SFC fuel cartridges by car, by train, by boat, and aircraft. The relevant authorities have given approval for distributing the original SFC 2.5 litre fuel cartridges, including the patented safety interface to customers and partners. SFC has also obtained official IATA (International Air Transport Association) certification as an official shipper of fuel cartridges.

In November 2002, SFC presented the next generation of its Mobile Power System, a compact external power supply with long runtimes for laptops and other electronic devices. The new prototype is half the size of the one presented six months ago, but it contains the same amount of energy – liquid methanol stored in an exchangeable cartridge. With just one cartridge a laptop can be operated for a complete working day. A display informs the user precisely about the remaining runtime (fuel gauging). The cartridge can be exchanged easily within seconds – even during operation.

3.2.24 SONY

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Although Sony has not made official announcements, it has been tackling the development of fuel cells behind the scene. The company discovered that carbon material fullerene (C60) can be used for a gas-permeable electrolyte that composes fuel cells. The existing fuel cell uses a macromolecule for a gas-permeable electrolyte, which requires use of H2O for power generation. The existing fuel cell cannot operate below zero as its electrolyte freezes. It must operate at the high temperature of around 100 degrees C.
On the other hand, fullerene does not require use of H2O and can operate at the temperature of -20 degrees C. Electrodes using fullerenes are effective for the range of

temperatures encountered by personal portable devices. Furthermore, it takes only one to two seconds before the power generation starts after injecting H2O.

So far, Sony says, "We have made a prototype and confirmed that fullerene can be used for a gas-permeable electrolyte." The company plans to accurately measure the conductivity of the gas-permeable electrolyte by establishing the membrane technology for fullerene. They also exhibit a far smaller lag between demand and supply; while other fuel cells take many seconds to generate power, fullerene technology kicks in within one to two seconds.

Its production cost is anticipated to be less than the cost of a macromolecule. The company also said that the time of commercialization has not been decided yet. The company has yet to sort out practical issues such as the recharging mechanism.

In May, 2002, Sony's Materials Laboratory announced that they had "improved the molecular structure of a proton conductor of a fullerene system being developed as a solid electrolyte membrane for fuel cells. The company intends to improve the basic properties, such as the proton conductivity. The study results were shown by Masafumi Ata, head of Sony's pie-electron materials research group, Materials Laboratories, who gave a lecture on the application of nanocarbons to energy electronics. The newly developed product can enhance the proton conductivity by chemically combining with C60, a functional group different from the hydroxyl group. The company is doing research on the improvement of structural membranes. Usually, a porous membrane carrying particles of a proton conductor of the fullerene system is used. However, Sony is considering the use of a structural substance produced by the materials of a fullerene system only, namely, a polymer of a proton conductor of the fullerene system.

3.2.25 TOSHIBA

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Background: Toshiba is considered a world leader in high technology. The company is the seventh largest integrated manufacturer of electrical and electronic products spanning information and communications equipment and systems, electronic components and materials, power systems and industrial equipment, and consumer products. The Corporate Research & Development Center is responsible for the development of a small fuel cell for portable electronics. In March, 2000, Toshiba and International Fuel Cells Corp. (now UTC Fuel Cells) established Toshiba International Fuel Cells Corporation (TIFC), a joint undertaking that engages in all aspects of fuel cell operations, from development through maintenance.

Management: Taizo Nishimuro, Director, Chairman of the Board; Tadashi Okamura, President and CEO; Kiyoaki Shimagami and Yasuo Morimoto, Corporate Senior Executive Vice Presidents; Makoto Azuma, Director, Corporate Research and Development Center.

Financial Status: $44.8 billion for FY2000, ending March 31, 2001. Power Systems had $4.7 billion in sales for FY2000.

Employees: 188,042 total; 52,263 (parent company only).

Manufacturing: Toshiba has manufacturing facilities worldwide.

Sales and Distribution: Toshiba has sales offices and distributors worldwide.

Research and Development: R&D expenditures were approximately $2.6 billion in FY2000. TIFC is accelerating its R&D efforts in Japan and the rest of Asia with a view of marketing fuel cells for commercial applications by 2004.

Toshiba is placing development emphasis on mobile devices and audio-visual equipment. The company claims they are "going to ship products this year – lots of products," according to Tetsuya Mizoguchi, president and CEO of Toshiba Corp.'s Mobile Communications Co. In the area of fuel cells for mobile devices, Toshiba demonstrated its "GENIO e" PDA prototype. Similar fuel cells are under development at NEC Corp. and Hitachi Ltd., but there are few reports of any designs offering an output capable of driving a PDA for a specific period of time. The company believes that "2005 is too late" for commercialization and plans to ship as soon as possible.

The prototype fuel cell is a DMFC design, with 30mW/cm^2 power density. The cell is capable of supplying a constant average power of 5W. The electrode material uses a proprietary catalyst developed by Toshiba. Normally, these catalysts are Pt-based with Ru, but Toshiba has modified both the component ratios and additional new materials.

The fuel cell is capable of a constant current for a long period of time, but is ill-suited to quickly producing the large currents needed to start up PCs. For that reason, the PDA uses an internal Li-polymer rechargeable battery for start-up. "When we actually commercialize this, we'll have to add some sort of auxiliary power source, maybe a double-layer capacitor," according to a Toshiba development engineer.

Recent Developments: In December, 2001, UTC Fuel Cells, a unit of United Technologies Corp. (Hartford, CT), announced the installation of the first commercial fuel cell power unit in China. The PC25 fuel cell power unit was installed at a farm in Guangzhou (Canton) city, in the Guangdong province of China located 90 miles northwest of Hong Kong. The unit was manufactured by UTC Fuel Cells and sold to Toshiba Corp., which modified and sold the unit to the customer. The project is managed by the Institute of Energy Economics of Japan and subsidized by the New Energy and Industrial Technology Development Organization of Japan.

In January, 2002, Toshiba announced that it had developed a new compact fuel cell for use in mobile devices. The invention of new materials for electrodes of the cell has paved the way for improvement of the output power density and the voltage. The new material lowers the loss of voltage that is caused on the positive electrode, which improves performance and achieves an output power density of 25mW to 30mW/cm-sq at cell temperatures between 30 to 40 degrees C, and 110mW/cm-sq at 90 degrees C. Toshiba aims to put the fuel cell on the market by 2003.

The increase in voltage has a direct bearing on the efficiency of power generation. The prototype cell outputs 5W on average and a maximum of 8W. Measuring 10cm-cu, the fuel cell allows continuous operation five times longer than with an intrinsic type of lithium-ion secondary battery. The dimensions are 127mm x 105mm x 25mm, and the volumetric capacity is 333cm-cm.

According to Toshiba, the cell can be further miniaturized through optimization of cell structure and the peripherals. The weight of the prototype is about 500g, but can be reduced down to 200g by alternating parts made of carbon or metal to plastics. A single cell generates between 0.4V to 0.5V, and the utilization factor is about 90 percent as 10 percent of the fuel is lost at a crossover. Power gained from 1g of fuel is about 2Wh with efficiency of power generation around 33 percent. In addition, a tank can be further reduced by using fuel of a high concentration and by installing a mechanism for diluting the fuel for downsizing.

In March, 2002, Toshiba announced that it had developed and manufactured a direct methanol fuel cell (DMFC) for its PDA Genio on a trial basis. The new material lowers the loss of voltage that is caused on the positive electrode, which improves the performance. The company achieved an output power density of 25 to 30mW/cm-sq at cell temperatures between 30 to 40 degrees C, and 110mW/cm-sq at 90 degrees C.
The prototype cell outputs 5W on average and a maximum of 8W. Measuring 127mm x 105mm x 25mm, the fuel cell allows continuous operation five times longer than with an intrinsic type of lithium-ion secondary battery. Specifically, a continuous operation indicator shows approximately 40 hours of operation instead of the eight hours observed with conventional cells.

According to Toshiba, the fuel cell can be further miniaturized through optimization of the cell structure and its peripherals. The weight of the prototype is about 500g, but weight saving is possible down to 200g by alternating parts made of carbon or metal to plastics. A single cell generates between 0.4V to 0.5V, and the utilization factor is about 90 percent as 10 percent or so of fuel is lost at a crossover. Power gained from one gram of fuel is about 2Wh with efficiency of power generation around 33 percent.
Toshiba aims to put the fuel cell on the market by 2003.

In October, 2002, Toshiba announced that it plans to market a fuel cell battery-operated notebook computer by 2004 with an operation time of about 10 hours, three times longer than conventional batteries. The company also reported that it plans to install fuel cell batteries in personal digital assistant products.

3.2.26 TRIMOL GROUP INC.
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U.S.A.
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Web: http://www.trimolgroup.com

Background: Trimol Group Inc. is a public company that holds the worldwide rights to an aluminum-air fuel cell technology for use in portable consumer products, such as cellular telephones, laptop computers and other handheld devices.

Partnerships: Trimol's aluminum-air fuel cell technology was developed by Aluminum-Power Inc., a Toronto, Canada based fuel cell development company.

Management: Boris Birshtein, Ph.D., Chairman of the Board; Alexander Gordin, CEO and President; Shmuel Gurfinkel, Chief Financial Officer; Donald Kirk, Ph.D., Chief Scientific Officer; Rafael Ferry, Vice President of Marketing.

Financial Status: For the nine months ended September, 2001, revenues increased 26% to $2.7 million. Most revenue generation is from Trimol's subsidiary, Intercomsoft Ltd., which makes a proprietary technology used to produce secure government identification documents. This has been a significant revenue generator for the company since its acquisition in 1998.

Employees: 25, as of March, 2002.

Manufacturing: The company anticipates full capacity production of its aluminum-air fuel-cell-powered telephone battery by mid-2002.

Products and Technology: The first product Trimol Group anticipates bringing to market is a cellular phone battery using aluminum-air fuel cell technology, to be followed by a portable computer battery. The company expects the cellular phone batteries to be available in six different models. The aluminum-air battery will consist of a battery shell and a replaceable, one-time-use, aluminum fuel cell cartridge that inserts into the shell.

Future applications will include digital cameras, pagers and two-way radios.

Sales and Distribution: The management of Trimol Group will identify business and consumer market segments where its technology can offer users a significantly improved, cost effective power delivery solution and where management feels the Company can compete effectively and earn superior returns. Management will seek to enter and dominate those market segments by bringing its own products to market both through OEM and proprietary brands. In the areas where Trimol Group's technology will have applications outside of core target markets, or in segments where it would not be prudent for the Company to compete, Trimol Group will consider the licensing of its technology.

Research and Development: The Trimol Group research and development team is headed by a group of scientists and engineers with international research, design and manufacturing experience spanning at least two decades. Extensive efforts have been expended to research and design aluminum-air energy storage devices that have superior performance, are environmentally friendly, and cost efficient.

Recent Developments: In May, 2001, Trimol Group announced that it had completed a cooperation agreement with SAGEM SA (France) to jointly develop an aluminum-air fuel cell application for SAGEM portable electronics, focusing on commercial as well as military applications. The companies anticipate commercializing aluminum-air fuel cell technology for use in portable consumer electronics to provide significantly longer power than batteries currently available.

Trimol Group recently acquired rights to the aluminum-air fuel cell technology for use in portable consumer electronic equipment from Aluminum-Power Inc. (Canada). Aluminum-Power has agreed to carry out the product development work on this project for the company. Under the agreement, Trimol, assisted by Aluminum-Power, and SAGEM have agreed to develop the fuel cell to be incorporated into a battery pack, which would constitute a power source for SAGEM's portable electronics. SAGEM has informed Trimol that it anticipates the potential of having the new aluminum-air battery in its next generation of portable electronics, currently under development. The agreement is non-exclusive and allows either party to work with others in the area of fuel cell or battery technology.

In June, 2001, Trimol Group announced that it had opened its International Fuel Cell Research and Development Center in collaboration with Aluminum Power Inc. (Canada). The center is dedicated to the continued development of its aluminum-air fuel cell technology, which Trimol has licensed from Aluminum Power for use in portable consumer electronics. The new facility is located in Toronto and is the product of a joint effort between Trimol and Aluminum Power. The two companies will share the space and work jointly on the development of the aluminum-air fuel cell technology.
Trimol's work at the research center will focus on the development of the aluminum-air fuel cell technology for use in portable consumer electronics. Aluminum Power's focus will be toward developing power sources for larger applications such as stationary and back-up power systems and portable generators. The center houses a prototype assembly facility and a spacious laboratory, together with a full complement of research and development staff, including mechanical engineers, design engineers, research and development scientists, and support staff.

In addition to its immediate use as a technology development facility, Trimol believes that the center could provide an easily accessible facility for both companies to ready products for future full-scale production and commercialization.

In July, 2001, Trimol Group announced that it had entered into a cooperation agreement with Hitachi Maxell Ltd. (Japan) to work on an aluminum-air fuel cell power source for portable consumer electronics. The agreement anticipates the cooperative efforts of the companies in the development of an aluminum-air fuel cell power source for possible license by Trimol to Hitachi Maxell. It provides that each company will designate a senior engineer to cooperate on technical issues surrounding the project. The agreement also anticipates further cooperation on a design and development phase based on the results of the initial cooperative efforts.

In April, 2002, Trimol Group announced the issuance of a US patent protecting the intellectual property rights to an aluminum-air fuel cell technology licensed to it by its majority shareholder, Aluminum-Power Inc. (Canada), for use in portable consumer electronics. The patent, entitled *Ecologically Clean, Mechanically Rechargeable, Air-Metal Current Source,* was issued by the US Patent and Trademark Office on March 12, 2002. "This patent strengthens the protection of our proprietary aluminum-air fuel cell technology, which is designed to provide an environmentally responsible, emission-free power source ideal for use in a variety of electric products, devices and systems such as those licensed to Trimol Group for portable consumer electronics," stated Alexander Gordin, president and CEO of Trimol Group.

In May, 2002, Trimol Group announced that it had "stepped up" its plans for the commercialization and distribution of products, devices and systems that make use of metal-air fuel cell technologies. New developments at the company's Research & Development Center in Toronto, Ontario, Canada, include the completion of a working prototype for an aluminum-air fuel cell power source designed for use in the next generation of miniature-sized cellular phones, as well as the successful demonstration of a 1.5kW power system designed as a back-up power source for small critical equipment such as vital life support systems at hospitals, police station facilities, water shed pumping stations, telecommunications services and various residential power back-up applications.

3.2.27 YUASA CORP.

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Japan
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Fax: 81-726-86-6345
Web: http://www.yuasa-jpn.co.jp

In January, 2002, Yuasa Corp. announced that it had developed a mini fuel cell powered by renewable fuels, which the company intends to commercialize in 2003. Yuasa claims the fuel cell system is a safe, compact power source powered directly from methyl alcohol instead of extracting hydrogen from methanol, natural gas or gasoline.

The system's power-generation capacity is half that of conventional fuel cells, and officials say it will not be suitable for vehicles, but will serve as a power source for outdoor activities and emergencies. The direct methanol fuel cell uses a water solution of methanol to create a chemical reaction with oxygen, making it safer to handle than other fuel cells. The company has prototyped two systems with maximum power outputs of 100W and 300W. Both can supply electric power for 24 hours on 1 liter of methanol, costing $0.35, but the 100W system weighs 25kg. Yuasa aims to commercialize products based on the technology after two years.

3.3 Components, Fuels and Materials Companies

3.3.1 3M

3M Center
St. Paul, Minnesota 55144
U.S.A.
Phone: (651) 733-1110
Fax: (651) 736-2133
Web: http://www.3m.com

3M is an industry leader in proton exchange membrane (PEM) fuel cell technology. The company has had a program since 1995, working on materials for PEMFC stacks. They are currently working with a limited number of companies in the U.S., Europe and Japan to offer membrane electrode assemblies (MEAs) commercially. 3M is developing MEAs for the distributed generation, portable, and transportation markets.

3M is leveraging its process expertise in coating, particle and dispersion processing, surface modification, and analytical and supply product from their manufacturing operations located in Minnesota and Wisconsin.

3.3.2 ALTAIR NANOTECHNOLOGIES INC.

230 S. Rock Blvd., Suite 21
Reno, Nevada 89502
U.S.A.
Phone: (775) 857-1966
Fax: (775) 857-1920
Web: http://www.altairtechnologies.com

In October, 2001, Altair Nanotechnologies reported progress on its solid-oxide fuel cell (SOFC) developments. The use of nano-sized yttria-stabilized zirconia (YSZ) enables production of a thinner film, which increases the oxyanion transfer efficiency. Altair has only recently made its nano YSZ available to fuel cell developers. The nano-sized YSZ is reported to form the porous substrates that support the catalysts and high-temperature conductive ceramics required for the fuel cell to perform on hydrocarbon fuels. Several development cells have been forwarded to MIT for catalyst loading and reaction testing under their agreement with Altair. Altair has also provided sample quantities of its YSZ nanoparticles to a leading automotive group for evaluation, and has agreed to send samples of its complete SOFC core structure for testing in a generation mode.

In February, 2002, Altair Nanotechnologies announced significant advancements in the company's solid-oxide fuel cell (SOFC) development program. According to Altair President William Long, gas-channeling features have now been incorporated into the all-ceramic solid-state fuel core structure allowing movement of air, fuel and exhaust gases to and from individual cells. Additionally, the density of the electrolyte has been increased to the 92-to-95-percent range, further enhancing cell performance.
To date, as many as 12 single layers, alternating electrode-electrolyte-electrode, were monolithically formed into an all-ceramic core structure. This compares to three SOFC cores in one solid-state structure. No degradation of core structure materials from thermal cycling (heating and cooling) has been observed to date.

"The program has moved along more quickly than anticipated," reported Long. "We have scheduled testing 'light off' for the near future. This series of tests will utilize a working bench-scale fuel cell made entirely from Altair produced nanomaterials. The test apparatus is near completion at Altair."

In May, 2002, Altair International Inc./Altair Nanotechnologies announced that it had completed a $1,000,000 equity placement with two accredited institutional investors. Under the terms of the agreement, Altair Nanotechnologies will issue units containing one share of the company's common stock in addition to one-quarter of a warrant. The warrant entitles the holder to purchase one share of Altair common stock. "Our partnership with these successful, experienced institutional investors is the first of a number of steps identified to increase the company's presence in the marketplace and grow revenues," said Altair CEO William Long. "We view this initial investment as a confirmation of our business strategy, the strength of our management team, and the significant potential presented the investors by an emerging industry where markets cannot be quantified."

In July, 2002, Altair Nanotechnologies announced that Professor Jackie Ying had joined the company's technical advisory board. Ying, a leader in the fields of nanostructured materials and heterogeneous catalysts, previously worked with Altair Nanotechnologies in the development of a reforming catalyst for its solid-oxide fuel cell program. "We are honored to have Professor Ying join our technical advisory board," commented Altair Nanotechnologies CEO William Long. "Professor Ying is renowned for her work in the study of advanced inorganic structures for catalytic, membrane, ceramic and biomaterial applications. We look to our technical advisory board for advice across multiple disciplines and Professor Ying will be a valuable asset as we proceed with the processing and development of the company's nanomaterials for various applications."

In August, 2002, Altair Nanotechnologies announced that it had purchased an approximately 90,000ft² building currently housing its corporate offices, laboratories and nanomaterials production facility from BHP Minerals International Inc. (BHP, Australia) for $3.0 million.

3.3.3 CHEVRON/TEXACO OVONIC FUEL CELL

2983 Waterview Drive
Rochester Hills, Michigan 48309
U.S.A.
Phone: (248) 293-8760
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Web: http://www.ovonic.com

In September, 2000, Texaco Energy Systems Inc. (TESI, White Plains, NY) and Energy Conversion Devices Inc. (ECD, Troy, MI) announced the formation of Texaco Ovonic Fuel Cell Company LLC, a fifty-fifty joint venture to further develop and advance the commercialization of the Ovonic Regenerative Fuel Cell. Under the terms of the joint venture agreement, ECD will provide proprietary technology and its fuel cell development expertise, while TESI will provide additional technological support and funding for development work and initial product launch. Work under this joint venture will commence immediately and the funding for initial product and market development is estimated to exceed $40 million.

Commenting on the announcement, William M. Wicker, senior vice president of Texaco Inc., said, "The Ovonic Regenerative Fuel Cell represents the kind of important advanced energy technology in which Texaco intends to be a leader. This joint venture not only moves us closer to that objective, but also builds upon our relationship with ECD and the strategic investment we made in the company earlier this year."

3.3.4 DELPHI AUTOMOTIVE SYSTEMS

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Troy, Michigan 48098-2815
USA
Phone: (248) 813-2000
Fax: (248) 813-2670
Web: http://www.delphiauto.com

In February, 2001, BMW (Munich, Germany) and Delphi Automotive Systems unveiled a development vehicle equipped with a solid oxide fuel cell (SOFC). The development vehicle uses the SOFC as the key component in an auxiliary power unit (APU), which could generate electrical energy for a wide range of potential vehicle systems and allows for the addition of further electrical features. The SOFC/APU provides sufficient energy for existing mechanically-driven sub-systems, such as the air-conditioning and water pumps, to be driven electrically.

Using a conventional, mechanically-driven generator, supplying 1kW of electricity requires around 1.5 liters of fuel per hundred kilometers. BMW and Delphi Automotive claim that using the SOFC/APU would cause a reduction in fuel requirements of nearly half. The companies are currently working to bring the system to market in a passenger car.

“This is a major breakthrough technology that will help protect our environment," stated Jose Maria Alapont, president of Delphi's Europe-Africa-Middle East section and a vice president of Delphi Automotive Systems Corp.

In May, 2001, Delphi Automotive Systems announced a co-development agreement with TotalFinaElf to collaborate on the research and testing of fuel cell technologies and fuel reformation. The goal of the partnership is to better understand the impact of fuel composition and additives on the performance of fuel reforming devices. The co-development agreement began April 9, 2001. Research and testing will take place at Delphi's Rochester, N.Y. technical center and at TotalFinaElf’s European facilities.

“The agreement with TotalFinaElf provides Delphi with significant support in terms of testing and technical knowledge of fuel sources and fluid options,” said Guy C. Hachey, president, Delphi Energy & Chassis Systems. “Our expertise in solid oxide fuel cell (SOFC) technology and TotalFinaElf’s expertise in the refining and marketing of fuel products and additives will lead to discovery and development that will benefit both organizations,” said Hachey.

“This cooperation is a unique opportunity for both companies to evaluate the potential of a wide spectrum of products, in relation to the development of SOFC technology for both mobile and stationary applications,” said Daniel Le-Breton, director for the fuel cells application program at TotalFinaElf. Studies will focus initially on the use of gasoline, then diesel, followed by domestic heating oil and liquid petroleum gas.

In August, 2001, Delphi Automotive Systems and Battelle (Columbus, OH) were selected by the US Department of Energy (DOE, Washington, DC) to receive a 10-year, $74.6 million cost-share contract from the DOE to assist in the further development of solid-oxide fuel cell (SOFC) technology. According to the DOE, exact cost sharing and other terms of the agreement will be negotiated over the next several weeks. The joint venture combines Delphi’s extensive systems integration engineering capability, manufacturing expertise, and access to automotive and related markets with Battelle's internationally recognized experience in SOFC and microsystem technologies, and knowledge of the energy markets.

Delphi and Battelle received one of four cost-sharing contracts awarded by the DOE, each focused on different developmental areas for fuel cells and totaling $271.0 million. Delphi and Battelle’s project is aimed at developing and testing a solid-oxide design that can be mass produced at a low cost for automotive and truck auxiliary power units, distributed-power generation, and military markets. The project will be based on a 5kW system that is adapted to operate on a variety of fuels.

In October, 2001, Delphi Automotive Systems, along with French government officials and representatives from several other companies, took part in a ground-breaking ceremony for a new fuel cell research center. The French Ministry of Research will oversee this national center for technical research, with the help of corporate partners like Delphi and PSA-Peugeot Citroen.

The development of the center is based on a tight collaboration between private companies and public research organizations in the Belfort-Montbeliard-Nancy region of

France. The partnership is designed to increase innovation and development in key areas of fuel cell research.

3.3.5 DUPONT

DuPont Building
1007 Market Street
Wilmington, Delaware 19898
U.S.A.
Phone: (302) 774-1000
Web: http://www.dupont.com

DuPont is the leading supplier of thin film membrane for fuel cell MEAs, with its unreinforced Nafion™ perfluorosulfonic/tetrafluorethylene copolymer.

In February, 2001, DuPont announced that it had formed a fuel cell unit to capture a piece of the growing market for clean-energy technology. Dupont stated that it expects this market to be worth $10 billion by the end of the decade. The formation of the DuPont fuel cell division provides a business platform from which to develop and commercialize technologies. Last year, DuPont opened a multimillion-dollar fuel cell technology center in Delaware that is focusing on materials technology and applications development. The company also is partnering with others in the industry to improve the capabilities, availability and economic feasibility of fuel cell technology.

DuPont reported that it will focus on the PEM fuel cells used in portable, stationary and transportation applications, and that it will at first supply materials, including its Nafion membranes, which have been used in fuel cells for space travel for more than 35 years, and engineering polymers. DuPont said it later plans to supply fuel cell system developers with other products, including PEM fuel cell stack components. DuPont also reported that the company is involved in the development of direct methanol fuel cell technology.

“Increasing global energy requirements and the desire for new, alternative energy sources in many markets make fuel cells an exciting new growth opportunity for DuPont," commented Richard J. Angiullo, vice president and general manager of DuPont Fluoroproducts. “Fuel cells are a natural fit for DuPont technology and capabilities," Angiullo said. “More than 50 percent of a PEM fuel cell stack, the real transactional center of a fuel cell, can be made from DuPont materials.”

In April, 2002, DuPont Canada announced that it would begin developing components for the fuel cell industry and planned to expand its research center with a $19 million investment from Ottawa’s federal technology partnerships fund. During the four-year R&D program, its fuel cell research work force is expected to grow from 27 to more than 80. If the program is successful, DuPont Canada said it could spend up to $45 million by 2009, with up to 500 development and production jobs created. The research will look at developing key components of fuel cells, the first of which is expected to be delivered to the industrial marketplace by 3Q2002.

In August, 2001, H Power Corp. announced it had formed a joint development agreement with DuPont Fluoroproducts aimed at developing direct methanol fuel cells (DMFC) for portable and mobile applications. Under the agreement, the two companies will work together to develop direct methanol fuel cell products in the range of 100W to 1,000W, initially targeted to mobile applications such as scooters, bicycles and golf carts. This technology could also be applied to consumer products such as power tools and other battery-replacement applications.

H Power will provide expertise in the area of designing, developing and manufacturing fuel cell stacks and systems where DMFCs can be used. DuPont Fluoroproducts will provide H Power with advanced DMFC materials based on its DuPont Nafion membrane technology, and will cooperate in the design of stacks and components. As part of the agreement, H Power has delivered a proof-of-concept product to a potential customer and intends to deliver an integrated system in the near term.

Also in August, 2001, DuPont and Mechanical Technology Inc. announced they had signed definitive agreements forming a strategic partnership to accelerate the development and commercialization of direct methanol micro fuel cells for portable electronics. Terms of the partnership include an agreement to develop selected fuel cell components based on DuPont™ Nafion® membrane technology. The components would be customized for Mechanical Technology's micro fuel cells, which are being developed for portable electronic applications including cellular telephones, personal digital assistants and portable computers. The partnership includes a supply agreement for DuPont to provide Mechanical Technology with membranes and related fuel cell components. DuPont also has obtained a minority equity interest in MTI MicroFuel Cells, a Mechanical Technology subsidiary established to commercialize micro fuel cells.

In November, 2001, DuPont contributed an additional $5.0 million in a second round of funding for MTI MicroFuel Cells Inc., a subsidiary of Mechanical Technology Inc. DuPont contributed additional cash to maintain its six-percent ownership position in MTI Micro. Mechanical Technology also reinvested during the round, maintaining the company's controlling position in its subsidiary.

The partnership between Mechanical Technology and DuPont, announced in August 2001, also included an agreement to customize selected fuel cell components based on DuPont Nafion membrane technology, as well as a supply agreement for DuPont to provide MTI Micro with membranes and related fuel cell components.

"The continued support of DuPont and Mechanical Technology allows us to maintain momentum in both our technical achievements and our business development, such as the recently announced agreement to cooperate with Alliant Techsystems in developing the military market," said James Bunch, CFO for MTI Micro.

In May, 2002, DuPont Fuel Cells announced that it would be expanding its product line beyond Nafion membranes to include such fuel cell components as membrane electrode assemblies (MEAs). Currently, MEAs are available only through confidential development agreements with the company. DuPont estimates that more than 50% of a fuel cell stack can be made using its products.

3.3.6 ELECTROCHEM INC.

400 W. Cummings Park
Woburn, Massachusetts 01801
U.S.A.
Phone: (781) 938-5300
Fax: (781) 935-6966
Web: http://www.fuelcell.com

Background: ElectroChem Inc. was founded in 1986 to provide leading-edge research and development in the fuel cell industry. ElectroChem has modified its business focus to include market and product development in the areas of fuel cell power systems, fuel cell test equipment and fuel cell research supplies. Since 1992, it has brought more than 15 product lines to market.

Management: Radha Jalan, Ph.D, President, Chairman & CEO; Michael C. Kimble, Ph.D., Vice President, Chief Technology Officer; Michael Pien, Ph.D., Lead Engineer and Research Scientist; Steven Lis, Ph.D., Senior Scientist and Market Development Specialist.

Manufacturing: ElectroChem supplies all major components needed to assemble PEM fuel cells. They are a direct manufacturer of components such as electrodes and membrane-electrode-assemblies (MEA), and for other items they act as distributors for the original manufacturers. All supplies are kept in stock, so ElectroChem deliveries often arrive before those ordered directly from the manufacturer.

Products and Technology: Products include the following:
- Fuel Cells (PEM Fuel Cell Hardware; Phosphoric Acid Fuel Cells).
- Laboratory Test Fuel Cell Stacks (50W PEM Fuel Cell Stack; 200W PEM Fuel Cell Stack).
- Testing and Demonstration Equipment (EC POWERPAK 200; Portable PEM Fuel Cell Demo Unit EC-PDU).
- Fuel Cell Laboratory Test Station Modules (FCT-2000 CCU Computer Control Unit; FCT-2000-MFC; FCT-2000 GDU Gas Distribution Unit; GH-500 Laboratory Gas Humidifier; GlobeTech's CompucellGT).
- Humidifiers; Membrane Electrode Assemblies (MEAs); Electrodes; Catalysts; Membranes and Electrode Backings; Nafion and Teflon; and Fuel Cell Parts.

Sales and Distribution: ElectroChem has international distributors in Europe, Japan, Taiwan, and India.

ElectroChem has clients on every continent and include small businesses, Fortune 500 companies, universities and governments. Clients include Anglo-American, CSIRO Manufacturing, Degussa, DuPont, U.S. Department of Energy, U.S. Department of Defense, DERA, Eskom, General Motors, Illinois Institute of Technology, L.G. Chemical, Johnson-Matthey, NASA, SGL Carbon, Tel Aviv University, Tokyo Gas, University of Dresden, Universidade De Sao Paulo, Washington Water Power, and W.L. Gore and Associates.

Research and Development: ElectroChem has worked on more than 20 research contracts for government agencies, universities, national laboratories, and domestic and international clients. Through these contracts, the company has developed saleable products and received several patents.

Recent Developments: In April, 2002, ElectroChem was awarded a $1.0 million NASA contract for the first-phase development and a $2.5 million option contract for the second-phase development of a fuel cell power plant for the next generation of reusable launch vehicles (RLVs). ElectroChem was one of two companies chosen to develop a pre-prototype proton-exchange membrane (PEM) fuel cell power plant for the Second-Generation Reusable Launch Vehicles Technology Risk Reduction Program.
At the end of phase one (17 months), ElectroChem will deliver its pre-prototype to NASA. After testing the pre-prototype from both companies, NASA will select one company for the 22-month phase-two option, which entails the development of a full-size engineering model PEM fuel cell power plant.

3.3.7 GE POWER SYSTEMS/HONEYWELL ADVANCED COMPOSITES

4200 Wildwood Parkway
Atlanta, Georgia 30339
U.S.A.
Web: http://www.gepower.com

In August, 2001, Motorola Labs (Tempe, AZ) researchers were notified that a Power and Energy Alliance Consortium that they formed with Honeywell International Inc., Engines and Systems, SAIC, the Massachusetts Institute of Technology (Cambridge, MA) and others had been awarded an eight-year, $49.0 million dollar cooperative agreement by the US Army Robert Morris Acquisition Center**,** RTP Division, on behalf of the US Army Research Laboratory**.** The program, called the Army Research Laboratory Collaborative Technology Alliances Program, is designed to stimulate scientific research. Motorola Labs claims to be at the forefront of the research on miniature fuel cells that are being targeted as on-board battery chargers and may one day replace the traditional batteries for portable electronics, from cellular phones to laptop computers. Motorola Labs researchers have demonstrated a ceramics-based microfluidics structure that provides fuel processing and delivery as well as air supply to the fuel cell.

"Fuel cell research is becoming a very hot research area encompassing a wide range of technologies and applications," said Jerry Hallmark, manager of Motorola Labs' Energy Technology Lab. "This commitment of resources by the Army will help make alternative energy technologies a reality. We are delighted to have won this award and are excited about co-leading such a high-caliber team."

In October, 2001, General Electric Co. (Fairfield, CT) and Honeywell International Inc. (Morristown, NJ) announced they had terminated their merger agreement, three months after European regulators rejected the $41.0 billion deal. GE agreed to reimburse Honeywell for merger-related expenses and to extend two financing arrangements. GE also agreed to acquire two businesses from Honeywell with estimated sales of $35.0 million for undisclosed terms. The businesses are Tensor (Round Rock, TX), an oil and gas sensor business, and Honeywell Advanced Composites (Newark, DE), which includes the intellectual property and certain equipment used in Honeywell's Fuel Cell and Microturbine operations. GE and Honeywell also released each other from all merger-related claims.

The Fuel Cell and Microturbine assets will be used to provide research and development expertise for fuel cell and microturbine power generation components. This acquisition provides GE Power Systems with development capabilities in these technologies. The Fuel Cell and Microturbine assets will become part of Power Generation Technology within the Energy Products business of GE Power Systems.

3.3.8 MILLENNIUM CELL INC.

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Background: Millennium Cell Inc. was founded in 1998 and is a development-stage company that has created a proprietary technology called Hydrogen on Demand™ that safely generates pure hydrogen or electricity from environmentally friendly raw materials. This technology has been incorporated into several automotive prototypes to demonstrate its feasibility. Millennium Cell went public in August, 2000.

Partnerships: Millennium Cell has announced business relationships with Ballard Power Systems, DaimlerChrysler, Rohm & Haas, U.S. Borax, and Air Products and Chemicals. The company also has a test agreement with Oak Ridge Laboratories and a research agreement with Avantium Technologies. The company's joint agreement with Ballard was initiated in October, 2000, to further develop Millennium's hydrogen generation system for use with Ballard's portable power fuel cell products.

A significant part of Millennium Cell's business plan is to form key strategic partnerships with leading companies in selected industries. These partnerships are chosen to ensure access to substantial markets such as portable power, transportation, and fuel supply; to give the company greater understanding of market needs; and to provide complementary technology, manufacturing, marketing and distribution expertise.

Management: Stephen S. Tang, Chief Executive Officer and President; Adam P. Briggs, Business Development for Distributed Generation; Terry M. Copeland, Vice President, Product Development; Norman Harpster, Jr., Vice President, International Business management and CFO; Rex E. Luzader, Vice President, Business Development for Transportation and Hydrogen Fuel Infrastructure; Katherine McHale, Vice President, Marketing and Communications.

Financial Status: No significant revenues yet.

Employees: The company currently employs 40 people, primarily in technology development.

Manufacturing: In the near-term, the company does not anticipate manufacturing on a large scale.

Products and Technology: The company is currently working on commercial applications in four major areas: transportation, micro power, batteries and supply chain. The company has demonstrated four prototypes:
- A Ford Crown Victoria whose compressed natural gas internal combustion engine was converted to run on hydrogen gas.
- A Ford Explorer that runs on a hydrogen-burning engine that powers a generator.
- The NJ Genesis is a prototype all-aluminum Mercury Sable, which is a hydrogen fuel cell hybrid electric vehicle that is equipped with fuel cells and the company's on-board hydrogen-generating system.
- The company's technology is used in a solar charging station that produces power from photovoltaic panels and four hydrogen fuel cells, with their sodium borohydride system providing hydrogen to the fuel cells.

Sales and Distribution: The company is pursuing partnerships to provide complementary marketing and distribution expertise.

Research and Development: Millennium Cell has invented, patented and developed a proprietary process call Hydrogen on Demand™ that safely generates pure hydrogen or electricity from environmentally friendly raw materials. Hydrogen from this system can be used to power fuel cells, as well as fed directly into internal combustion engines.

Millennium Cells holds two U.S. patents and three non-U.S. patents, which cover a wide variety of uses and applications of various boron chemistries. The company has filed an additional five U.S. and 25 non-U.S. patent applications.

Oryza Labs and Avantium Technologies are working on optimizing Millennium Cell's proprietary catalyst and the re-generation process related to sodium borohydride ($NaBH_4$), both key parts of the company's Hydrogen on Demand™ hydrogen generation technology.

Recent Developments: In May, 2001, Millennium Cell announced the expansion of laboratory and office facilities to accommodate future growth, including an estimated 200% increase in employees. Millennium Cell signed long-term leases on 32,500 square feet of office and lab space at the company's Eatontown, NJ headquarters, and has an option for an additional 10,000 square feet. Lab space will grow at a greater rate than office space — nearly 300% during 2001. The expansion will accommodate a planned staff increase from the current 45 employee level to approximately 85 scientists, engineers, laboratory technicians and administrative support staff.

In addition to the expansion in Eatontown, Millennium Cell has contracted lab space with Avantium Technologies in Amsterdam, the Netherlands and Oryza Laboratories in Chelmsford, Massachusetts. Millennium Cell is actively pursuing additional relationships with other laboratory facilities in order to expedite the commercialization of the company's patented boron-based energy technology.

With additional lab space in Eatontown, contracted advanced research taking place in Massachusetts and the Netherlands, and future relationships with labs down the pipeline, Millennium Cell continues to make progress toward commercialization of their energy technology, according to Terry Copeland, Millennium Cell Vice President, Product Development.

In November 2001, Millennium Cell announced it had moved into new facilities and had significantly expanded its laboratory space to include a Process Development Unit (PDU) for validation of new technologies. The expansion involves 32,500 square feet adjacent to the company's current offices in Eatontown, N.J. The newly inaugurated PDU will be used to validate new processes for the manufacture of sodium borohydride, the foundation of Millennium Cell's proprietary Hydrogen on Demand(TM) process. At the new facilities, researchers also will focus on emerging processes for recycling the fuel's byproduct - consisting of borax and water - into new fuel.

3.3.9 SYNERGY TECHNOLOGIES CORP.

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In April, 2001, Synergy Technologies Corp. announced that it was planning to enter the fuel-cell market by aggressively pursuing joint ventures and strategic partnerships with major fuel cell and transportation companies that could potentially benefit from a number of applications of the company’s patented SynGen technology. The SynGen reactor, or reformer, converts natural gas and other fossil fuels into a synthetic gas composed of hydrogen and carbon monoxide via the use of a cold plasma electrical discharge. This synthetic gas is the feedstock used to produce clean-burning liquid fuels. Based on internal testing, Synergy’s management claims that its SynGen process can reduce the capital and operating costs of gas-to-liquids plants and also improve efficiencies in fuel-cell technology.

According to Thomas E. Cooley, CEO and CTO of Synergy, “We are pleased by early indications that our SynGen technology can produce hydrogen-rich streams for fuel cells from liquid gasoline and diesel without soot formation. Power consumption by

SynGen to reform liquid gasoline is only five percent of the theoretical power from the fuel cell. We believe that improvements in efficiencies are possible and further testing and development, to include additional miniaturization studies, will be continuing in the company's Calgary laboratory."

Synergy has entered into discussions with certain fuel-cell and transportation companies to evaluate the potential use of the SynGen reformer in fuel-cell power generation.

In May, 2001, Synergy Technologies announced that a 2.5 liter SynGen reactor system, designed by the company and installed at its Calgary facility, had successfully reformed feeds of natural gas into the hydrogen-rich fuel required for fuel cells. The company claims that the 2.5 liter system, which has been developed to demonstrate and optimize reformer design for the home and automotive fuel cell markets, will also be used to optimize the insitu water shift reaction to increase hydrogen production. The insitu water shift process is used to maximize hydrogen production for PEM and alkaline fuel cells, which cannot consume carbon monoxide as fuel as is the case with Solid oxide (SOFC) and Molten Carbonate (MCFC) fuel cells. The process causes injected water recovered from the fuel cell to react with carbon monoxide to produce carbon dioxide and additional hydrogen. Test work performed in Orleans, France has shown that SynGen can achieve a high insitu conversion of carbon monoxide. According to the company, SynGen reformers exhibit a high degree of scalability, and energy efficiency.

"We have analyzed many of the various types of fuel cells being developed in the marketplace, as well as their fuel requirements," said Thomas E. Cooley, Synergy's CEO and chief technology officer, "and we believe the 2.5 liter SynGen reactor system offers significant size and cost benefits in many stationary fuel cell applications. Also, based on the testing results to date, we are confident that SynGen will prove to be an excellent fit for on-board fuel cell systems based on liquid fossil fuels."

In February, 2002, Synergy Technologies announced that it had successfully reformed each of the five major fossil fuels into the free hydrogen and other feeds commonly utilized as fuel for most types of fuel cells. The company obtained these results while both eliminating the production of soot traditionally associated with heavy fossil fuel reforming, and reducing the power consumption of the reformer system to less than five percent. Synergy's SynGen reformer successfully converted natural gas, propane, gasoline, diesel and toluene into the hydrogen and other feeds suitable to supply all major types of fuel cells, including the commonly used proton-exchange membrane, solid-oxide fuel cell, and the molten-carbonate fuel cell. SynGen's cold plasma technology virtually eliminates soot production and allows for considerably improved power output by the fuel cell. "We are very excited by these results," said Synergy CEO Barry Coffey. "We believe they bring us considerably closer to securing business and product development arrangements with manufacturers of each of the major types of fuel cells."

In April, 2002, H Power and Synergy Technologies Corp. (Calgary, Canada) announced that they had entered into a memorandum of understanding (MOU) to jointly pursue development of fuel cell systems utilizing H Power's proton-exchange membrane (PEM) fuel cell technology and Synergy's patented SynGen cold plasma process for reforming heavy fossil fuels to produce hydrogen. “We are extremely pleased with this understanding,” said Barry Coffey, CEO of Synergy. “We look forward to the opportunity to work with H Power, a leader in the development and manufacturing of PEM fuel cell systems. We believe this agreement provides validation of the potential for commercial applications of Synergy's reforming technology.”

In August, 2002, Synergy Technologies announced that it had completed a $500,000 common stock private placement with the company’s largest institutional shareholder, a private energy investment fund. The fund purchased 1,246,884 restricted shares of Synergy common stock at $0.401 per share. As a result of the current and two earlier private placements with Synergy, this particular institutional shareholder has made an aggregate investment of $1.75 million in Synergy and now controls 3,118,545 shares, or 6.9 percent, of the company's 45,208,712 outstanding common shares. Funds from this offering will be used for the continuing development of Synergy’s two proprietary technologies, SynGen (for fuel cell applications) and CPJ, and for general working capital purposes.

3.3.10 TELEDYNE ENERGY SYSTEMS

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Background: Teledyne Energy Systems Inc. (TESI), Teledyne Technologies Company, is a leading global provider of on-site gas and power generation systems based on proprietary fuel cell, electrolysis and thermoelectric technologies. In addition, TESI is pursuing new products in the fuel cell testing, vehicle refueling PEM fuel cell markets.

Mergers & Acquisitions: With the recent acquisition of Energy Partners Inc., a leading developer of fuel cell technology, TESI has added the skills and knowledge to expand its electrochemical expertise across the entire product spectrum. TESI has also teamed with Scribner Associates to provide their software, Fuel Cell™ for Windows, which provides system control and data collection.

Management: Dr. Robert Mehrabian, Chairman, President and Chief Executive Officer, Teledyne Technologies Inc.; Rhett Ross, President; Jan Hess, Chief Financial Officer; Charles Wolf, Director, Engineering and Products; Jay Laskin, Director, Marketing and Sales.

Financial Status: Teledyne Technologies had total sales of $744.3 million in 2001. Energy Systems accounted for 2% of these sales, or about $14.9 million.

Employees: About 120 employees, with approximately 50% devoted to engineering.

Manufacturing: Manufacturing of all TESI products takes place at the 100,000 square foot facility in Hunt Valley, Maryland.

Products and Technology: The Teledyne MEDUSA™ RD Fuel Cell Testing Station Series provides a completely integrated system for fuel cell testing needs. MEDUSA RD provides precise gas humidification, mixing, metering, and safety to fuel cell testing facilities. MEDUSA RD Fuel Cell Test Stations are currently in operation worldwide. Typical applications include: fuel cell design verification, fuel cell component R&D, fuel cell endurance testing, quality testing, and benchmark testing. The system is available in 100W, 500W and 1,000W sizes. The system works with their Fuel Cell™ for Windows software.

Sales and Distribution: A global infrastructure backs all of TESI's products and efforts. TESI has sales in more than 30 countries, supported by local representatives. Sales regions include North America & Caribbean; Latin America; Pacific Rim & Asia; and Eurasia, Africa & Middle East.

Research and Development: TESI has a 10,000 square foot R&D facility in West Palm Beach, Florida. This facility includes fuel cell stack prototyping and analysis, fuel cell system prototyping and analysis, and fuel processor testing. Engineering and design take place at TESI's Hunt Valley facility.

Recent Developments: In August, 2001, Teledyne Technologies Inc. (Los Angeles, CA) announced that Teledyne Energy Systems delivered its first three Teledyne Medusa RD automated fuel cell test stations, used in testing and evaluating proton-exchange membrane (PEM) fuel cell products. Teledyne Medusa RD is a next-generation fuel cell test station that provides an easy-to-use platform for the automated testing of fuel cell components and stacks rated at less than 1kW. The test station provides a Windows-based interface that enables the user to begin immediate testing without special facilities, training or programming skills. The system includes hydrogen plumbing, electronic load, process control and safety systems designed to support unattended 24-hour-per-day testing under conditions likely to be encountered by a PEM fuel cell designed for automotive or stationary applications.

In October, 2001, Teledyne Technologies announced that Teledyne Energy Systems had successfully completed operational tests of its prototype 3kW natural-gas-fueled stationary fuel cell power system. The test results demonstrated the performance necessary to meet power-generation requirements for the residential and telecommunications markets. The 3kW unit is an alpha prototype of an integrated power system incorporating necessary fuel processing, fuel cell and control systems required for independent operation. The prototype unit will support the development of commercial products offering uninterruptible and backup power generating capabilities for telecommunications, premium residences and remote premium-power applications.

"Completion of the stationary prototype is an important milestone for Teledyne Energy Systems as we transition our electrochemical experience and integration with Energy Partners into effective fuel cell products for the market," said Robert Mehrabian, chairman, president and CEO of Teledyne Technologies. "This unit provides the basis for a strong product-commercialization effort covering a variety of power ranges and fuels planned for 2002."

In January, 2002, Teledyne Technologies announced that Teledyne Energy Systems executed a contract modification to deliver a prototype proton-exchange membrane (PEM) fuel cell power system to the US Department of Energy (DOE) under the continuation of work begun by Energy Partners Inc. (West Palm Beach, FL). The prototype system will be rated at 7kW and fueled by natural gas. Scheduled for delivery late in 2002, the unit will be used by the DOE to evaluate the operating characteristics of PEM fuel cell systems under operating conditions similar to those encountered by both vehicle and stationary power plants. The unit will be self-contained with all systems necessary for operation on natural gas. It will also have a state-of-the-art data-acquisition system to aid in data collection and analysis.

In May, 2002, Teledyne Technologies Inc. announced that its subsidiary, Teledyne Energy Systems Inc., was awarded a multi-year contract to supply 32 MEDUSA RD test stations to a leading PEM fuel cell component manufacturer. The systems will expand the customer's test capabilities and be used in the development of components used in the manufacture of PEM fuel cells.

The MEDUSA RD system is a next-generation fuel cell test station that provides automatic testing of fuel cells in power ranges up to 1,000W. The test station provides water, fuel and thermal management, as well as software and an electronic load designed specifically for fuel cell testing. The system control and safety features permit unattended 24/7 operation to allow customers to concentrate more on their fuel cell research and development rather than on their test hardware.

In July, 2002, Teledyne Technologies Inc. (Los Angeles, CA) announced that its subsidiary, Teledyne Energy Systems Inc., was awarded a contract to supply 32 MEDUSA RD test stations to a leading proton-exchange membrane (PEM) fuel cell component manufacturer. The systems supplied under this multi-year contract will expand the customer's test capabilities and be used in the development of components used in the manufacture of PEM fuel cells. The MEDUSA RD system, the result of an alliance between Teledyne Energy Systems and Scribner Associates Inc.**,** is a next-generation fuel cell test station that provides automatic testing of fuel cells in power ranges up to 1,000W. The test station provides water, fuel and thermal management, as well as software and an electronic load designed specifically for fuel cell testing. The system control and safety features permit unattended 24/7 operation.

3.3.11 W.L. GORE & ASSOCIATES

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Gore designs and manufactures high-power density membrane electrode power assemblies. Designed for a variety of fuel cell applications, these high-performance PRIMEA power assemblies take advantage of the benefits of the GORE-SELECT® membrane, which provides a uniquely effective combination of high ionic conductance and high strength. In PRIMEA power assemblies, Gore combines GORE-SELECT membranes with its state-of-the-art electrode and CARBEL gas diffusion media technologies. The result is a class of membrane electrode assemblies with very low resistance, outstanding mechanical properties, simplified water management, and excellent catalyst utilization.

In July, 2002, W.L. Gore announced the commercial availability of next-generation GORE EXCELLERATOR® electrode assemblies and separators for electro-chemical double-layer capacitors (EDLC), which are engineered to provide the capacitor industry with improvements in energy density, power delivery and high-volume manufacturing throughput. Suitable for regenerative braking systems, uninterruptible power supplies, energy production and storage, and membrane electrode assemblies for PEM fuel cell applications, the new EDLC components allow for high-carbon loading, which translates into greater energy densities. The components feature uniformity, tortuosity and a high filtration efficiency that prevent electrode particle penetration, reducing shorts and manufacturing rejects. The highly porous structure provides for high ionic conductivity, resulting in low equivalent series resistance, faster response and lower time constants.

In September 2002, the Southwest Research Institute™ (SwRI®, San Antonio, TX) opened a pilot plant for the high-volume production of fuel cell electrodes, key components of membrane electrode assemblies (MEAs) and fuel cell systems. The plant was built as part of a $12.0 million contract, funded by the US Department of Energy (DOE, Washington, DC), with cost share provided by SwRI, W.L. Gore and Associates and General Motors Corp. (GM, Detroit, MI). “Producing low-cost MEAs is a challenge because the catalyst on the electrode is platinum, which typically costs $600 an ounce,” said James Arps, manager of SwRI's Surface Engineering Section and project manager of the DOE effort. “We’ve designed a facility that allows us to deposit a very thin layer of platinum on the electrode, which should meet or exceed the DOE cost target.” Experiments are under way at the plant to assess the uniformity of the deposition process and scrap rate. The fuel stacks will be constructed by GM and provided to DOE’s Argonne National Laboratory for evaluation upon completion of the project. The pilot plant will remain available for continued production demonstrations.

Section IV: BATTERIES VERSUS FUEL CELLS

4.1 Battery Pricing

Because fuel cell manufacturers cannot count on the obsolescence of batteries to create a demand for fuel cells, competition will come from the value fuel cells offer vs. batteries. A useful scenario for comparison is the introduction of Li-polymer batteries, which were also designed as an alternative to Li-ion batteries. Li-polymer batteries have a flexible form factor and are considered safer than Li-ion batteries. When they first came on the market, they were also expected to take significant market share away from Li-ion, even with a price premium.

In Darnell Group's 1999 report on the Worldwide Battery Pack market, the average price for Li-ion was $1.09/Wh; the average price for Li-polymer was $1.60/Wh. In 1999, the average selling price for a Li-ion battery pack for a mobile phone was $13.59; a Li-polymer pack was $16.39 – a price premium of about 21%. For notebook computers, the Li-ion battery pack ASP was $60.39, and the Li-polymer ASP was $79.77 – a slightly higher price premium of 32%.

Three years ago, Li-polymer prices for these applications were expected to drop by about 14% per year, bringing their price premium over Li-ion to 11%-17% by 2004. This did not happen, and as a result, Li-polymer "failed" in the marketplace – at least as a serious competitor to Li-ion. The current pricing forecasts for Li-ion and Li-polymer are shown in Exhibits 1 and 2.

Exhibit 1
Worldwide Battery Pack Market
by Application, Li-ion
($/unit)

	2002	2003	2004	2005	2006	2007	CAGR
Camcorders	11.78	10.96	10.15	9.42	8.71	8.08	-12.7%
Battery Charger	5.67	5.55	5.42	5.31	5.23	5.13	-2.2%
TOTAL	17.45	16.51	15.57	14.73	13.94	13.21	-5.4%
Digital Cameras	7.07	6.49	6.11	5.61	5.27	4.87	-14.7%
Battery Charger	6.02	5.68	5.36	5.05	4.78	4.51	-5.6%
TOTAL	13.09	12.17	11.47	10.66	10.05	9.38	-6.5%
Mobile Phones	7.22	6.54	5.92	5.36	4.85	4.40	-13.1%
Battery Charger	2.52	2.37	2.22	2.06	1.96	1.84	-6.1%
TOTAL	9.74	8.91	8.14	7.42	6.81	6.24	-8.5%
Notebook Computers	32.91	31.26	29.50	27.79	26.08	24.42	-10.7%
Battery Charger	19.35	18.35	17.84	17.10	16.43	15.78	-4.0%
TOTAL	52.26	49.61	47.34	44.89	42.51	40.20	-5.1%
PDAs	9.82	8.91	8.05	6.90	6.63	5.99	-12.5%
Battery Charger	7.26	7.07	6.88	6.70	6.53	6.36	-2.6%
TOTAL	17.08	15.98	14.93	13.60	13.16	12.35	-6.3%

Exhibit 2
Worldwide Battery Pack Market
by Application, Li-polymer
Projected Price Declines
($/unit)

	2002	2003	2004	2005	2006	2007	CAGR
Digital Cameras	16.35	14.62	13.07	11.68	10.45	9.34	-10.6%
Battery Charger	6.02	5.68	5.36	5.05	4.78	4.51	-5.6%
TOTAL	22.37	20.30	18.43	16.73	15.23	13.85	-9.1%
Mobile Phones	9.99	8.93	7.98	7.14	6.38	5.71	-10.6%
Battery Charger	2.52	2.37	2.22	2.06	1.96	1.84	-6.1%
TOTAL	12.51	11.30	10.20	9.20	8.34	7.55	-9.6%
Notebook Computers	69.04	61.72	55.18	49.33	44.12	39.46	-10.6%
Battery Charger	19.35	18.35	17.84	17.10	16.43	15.78	-4.0%
TOTAL	88.39	80.07	73.02	66.43	60.55	55.24	-9.0%
PDAs	13.63	12.18	10.89	9.74	8.71	7.79	-10.6%
Battery Charger	7.26	7.07	6.88	6.70	6.53	6.36	-2.6%
TOTAL	20.89	19.25	17.77	16.44	15.24	14.15	-7.5%

Since fuel cells do not require a battery charger, the total cost of a battery and its respective charger needs to be considered when looking at fuel cell pricing. The fuel cell system will be competing against the combined price of the battery and the charger, giving it an edge. This is particularly true with applications where the charger is a significant portion of the price of the total battery system (such as digital cameras and PDAs); or where the charger is a higher-priced component of the system (such as notebook computers).

Li-ion prices have actually declined at a faster rate in the Mobile Phone segment than predicted in our 1999 report (13.1%, compared with 12.5%). Battery charger prices have also declined faster in this segment (6.1% per year) than in any of the others, giving them the lowest ASPs ($1.84 by 2007). The overall ASPs for a Mobile Phone battery system are expected to decrease at 8.5% per year, the fastest rate of any application.

In the Li-ion Notebook Computer segment, prices declined less quickly than projected (10.7%, instead of 12.3%). Battery charger prices are going down at a moderate pace, about 4.0% per year. Overall, the Notebook Computer battery system segment will experience the slowest drops in ASPs over the forecast period.

On the other hand, Li-polymer pricing remained flat between 1999 and 2002. In the Notebook Computer segment, pricing went up, in fact. Between 2002 and 2007, Li-polymer prices in all segments are now expected to decline approximately 10.6% per year. The average price decline expected in 1999 was 14.8%. Adding the battery charger to the total battery system price does not affect the pricing drops much, either. Li-polymer batteries for Notebook Computers are dropping 10.6% per year; add the battery charger and prices still drop fairly quickly, about 9.0% per year.

Because Li-polymer pricing did not come down, this chemistry has not taken away as much market share from Li-ion as expected. Even with the above projected price declines, Li-polymer's market share is expected to flatten out by 2007, as shown in Exhibit 3.

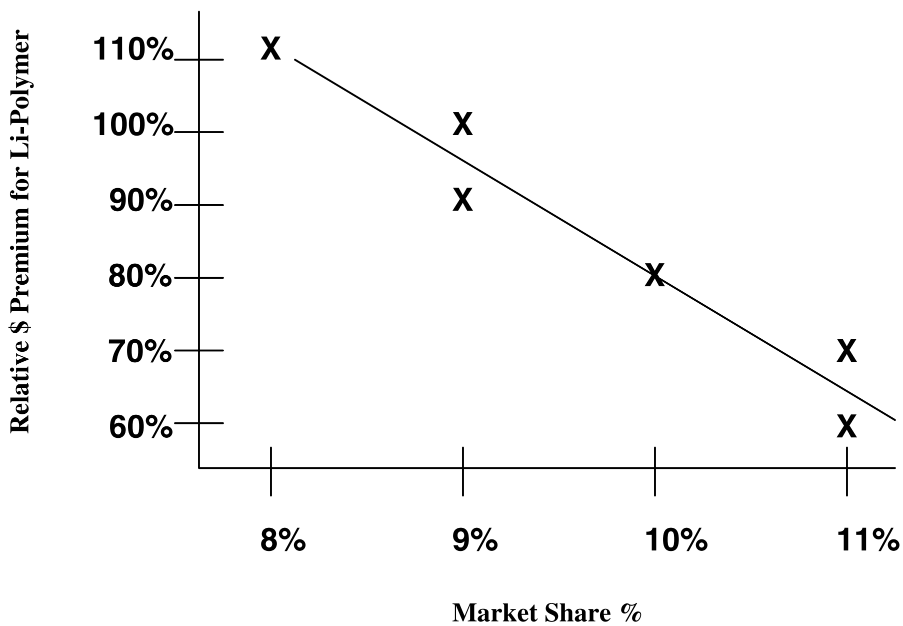
Exhibit 3
Worldwide Battery Pack Market
Li-ion & Li-polymer
(projected market share)

	2002	2003	2004	2005	2006	2007
Li-Ion	92%	91%	91%	90%	89%	89%
Li-polymer	8%	9%	9%	10%	11%	11%

The failure of Li-polymer to supplant Li-ion in the marketplace is a good object lesson for fuel cells. Several issues have emerged from this, the most important of which is price elasticity of demand (the amount sales drop for a given price increase). It is useful to look at price premiums when a new product is being introduced to an existing market. Since fuel cells have not yet penetrated the market, other products that have attempted to penetrate these same markets can be illustrative.

Exhibit 4 shows the price elasticity of demand for Li-polymer battery packs, using the pricing and market share data from Exhibits 2 and 3. If prices come down as forecasted, Li-polymer can expect 8% of the market currently held by Li-ion with a 110% price premium. This is very high, but the fuel cell price premium is expected to be higher, as will be discussed later in this section. Bringing Li-polymer's price premium down to 70% will give it about 11% market share.

Exhibit 4
Worldwide Battery Pack Market
Li-polymer
(price elasticity)



Li-polymer's failure to live up to its initial hype is very much related to flat pricing in the years of its introduction. If pricing can come down between 2002 and 2007, even at an 80% price premium Li-polymer can expect to capture 10% of the total lithium market. Pricing of Li-polymer may, indeed, be poised to drop considerably. In July, 2002, battery manufacturers Samsung SDI, LG Chemical and SKC (all in Korea) announced that they were planning to make "large investments" in lithium-polymer battery technology. The three companies are each expected to invest 10 billion won (about $8.5 million) in this technology this year to meet "growing demand from wireless devices, including mobile phones and PDAs." In addition, the Korean government said it plans to establish a "large-scale project aimed at the development of a highly efficient Li-polymer battery and small-sized but long-lasting rechargeable batteries," including establishing an R&D center and offering tax exemptions for imported crude materials needed in the development of the batteries. This means lower prices for Li-polymer, which means even lower Li-ion prices and increased pricing pressure on fuel cells.

Fuel cell manufacturers cannot focus on the current price of Li-ion or Li-polymer; pricing is a moving target, and with commercialization a few years off, the pricing goals have to consider projected lithium prices in the 2004-2005 time frame. That means the Li-polymer reference point for a mobile phone should aim for an ASP (OEM price) of $8.14-$10.20, while a notebook Polymer battery should be around $47.34-$73.02.

Manufacturing yields are another key factor in why Li-polymer has been less successful commercially. Like fuel cells, materials posed a major problem in obtaining good yields. The polymer membrane could not be manufactured as cost-effectively as the materials used in Li-ion cells, and it took a long time to refine the materials and processes to obtain effective yields. When looking at ways to reduce costs, manufacturing yields cannot be sacrificed in the process.

Certain factors will come into play when considering fuel cells over batteries, including how portable devices are used; new devices with increased battery needs; new battery chemistries; and determining the "functional equivalence" of batteries versus fuel cells. For example, mobile phones and notebook computers are not used in the same way. Notebooks are frequently used with their adaptors plugged into the wall, bypassing battery use altogether and recharging the battery at the same time. In other words, the notebook is functional without a battery and is often used that way. A person buying a notebook computer would probably buy an adaptor even if it came with a fuel cell. So the battery charger savings that come with a fuel cell are lessened.

A mobile phone, on the other hand, does not plug into the wall. Eliminating the charger reduces the cost of the battery system and is more convenient. A cellular phone might even be recharged using an automobile adaptor. Alternative ways of using portable products will determine, in part, whether fuel cells will be accepted by users.

The adoption of 3G is a factor that could make fuel cells a more attractive alternative to batteries. Currently, 3G is mired in the global telecommunications crash; but as a standard, it is expected to be adopted eventually. The date keeps getting pushed out (estimates are now being put at 2005), but this could coincide nicely with the widespread commercial introduction of fuel cells. Even though 3G-enabled phones have been used on a limited basis in some parts of the world (such as Japan), this is a future market opportunity for fuel cells. The services simply "aren't there" yet, but when they are, fuel cells will most likely offer the higher energy density these devices will require due to the increased usage of the phone these services will drive.

A possible threat to the adoption of fuel cells is improvements in Li-ion battery chemistries that will increase the energy density to meet the needs of future devices. Current forecasts from the major Li Ion and Li Polymer manufacturers predict that energy density increases can be expected over the next five years.

Finally, comparing fuel cells with batteries is problematic. Batteries provide energy for a given amount of time; fuel cells provide energy for an arbitrary amount of time. Peak loading will reduce the run-time of batteries, as with standby or talk time for a cell phone. A battery that measures its energy capacity in Watt-Hours is not directly comparable to a fuel cell that measures its energy capacity in Watts. The best method of comparison is "functional equivalence," where the average Wh per device, the average run-time of the battery, and estimated peak loading are calculated to produce an "equivalent"-wattage fuel cell.

Take a 38Wh notebook computer battery that has a run-time of 3 hours. To calculate an equivalent fuel cell:

$$\frac{38Wh}{3h} = 12.7W \times 1.25 \text{ (to account for peak loading of 25\%)} = 16W$$

This means a 38Wh notebook battery is functionally equivalent to a 16W (rounded) fuel cell.

According to MIT's Technology Review, today's best lithium-ion cellphone batteries provide an average of 4 hours of talk time. So, for an average 5.5Wh cellular phone battery with a run-time of 4 hours, the equivalent fuel cell would be:

$$\frac{5.5Wh}{4h} = 1.4W \times 1.25 \text{ (to account for peak loading of 25\%)} = 2W$$

So a 5.5Wh cellular phone battery is functionally equivalent to a 2W (rounded) fuel cell.

To arrive at the appropriate price points for fuel cells for portable devices, Li-polymer battery systems were used as a "target price," since Li-polymer is the highest price the market has been able to absorb for batteries. Since fuel cells are not expected to be widely available commercially until 2004-2005, ASPs for both 2002 and 2005 were chosen. Based on the functional equivalence of batteries and fuel cells given for notebooks and mobile phones above, the following $/W for fuel cells was derived:

Exhibit 5
Worldwide Pricing
Li-polymer & Fuel Cells
(ASPs & $/W)

	2002	**2005**
Notebook Computer		
Li-Poly Battery System (OEM)	$88.39	$66.43
Fuel Cell (OEM)	$5.52/W	$4.15/W
Mobile Phone		
Li-Poly Battery System (OEM)	$12.51	$9.20
Fuel Cell (OEM)	$6.26/W	$4.60/W

The above pricing includes all costs associated with the battery or fuel cell system, including materials, components, manufacturing, overhead, and marketing. Based on commercial sales in 2005, fuel cells will have to target the $4.15/W-$4.60/W range to be competitive with Li-polymer, the more realistic competitor to fuel cells. To be competitive with Li-ion batteries, fuel cell pricing would have to be closer to $2.81/W-$3.71/W.

Also, wireless portable devices might use batteries or ultracapacitors in addition to the fuel cell. This would add extra costs not reflected here. For example, the discharge profile of a GSM handset can involve more than a 1A amplitude pulse at about 25% duty cycle. During the standby mode, it is less than 10mA. To handle this, a fuel cell system might need an ultracapacitor, which adds costs to the system that are not part of a battery system.

4.2 Materials

Materials availability and cost are critical to any discussion of fuel cell cost reductions. With batteries, alternative materials are available if one material becomes scarce or too expensive. This is not true with fuel cells. Present fuel cell prototypes often use materials selected more than 25 years ago. Cost and durability have revealed inadequacies in some of these materials.

The most important materials under development for PEMFC stacks are construction materials for the cell frames, bipolar plates, electrocatalysts for the fuel and air electrode, and the ion conducting membrane. Platinum is the most active material in the electrocatalyst, and to reduce the cost, nanoparticles of platinum on a carbon support have been developed. For fuels containing traces of CO, or methanol in the DMFC, a CO-tolerant catalyst is required. This remains one of the most challenging tasks for the successful development of commercial PEMFC systems.

Platinum and ruthenium both need to be reduced, if not eliminated. But even if these materials are reduced, the cost of a fuel cell system will still be too high. Nafion (made by DuPont) and GORE-SELECT® (from W.L. Gore & Associates) are favored options and are commonly used in fuel cell stacks even though the costs remain high. Cheaper (usually fluorine-free) membrane materials are being developed as an alternative. But cost reductions need to be in all areas, not just membranes, where many developers focus. For this reason, some researchers believe it may be difficult to attain sufficient market share to justify the investment for mass production while competing against established technology. For the portable market, going after “hybrid” systems that require higher energy densities and utilize fabricated techniques developed for the semiconductor industry could prove more successful.

4.3 System Needs

Like pricing, fuel cells need to be competitive with batteries when it comes to system component cost breakdowns. The components of a Li-ion battery pack, for example, include:

Li-ion Rechargeable Battery
- Cathode active material
- Anode active material
- Collector
- Separator
- Electrolyte
- Casing

Protection IC
Control Switches
Positive-Temperature-Coefficient resistor (PTC)

Following are comparisons of some of the various fuel cell cost breakdowns:

PEMFC Cost Breakdown:
Fuel Cell - 60%
Fuel Processor - 29%
Assembly & Indirect - 8%
Balance of Plant - 3%

DMFC Cost Breakdown:
MEA (GDL, Membrane, Electrodes, Bipolar Plate, Gaskets, Other) - 40%
Other components and assembly (Fuel Processor, Balance of Plant, System Assembly) - 60%

SOFC Cost Breakdown:
Systems - 61%
Components - 25%
Materials - 8%
Materials Processing - 6%

Cost Breakdown for Fuel Cell Technologies in General:
Fuel Processor - 40%
Stack - 27%
Power Conditioning - 18%
Control - 15%

4.4 By Application

The technical requirements for delivering a DMFC to the consumer is cost reduction and mass production process development. SunTrust Robinson Humphrey, a venture capital firm, believes that the value of back-up power is nearly high enough to support fuel cell systems. But fuel cell companies need to show a “path to profitability” through alternative portable products to those that are currently running into regulatory problems.

For instance, most of the fuels that are used with fuel cells currently are prohibited in air passengers' carry-on luggage or on their person in the aircraft cabin. Safety standards and regulations for fuel cell technology have been established, including Department of Transportation regulations where methanol fuel has been classified as a "Hazard Class 3" flammable and combustible liquid that could result in spontaneous disassembly, or an explosive rupture in the fuel cell.

If fuel cells are positioned to compete with batteries, the best applications are those which are high-value, or those where the benefits of the fuel cell outweigh the costs. Lithium-ion has a stranglehold on the consumer electronics market, and semiconductor makers are actively finding ways to make batteries work more efficiently with consumer devices. This is not true in all portable markets, however.

For example, auxiliary power units (APUs) are traditionally a cheaper product – not necessarily a "high value" product that would use a fuel cell. But a commercial or residential site might be willing to use a quiet, less smelly fuel-cell-driven APU if they are already installing photovoltaics, which are expensive. In other words, fuel cells could target portable applications that are used in high-cost environments that are less price sensitive.

Section V: TECHNOLOGY ASSESSMENT

5.1 System Architectures

DMFCs use platinum or ruthenium at the anode and cathode. A certain "Platinum loading" is necessary for reasonable power density, yet it represents a significant increase in cost. If, however, platinum can be reduced with a reduction in peak power only, system architectures can be altered to make up the power loss. For example, an ultracapacitor can be added to augment the peak power requirements. Maxwell Technologies is collaborating with Avista Labs and several other companies that are incorporating ultracapacitors into new UPS and fuel cell system designs.

Avista Labs is developing fuel cell products initially for applications in distributed power generation and industrial power backup systems and, on the basis of its intellectual property position, may pursue future applications in vehicle auxiliary power units (APUs) and industrial and consumer electronic devices. Avista Labs says that, "Incorporating ultracapacitors to meet peak power demands provides superior dynamic range and establishes a clear path to dramatically reduce cost by sizing the fuel cell system to match customer power requirements. Our proprietary method of integrating ultracapacitors into our power management circuitry will allow us to make components and systems across a range of voltage applications with significant reductions in size and cost."

In April, 2002, T/J Technologies Inc. (Ann Arbor, MI) announced a three-year project through NIST's Advanced Technology Program Competition in which they would design, assemble, and test a power pack for portable electronics that integrates ultracapacitors with fuel cells and provides the necessary fluid management and control electronics. This approach, which would separate energy storage from power delivery and improve overall performance, is patterned after the company's success in combining ultracapacitors with batteries to increase the runtime of cell phones. T/J will produce the ultracapacitors, which will provide startup power and enable reductions in the size of the fuel cell system, and integrate the components.

The design and construction of the miniature methanol/air polymer electrolyte fuel cell array will be subcontracted to the University of Minnesota (Minneapolis, Minn.), and Advanced Sensor Technologies Inc. (Farmington Hills, Mich.) will develop the microfluidics needed to provide fuel to the fuel cell. The project will focus on defining the load requirements and determining the optimal partitioning of size, energy, and power between the ultracapacitor and fuel cell. Fuel cell efficiency will be improved through use of the ultracapacitor to manage peak power demands. As a final step, the researchers will assemble and test an integrated hybrid power pack mounted to a commercial electronic product. If successfully developed and commercialized, T/J Technologies claims the new technology would enable manufacturers to offer longer runtimes, faster recharge, and more features in cell phones, laptop computers, robotic systems, and other civilian and military products relying on batteries. In addition, U.S. firms could make inroads into markets for rechargeable batteries dominated by foreign competitors.

5.2 Fuel Considerations

Currently, there are three classifications of fuels that are being looked at most seriously for fuel cells used in portable applications:

- Hydrogen
- Metal Hydrides (flammable & water-reactive)
- Chemical Hydrides
- Methanol
- Ethanol

Based on the following competitive and regulatory issues, methanol appears to be leading as the fuel of choice for development in portable fuel cells. It is the most likely to be approved for transport; and Japan's Ministry of Economy, Trade and Industry has chosen it as the "likeliest way of supplying hydrogen for small fuel cells."

5.2.1 Competitive Environment

Japan's Ministry of Economy, Trade and Industry took the lead in August, 2002, when they announced that they would subsidize projects to develop fuel cells small enough to use in mobile phones and notebook computers, starting from the next fiscal year. The

Ministry indicated that "the likeliest way of supplying hydrogen for small fuel cells is by extracting it from methanol sold in exchangeable cartridges." This means the cartridges may not be disposable.

The Ministry also "intends to take the lead in establishing standards for small fuel cells and cartridges so that they are compatible with any type of electronic product." Since Japanese companies already have a lead in the portable, rechargeable Li-ion market, any steps they take in this direction need to be watched closely.

5.2.2 Pros/Cons/Issues

Major Points to Consider From the U.S. Department of Transportation (DOT):

Currently, hydrogen and water-reactive metal hydrides are forbidden on passenger-carrying aircraft or rail cars.

Methanol is allowed up to 1 liter maximum, but only in cargo. Methanol is classified as a "Hazard 3, Packing Group II" material. "Packing Group II" designates "medium danger." As such, a "consumer commodity" exemption is possible, which would allow "limited quantities" of methanol on board planes or rail transport. Based on previous exemptions (e.g. cigarette lighters), it is likely that "consumer quantities" of methanol, properly packaged, could be similarly exempted. UL2265 is the workgroup that is developing guidelines for the use of portable fuel cells on board airplanes.

The Department of Transportation (DOT) may eventually authorize an exemption for methanol on board aircraft due to its limited toxic hazard. However, the newly created Transportation Safety Administration (TSA) may restrict carriage on board aircraft due to safety (i.e. terrorist) concerns. Currently, the new TSA security personnel do not allow cigarette lighters on board the aircraft even though they are permitted by DOT regulations.

Limited amounts of flammable metal hydrides are allowed on passenger aircraft.

Depending on meetings with the DOT, methanol appears to be the most likely fuel to be approved.

Under the United Nations Economic Commission for Europe (UNECE):

In July, 2002, a miscellaneous amendment proposal was submitted to the Sub-Committee of Experts on the Transport of Dangerous Goods regarding "Metal Hydride Storage System for Hydrogen-powered Proton Exchange Membrane (PEM) Fuel Cells." The paper was submitted to request comments from members of the sub-committee with a view to preparing a formal proposal for the December, 2002, meeting if there is sufficient support to do so.

The proposal indicates that it is anticipated that "portable power generating units equipped with hydrogen in metal hydride storage systems will be transported, including to remote areas. Hydrogen in metal hydride storage systems presents a unique hazard not covered by any entries in the Dangerous Goods List. Hydrogen is a flammable gas while the metal hydrides are currently classified in the Model Regulations as either flammable solids or water-reactive." The proposal asks the members of the Sub-Committee to consider adding hydrogen in metal hydride storage systems to the Dangerous Goods List. They also suggested that these storage systems should always be considered as containing hydrogen, unless it can be shown that the storage system has been cleaned and purged so that a danger no longer exists.

One of the "unsolved issues" in fuel cell technology is the preferred method of generating and storing hydrogen. Storage challenges in the portable fuel cell market include a large variety of emerging storage media, reformer feed-stock chemicals, and customers who expect a seamless power solution.

As in the U.S., the regulatory concerns in Europe with hydrogen and metal hydrides point to methanol as the preferred fuel for transport.

5.2.3 Options

At the 2002 "Small Fuel Cells for Portable Power Applications" conference, a venture capital company that represents consumer electronics firms said that device manufacturers want fuel cells to run on "as ubiquitous a fuel as possible." This may be a long-term goal, when manufacturing reaches a scale that allows such standardization. But as a short-term issue, fuel could pose a barrier to entry for consumer devices that run on standard battery products.

Section VI: COST REDUCTION OPPORTUNITIES

When considering the potential commercial success of an emerging technology, it is useful to look at previous technology introductions and what made them successful. Industries tend to operate like the industry that came before, and in the case of fuel cells for portable applications, the lithium-ion battery industry is the best model. Fuel cells are expected to be competitive with Li-ion, both in terms of price and performance. But fuel cells cannot be simply a substitute for Li-ion.

When portable, rechargeable Li-ion batteries were first introduced commercially, they were marketed as substitutes for NiMH batteries. They were marketed as a higher energy density battery for "mobile" computing. In fact, looking at the price differential between Li-ion and NiMH in 1995, Li-ion was twice as expensive as NiMH, but it was still successfully introduced because it met the increasing power demands of a new generation of mobile computing devices. Notebook computers demanded longer battery life to power large-capacity hard disks, LCD backlighting, color screens, megabytes of RAM, high-powered CPUs and CD-ROM drives. Enabling “mobile computing” was the first step for a new energy storage technology. Li-polymer was not able to offer higher energy density (and it cost more), so it was not as successful as Li-ion

The second step is what we call “mobile connectivity.” Fuel cells could enable the universal connectivity of wireless devices, such as notebook computers and 3G phones. Currently, these devices cannot be wirelessly connected to each other, except using short-range, lower bandwidth applications, such as Bluetooth or 802.11. Long-range, high bandwidth wireless connectivity requires a lot of power, which fuel cells could provide. The early adopters of these devices will, in essence, be the “road warriors” of mobile connectivity. And that will raise one of the biggest challenges for fuel cell manufacturers: channels of distribution.

Right now, a laptop battery can be recharged as long as there is a place to plug it in. In other words, the end user does not have to go out and buy anything. Fuel cells need cartridges. If an end user runs out of cartridges, another one has to be bought. Therefore, fuel has to be convenient and readily available – anywhere. The road warrior/early adopter could be in Europe, Asia or South America. Fuel cell companies will have to establish distribution channels (or team with companies who have them) to enable mobile connectivity.

Another fuel problem, discussed earlier, is fuel safety. As mentioned above, methanol fuel cannot be legally brought in the passenger compartment of airplanes, although “consumer quantities” might be legal in the checked baggage compartment. This could pose a serious challenge, along with any fuel that is deemed hazardous or simply too difficult to obtain anywhere in the world. Fuel cell companies might consider investing their research and development dollars in safer fuel options that would enable wider distribution and availability for the early adopters most likely to use fuel cells.

On the other hand, the DOT has made exceptions for “new devices” using hazardous materials, and as a result, cigarette lighters containing flammable fuels, lithium-ion batteries for portable devices, and batteries for wheelchair mobility have been approved. Therefore, even though no provisions currently exist for fuel cells, it is expected that weight and quantity limits will be established in the future.

A few years ago, lithium-ion batteries, in particular, were seen as a potential safety hazard on airplanes (and elsewhere). Several incidents of “spontaneous disassembly” occurred in the passenger and cargo departments of planes, raising some real issues of regulation. Li-polymer was even touted as a “safer alternative” to Li-ion. But those issues were resolved to the point that “safety” is not even used anymore as a major marketing point for polymer. Based on the precedent set by Li-ion and the willingness of the DOT to discuss regulatory approval of fuel cells, it does not seem likely that limited quantities of fuel packaged appropriately will be banned from planes.

In the same way, fuel cells will have to provide things that Li-ion batteries cannot. Currently, high-bandwidth electronic devices are taking rechargeable batteries to their limits, and research suggests that unless battery technology is upgraded, "portable devices will have to cut power consumption to improve performance." Commercial success of small fuel cells includes targeting the right markets.

This kind of strategy does not necessarily mean that any device that uses a Li-ion battery is a good candidate for fuel cells. Li-ion was originally aimed at mobile computers because this is where their advantages as a technology stood out. Also, laptop computers were already expensive; a $100+ lithium battery was not a large percentage of the total system cost. The mobile phone market was already fairly large outside of the United States, but these devices did not have the power demands that made Li-ion so attractive for notebook computers. Plus, a lithium battery would have been a much larger portion of the system cost. Only later, as cell phones got smaller and lighter, could Li-ion compete with cheaper batteries.

Because of their higher cost, fuel cells need to target markets where batteries cannot "do the job." 3G phones and other "convergence" devices may eventually need the energy density of fuel cells, but demand for 3G and similar phones is not expected to be significant for several years, at least. So the potential market for fuel cells in mobile phones and convergence devices is considered a longer-term opportunity.

Many fuel cell companies are focused on the "total cost of ownership" (TCO) as a strategy for successfully commercializing fuel cells. TCO includes initial capital and installation costs, along with operational and maintenance costs over the lifetime of the product. Focusing on the TCO – as either a hurdle or an advantage – is not necessarily useful when considering cost reduction opportunities for consumer applications, but it can be more useful for commercial, military and industrial applications. And for fuel cells, the cost of fuel replacement could make TCO a hurdle rather than an advantage.

Total cost of ownership can be a important factor when looking at regulated industries, such as telecom or utilities. In those cases, the initial investment is often used to determine rates charged to consumers, and the higher the initial cost, the higher the rates. If long-term operating and maintenance costs are lower, that can make profits even higher. When looking at portable consumer devices, however, TCO is not generally a significant factor. A customer buying a cell phone is not going to pay a substantial initial cost for his or her phone because the TCO is lower. Using that argument, an industry study found that Mercedes-Benz was the best car to buy because it had the lowest TCO of any vehicle. Consumers would have to hold on to their Mercedes for a long time to reap this benefit, however. Devices such as mobile phones, laptop computers, and so on become obsolete quickly, which is another factor reducing the importance of TCO.

Consumers purchasing portable devices – whether cell phones or APUs – generally are not interested in TCO, just how much they have to pay upfront. Manufacturers of fuel cells for portable devices need to focus on initial costs, not total cost of ownership costs. A low TCO is not undesirable; it just is not the deciding factor in the portable consumer market. The Military market, on the other hand, is relatively price-insensitive. High initial costs are not a showstopper for this segment. They want a reliable, rugged product that preferably lasts a long time in the field and that does not need to be replaced often.

With that in mind, the following sections look at ways of reducing costs in the materials, volume, design and manufacturing phases of fuel cell production. Each section includes information from specific companies as to what they are doing to reduce costs, along with a discussion that provides broader implications for the fuel cell industry.

6.1 By Stack

Fuel cell stack components include the bipolar plates, membrane electrode assembly (MEA) and gas diffusion layer (GDL), packaging, end plates, gaskets and seals. Materials used in fuel cell design include thermosets (vinyl ester, epoxies, phenolics, SMC); thermoplastics (PPS, LCPs, fluoropolymers, PBT, nylon, polyethersulfone, long-fiber-reinforced plastics); elastomers; nanofibers; and other materials, such as carbon black, graphite/carbon fiber, nickel, lithium and platinum.

Materials development is critical to the success of the commercialization of fuel cells. The most promising materials are expected to be metal catalysts, carbon/graphite, polymers and ceramics.

6.1.1 Materials-based

According to a paper presented at the Small Fuel Cells Conference in April, 2002, "MEAs are the largest single contributor to cost" of a fuel cell, and "Materials costs account for about 50% of MEA cost." Precious metals costs do not decline with volume; in fact, using more of a limited resource can actually increase the price.

Fuel cells typically use platinum at both the anode and the cathode. The Department of Energy (DOE) indicates that platinum catalyst loadings have been reduced by over a factor of ten, with only a 30% reduction in peak power.

Looking at metal resource constraints, platinum production appears to be sufficient for the amount required in portable fuel cells. Based on the DOE platinum loading, if fuel cells were used in all cellular phones (10W), laptop computers (15W), and PDAs (5W) expected to be produced in 2002, this would amount to almost 9 million grams of platinum, or 5% of world production.

But demand for platinum is expected to increase dramatically over the next 10 years. The automotive industry accounts for roughly 80% of the industrial uses of platinum each year (mainly in catalytic converters), and the demand for platinum in fuel cell technology is projected to be three to four times greater than that for catalytic converters. The reason for this increase is because platinum is an integral part of the emissions system, and stricter pollution controls are being put on automotive manufacturers. In addition, electronics consumption of platinum, although a "smaller" use of the precious metal, is expected to increase due to the demand for optically pure flat glass for high-definition TV screens and similar products.

Fuel cell vehicles, in particular, pose a significant threat to the world supplies of platinum. A recent study from Chalmers University (Råde, 2001), "Requirement and Availability of Scarce Metals for Fuel-Cell and Battery Electric Vehicles," included a baseline scenario for platinum content, recycling losses and lifetime of autocatalysts and fuel cells. The researchers used a catalyst intensity of 0.39 g Pt/kW and assumed a fairly small vehicle or hybrid with a fuel cell power requirement of 50kW (gross). The platinum content for autocatalysts was 2 grams, while the platinum content for fuel cells was 19 grams.

In this baseline scenario, the total cumulative demand for primary platinum amounted to 159 Gg. Of these applications, fuel cell vehicles dominated with 78% of the cumulative demand for primary platinum, followed by industry with 10%, jewelry with 9% and autocatalysts with 3%. Refined reserves and refined identified resources in 1999 were estimated at 30 and 53 Gg of platinum, respectively. The cumulative demand of 159 Gg in the baseline scenario is three times the refined identified resources and more than five times the refined reserves.

In addition, in the baseline scenario, the annual demand for primary platinum reaches 3,400 Mg in 2100, almost 20 times the annual demand in 2000 of 180 Mg. In absolute terms, to reach this level in 2100, the annual increase in mine production has to be, on average, 32 Mg of platinum. Historically, such large increases have never been seen. The annual average increase in absolute terms during the last 60 years is about 2.6 Mg.

The Chalmers scenario only looked at platinum requirements in fuel cell vehicles. Fuel cells will be used in other applications, as well. The 9 million grams for portable applications only looks at cell phones, laptops and PDAs. It does not consider other portable applications (such as military or APUs), stationary applications (such as telecom or back-up power systems), or other motive applications (such as fleet vehicles).

Another trend is substituting higher platinum loadings for palladium in autocatalysts to cut costs. A 2001 economics report indicated that "a complete replacement of palladium catalysts with platinum would increase the total demand for platinum by 7 million ounces, or 123%. If this were even halfway possible, the price of platinum would probably rise above $5,000 per ounce, and palladium plummet to below $150." Even a partial replacement of 10% of total palladium represents a 12% increase in overall platinum demand.

A long-term materials consideration is recycling. Although currently there are no requirements for recycling platinum, efforts will be initiated for platinum in the same way that lead-acid batteries need to be recycled. This will be more for economic and production reasons than for environmental reasons. For most platinum group metal (PGM) applications, the actual loss during use of the metal is small, hence the ability to recover the metal efficiently contributes greatly to the economics of PGM use. The rise in PGM prices has prompted even small vehicle dismantlers to remove catalytic converters for recycling. This led to an increase in the amount of platinum recovered, from about 9,800 kg in 1999 to about 10,900 kg in 2000. As the demand for platinum goes up, both PGM pricing and concerns regarding the supply of platinum will most likely prompt recycling regulations worldwide.

Although membrane electrode assemblies (MEAs) are considered to be the single largest contributor to cost, and precious metal can be anywhere from 41% to 74% of the MEA, PM still represents just 30% (at most) of the total cost of a DMFC. Raw materials and fabrication costs of MEAs are both important; details depend on the specific application. In other words, companies do not have to focus just on platinum reductions; they can work on reducing costs in the other 70% of the fuel cell, as well.

Thermoplastics and high-temperature polymers can provide system cost reductions in the same way that plastics have replace metal over the years. The increasing demand for these materials in fuel cells could, however, result in cost increases. An example is the current short supply of polyetheretherketone (PEEK) resin, whose sole commercial-scale producer is Victrex plc in the U.K. PEEK has potential as a membrane material in fuel cells because it has very low moisture uptake and "outstanding" hydrolysis resistance, particularly in high temperature steam. Ballard has an exclusive agreement with Victrex to make two types of proton-conductive polymers that were jointly developed by the partners.

But soaring demand for PEEK in semiconductor manufacturing and energy-related applications has resulted in demand outpacing capacity for making it. The shortage has been accompanied by a rise in PEEK prices. Overall, the pace of new applications development for polyketones in general remains high, stimulated by new base resins and higher-performance versions of existing compounds. Even though thermoplastics and high-temperature polymers can, theoretically, provide system cost reductions, competition from other high-growth industries for these materials could keep costs higher – at least until production catches up with demand.

6.1.2 Design-based

The cost of raw materials is a big part of fuel cell costs. The cost of precious metals could go up; it won't necessarily go down. Precious metals cost is the largest portion of raw materials cost, no matter how it is broken down, according to Superior MicroPowders. Technical issues include the high materials cost of the product (mostly in the catalyst, which is the main concern).

But when looking at problems associated with the materials, what is the right "problem" to fix? For example, should it be at the stack level or the system (such as the reformer) level? The problems associated with reformers, for instance, are very different from those related to the stack, and finding ways to reduce costs associated with the reformer could be more productive than looking at the stack.

Powerzyme believes that microfluidic and control systems that use plastics rather than MEMS are cheaper to produce. But InnovaTek feels that micro-technology can reduce product cost by reducing the volume of materials used in the reactor, in the catalyst bed, and in thin film coatings.

Looking at fuel cell design, companies are considering different ways to reduces costs. Plug Power is looking at materials substitutions, component elimination and specification changes that result in lower-cost parts. Manhattan Scientifics believes that the distances between bulk conductors in a fuel cell need to be as short as possible to reduce costs. Motorola is trying to integrate the fuel processor into the stack – a "full integration in system design," where microfluidics, mixing and pumping can all take place within the ceramic structure or stack itself. The electronics, including drivers, microcontrollers and any other necessary components, can be mounted within cavities on the top surface of either side of the stack.

Protonex found that exploiting patented technology reduces stack costs. For example, the company uses biopharmaceutical filtration technology in their PEM fuel cell stacks to reduce stack cost, including no dynamic seals (i.e. no gaskets), relaxed component tolerances, and flexible design. Everything comes on a roll and is stamped onto the product, making the manufacturing process low-cost.

MEAs are a significant contributor to the cost of PEMFC and DMFC fuel cell systems. For an automotive fuel cell, the MEA is 40% of the cost; all other components and assembly are 60%. The total cost of a 10W system is $55, with the MEA being $22.

Methanol is much cheaper than hydrogen in $/Wh. And, as mentioned above, microfluidic and control systems that use plastics rather than MEMS are cheaper to produce. And from a raw materials point of view, DMFCs are feasible. But performance and PM loading are critical elements.

6.1.3 Manufacturing-based

Using baseline assumptions, Superior MicroPowders stated that materials costs account for about 50% of MEA cost. Companies need to achieve fabrication costs and margins from the remaining 50%. Fabrication costs include:

- Chemical precursor from precious metals bullion
- Electrocatalyst powder
- Electrode ink
- Catalyst-coated membrane
- Hydrophobized GDL

- Assembly of MEA

Protonex uses Nafion™ (DuPont) PEM and available gas diffusion layer (GDL), catalyst and off-the-shelf sealants. As a result, production requires minimal labor (low skill assembly). Their manufacturing process uses low-cost molds, and as they scale up, their process is injection-molding compatible.

For Plug Power, volume increase is a combination of volume price breaks and changes in manufacturing methods that are driven by volume, such as molded versus machined parts.

6.2 By System

Other parts of the fuel cell system can include the electronics, fuel tank, heat exchanger, water filter, compressor, pumps, evaporator, and reformer.

6.2.1 Design-based

MTI Micro Fuel Cells is encountering some design issues with dc-dc converters that could affect both small and large fuel cell systems. For low-voltage applications, the power converter has to take a very low dc voltage (e.g. 0.25V) and step it up to 2.5V or 3.0V. This is a step-up rate of 10x, which is not very efficient. It certainly can be done, which is probably why most fuel cell developers haven't focused too much on it. But the solutions (such as adding additional stacks) increase cost, size and/or weight.

MTI Micro said the power electronics could be a "showstopper." Fuel cells are already expensive, and the costs associated with power conversion may prove unavoidable. Even though these design issues are associated more with low-voltage (i.e. portable) fuel cell systems, the same problems are expected to exist to a lesser extent with the larger systems.

Since costs must be reduced in all areas, fuel cell manufacturers can benefit from technology developments that might be transferred to fuel cell design. For example, in June, 2002, Delphi Corp. announced that it had developed a new, low-cost hydrogen enrichment technology that could help improve vehicle environmental performance by adding hydrogen to a gasoline engine to reduce cold-start hydrocarbon (HC) and oxides of nitrogen (NOx) emissions and NOx during cruise conditions. Using a Delphi micro reformer, the hydrogen enrichment system generates a hydrogen-rich gas by partial oxidation of fuel. The micro reformer is approximately the size of a soda can and can be placed nearly anywhere on the vehicle. Control valves are utilized to manage fuel delivery to the reformer and reformate delivery to the engine and exhaust catalyst. This kind of reformer size reduction could have implications for fuel cell reformers, if similar miniaturization techniques could be applied.

6.2.2 Manufacturing-based

At 10W and above, fuel cell system manufacturing is costly for DMFCs. Fuel cell developers are using different methods to reduce costs. Protonex's manufacturing process uses low-cost molds, and as they scale up, their process is injection-molding compatible. Minimal tooling is a way to lower production capital.

The use of low-cost materials and existing, patented technology has only been mentioned by a few companies, but this is a key to keeping initial costs down. Many fuel cell companies seem intent on developing proprietary, unique technologies that may keep initial costs high. These companies often focus on total cost of ownership, but as discussed previously, this is not a valid argument for the portable market. As "unsexy" as it is, keeping a fuel cell design as simple as possible is critical to keeping it as cheap as possible. That means using low-cost manufacturing processes, off-the-shelf components, and already-existing materials that are likely to remain in strong supply. Even with low-cost materials, such as plastics, there are "cutting-edge" technologies that distract developers from the fact that other industries might be competing for these materials, thus reducing supply and raising costs.

Using established manufacturing facilities and processes will reduce costs. Since initial cost is the key issue for commercializing fuel cells, having the lowest price will be key for any company wanting to be "first to market." Japanese companies have an edge here, because they already have a manufacturing and distribution system in place for the very products fuel cells are expected to replace (batteries). Toshiba, NEC, Sony, Casio, Samsung, Sanyo, Panasonic and Hitachi are all preparing to introduce fuel cells to the market within a couple of years. No matter how low in price any non-Japanese company is prepared to go, one of these manufacturers can go lower. Panasonic sums up its cost-reduction strategy below, and a summary of their approach is offered.

6.2.3 Fuel Packaging/Distribution-based

It is generally accepted that fuel processors represent 35-40% of the total cost of a fuel cell system that includes an integrated fuel processor. Compared to compressed hydrogen, reformed diesel/JP8 fuels offer a significant cost advantage in the delivery of power. A cost reduction opportunity is reducing the power consumption for fuel delivery and water recovery system. In fuel cell packaging and testing, as with other materials, plastic materials can be a low-cost part of the integrated assembly of PEM cells.

Plug Power's supply chain initiatives include alternate sources of material, vendor collaboration on design for manufacturing and price negotiations.

6.3 Relevance of Cost Reductions to Larger Fuel Cell Systems

As discussed above, when looking at the potential commercial success of an emerging technology, it is useful to look at previous technology introductions. This applies to both smaller fuel cell systems for portable devices and larger fuel cell systems for stationary or mobile applications. In that sense, both large and small fuel cell systems must compete successfully with the existing premium energy storage products.

Some of the design-based solutions to reduce costs in portable fuel cell systems will not directly reduce costs in larger system design. Micro-technology, for instance, reduces costs by reducing the volume of materials used in the reactor, catalyst bed and thin film coatings. But such technology is less significant in reducing costs in a large fuel cell system that does not benefit from micro-components (especially if the micro-technology is more expensive upfront).

As noted above, DMFC manufacturing is costly at 10W and above. Volume pricing is very important in reducing costs for both portable and large fuel cell systems. Manufacturing methods that are driven by volume, such as molded versus machined parts, will benefit both portable and stationary fuel cell markets. Using off-the-shelf parts can also result in minimal labor production.

Panasonic lists sales and distribution channels as critical to a successful portable fuel cell business model. The survey of stationary fuel cell manufacturers also indicated that local distribution, servicing and/or manufacturing facilities were important to establish a "presence" in the market. Partnerships with companies that have worldwide factories can be beneficial to both portable and stationary fuel cell makers.

Panasonic lists the following as necessary to a successful fuel cell business model:
- OEM relations
- Sales and distribution channels
- Relations to potential internal (vertical) customers
- Mass production capability
- Commercialization experience: prototype to mass production
- Factories located worldwide
- Brand name
- Battery and/or capacitor production for fuel cell hybrids

Having a vertical business model is the best (some might say, the only) way to reduce costs with an emerging technology. Unless the product is being used in regulated industries that value total cost of ownership (such as utilities or telecom) or industries that are relatively price-insensitive (such as military), initial cost is what the customer is going to look at. In that sense, having the "best technology" does not matter. If the fuel cell technology is "good enough," it will win. Focusing on reducing initial costs is more valuable than focusing on improving the technology.

Panasonic's model includes several critical factors that help reduce initial cost, although certain points need to be elaborated. Having commercialization experience, especially in the product area fuel cells are expected to replace, is certainly important. Volume manufacturing is key to reducing costs, and having that capability, along with factories throughout the world, is essential to fuel cells being more cost-competitive with Li-ion batteries. Since many fuel cell companies do not have these capabilities, they need to consider partnerships with companies that do.

Section VII: PORTABLE POWER MARKET FORECASTS

7.1 Introduction

This section provides market forecasts for fuel cells and includes a detailed discussion of how these forecasts were obtained. Since fuel cells are considered an "emerging technology," a number of different factors had to go into the forecasting methodology. Several economic theories and business models are discussed that provide the factors needed to determine a valid and reasonable market forecast. The forecasts were developed with the purpose of this report in mind: To pinpoint the best entry markets for a commercially successful fuel cell for portable power products. To that end, the forecasts focus specifically on market sizes, timing and growth potential, cost sensitivity and a "path to commercialization."

The forecasts build from existing portable applications that use premium (i.e. lithium) batteries, and then apply adoption rates, production assumptions, pricing assumptions and price elasticity to derive unit sales, dollar sales, and average selling prices. In addition, a "target price" is given for each application that will allow fuel cells to "cross the chasm" from the early adopters to the mainstream. "Target prices" are determined by market forces; they are not chosen arbitrarily and do not always meet a given company's idea of what is feasible.This end user model is a critical part of the typical adoption of emerging technologies and is discussed in the section below on "Early Adopters."

7.2 Total Available Market (TAM) Forecasts

Many applications are being considered for small fuel cells. These include mobile phones, notebook computers, PDAs, smart cards, digital cameras, handheld game devices, battery chargers, military applications, electric wheelchairs, scooters, lawnmowers, auxiliary power and other remote power units, and medical devices. The purpose of this report is to "identify and evaluate potential markets for fuel-cell-based portable power products." Darnell believes that the best "potential markets" for portable fuel cells under 1kW are those that currently use premium, rechargeable batteries.

Still, a brief discussion of some of these other markets is in order, if only to explain why they are not as good of opportunities as those for premium batteries. For example, handheld gaming devices, portable DVD players and other consumer devices typically use nonrechargeable, alkaline batteries. These products are not good candidates for a premium battery, such as lithium-ion, since they are inexpensive and often replaced before the extra cost of a premium battery would pay for itself. Some of these markets are quite small, as well – sales of portable DVD players in North America are only expected to be 3.2 million in 2002, for example.

The small, portable power market faces a similar situation as the handheld entertainment device market: an existing power source (in this gas, gasoline or diesel fuel) that is relatively inexpensive compared with fuel cells. Small, portable generators (1kVa class) constitute about 35% of the world market for portable generators; about 700,000 units are sold in the United States each year, with an 8.0% compound annual growth rate projected through 2003. Japanese manufacturers, such as Yamaha and Honda, dominate this market, and they are very competitive on price. With inexpensive fuels contributing to this price competitiveness, it is likely that fuel cell use in portable generators (such as the Coleman Powermate that Ballard is working with) will remain a "niche" market, especially as long as the Japanese companies remain dominant.

On the other hand, the market for lower-wattage portable power units could constitute a small, but promising, "introductory market" for fuel cells. These units would be in the 25-100W range, up to about 200W. One of the differences between these products and comparable 25W products for consumer devices is longer runtimes. A laptop computer only needs hours of runtime, whereas Portable Power Units (such as military or industrial units) require days of runtime (i.e. lots of fuel). Fuel cells add value, in this respect, since they can accommodate the longer runtimes. This market will be forecast in more detail in Section 7.3, below.

The battery charger market is another segment facing cost pressures, depending on the wattage range. Due to the large dollar market share of Notebook Computers and Mobile Phones, the Worldwide Battery Charger dollar market is expected to be approximately $2 billion in 2002. Wattage categories can be defined as follows:

<10W - Typical applications include Digital Cameras, PDAs, Portable Audio, Mobile Phones, Camcorders, and Handheld Computers.

11-50W - Typical applications include Camcorders, Digital Cameras, Handheld Computers, Mobile Phones, and Notebook Computers.

51-100W - Typical applications include Notebook Computers.

Prices for battery chargers and adapters are dropping the fastest in the <5W portion of the <10W segment, due to the quick drop in worldwide cellular pricing. These pricing drops can be seen more specifically in Exhibits 1 and 2 in section IV above. The slowest price drops are in the 51W-100W segment.

Emergency battery chargers are "niche" products; and the cheaper, mass-produced models use alkaline batteries. In fact, inexpensive battery chargers for mobile phones are being advertised as "promotional" giveaways, along with being "bundled" with cell phones. We do not believe such products are good opportunities for fuel cells.

Another indication that such products might not be successful is Electric Fuel's announcement in August that it planned "to sell its Instant Power chargers [using their zinc-air fuel cell technology] for digital cameras and camcorders at 1,200 Ritz Camera stores, as well as on the Ritz Camera website." When Ritz Camera was contacted recently, however, they said they "do not have plans to sell these chargers" at this time. Electric Fuel also announced that a UK direct television channel and a French airline carrier were planning to bundle or sell the chargers, but these are also "niche" markets.

We recently spoke to three battery charger manufacturers and asked them about using fuel cells in their products. The general response was that they are taking a "wait and see" attitude, with a bit of "blue sky" thrown in. One company indicated they would probably stick with batteries. None of them have gotten any interest in a fuel-cell-driven battery charger, and none of them are doing research in this area.

Still, certain kinds of battery chargers could be seen as a "stepping stone" to successfully introducing fuel cells to the commercial market. For example, MTI Micro Fuel Cells is working on reducing the size of fuel cells for mobile phones. Their first product, however, might be a slightly larger accessory, such as a portable charger. In this case, chargers would be an transitional product, but the main value would be as a technological proving ground. Also, Smart Fuel Cell recently introduced their SFC 25.2500 R Power Supply. The system is used by a variety of business users in fields like traffic systems, environment sensors, camping and outdoor equipment, and is now being offered commercially to other industrial customers.

Except for the small, portable power unit/battery charger "introductory" market, Darnell does not believe that the above applications have the (1) unit sales; (2) price premium; and (2) market opportunities for fuel cells to make the quick inroads necessary to achieve the cost reductions needed for larger (including vehicle) fuel cell systems. Except for Electric Fuel's foray into the digital camera/camcorder battery charger market, none of the above applications currently use "premium" energy storage back-up or fuel; in fact, most of them use relatively inexpensive fuels and back-up. The exception might be communications devices for remote locations used in military applications (two-way radios, portable chargers for military, and so on). This is a somewhat price insensitive market, but the unit sales would be small, as well.

So, looking at the "best" market segments for fuel cells for portable devices, the total available market (TAM) can be broken down in a number of ways. For the following forecasts, "Portable" refers to devices under 500W, with most under 50W. The devices chosen are those that use "premium" batteries (i.e. Li-ion and Li-polymer) and therefore are likely to best absorb the price premium of fuel cells.

It should be noted that none of these devices use lithium batteries exclusively. Even Notebook Computers, which have the highest percentage of lithium battery penetration, still use NiMH batteries to a small degree. Therefore, even though the following forecasts are considered "total available markets," they only reflect sales of units that use portable, rechargeable Li-ion and Li-polymer batteries. In that sense, the TAM for fuel cells is only the portion of the market that uses "premium" batteries, not the total market for devices that use portable, rechargeable batteries.

Exhibit 6
Worldwide Premium Battery Market
Total Available Market
(millions of units)

	2002	2003	2004	2005	2006	2007	CAGR
Camcorders	10	11.5	13.3	15.5	17.8	20.3	15.2%
Digital Cameras	7.1	9.5	11.7	15	19.3	25.3	28.9%
Mobile Phones	304.6	322.5	343.6	371	408.4	447.2	8.0%
Notebook Computers	33.8	37.1	41.2	47	54	62.5	13.1%
PDAs	13.4	16.7	19.7	23.7	29.2	36	21.9%
TOTAL	368.9	397.3	429.5	472.2	528.7	591.3	9.9%

Exhibit 7
North America Premium Battery Market
Total Available Market
(millions of units)

	2002	2003	2004	2005	2006	2007	CAGR
Camcorders	3.5	4.2	5.1	6.3	7.7	9.3	21.6%
Digital Cameras	3	4.2	4.9	6.4	8.3	10.9	29.4%
Mobile Phones	83.8	89.6	96.9	104.7	115.5	126.4	8.6%
Notebook Computers	14	15.4	17.4	20.2	23.4	27.3	14.3%
PDAs	6.3	7.9	9.8	12.1	15.2	19.1	24.8%
TOTAL	110.6	121.3	134.1	149.7	170.1	193	11.8%

Exhibit 8
Europe Premium Battery Market
Total Available Market
(millions of units)

	2002	2003	2004	2005	2006	2007	CAGR
Camcorders	4.1	4.5	5	5.7	6.3	6.9	11.0%
Digital Cameras	2.1	2.8	3.8	5.2	7.1	9.8	36.1%
Mobile Phones	123.8	129.9	136.4	146.3	160.6	175.8	7.3%
Notebook Computers	9.4	10.5	11.8	13.6	15.7	18.2	14.1%
PDAs	4.6	5.6	6.8	8.3	10.4	13	23.1%
TOTAL	144	153.3	163.8	179.1	200.1	223.7	9.2%

Exhibit 9
Asia Premium Battery Market
Total Available Market
(millions of units)

	2002	2003	2004	2005	2006	2007	CAGR
Camcorders	2.4	2.8	3.2	3.5	3.8	4.1	11.3%
Digital Cameras	2	2.5	3	3.4	3.9	4.6	18.1%
Mobile Phones	97	103	110.3	120	132.3	145	8.4%
Notebook Computers	10.4	11.2	12	13.2	14.9	17	10.3%
PDAs	2.5	3.2	3.1	3.3	3.6	3.9	9.3%
TOTAL	114.3	122.7	131.6	143.4	158.5	174.6	8.8%

Exhibits 1-4 show the Total Available (unit) Market for Camcorders, Digital Cameras, Mobile Phones, Notebook Computers and PDAs. The largest potential market for fuel cells is Mobile Phones, representing 86% of applications in Europe, 85% in Asia, and 76% in North America in 2002. This dominant market share will persist over the five-year forecast period, although it will decline in all regions to 83% in Asia, 79% in Europe, and 65% in North America. This is due to a relatively slow, overall Worldwide compound annual growth rate (CAGR) of just 8.0%. Worldwide, the unit market for Mobile Phones will increase from 304.6 million to 447.2 million units between 2002 and 2007.

Again, these numbers do not represent total sales of mobile phones in these markets – only sales of devices using premium batteries. So even though Asia is expected to have the highest unit sales of mobile phones over the forecast period, it is still a lower number than the total number of mobile phones expected to sell in Asia.

Notebook Computers is the second-largest potential market for fuel cells, but its market share is significantly lower than Mobile Phones. Still, Notebook Computers is expected to gain market share over the forecast period in all three regions. North America is the largest market, with Notebook Computers holding 13% share of this region's premium battery market in 2002, increasing to 14% in 2007. Asia's market share will grow from 9% to 10% during this period, and Europe's share will increase from 7% to 8%. In North America, Notebook Computers will grow from 14.0 million in 2002 to 27.3 million units in 2007, a CAGR of 14.3%.

The remaining segments (Camcorders, Digital Cameras and PDAs) are small but fast-growing. Of these applications, PDAs present the best opportunity, with the largest market share of the three in 2002. North America, in particular, is expected to be a good market for PDAs, with 6% market share in 2002, increasing to 10% in 2007. PDAs will have the second-fastest growth rate of 24.8%, as well. In this region, PDAs will grow from 6.3 million to 19.1 million units between 2002 and 2007.

Europe's PDA market will gain share due to a fast growth rate of 23.1%, increasing from 3% of this region's total premium battery market to 6%. Asia is not expected to be as good of an opportunity, with PDAs growing only 9.3% per year, the second-slowest-growing application in this region. Market share will remain flat at 2% during the forecast period.

Camcorders and Digital Cameras will remain smaller, "niche" markets for premium batteries. In 2002, about 50% of Digital Cameras are still expected to use NiMH batteries, so the penetration of premium batteries into this segment will lag behind Mobile Phones, Notebook Computers and PDAs. Only high-end Digital Cameras are considered candidates for fuel cells, with Worldwide unit sales expected to be 7.1 million in 2002, increasing to 25.3 million in 2007, a CAGR of 28.9%.

Camcorders are not expected to use Li-polymer batteries in significant numbers at all during the forecast period. Although the number of Camcorder units using Li-ion batteries is larger than Digital Cameras in 2002, many Camcorders still use NiMH and NiCd batteries. Again, only higher-end, professional-level Camcorders are expected to be good candidates for fuel cells. The Worldwide Camcorder unit market will grow from about 10 million units to 20.3 million units during the forecast period, a CAGR of 15.2%.

A note about Camcorders: The overall Camcorder market Worldwide is relatively slow-growing, which includes units that still use NiMH and NiCd batteries. In fact, both of these markets are declining, which contributes to flatter growth overall. The above forecast focuses only on higher-end Camcorder units, which are considered better candidates for fuel cells, and this market is growing faster than the overall Camcorder market. Therefore, the higher growth rate is reflective of "niche" market.

Looking at the forecasts from Darnell Group's "Power Packs for Portable Electronic Devices" report, published in July, 2002, fuel cells are expected to penetrate all the above application segments by 2005, with the exception of Camcorders. Fuel cells are expected to penetrate that market segment in 2006. Notebook Computers and PDAs are projected to have the "highest" initial penetration rates of 0.8%, but this is relative. For all five application areas, the initial penetration rate is expected to be under 1%.

7.3 Targeted Fuel Cell Adoption (Aggressive) Forecasts

The following tables present an aggressive target for fuel cell adoption, based on certain assumptions regarding the introduction of fuel cells and their potential success in the market. They are not so much "forecasts" as "targets" that must be met in order for fuel cells to reach widespread commercial adoption by 2004-2005. Several factors have gone into producing these "potential served available markets." Among the economic assumptions are:

(1) The TAM can be parsed into the following sub-segments: Innovators, Early Adopters, Early Majority, Late Majority, and Laggards. Different segments of the user market will adopt fuel cells at different rates (see discussion of Moore's Product Life Cycle under "Early Adopters," below).
(2) The Learning Curve is 80% (source: Princeton University study of PEMFCs, 2000).
(3) The first (maximum) premium pricing is 120% over Li-ion pricing.
(4) The price premium the Early Majority is willing to pay is 20% over Li-ion pricing.
(5) The adoption rate assumes that 60% of the current SAM (based on current pricing levels) is penetrated within 12 months.
(6) The Start Quantity is the quantity at which the first premium pricing intersects the Learning Curve. This is the most arbitrary factor in the model and can be adjusted accordingly. The percentage used (3%) is of the whole market and does not represent a single company's production.
(7) The medium-term price decline is 50% greater than the lithium price decline rate. The medium-term period is defined as the next two years after the Learning Curve ends.
(8) The Learning Curve effect applies until Fuel Cells have fully penetrated both the Innovator and Early Adopter sub-segments (in this case, the Learning curve continues through mid-2006).
(9) The long-term price decline is assumed to be the same as for the lithium battery and charger pricing.
(10) Key demand suppressants include: Cross-elastic impact of alternative technologies (see Moore's Product Life Cycle, below; Fisher-Pry Model [Fisher, J.C. and Pry, R.H., A Simple Model of Technological Change. Technological Forecasting and Social Change, 1971]; Learning Curve Theory; overall economic conditions; and regulatory environmental factors. The latter two factors are accounted for in Darnell's forecasting assumptions.

Among the fuel cell technology assumptions are:

(1) That certain fuels for fuel cells (e.g. methanol) will be legal on airplanes;
(2) That no new competing technology will emerge;
(3) That Li-ion portable battery pack pricing declines at an approximate rate of 6.3% per year, worldwide, between 2002 and 2007;
(4) That the energy requirement increase from 2G to 3G is expected to be (in general) about 150% (approximately 0.4W to 1.0W);
(5) **That a portable fuel cell can provide 3x-4x the energy density of Li-ion batteries in 2004** (this is based on Casio's plan to introduce a portable fuel cell with "4x the life of Li-ion by 2004"; a fuel cell and ultracapacitor providing 5x energy density of Li-ion; and an "ultimate goal" of 5x-10x energy density).
(6) That a portable fuel cell refill cartridge is readily available, with the goal of selling for less than $10 each. In the conservative forecasts, the target price for a fuel cell cartridge (retail) is <$1.00 for cell phones/convergence devices; $1.50 for PDAs; $3.00 for digital cameras; and $5.00-$10.00 for a laptop computer.

It should be noted that all the forecasts begin with the year 2004. The reason for this is that Casio, Toshiba, Samsung, MTI Micro Fuel Cells and NEC have all announced commercial fuel cell production beginning in 2004. This might be overly optimistic, and the forecast would be pushed back accordingly. *These forecasts are not predictions*. They only present a sales target based on certain assumptions that Darnell Group believes are reasonable in order to achieve commercial adoption by 2004-2005. This is an aggressive forecast. A more conservative forecast, based on input from system makers and fuel cell manufacturers, is given in section 7.4.

But even with the more aggressive forecast, a less optimistic Learning Curve of 90% could be made for comparison purposes. This scenario would make certain assumptions, such as the cost of materials (e.g. platinum) not coming down or staying the same; technology not progressing sufficiently to solve the materials problem (or find ways around it); or factors that force fuel cell design to stay exactly where it is today with no development in the next few years. Because alternatives to these problems (such as nanotechnology) are already being developed, Darnell Group assumes a more optimistic scenario, particularly with the backing of the Princeton study.

Still, the Mobile Phone section, below, provides one of these "alternative" scenarios that assumes a 90% Learning Curve (10% progress rate) and the effect that would have on pricing.

In addition, Exhibit 10 gives our assumptions for various portable applications in terms of (1) runtime; (2) average Wh (for batteries); and (3) average Wattage (for fuel cells).

Exhibit 10
Portable Applications
Power Requirement Assumptions

	Runtime (hours)	Wh Requirements (Batteries)	Fuel Cell Wattage Requirement
Mobile Phones	4.0	5.5Wh	2W
Convergence Devices			
PDAs/Handhelds	3.0	7.5Wh	3W
Notebook Computers	3.0	38Wh	16W
Digital Cameras	2.0	9Wh	6W
Camcorders	2.0	15Wh	9W
Battery Chargers	-	-	1W-50W
Portable Power Units	-	-	15W-1kW
Two-way Radios & Portable Audio Devices	4.0	9Wh	3W

The forecasting methodology is valid for "substitute products" only. In other words, fuel cells are a product expected to replace an existing product, with sales of fuel cells reducing sales of battery products. The model does not apply to "complementary products," which tend to be sold as a "complement" to another product. Cell phones and cell phone batteries are complementary products, as sales of one tends to increase sales of the other.

In that sense, a battery charger is not technically a substitute product. Battery chargers are a complementary product to batteries, or (when used as an adapter) simply an auxiliary product. Battery chargers do not replace batteries. But since they are an added cost to a battery system, fuel cells can be introduced with a higher price premium for any product that needs a battery charger. Notebook Computers, on the other hand, are frequently run using the adapter only. In this segment, fuel cells are competing more equivalently with the batteries alone.

For all the forecasts given below, the critical year is 2006. This is the point that corresponds with "the Chasm" in Moore's model. It is the point at which fuel cells must "cross over" from Early Adopters to Early Majority in order to reach "significant market penetration" and enter the mainstream. Each of the following sections will include a discussion of the "target price" needed by the end of 2006 to achieve this. This price is more specific than the overall ASP given in the forecast (i.e. where fuel cell pricing will be, based on the Learning Curve). Instead, it pinpoints where fuel cells will need to be, given the competitor's (i.e. battery) pricing.

Exhibits 11 and 12 give the total unit and dollar markets, by region, for all portable applications forecast in this section. Subsequent sections break down these total markets by specific application.

Exhibit 11
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
All Portable Applications
(millions of units)

	2004	2005	2006	2007	2008	2009	CAGR
North America	3.3	20.0	58.9	134.4	191.3	218.1	131.2%
Europe	4.2	19.8	69.1	155.6	217.3	243.2	125.2%
Asia	3.5	16.0	54.6	121.4	167.1	183.7	120.8%
Worldwide	11.0	55.8	182.6	411.4	575.7	645.0	125.8%

Exhibit 12
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
All Portable Applications
(millions of $)

	2004	2005	2006	2007	2008	2009	CAGR
North America	243	497	930	1,714	2.127	2,273	56.4%
Europe	232	461	898	1,661	2,030	2,125	55.7%
Asia	177	366	709	1,291	1,542	1,564	54.6%
Worldwide	652	1,324	2,537	4,666	5,699	5,962	55.7%

7.3.1 Portable Power Units/Battery Chargers

Portable Power Units/Battery Chargers is a small market of portable fuel cell products. These units are 1kW and below, with smaller units being 25-100W, up to about 200W. This segment includes battery chargers and other portable units that are used to power:

- remote sensing (traffic monitoring; environmental monitoring);
- back-up power for railroad substations and signaling;
- remote security applications, such as nodes for a temporary security network;
- remote communications networks;
- recreational, outdoor products for camping, parks, and so on;
- other industrial activities where remote electronics are used in small nodes;
- mobile military devices, such as power generators, wearable computers, and other equipment to extend mission lengths.

One of the differences between these products and comparable 25W products for consumer devices is longer runtimes. A laptop computer only needs hours of runtime, whereas Portable Power Units (such as military or industrial units) require days of runtime (i.e. lots of fuel). Fuel cells add value, in this respect, since they can accommodate the longer runtimes.

The Portable Power Unit/Battery Charger market could be a good market entry opportunity to provide a “transition” to larger portable markets. During the beginning of the forecast period, unit sales are expected to be primarily smaller power units (200W and below), with larger power unit sales increasing during the latter part of the forecast period. Because of this trend, pricing ($/kW) will be higher at the beginning of the period, then decline rapidly through 2009.

Since no commercial Portable Power Units/Battery Chargers are available yet, the small residential market was chosen for price points, based on $/kW. Currently, 5kW residential systems are about $1,700 per kilowatt, but this is for larger systems in the U.S.

State-of-the-art fuel cells are likely to cost around $1,200 per kilowatt, with the DOE wanting to cut costs to as low as $400 per kilowatt by the end of this decade. By contrast, a diesel generator costs $800 to $1,500 per kilowatt, and a natural gas turbine can be even less.

Our pricing is based on the trends anticipated by the DOE, but if these pricing points are not met, dollar sales could fall short of these forecasts. Again, fuel cells for residential portable power units are currently high, but the $/kW is expected to decline over 30% per year during the beginning of forecast. This will slow to around -18.0% toward the end of period. So the -20.3% CAGR only represents the overall five-year decline, not year-to-year declines.

Exhibit 13
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
Portable Power Units (<1KW)/Battery Chargers
(millions of units)

	2004	2005	2006	2007	2008	2009	CAGR
North America	0.08	0.1	0.2	0.2	0.3	0.4	38.0%
Europe	0.07	0.1	0.1	0.2	0.2	0.3	33.8%
Asia	0.05	0.07	0.09	0.1	0.2	0.2	32.1%
Worldwide	0.2	0.3	0.4	0.5	0.7	0.9	35.1%

Exhibit 14
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
Portable Power Units (<1KW)/Battery Chargers
(millions of $)

	2004	2005	2006	2007	2008	2009	CAGR
North America	138	175	184	200	211	223	10.1%
Europe	121	125	133	142	157	167	6.6%
Asia	87	93	96	100	109	111	5.0%
Worldwide	346	393	413	442	477	501	7.7%

Exhibit 15
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
Portable Power Units (<1KW)/Battery Chargers
($/unit)

	2004	2005	2006	2007	2008	2009	CAGR
Worldwide	1731.00	1250.00	1021.00	834.00	682.00	557.00	-20.3%

The Portable Power Unit/Battery Charger market forecasts are derived differently than the forecasts discussed below. This is not a consumer market; it is an industrial/military market segment, with a very small percentage of consumer-level products. In many ways, this segment will exhibit many of the characteristics of Early Adopters, in terms of its small size and relative price insensitivity. As a "transitional" market, production economies of scale are less important than the segments forecasted below. We assume fewer units will be sold and pricing will be higher. This market might more readily be a path to automotive fuel cells, since it encompasses more of the characteristics of the stationary fuel cell market.

As previously mentioned, the above forecasts are for 1kW and Below systems and represent a starting market penetration rate of about 5% of the total Portable Power Unit/Battery Charger market. These units are similar in size to the smaller, stationary fuel cells used in residential markets. In the United States, residential fuel cells generate from 2kW to 5kW. Most residential systems being developed in Japan are closer in size to the Portable Power Unit market, with fuel cells in the 1kW range.

Even though the Portable Power Unit/Battery Charger unit market is small, it is still a potentially large dollar market, due to the higher prices that a non-consumer market can absorb. Worldwide, this segment could grow from 200,000 units in 2004 to 900,000 units by 2009, a CAGR of 35.1%. Even with a five-year price drop of 20.3%, this would produce a dollar market of $346 million in 2004, growing to $501 million in 2009, a CAGR of 7.7%.

As noted above, North America represents about 35% of the Portable Power Unit market at 1kW and below. This region will have the fastest unit growth of 38.0% (although numbers this small are subject to errors of rounding) and the fastest dollar growth of 10.1%. Still, since this market is seen as "transitional," it is expected that other, higher-volume consumer segments will become more viable opportunities during the forecast period.

Smart Fuel Cell has launched its SFC 25.2500 R portable, standalone power supply powered by an exchangeable methanol cartridge. The system is used in fields such as traffic systems, environmental sensors, and camping and outdoor equipment. The power output is from 25W continuous up to 80W peak, and the system operates in a wide temperature range.

The SFC 25.2500 R is currently only being given to Smart Fuel Cell's business partners in Germany for evaluation of the requirements for integration into their own products, however. Pricing has not been fixed, but the company expects to offer the Remote Power System as a standard product for the consumer market, as well. The expected launch period is mid-2003.

The military has a number of short-term and long-term research initiatives underway to develop fuel cell technology. Their most pressing need is fuel cells for use in power generators lightweight enough for a soldier to carry. The DOE's Pacific Northwest National Laboratory for the U.S. Army's Communications-Electronics Command is one such project, along with NASA's Jet Propulsion Laboratory.

7.3.2 Mobile Phone Market

The adoption of 3G is a factor that could make fuel cells an attractive alternative to batteries, since they could enable features that batteries currently cannot handle. In the United States, Sprint recently announced its Nationwide PCS Network, based on code division multiple access (CDMA), which is a "nationwide 3G 1X network upgrade." In conjunction with this upgrade, Sprint is introducing four CDMA-compatible devices, which can provide either voice and data, or data only. The company believes that enterprise "road warriors" (the equivalent to Innovators/Early Adopters in Moore's model) who rely on data-rich applications will likely require the upper-end services – and the upper-end devices that go with them.

Such "convergence devices" are not broken out of these forecasts because there is no real market for them yet. By "convergence device," we mean electronic devices that combine the functionality of several different devices, such as cell phones and PDAs, handheld computers and digital cameras, and so on. Doing a forecast for a product that isn't yet available commercially for a device that isn't yet available commercially is problematic, at best, and invalid at worst. High-end convergence devices would be a portion of the existing mobile phone handset market, but speculating on what that percentage would be is not reasonable at this time.

These upper-end 3G handsets are projected to cost around $647 for a "basic model." If additional features are added, they could cost closer to $1,000. Currently, lithium batteries are being used with these products, but the demands of 3G will push the power capacity of batteries enough to make fuel cells a desirable alternative. And the cost of 3G handsets, although projected to come down in price over the next few years, are high enough to absorb the increased cost of fuel cells – especially if they replace the battery charger, as well. In March, 2002, Toshiba Corp. and Mitsubishi Electric Corp. announced that they would collaborate on the development of 3G cellular phone handsets with the aim of shipping commercialized products in 2004.

Fuel cell development for these devices is following a similar timeframe. Casio Computer Co. Ltd. and Toshiba Corp. announced that they are aiming to ship fuel cells products for "mobile information terminals" in 2004. Hyuk Chang, a member of the research staff at the Materials and Devices Lab at Samsung Advanced Institute of Technology indicated that they also want to ship fuel cells for mobile devices in 2004, "to stay on top of our competitors." MTI Micro Fuel Cells recently announced that they "plan to develop a practical implementation built into a cell phone in 2004, and are already engaged in joint development with a cell phone manufacturer." And NEC recently announced plans to begin mass production "within three years" of long-life fuel cells for mobile phones and notebook PCs based on proprietary carbon nanohorn technology.

Therefore, the forecasts presented here assume "significant" sales beginning in 2004, although that could be extended out to 2005, depending on economic, business and technological factors. Darnell Group's recent "Power Packs" study gave 2005 as a more conservative introduction date. But because products are expected to be introduced in 2004, Darnell Group considers 2004 to be the most "aggressive" point at which commercial sales could occur. Because of this, the forecast has been extended out to 2009.

Some companies do not believe that mobile phones will necessarily be the earliest or biggest market for fuel cells, due to bringing down the fuel cell size to fit the cell phone, along with peak power problems. Still, the Japanese companies mentioned above are aiming to resolve any problems associated with fuel cells for mobile phones. They might not be successful, but there is tremendous pressure to be. Again, 2004 is an "aggressive" point at which commercial sales could occur. These forecasts account for that introduction date, and since these are not predictions, it could change.

Exhibit 16
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
Mobile Phones
(millions of units)

	2004	2005	2006	2007	2008	2009	CAGR
North America	2.4	11.5	39.8	87.8	120.3	131.5	122.3%
Europe	3.4	16.1	55.4	122.2	166.4	181.0	121.3%
Asia	2.8	13.2	45.6	100.8	138.1	151.3	122.8%
Worldwide	8.6	40.8	140.9	310.8	424.9	463.8	122.1%

Exhibit 17
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
Mobile Phones
(millions of $)

	2004	2005	2006	2007	2008	2009	CAGR
North America	52	154	346	659	779	780	71.8%
Europe	73	216	482	919	1081	1076	71.1%
Asia	59	177	395	754	893	895	72.1%
Worldwide	185	547	1223	2331	2753	2750	71.6%

Exhibit 18
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
Mobile Phones
($/unit)

	2004	2005	2006	2007	2008	2009	CAGR
Worldwide	21.49	13.39	8.66	7.48	6.46	5.92	-22.7%

Mobile Phones represent the largest potential portable market for fuel cells between 2004 and 2009, in every geographical region. Europe is expected to hold the largest market share of potential fuel cell unit sales, at about 40% in 2004, declining slightly to 39% by 2009. Asia's unit market share will increase slightly, from 32% to 33% between 2004 and 2009, while North America's remains constant at 28% over the forecast period.

Even though Europe is currently hashing through difficulties with their 3G licenses, most of these assume a delay of deployment, which is both logical and practical. Darnell does not believe widespread deployment of 3G services would occur before 2005 or so in any region, even though Japan has already launched 3G service. Vodafone, TMN and Optimus have "delayed" deployment until 2003, and Orange has indicated plans to launch service in 2006. The United States will most likely have 3G commercialization by 2004. And commercialization dates for developing countries are not expected until 2007 or later.

3G services launched in Japan earlier than in any other market in the world. For this reason, growth is expected as users replace current cell phones with 3G-enabled cell phones. In 2002-2003, replacement demand is expected to be led by handsets with built-in cameras, handsets that support CDMA2000 1X systems, and handsets that support personal digital cellular (PDC) high-speed packet communication. Demand in Japan is expected to grow even more from 2005 on, as third-generation W-CDMA system phones replace current cell phones.

Therefore, Worldwide, fuel cells could account for 8.6 million unit sales for Mobile Phones in 2004, increasing to 463.8 million in 2009, a CAGR of 122.1% – if the right price points are achieved. Using this forecast model, fuel cells would potentially penetrate just under 89% of the total available worldwide unit market by 2009. Again, the TAM represents mobile phones using premium (i.e. lithium) batteries only. Fuel cells are expected to enable 3G-related features the same way lithium-ion batteries enabled mobile computers. Lithium batteries penetrated the market in a relatively short space of time, and if pricing follows the model presented, fuel cells could do the same.

Fuel cell pricing can actually start out relatively high ($21.49 per unit) and expect to achieve a potential 8.6 million unit sales in 2004. This produces worldwide revenue sales of $185 million. To successfully emerge out of its niche status, pricing will have to drop at a rate of 22.7% per year, reaching an average selling price of $8.68 in 2006. By the end of 2006, this price should be down to about $8.15. The “target price” for fuel cells in 2006 (the point at which it becomes competitive with existing lithium battery technology) is $8.17. This is an aggressive decline in pricing, but it is necessary to achieve the “crossover” to the Early Majority segment, considering the competition.

If the Learning Curve goes up to 90% (i.e. only 10% progress rate instead of 20%), the pricing will not come down as fast and the price points needed to compete successfully in the Mobile Phone market may not be achieved. Such a Learning Curve produces prices declining at 16.6% per year, from $21.49 in 2004 to $8.68 in 2009. In other words, fuel cells will not reach the target point of $8.17 during the forecast period.

If fuel cells can meet these targets, the potential dollar market worldwide could be $2,750 million by 2009, at $5.92 per unit.

7.3.3 Notebook Computer Market

Like Mobile Phones, Notebook Computers represent a good market opportunity for portable fuel cells. Unlike Mobile Phones, however, this is due not to the size of the market, but to the high pricing in this segment. Notebook Computers still command high prices relative to other portable segments, making a higher-priced battery easier to justify. And, like Mobile Phones, new products could be introduced that fuel cells could help enable.

For example, Microsoft hopes to launch its new Tablet PC in late 2002. This “convergence device” is supposed to combine the wireless functionality of a notebook computer with the power of a desktop computer. Plus, it is expected to have additional features that make it product for “corridor warriors” – users who go from meeting to meeting.

The "preproduction" unit is an Acer TravelMate 100 with a 10.4 inch screen, built-in 802.11b wireless Ethernet, and lithium battery. The goal is to allow a "full workday's use of the tablet before needing to recharge" the battery, but it is acknowledged that the "first wave of Tablet PC machines are unlikely to achieve this." Using the wireless network connection, in particular, shortens battery life. Also, complaints about the small screen size are likely to produce a 12-inch screen in future models, which will put additional strain on the battery. These are the types of devices that could enable portable fuel cell adoption, since current lithium batteries cannot provide a "full workday's use."

Fuel cells are also being touted as enabling "always on" notebooks – another possible future evolution of notebook computers. These devices would have the equivalent of a "standby mode," when the computer could be wirelessly downloading e-mails or forwarding messages, for example. But even when not in standby mode, the notebook might still be able to run for a full day in active mode. Such notebook computers could emerge in the future as a result of new microprocessors, such as the "Banias" from Intel, and similar chips from Transmeta and VIA Technologies.

Exhibit 19
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
Notebook Computers
(millions of units)

	2004	2005	2006	2007	2008	2009	CAGR
North America	0.4	2.2	8.1	19.0	27.6	32.1	136.3%
Europe	0.3	1.5	5.4	12.6	18.3	21.1	135.0%
Asia	0.3	1.5	5.1	11.8	16.6	18.7	128.4%
Worldwide	1.0	5.2	18.6	43.4	62.5	71.8	133.7%

Exhibit 20
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
Notebook Computers
(millions of $)

	2004	2005	2006	2007	2008	2009	CAGR
North America	34	106	247	506	642	687	82.5%
Europe	23	72	166	338	427	453	81.6%
Asia	23	70	160	321	394	407	77.1%
Worldwide	80	249	573	1165	1463	1547	80.7%

Exhibit 21
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
Notebook Computers
($/unit)

	2004	2005	2006	2007	2008	2009	CAGR
Worldwide	77.88	47.91	30.56	26.66	23.26	21.41	-22.8%

In terms of units, the potential fuel cell market for Notebook Computers will be quite a bit smaller than Mobile Phones, but it will still remain the second-largest unit market of the five portable applications discussed in this report. North America is projected to hold the largest market share in Notebook Computers, growing from 40% to about 45% between 2004 and 2009. And due to higher ASPs, the overall revenue from these sales could potentially reach $687 million by 2009. Worldwide, dollar sales could grow from $80 million in 2004 to $1,547 million in 2009, a compound annual growth rate of 80.7%.

In terms of pricing targets, ASPs need to come down at the same rate as those of Mobile Phones. But whereas the target price for Mobile Phone fuel cells was slightly lower than the overall ASP for 2006, the target price actually comes in slightly higher ($31.40) than the overall ASP for 2006 ($30.76). This is partly because Notebook Computer battery pricing is not declining quite as fast as Mobile Phone battery pricing. Also, the Notebook Computer segment potential forecasts and target pricing were based only battery pricing, not on both battery and battery charger pricing like the other segments. In the case of Mobile Phones, for example, both the battery and charger were figured into the competition pricing. This is because of the way Notebook Computers are used: Unlike chargers for Mobile Phones and many other portable devices, the Notebook charger can also be used to run the computer.

Pricing for fuel cells in Notebook Computers need to decline by about 22.8% per year, from $77.88 in 2004 to $21.41 in 2009, with the target price of $31.30 being achieved in 2006 in order to win the Early Majority.

7.3.4 PDA Market

The PDA market, although potentially a good opportunity for fuel cells, could cease to exist in its current form in the future. If Mobile Phones become “3G devices,” or start incorporating many of the features currently designed into PDAs, the latter could evolve more into a “convergence” device. The following forecasts assume that PDAs will continue, more or less in their current form.

Exhibit 22
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
PDAs
(millions of units)

	2004	2005	2006	2007	2008	2009	CAGR
North America	0.2	1.3	5.2	13.3	20.8	25.9	154.0%
Europe	0.2	0.9	3.6	9.0	14.0	17.4	152.4%
Asia	0.1	0.4	1.2	2.7	3.7	4.0	119.6%
Worldwide	0.5	2.6	10.1	25.0	38.5	47.3	149.2%

Exhibit 23
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
PDAs
(millions of $)

	2004	2005	2006	2007	2008	2009	CAGR
North America	10	32	79	179	253	296	98.3%
Europe	7	22	54	123	171	200	97.1%
Asia	3	9	20	39	48	48	73.6%
Worldwide	19	63	153	341	472	544	94.7%

Exhibit 24
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
PDAs
($/unit)

	2004	2005	2006	2007	2008	2009	CAGR
Worldwide	39.42	23.95	15.00	13.51	12.17	11.41	-22.0%

The PDA unit and dollar markets are the largest in North America and the smallest in Asia. North America will increase in unit market share from 40% to 55% between 2004 and 2009, while Asia shrinks from 20% to 8%. This is partly due to the larger Mobile Phone market in Asia, relative to North America. Mobile Phones in Asia are expected to have many of the features currently used in PDAs, while the latter are still expected to be a separate product in North America throughout the forecast period.

The target price for PDAs in 2006 is $15.79, which is somewhat higher than the battery competition price of $13.16. The overall price for PDAs is higher here because this segment includes higher-end devices that have higher power requirements. This is because fuel cells will help enable the increased functions of handheld computerized devices, making their higher price somewhat justified. Fuel cell pricing for PDAs will need to decline 21.8% per year, from $39.42 in 2004 to $11.54 in 2009.

7.3.5 Digital Camera Market

The last two portable segments in this report – Digital Cameras and Camcorders – are the smallest opportunities for fuel cells of all the segments discussed. The devices they represent are not consumer-level devices – they are the professional-level digital cameras and camcorders that are fairly high-priced to begin with and could potentially absorb the higher price of a fuel cell.

Exhibit 25
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
Digital Cameras
(millions of units)

	2004	2005	2006	2007	2008	2009	CAGR
North America	0.1	0.7	2.9	7.6	12.4	16.1	165.5%
Europe	0.1	0.6	2.4	6.8	11.7	16.0	178.9%
Asia	0.1	0.4	1.3	3.2	4.6	5.3	134.5%
Worldwide	0.3	1.7	6.7	17.6	28.7	37.5	164.0%

Exhibit 26
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
Digital Cameras
(millions of $)

	2004	2005	2006	2007	2008	2009	CAGR
North America	4	13	32	77	112	137	105.7%
Europe	3	10	27	67	103	133	115.1%
Asia	2	7	16	34	44	48	84.0%
Worldwide	9	30	75	178	260	317	104.6%

Exhibit 27
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
Digital Cameras
($/unit)

	2004	2005	2006	2007	2008	2009	CAGR
Worldwide	30.28	18.19	11.27	10.10	9.05	8.46	-22.5%

Of these two segments, Digital Cameras is the best potential opportunity. North America and Europe represent the largest markets, with both being somewhat equal in size in terms of dollars and units. North America's unit market will grow from 0.1 million to 16.1 million between 2004 and 2009, a CAGR of 165.5%, while Europe's unit market grows from 0.1 million to 16.0 million during the same period. Looking at potential revenue, North America will increase 105.7% per year, from $4 million to $137 million between 2004 and 2009. In Europe, this market will grow from $3 million to $133 million during the forecast period, a CAGR of 115.1%.

To achieve these sales, pricing must decline at 22.4% per year, from $30.28 in 2004 to $8.52 in 2009. The target price in 2006 is $12.06, which is slightly above the competitive battery technology price of $10.05.

7.3.6 Camcorder Market

Camcorders is the smallest portable market for fuel cells of the five application segments discussed in this report. Again, these are professional-level camcorders, not the less-expensive consumer models. As such, the total Worldwide unit market for fuel cells is only expected to increase from 0.3 million to 23.7 million, which is a very high growth rate of 134.8% because of the very small starting base. Although regional market share will start out equal due to this small base, most of the sales will occur in North America. By the end of the forecast period, about 51% of the unit sales will be in this region.

Pricing needs to decline at a rate of 21.3% per year, from about $41.10 in 2004 to $12.42 in 2009. The crossover target price point is $16.73 in 2006.

Exhibit 28
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
Camcorders
(millions of units)

	2004	2005	2006	2007	2008	2009	CAGR
North America	0.1	0.7	2.7	6.5	9.9	12.1	148.5%
Europe	0.1	0.6	2.2	4.8	6.7	7.4	126.4%
Asia	0.1	0.4	1.3	2.8	3.9	4.2	120.9%
Worldwide	0.3	1.7	6.1	14.1	20.4	23.7	134.8%

Exhibit 29
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
Camcorders
(millions of $)

	2004	2005	2006	2007	2008	2009	CAGR
North America	5.2	17.3	41.7	92.8	129.8	150.1	95.6%
Europe	5.1	15.9	35.5	71.6	91.2	96.1	79.6%
Asia	3.3	9.8	21.7	43.2	53.7	55.2	75.8%
Worldwide	13.7	43.1	99.0	207.6	274.7	301.3	85.6%

Exhibit 30
Worldwide Fuel Cell Potential Adoption
Aggressive Forecast
Camcorders
($/unit)

	2004	2005	2006	2007	2008	2009	CAGR
Worldwide	41.10	24.98	15.71	14.36	13.13	12.42	-21.3%

7.4 Targeted Fuel Cell Adoption (Conservative) Forecasts

The previous section provided forecasts based on an "aggressive" commercial introduction of 2004-2005, with pricing going down to achieve widespread production and sales by 2010. System OEMs interviewed for this section reported that fuel cells for portable devices will be introduced in this time frame, but certain factors (such as pricing declines) could make "widespread production" unrealistic by 2010.

With that in mind, this section provides a more "conservative" set of forecasts based on a later introduction date, slower price declines, and lower market penetration. These assumptions are based on interviews with portable system OEMs and portable fuel cell manufacturers (the complete set of questions and assumptions matrix is given in Appendix C), and their projections as to when fuel cells for portable devices can "realistically" be expected to penetrate the market.

These interviews were based on a targeted series of questions (see Appendix C) and a set of assumptions, both provided by the Fuel Cell Council. The assumptions (Exhibit 31) were e-mailed to the respondents in advance, and they served as the basis for certain questions (see "Purpose, Scope and Methodology," above). The "Fuel Cell System Selling Price to OEM" was the base assumption for the pricing forecasts in this section, as well.

Exhibit 31
Assumptions Used for Portable Fuel Cell Market Survey

Application	Fuel Cell Power	Battery Power	System Size & Fuel	Total WH	Runtime (hours)	Retail Fuel Cartridge Cost	Fuel Cell System Selling Price to OEM	
							2005	2007
Cell Phone/ Convergence Device	1W	2W	10-15cc	12	12	<$1	$10	$7
PDA	1W	none	20cc	20	20	$1.50	$10	$7
Digital Camera	2W	3W	20cc	10-15	5-7	$3	$25	$20
Laptop	15W	15W	300cc	120	8	$5-$10	$75	$50

Looking at the technical data presented in Exhibit 31, the respondents provided the following feedback:

(1) Overall, increasing the system size and volume of fuel is okay, but if they are much bigger, consumers will not buy the product.

(2) For laptops, 15W for fuel cell and battery power is low for peak power needs (30W is needed for peak power). One respondent said that 15W was a "bit light" for a full-featured laptop, unless it was a lightweight line of products – but then there would be difficulty with 300cc of fuel.

Two respondents indicated that 300cc for fuel volume was okay, although one person said more units would be sold at "half this size." Weight is important with laptops, and the fuel cell system should not weigh more than one pound. Eight hours of runtime is good, but 5x (10-15 hours) would be better.

One respondent said a fuel cell charger for laptops is good, since there would be about 50W of heat dissipated in these systems, and that cannot be inside the notebook – you need an external charger.

(3) For PDAs, 20cc of fuel is higher than what is used today. The runtime shown in the grid is low; 25-30 hours would be better (which are the current runtimes). Palm said they would need 50% more energy than a battery in the same size system. Physical size is very important. 4mm-5mm is the limit for thickness.

The amount of time OEMs put into product planning varies considerably. Changes to existing technologies or simple device planning takes less time – about six to nine months. For new products or emerging technologies, the cycle can be anywhere from one to four years, with three years being the average. Cell phones and PDAs are typically 18 months.

When asked when batteries would put "hard limits" on system technology, four respondents said, "Now." Two respondents said that runtime was the most important, not battery technology, per se. The question is how frequently the user has to buy a cartridge, with "convenience versus operating cost" being the most important issue. Palm indicated that worldwide fuel distribution and availability was the most important issue for them as system makers. Palm said that there must be standardized cartridges, standardized fuel, and worldwide distribution of fuel.

One computer manufacturer said that laptops were unlikely to put limits on batteries. Intel would never design chips that push batteries beyond their limits, since they rely on batteries to run the products their chips go into. They would not assume that something new (like fuel cells) would replace batteries. An increase in clock speed is the main driver pushing battery technology. And battery capacity "already limits microprocessor speed." Competition between microprocessor and wireless power demands, as well as battery energy content, are driving the development of power management techniques. Another respondent said he felt laptops were the "only viable portable system" (in the grid) for fuel cells. Below this energy point, he felt that fuel cells were "not realistic."

PDAs have a big display to power, and 802.11 has higher power requirements, so Palm is already making trade-offs in size. The company said they would pay more for smaller sizes, as long as the loss of energy density was linear.

Looking at system size and weight, most OEMs of portable devices are very sensitive to changes in these areas. As mentioned above, if "portable" systems are too big, the consumer will not buy them. Palm indicated that they would need 50% more energy than a battery in the same size system to make fuel cells viable. A laptop manufacturer said their research indicated that 5x better runtime is important for customers to make a change to any new technology.

A first-tier computer manufacturer said the "probable constraints" on fuel cell system size and capacity would be: volume 0.1-0.2 liters; 0.3 liters possible if really 120Wh; thickness equal to DVD drive. Only about one-third or less of the space under the laptop keyboard is available for energy. A fuel cell manufacturer indicated that, by weight, a 3x to 4x increase is considered "realistic." For volume, 1.5x to 2x is realistic.

Fuel cell chargers for portable devices were generally viewed in a positive light. One respondent said "starting with a charging unit for notebooks is good; the pricing could be slightly higher." Palm would not find stationary chargers useful, but they were favorable to mobile chargers. On the other hand, a first-tier computer OEM said an external fuel cell charger for laptops would never be attractive to their customer set – he said wall plugs are too accessible, and free. If the charger were integrated into the unit, it might be attractive if the fuel cell could achieve "90% efficiency." But he also felt that fuel cell chargers "would never be the exclusive charging mode." He felt they would be used as needed by "wilderness remote users." But Darnell believes this could include business users at remote field sites, such as construction, oil fields, and similar sites.

For cell phones, customers will still buy wall chargers, as well, and they will be used more often. A portable charger is not really needed and will be considered an "extra" device, not a "necessary" device. Smart Fuel Cell feels that fuel cell chargers will have a "faster rate of introduction," but they will be limited in unit sales.

Fuel cell chargers could lower risk for OEMs. If the charger is sold separately, any problems with the fuel cell device are separate from the system device itself. The portable system is still battery-driven, and no changes need to be made to integrate a charger into the system. Keeping the charger as a optional product for the system keeps the "new technology" risk down for the OEM.

For the following forecasts, certain assumptions were made for all the application segments:

(1) Based on the industry interviews, "market introduction" was acknowledged to be around 2004, with wider use by 2006. We used the latter date, since it likely represents "significant" sales. For Camcorders and Digital Cameras, we used a 2007 introduction date, since these products were seen as devices less likely to adopt fuel cells.

(2) The interview respondents gave a range of market penetration rates for the product forecasts. For 2005, the market penetration rate projected was between 0% and

20%. For 2008, the rate was 0% to 50%. Individual market penetration rates chosen for each application are discussed for each forecast, below.

(3) For pricing, we used the assumptions given in the "Assumptions Used for Portable Fuel Cell Market Survey" in Exhibit 31, above. Applications not included in this grid are explained separately below. Prices in the forecasts are the Fuel Cell System Selling Price to OEMs.

(4) It is worth noting that even with the more conservative forecasts presented here, the dollar market for fuel cells is potentially $616 million (total) in 2006. By 2011, that figure increases to a potential $2.1 billion market. Even if these forecasts are further cut in half, that is still a $308 million market in 2006, growing to about $1 billion in 2011.

As with the aggressive forecasts, the following two tables provide total unit and dollar market forecasts, with more detailed forecasts for each application given in the sections below.

Exhibit 32
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
All Portable Applications
(millions of units)

	2006	2007	2008	2009	2010	2011	CAGR
North America	7.6	15.2	28.8	33.9	39.9	47.2	44.1%
Europe	6.5	12.7	24.1	27.6	31.8	36.8	41.5%
Asia	4.8	8.8	16.0	17.5	19.0	21.0	34.4%
Worldwide	18.9	36.7	68.9	79.0	90.7	105.0	40.9%

Exhibit 33
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
All Portable Applications
(millions of $)

	2006	2007	2008	2009	2010	2011	CAGR
North America	266	440	682	801	889	988	30.0%
Europe	174	295	490	545	610	687	31.6%
Asia	176	272	402	422	442	467	21.6%
Worldwide	616	1,007	1,574	1,768	1,941	2,142	28.3%

7.4.1 Portable Power Units/Battery Chargers

Portable power units/battery chargers were not included in the assumptions grid, above. Therefore, the forecasts are based on a 2006 introduction date, a 5% initial market penetration rate (due to the availability of lower-priced powering alternatives; and the industry response that fuel cell chargers, in general, would have about 5% of the market at introduction), and the 2006 price from the aggressive forecast, but dropping at a rate of about 18% in the first three years, then slowing down to about -5.0% per year.

Worldwide, unit sales of portable power units will still be small – about 100,000 units in 2006, growing to about 600,000 units in 2011, a CAGR of 43.5%. But pricing will be higher for these units than for other portable devices, producing a fairly good-sized dollar market of $103 million in 2006, increasing to $352 million in 2011, a CAGR of 27.9%.

Exhibit 34
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
Portable Power Units (<1KW)/Battery Chargers
(millions of units)

	2006	2007	2008	2009	2010	2011	CAGR
North America	0.04	0.07	0.1	0.2	0.2	0.3	50.0%
Europe	0.03	0.05	0.07	0.1	0.1	0.2	47.5%
Asia	0.03	0.05	0.07	0.08	0.09	0.1	29.0%
Worldwide	0.1	0.2	0.2	0.4	0.4	0.6	43.5%

Exhibit 35
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
Portable Power Units (<1KW)/Battery Chargers
(millions of $)

	2006	2007	2008	2009	2010	2011	CAGR
North America	41	58	68	130	148	176	33.9%
Europe	31	42	48	65	86	117	30.5%
Asia	31	42	48	50	55	59	13.8%
Worldwide	103	142	164	245	289	352	27.9%

Exhibit 36
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
Portable Power Units (<1KW)/Battery Chargers
($/unit)

	2006	2007	2008	2009	2010	2011	CAGR
Worldwide	1021.00	834.00	682.00	648.00	616.00	585.00	-10.5%

7.4.2 Mobile Phone Market

The Mobile Phone market is also based on a 2006 introduction date, although industry introductions could possibly occur as early as 2004. A mobile communications and computing battery packs, first-tier OEM indicated that "industry introduction" could be a single company, and there are no guarantees of product acceptance. "Market introduction" would include at least three to five companies introducing products, and the company felt a more realistic date was 2006-2007.

Exhibit 37
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
Mobile Phones
(millions of units)

	2006	2007	2008	2009	2010	2011	CAGR
North America	2.3	4.0	6.9	7.5	8.1	8.8	30.8%
Europe	3.2	5.5	9.4	10.1	10.8	11.6	29.4%
Asia	2.6	4.5	7.9	8.6	9.3	10.1	31.2%
Worldwide	8.1	14.0	24.2	26.2	28.2	30.5	30.4%

Exhibit 38
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
Mobile Phones
(millions of $)

	2006	2007	2008	2009	2010	2011	CAGR
North America	23	33	48	50	51	53	18.2%
Europe	32	46	66	67	68	70	17.0%
Asia	26	38	55	57	59	61	18.6%
Worldwide	81	117	169	174	178	184	17.8%

Exhibit 39
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
Mobile Phones
($/unit)

	2006	2007	2008	2009	2010	2011	CAGR
Worldwide	10.00	8.37	7.00	6.65	6.32	6.00	-9.7%

The mobile communications and computing battery packs, first-tier OEM felt that the percentage of cell phones using fuel cells would be 0% in 2005, but this is at the $10.00 fuel cell system price. By 2007, the pricing becomes more attractive. Pricing for Li-polymer batteries used in cell phones was projected to be $6.38 in 2006, so the $10.00 price is still above a “premium” battery. In fact, the company indicated that “no one will pay $10.00 for 12 hours runtime.”

The unit forecasts above assume a market penetration rate of approximately 2% in 2006, increasing to about 5% in 2008. The industry consensus was that cell phones are not as good of a market as Portable Power Units, Notebook Computers, or PDAs. They do not need the power of a PDA, for instance, and they would need much longer runtimes for the price. Worldwide, unit sales are likely to be just 8.1 million in 2006, increasing to 30.5 million in 2011, a CAGR of 30.4%.

7.4.3 Notebook Computer Market

The Notebook Computer market (which includes “tablet PCs”) shows a market introduction date of 2006. One OEM interviewed said that fuel cells for notebook computers “was not restricted on the demand side, but on the supply side.” He said system OEMs are ready for fuel cells “now.” But he feels that there are “fuel cell materials problems” affecting quality and reliability. For this reason, he felt that starting with a charging unit for notebooks was good; the pricing could be higher, as well. As mentioned above, however, another OEM said that external chargers would not be accepted by customers because wall plugs are too accessible and free. And an integrated charger would have to achieve 90% efficiency to be accepted.

In terms of market penetration, one OEM said 10% penetration by 2005 was a possiblity, with no more than 30%-40% by 2008. We used a 10% market penetration rate for 2006, increasing to about 30% by 2008, and then leveling off. Since no OEM felt that fuel cells could capture more than 50% of any portable market, none of the forecasts in this section project beyond that percentage, even by 2011.

The Almaden Research Center at IBM was the one wet blanket of the group. They felt that batteries would maintain 100% of the market up through 2008, with a fuel cell charger possibly capturing just 2% of the market by 2008. This "company line" was confirmed in a recent article that cited Leo Suarez, vice president of marketing at IBM's personal computing division. He said, "Fuel cell manufacturers can't deliver [fuel cells] at a price eual to that of today's batteries."

Exhibit 40
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
Notebook Computers
(millions of units)

	2006	2007	2008	2009	2010	2011	CAGR
North America	2.3	4.7	9.4	10.7	12.3	14.0	43.6%
Europe	1.2	2.7	6.2	7.1	8.1	9.2	50.4%
Asia	1.5	2.9	5.6	6.2	6.8	7.5	38.0%
Worldwide	5.0	10.3	21.2	24.0	27.2	30.7	43.8%

Exhibit 41
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
Notebook Computers
(millions of $)

	2006	2007	2008	2009	2010	2011	CAGR
North America	172	288	470	508	555	600	28.4%
Europe	90	165	310	337	366	394	34.4%
Asia	112	178	280	295	307	322	23.5%
Worldwide	374	631	1060	1140	1228	1316	28.6%

Exhibit 42
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
Notebook Computers
($/unit)

	2006	2007	2008	2009	2010	2011	CAGR
Worldwide	75.00	61.28	50.00	47.50	45.13	42.87	-10.6%

Notebook computer OEMs provided a wide range of feedback on pricing. All felt the $5.00-$10.00 pricing for a fuel cell cartridge was too high, except possibly for "professional users." One respondent said $3.00-$4.00 was probably the highest that pricing could go. Another said, "$1.00 per month was ideal." The street price is "normally 3x to 4x the OEM price." For laptop manufacturers, refueling costs are a major issue.

On the other hand, the $75.00 for the fuel cell system was considered okay. Another respondent said that the price is okay if the fuel cell system is "buried in the machine." But thermal issues make this problematic (see above comments). He also said that the fuel cell "must not exceed a battery of equivalent capacity. If the cell were 180Wh, then the price would be much more attractive, less than half the battery cost on a Wh/$ basis."

Because of the higher price of the fuel cell system, the dollar market for fuel cells used with Notebook Computers is the largest of any of the portable devices forecast (even for a reduced, more conservative forecast). Between 2006 and 2011, fuel cells used in Notebooks could grow from a $374 million market to a $1,316 million market, a compound annual growth rate of 28.6%.

7.4.4 PDA Market

Palm indicated that commercial introduction of fuel cells for PDAs would occur in late 2004/early 2005. Still, for wider market introduction and consistency with the other product groups, we chose 2006 as the introductory date. Palm felt that by 2005, about 80% of PDAs would be battery-powered. "Assuming fuel availability," by 2008, approximately 50% of PDAs could be fuel-cell-powered. They felt the percentage for fuel cell chargers would be smaller, about 5% fuel cell chargers in 2004, increasing to perhaps 30% by 2007.

Exhibit 43
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
PDAs
(millions of units)

	2006	2007	2008	2009	2010	2011	CAGR
North America	3.0	6.0	11.9	14.8	18.5	23.1	50.4%
Europe	2.1	4.1	8.0	9.8	12.1	14.9	48.0%
Asia	0.7	1.2	2.2	2.4	2.6	2.9	33.0%
Worldwide	5.8	11.3	22.1	27.0	33.2	40.9	47.8%

Exhibit 44
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
PDAs
(millions of $)

	2006	2007	2008	2009	2010	2011	CAGR
North America	30	50	83	98	117	139	35.9%
Europe	21	34	56	65	76	89	33.5%
Asia	7	10	15	16	16	17	19.5%
Worldwide	58	94	154	179	209	245	33.4%

Exhibit 45
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
PDAs
($/unit)

	2006	2007	2008	2009	2010	2011	CAGR
Worldwide	10.00	8.37	7.00	6.65	6.32	6.00	-9.7%

According to Palm, customers will pay more for smaller sizes. At $1.50, the cartridge would only last 1-2 days. They felt that the above pricing of $10.00, coming down to $7.00, was good. $10.00 for a fuel cell system is today's price, but at half the volume given in the Assumptions matrix.

In terms of unit sales, PDAs are potentially the largest market. As indicated above, PDAs have higher power requirements than cell phones. Although unit sales would start off lower than Mobile Phones, by 2011, fuel cells for PDAs would eclipse those for Mobile Phones. Of course, the continuing evolution of cell phones and PDAs into various kinds of "convergence devices" could affect this. The power needed by the display and 802.11 wireless networking are all related to how PDAs will evolve in the future. As the forecast stands, however, the Worldwide PDA unit market is expected to grow from 5.8 million units to 40.9 million units between 2006 and 2011, a CAGR of 47.8%.

7.4.5 Digital Camera Market

Digital Cameras were not seen as a good market opportunity for fuel cells. As mentioned in the aggressive forecast section, the only units considered appropriate would be "professional-level" devices, and this was confirmed by the interview respondents. The main problem with this market is that digital cameras can use primary batteries, which are much less expensive. Even $3.00 for a fuel cell cartridge is considered too steep for this segment.

Exhibit 46
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
Digital Cameras
(millions of units)

	2006	2007	2008	2009	2010	2011	CAGR
North America	n/s	0.2	0.3	0.4	0.5	0.6	32.0%
Europe	n/s	0.2	0.3	0.4	0.5	0.7	37.0%
Asia	n/s	0.09	0.1	0.1	0.1	0.2	22.5%
Worldwide	n/s	0.5	0.7	0.9	1.1	1.5	31.7%

Exhibit 47
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
Digital Cameras
(millions of $)

	2006	2007	2008	2009	2010	2011	CAGR
North America	n/s	5	7	8	10	11	21.9%
Europe	n/s	5	7	8	10	13	27.0%
Asia	n/s	2	2	2	2	4	19.5%
Worldwide	n/s	12	16	18	22	28	23.7%

Exhibit 48
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
Digital Cameras
($/unit)

	2006	2007	2008	2009	2010	2011	CAGR
Worldwide	n/a	25.00	22.38	20.00	19.20	18.43	-7.3%

So, with that in mind, the introductory date for fuel cells used with digital cameras was pushed back a year from the previously discussed applications. Unit sales are not expected to exceed one million in any region, even by 2011. Worldwide, unit sales will only reach 1.5 million by 2011, with a dollar market of $28 million that same year. We do not expect market penetration to exceed 2% throughout the forecast period. Pricing will decline more slowly than the other segments, as well, at 7.3% per year.

7.4.6 Camcorder Market

The Camcorder market was not included in the grid, either. We believe it will follow the same pattern as Digital Cameras, however, so the introductory date is the same (2007) and the market penetration rate is the same between 2006-2011 (2%).

Exhibit 49
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
Camcorders
(millions of units)

	2006	2007	2008	2009	2010	2011	CAGR
North America	n/s	0.2	0.2	0.3	0.3	0.4	19.0%
Europe	n/s	0.1	0.1	0.1	0.2	0.2	19.0%
Asia	n/s	0.08	0.09	0.1	0.1	0.2	25.9%
Worldwide	n/s	0.4	0.4	0.5	0.6	0.8	18.9%

Exhibit 50
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
Camcorders
(millions of $)

	2006	2007	2008	2009	2010	2011	CAGR
North America	n/s	6	6	7	8	9	10.8%
Europe	n/s	3	3	3	4	4	8.0%
Asia	n/s	2	2	2	3	4	19.0%
Worldwide	n/s	11	11	12	15	17	11.5%

Exhibit 51
Worldwide Fuel Cell Potential Adoption
Conservative Forecast
Camcorders
($/unit)

	2006	2007	2008	2009	2010	2011	CAGR
Worldwide	n/a	30.00	26.85	24.03	23.07	22.15	-7.3%

The Camcorder market is expected to be the smallest of all the application segments, both in terms of unit sales and dollar sales. Worldwide, unit sales will reach just 800,000 by 2011, while dollar sales are approximately $17 million that same year. Pricing will decline at the same rate as the Digital Camera segment, about 7.3% per year.

7.5 Early Adopters

The sizes of the served available markets for fuel cells were developed using the terminology of "Moore's Product Life Cycle" (Moore, Geoffrey A., *Crossing the Chasm*, 1991): Innovators, Early Adopters, Early Majority, Late Majority, and Laggards. These are defined as follows:

Innovators - Individuals who are the first to adopt any new technology.

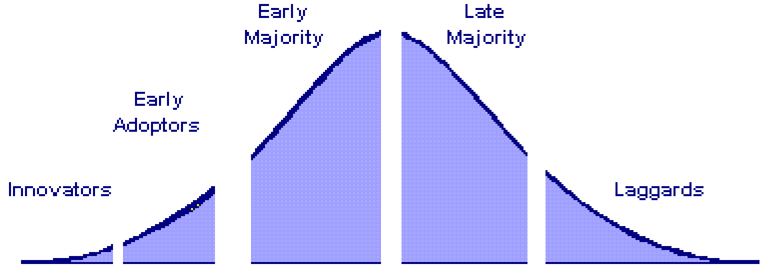
Early Adopters - Pilot line and production line managers looking for a competitive advantage and comfortable with managing new technologies.

Early Majority - Managers who are comfortable with new technologies but want guarantees, service infrastructure, maintenance contracts, manuals, training, user friendliness, and so on.

Late Majority - Managers who are against discontinuous innovations and will cling to current technologies that have earned their trust.

Laggards - Buyers who do not want anything to do with technology, unless it is buried inside another product or has been accepted already. Decisions are based on margins; they are looking for the best deal.

Exhibit 52
Moore's Product Life Cycle Curve



For purposes of the commercialization of an emerging technology, this analysis combines the Innovators and Early Adopters into a single group. The Innovators group is small (about 5%) and has an inelastic demand for new technologies (they will purchase new technologies at arbitrarily high prices, simply because the technology is new). The Early Adopters are a more demanding group but still have a relatively inelastic demand; they are also a much larger group, typically about 12% of the total market. The significant size of this group, together with its relatively inelastic demand, makes the Early Adopters one of the two critical groups to consider when introducing a new technology.

The second critical group is the Early Majority. This group has a more elastic demand than the Early Adopters, but typically accounts for over one-third of the overall market. One of the most critical events in the successful commercialization of an emerging technology is the expansion of the SAM from the Early Adopters to also include the Early Majority. If the SAM cannot be expanded to include the Early Majority segment, the technology will be trapped in a market niche, or could disappear from the market altogether.

When positioning products for the mainstream market, features are less important than "adoptability." Features are important to the Innovators and Early Adopters, and they can assure a "niche" market for the product. But getting a product adopted beyond this point depends on a number of factors, such as the perceived value of any improvements in performance enabled by the fuel cells or the changing regulatory climate. Setting an appropriate "target" price is necessary to ensure successful commercialization, and this price is different from the initial "introduction" price that gets the technology accepted by the Innovators and Early Adopters. Keeping the product target price at the same level that was successful with the Early Adopters may doom fuel cells to niche status or (if the price is much too high), the technology will fail in the marketplace. The dynamics behind this reasoning are discussed in the next section.

7.5.1 Pricing Dynamics of Emerging Technologies

When first introduced, new technologies such as fuel cells can be priced arbitrarily higher than the competing/established technologies (e.g. lithium batteries). These technologies are marketed toward "early adopters" who are willing to pay a significant premium over current technologies in order to get a specified benefit. But this "arbitrarily high" price has boundaries, depending on the targeted early adopter segment. And unless the price comes down quickly (usually within about 12 months), the technology is likely to remain a "niche" product.

For example, flywheels have been available commercially for a number of years, but the cost of a flywheel system used in remote telecom backup installations is $20,000 or more, compared to about $10,000 for a lead-acid battery system. This is a 100% price premium being applied years after flywheels were introduced, pretty much dooming flywheels to "niche" status in this environment.

Another example is a Bluetooth headset for mobile phones from Motorola that is priced at $199 retail. This product is aimed at an "early adopter" segment of Road Warriors, who will pay a premium for the wireless convenience. But Road Warriors are no more than 15% of the Mobile Phone end-use market, and it is unlikely that the Bluetooth headset will capture that entire market share. But this particular product is not being positioned to replace existing mobile phone headsets. Cost-of-goods are judged to be around $30, so even if the price comes down to $60-$100, it will still command too high a price premium over cheaper, wired headsets. This is also an example of "niche pricing."

This is a good object lesson for fuel cells, which initially will be considered a high-priced option for mobile phones. Early adopters will pay the premium, and fuel cells can enter the market at a higher premium with a reasonable market share. But to gain market share beyond the early adopter segment, prices have to come down quickly enough to move the product into lower-price-premium end user segments.

DuPont, which developed the Nafion membrane for fuel cells and now produces other fuel cell components such as MEAs and bipolar plates, has implemented a program that produced Nafion price decreases of 50% over the past three years. The company anticipates that another 45% price drop will be accomplished in 3-4 years' time. But volume production is still needed.

The starting price point, combined with the elasticity of demand among the users, will determine the initial sales potential for the new technology. The greater the price premium for the emerging technology compared with the price for the established technology, the smaller the market that is available to the emerging technology.

Once sales have started, the "learning curve effect" comes into play. The learning curve states that every time cumulative production doubles, pricing declines by a given percentage. This occurs only after the technology has reached "full manufacturing" status. It cannot be applied to units produced in the lab or to pilot production lines.

Fuel cells will only reach full commercialization when both process control and manufacturing development are achieved. A fuel cell company can have batch production with relatively high yields, but such production is still not at levels efficient enough to bring prices down in the long run.

For an accurate analysis, it is necessary to combine the learning curve effect for the emerging technology with the price declines projected for the established products. Industrial products have typical "progress rates" between 10% and 20%, according to a United Kingdom government report issued in February, 2002. Mature electronic products can have progress rates of 6% or less. A study on "Commercialization Prospects for Fuel Cell Buses" done by Princeton University in 2000 found a progress rate of 21% for PEM fuel cell stacks.

So, if the learning curve is expected to account for a 20% price reduction in the new technology, and prices for the established products are expected to decline 5% during the same period, the price gap will narrow by 15%. If the gap was originally 100%, i.e. the emerging technology cost 100% more than the established technology, the new gap would become 85% (100% - 15%). The narrowing of the pricing gap can be combined with the price elasticity of demand to determine the growth in market share for the emerging technology. This assumption was incorporated into the methodology used to determine the Fuel Cell Potential Adoption forecasts in section 7.3, above.

As discussed above, a less optimistic progress rate of 10% can be examined for comparison purposes. This scenario would make certain assumptions, such as the cost of materials (e.g. platinum) not coming down or staying the same; technology not progressing sufficiently to solve the materials problem (or find ways around it); or factors that force fuel cell design to stay exactly where it is today with no development in the next few years. Because alternatives to these problems (such as nanotechnology) are already being developed, Darnell Group assumes a more optimistic scenario, particularly with the backing of the Princeton study.

So successful commercialization of fuel cells depends on multi-dimensional factors, starting with the initial, maximum price premium; the price elasticity for the product and the market share to be captured as the price premium comes down; manufacturing production and how pricing will decline relative to production yields; the point at which price declines open up new markets beyond the early adopters (so-called "price points); and the "critical market share percentage" that determines the product has successfully penetrated the market. Some of these factors occur sequentially and some occur simultaneously. Fuel cell companies can determine some of the factors, such as the maximum price premium. Companies do not have to have absolute pricing, but they do need a pricing ratio relative to competing technologies.

Expansion in critical market share will lead to faster doubling of cumulative production volumes for the emerging technology, pushing the technology more quickly down the learning curve, and reducing the pricing premium at a faster rate. Of course, accelerating price reductions do not continue forever. This acceleration only continues until the emerging technology begins to mature in terms of production technologies, at which time the rate of price declines will drop until it reaches a "steady state" that reflects long-term reductions in related materials used in the new technology and other similar factors.

This is not meant to imply that fuel cells have to be priced the same as lithium batteries. Even after volume production was achieved, lithium remained a higher-priced chemistry than nickel-metal hydride. As discussed in Phase One of this project, lithium batteries increased the performance and functionality of mobile computing devices. Fuel cells are expected to increase performance of 3G phones and "interconnectivity" devices, which gives them increased value and justifies prices that are higher than lithium batteries.

In conclusion, the price reductions given in this report represent fairly significant fuel cell unit volume at a high price premium at the beginning of the forecast period. For example, in 2004, a 2W fuel cell for a Mobile Phone is expected to be $10.75/W or $10,750/kW. By 2009, the cost will come down to $2.96/W or $2,960/kW. A 16W fuel cell for a Notebook Computer is expected to be $4.87/W or $4,870/kW in 2004, declining to $1.33/W or $1,330/kW in 2009. Even though the costs are still high in 2009, the declines are significant, and this cost reduction path will be similar for fuel cells used in electric vehicles – perhaps even steeper declines. This is because a larger fuel cell is relatively less expensive, but the relative reduction in cost is greater at the kW level.

Section VIII: SUMMARY OF FINDINGS

8.1 Product/Application Matches

The tables below present a summary of the various portable applications discussed in this report, along with a summary of the fuel cell technologies being considered for portable applications. Exhibit 30 is a SWOT analysis of each portable application, and Exhibit 31 gives opportunities and challenges for each fuel cell technology. There is no "perfect match" between a specific product and application, although there are strengths and weaknesses to pursuing different options. Section 8.4, "Recommendations for Successful Commercial Introduction of Fuel Cells for Portable Devices," will give our recommendations, based on the information contained in this study.

Exhibit 53
SWOT Analysis of Fuel Cells
by Portable Market

	Strengths	Weaknesses	Opportunities	Threats
Mobile Phones	- Largest potential market for fuel cells. - Fuel cell will compete against combined price of battery & charger.	- Longer-term market. - Current mobile phones do not require the energy density of fuel cells. - Total cost of ownership not a significant factor. - Do not necessarily require more batteries or higher energy-density batteries.	- Adoption of 3G devices. - Could enable "wireless connectivity." - "Road warriors" good early adopter segment. - Japan has already launched 3G service. - If the right price points are achieved, fuel cells for Mobile Phones could hit 8.6 million units in 2004.	- New systems do not necessarily require more batteries. - Korean entry into Li-poly market means lower Li-ion prices and more pressure on fuel cells. -Pricing goals have to meet projected Li-ion prices for 2004-2005. - Fuel cell pricing will have to come down 22.7% per year. - Future battery chemistries. - Fuel in fuel cells may not be allowed on planes. - Fuel cell size might not come down enough to fit cell phone. - Peak power problems.

	Strengths	Weaknesses	Opportunities	Threats
Convergence Devices	- Fuel cell will compete against combined price of battery & charger. - “High-value” application.	- Some “hybrid” portable devices might have to use batteries or ultra-capacitors along with fuel cell. - Current devices do not require the energy density of fuel cells. - Longer-term; no real market currently exists for these devices. - Total cost of ownership not a significant factor.	- Could enable “wireless connectivity.” - Would take a portion of the Mobile Phone market. - Cost of 3G handsets could absorb the increased cost of fuel cells.	- New systems do not necessarily require more batteries. - Future battery chemistries. - Fuel in fuel cells may not be allowed on planes.
PDAs/Handhelds	- Fuel cell will compete against combined price of battery & charger. - Considered a higher-end device because of devices with higher power requirements. - Nearly 55% of unit sales are projected to be in North America by 2009.	- Total cost of ownership not a significant factor. - Small market. - Market could cease to exist in its current form if devices become more “convergent.” - Do not necessarily require more batteries or higher energy-density batteries.	- Fast-growing market.	- Korean entry into Li-poly market means lower Li-ion prices and more pressure on fuel cells. -Pricing has to meet projected Li-ion prices for 2004-2005. - Fuel cell pricing needs to decline by 21.8% per year. - Future battery chemistries.
Notebook Computers	- “High-value” application. - Second-largest market for fuel cells.	- Battery charger savings that come with a fuel cell are less. - Total cost of ownership not a significant factor.	- New products, such as Tablet PC and “always-on” computers, could be enabled by fuel cells.	- New systems do not necessarily require more batteries. -Pricing has to meet projected Li-ion prices for 2004-2005. - Fuel cell pricing needs to come down by 22.8% per year. - Future battery chemistries. - Fuel in fuel cells may not be allowed on planes.

	Strengths	Weaknesses	Opportunities	Threats
Digital Cameras	- Fuel cell will compete against combined price of battery & charger.	- Total cost of ownership not a significant factor. - Small market; only high-end, professional units. - Do not necessarily require more batteries or higher energy-density batteries.	- Fast-growing market.	-Pricing goals have to meet projected Li-ion prices for 2004-2005. - Fuel cell pricing needs to decline by 22.4% per year. - Future battery chemistries.
Camcorders	- 51% of unit sales are projected to be in North America by 2009.	- Total cost of ownership not a significant factor. - Small market; only high-end, professional units.	- Fast-growing market.	-Pricing goals have to meet projected Li-ion prices for 2004-2005. - Fuel cell pricing needs to decline by 21.3% per year. - Future battery chemistries.
Battery Chargers	- Can participate in the battery-powered applications market without displacing the battery. - Could be a good “transitional” product to be used as a technological “proving ground.”	- Total cost of ownership not a significant factor. - Emergency chargers are a “niche” product. - Cheaper models use alkaline batteries.	- Military and industrial markets might be good opportunities. - Medis Technologies working with General Dynamics on mobile battery charger for U.S. Army. - Electric Fuel and H Power have fuel cell battery chargers for various portable applications.	- Prices are dropping very fast in certain wattage segments. - Ritz Camera no longer has plans to sell Electric Fuel’s zinc-air fuel cell chargers at this time.
Portable Power Units	- Can be used in high-cost environments that are less price-sensitive. - Could be a good “market entry opportunity.” - Total cost of ownership more important for military market; high initial costs not a showstopper.	- Typically use an inexpensive power source.	- Military market might be good opportunity.	- Japanese companies dominate this market, and they are very competitive on price.

	Strengths	Weaknesses	Opportunities	Threats
Two-way Radios & Portable Audio Devices	- Total cost of ownership more important for military products; high initial costs not a showstopper.	- Total cost of ownership not a significant factor. - Portable consumer devices typically use alkaline batteries; not a good market for premium products. - Portable DVD market in NA is small.	- Military market might be good opportunity for 2-way radios.	- Portable audio devices not considered good opportunity.

Exhibit 54
Challenges for Fuel Cells
in the Portable Market

DMFC	SOFC	PEMFC	Metal-Air
- Platinum needs to be reduced, even though it represents about 30% (at most) of the total cost of a DMFC. - CO-tolerant catalyst required. - Cost reduction and mass production process needed. - Fuel may not be allowed on planes. - MEAs are a significant contributor to cost. - At 10W and above, system manufacturing is costly. - Medis Technology announced a catalyst for use on its cathode that doesn't require platinum. - Considered to be most suitable for transportation and portable applications. - Cost breakdown: MEA (40%); Other components and assembly (60%). - Companies profiled in this report doing DMFCs: Ball, Casio, Giner, H Power, Lynntech, Manhattan Scientifics, Medis, MTI Micro Fuel Cells, Motorola, NEC, Polyfuel, Samsung, Smart Fuel Cell, Toshiba.	- Making headway in the APU market, with other small applications (1kW) being investigated. - SOFC components are potentially cheaper and easier to manufacture than PEMs, although manufacturing costs are still high. - High efficiency. - Lenient to fuel; no reformer needed. - Cost breakdown: Systems (61%); Components (25%); Materials (8%); Materials Processing (6%). - Companies profiled in this report doing SOFCs: Lynntech, ZTEK, Altair Nanotechnologies, Delphi Automotive Systems.	- Platinum needs to be reduced. - Most important are construction materials for cell frames, bipolar plates, electrocatalysts for fuel and air electrode, and the ion-conducting membrane. - CO-tolerant catalyst required. - Fuel may not be allowed on planes. - Protonex uses biopharmaceutical filtration technology to reduce stack cost. - MEAs are a significant contributor to cost. - Plastic materials can be a low-cost part of the integrated assembly. - Learning Curve is 80% for PEMFCs (Princeton University). - Use inexpensive manufacturing materials (plastic membrane). - Cost breakdown: Fuel Cell (60%); Fuel Processor (29%); Assembly & Indirect (8%); Balance of Plant (3%). - Companies profiled in this report doing PEMFCs: Avista Labs, Ballard, DCH/Enable, Giner, H Power, Lynntech, Nuvera, Panasonic, Samsung, 3M, DuPont, ElectroChem, Synergy Technologies, Teledyne Energy Systems.	- Zinc-air has high specific energy. - Material costs are low. - Ritz Camera no longer has plans to sell Electric Fuel's zinc-air fuel cell chargers at this time. - Companies profiled in this report doing metal-air fuel cells: Electric Fuel, Trimol Group.

8.2 Technical Approaches

Reducing materials costs is one of the critical challenges facing successful commercialization of fuel cells. This includes finding ways of lowering costs with existing materials, as well as developing new technologies that will reduce costs. When lithium batteries were first introduced, a number of technical challenges existed that, if met, could reduce costs. "Rocking-chair technology," for example, was seen as difficult to surmount, but the problem was solved eventually. We anticipate that similar engineering problems with fuel cells will be overcome, such as the following.

8.2.1 Platinum

The high costs of platinum loading have been discussed from several angles in this study. Ultimately, platinum is not a showstopper for fuel cell commercialization. Platinum reduction is necessary, but it does not have to be eliminated. In March, 2001, Medis Technologies announced that it had achieved "an important breakthrough in developing a catalyst for use on the cathode in its DMFC fuel cell, which no longer requires platinum or other precious metals as a component, reducing the cost of the fuel cell." This is one extreme of the platinum cost reduction continuum, but it is not necessary to achieve the lower costs needed for successful commercial introduction.

For example, Brookhaven National Laboratory announced in April, 2002, that they had developed a new method of creating catalysts that could allow the production of cheaper and more efficient fuel cells. This method reduces the amount of platinum present in the catalyst, thus limiting carbon monoxide accumulation and improving fuel cell performance. Platinum atoms are deposited on the surface of tiny ruthenium crystalline particles. Typical platinum-ruthenium alloy catalysts have platinum throughout. "Our method very likely makes almost all of the platinum atoms available to react with the hydrogen," according to chemist Radoslav Adzic, the head of the Brookhaven team.

A recent study by researchers at Johnson Matthey Technology Centre in the U.K. indicated that "future research needs to be on improved performance and not on lower cost alternatives to Pt with comparable or lower performance." The indicated that, "Improved performance can be achieved at the lower electrode Pt loadings by improving the utilization of the cathode electrocatalyst."

Scientists from the Department of Chemistry at Vanderbilt University have developed a Pt-Ru/graphitic carbon nanofiber (GCNF) nanocomposite that exhibits high relative performance as a DMFC anode catalyst. The composite enhances fuel cell performance by ~50% relative to that recorded for an unsupported Pt-Ru colloid anode catalyst. Further work on the metal alloy/GCNF anode catalysts is expected.

Similar work on catalysts is occurring at Los Alamos National Laboratory, including the evaluation of new materials with low Pt content. This group reported substantial improvement in cathode performance with low Pt loading, and significant decrease in anode loading needed for tolerance to 100 ppm CO. They plan to initiate work on non-precious metal catalysts for fuel cell cathodes.

Researchers at Naval Research Laboratory and the University of Pennsylvania are aiming to decrease or eliminate the noble metal content of oxygen reduction reaction (ORR) catalysts by developing advanced hydrous oxide catalysts designed for rapid transport of protons, water, electrons and oxygen. Results showed that ORR activity of Pt is greatly enhanced by dissolving it in a matrix that is a good proton and water conductor. Upcoming testing of the catalysts in Los Alamos National Laboratory's PEMFCs will indicate their actual activity and corrosion stability. The decreased Pt in the PEMFC will result in a significant decrease in the cost of PEMFCs. Other transition-metal oxide systems containing little or no Pt will continue to be developed.

Improving the catalytic activity of Pt by adding non-noble metals is also part of 3M's research. Scientists want to take advantage of nontraditional ternary catalyst combinations through 3M's "unconventional" processes and unique substrate, and a variety of PtAB compositions are under evaluation. Their initial conclusions are that "ternary catalysts improve the fuel cell performance and/or decrease the Pt loading."

Lawrence Berkley National Laboratory has focused on conducting research on the kinetics and mechanism of electrode reactions in low-temperature fuel cells. Their research concluded that the use of Pt-Co alloy catalysts with optimized particle size should enable Pt loadings on the air cathode to be reduced by about a factor of two from current practice with standard pure Pt catalysts. New commercially available Pt-Ru alloy catalysts having a greater Ru content than used at present should enable the previous metal content in anodes to be reduced by about 50%.

In 2001, Superior MicroPowders (SMP) received a $3.63 million contract from the Department of Energy for the development of low-platinum-content electrocatalysts and MEAs for PEM fuel cell applications. In July, 2002, the company announced that it had been granted a NIST ATP (National Institute of Standards and Technology Advanced Technology Program) award to further the development of MEAs for direct methanol fuel cells (DMFC) for portable power applications such as two way radios and cell phones.

SMP's NIST award is a three-year effort designed to remove significant existing barriers to commercialization including cost prohibitive precious metal loadings and unreliable manufacturing methodologies. SMP's major program objectives are to develop materials and digital deposition technology, which will reduce precious metal content and enable flexible manufacturing techniques.

SMP will use a spray-based process to make electrocatalyst powders that can be deposited by ink-jet printing. These powders will have increased utilization compared to catalysts prepared by traditional methods, increasing catalytic activity thereby reducing the precious metal content and increasing performance. Major upstream partners in this effort include CFDRC, who will develop simulation models to guide the design of MEAs; and Spectra Inc., a leading piezoelectric ink-jet print head manufacturer, who will collaborate in the development of the ink-jet printing systems. The major downstream partner in this effort is Motorola Labs, who will help design the MEAs and integrate them into DMFC systems for testing. Motorola is also a leading producer of portable electronic products that are the target market for the DMFCs developed under this work. The first market for this program will be chargers for batteries in commercial two-way radios.

Medis Technology believes that eliminating the use of platinum as a component of the catalyst for the cathode would reduce the cost of making their fuel cells when they come to market by an estimated 20%. The company's scientists are focusing on the elimination of platinum from the catalyst for the anode, as well. But simply reducing the platinum loading may be enough to bring costs down to a viable level.

8.2.2 Nanotechnology

Another approach to reducing fuel cell costs is nanostructured materials for advanced energy storage devices, including fuel cells. Several companies and organizations are focusing in this area, including Superior MicroPowders, Hyperion Catalysis International, MicroCoating Technologies, Carbon Nanotechnologies, Aerogel Composite, Nanomix Inc. and the Karlsruhe Research Center. Carbon nanotubes, conductive plastics and catalyst layers are a few of the areas under investigation. Specific developments include:

• In September, 2001, NEC Corp., the Japan Science and Technology Corp. and the Institute of Research and Innovation (IRI) announced that they had developed a small-sized fuel cell for mobile terminals using nanotechnology. NEC adopted for the electrode of the fuel cell a "carbon nanohorn," one kind of carbon nanotube. NEC says that cells with the carbon nanohorn electrode generate about 20 percent more electric power than conventional fuel cells with activated-carbon electrodes. The carbon nanohorn has a finer structure than activated carbon, and can disperse on the electrode the fine particles of platinum that are the catalyst for decomposing hydrogen. This enhances the efficiency of the decomposition of hydrogen, the company said.

• Nanomix Inc., a U.C. Berkeley spin-off developing commercial nanotechnology sensors and hydrogen storage systems for portable and automotive fuel cells, announced in September, 2002, that it had received $9 million Series B financing. Using novel new nanomaterials, Nanomix has developed a new hydrogen storage system that they claim equals the energy density of gasoline. Engineering prototypes are being used to demonstrate the technology's feasibility for "the fuel-cell-powered automobiles slated for commercial production in 2005." Also, efforts are underway to design new hydrogen storage materials to power micro-fuel cells in portable electronics, toys and power tools.

• MicroCoating Technologies (MCT) has developed a methodology for producing a variety of nanopowders and thin films based on MCT's patented flame-based, open atmosphere combustion chemical vapor deposition (CCVD) process to manufacture thin films on a variety of substrates. The proprietary Nanomiser® device enables ultra-fine aerosolization and gas-like combustion of liquid precursors in their NanoSpray flame synthesis process, and allows MCT to produce metal and oxide nanopowders in colloidal or dry form. Nanostructured materials have been created for applications in fuel cells.

• Buckytubes are considered "very promising" for applications in energy storage and conversion devices, including fuel cells. Carbon Nanotechnologies has focused on their electrical and thermal conductivities and tensile strength. Also, the unique arrangement of atoms within a Buckytube results in a structure that has highly accessible surface area and a very high aspect ratio.

• Superior MicroPowders has developed a spray-based powder manufacturing process to produce nanostructured materials for catalysts and electrocatalysts for fuel cell applications.

• Reduction in the amount of platinum is essential to lowering the cost of fuel cells. To address this problem, Aerogel Composite has developed carbon-aerogel-supported platinum electrocatalysts. The material is mesoporous monolith with sharp pore size distribution. The surface areas range from 400 to 1000 m^2/g, and the average pore size can be controlled between 3 and 10 nm. The size of the platinum crystallites as determined by transmission electron microscopy (TEM) is around 1 nm at low platinum loadings, resulting in good dispersion, along with uniformity of crystallite size and distribution of the crystallites. Tests conducted in fuel cells using gas diffusion electrodes and these catalysts have shown promise.

• The group of alkali metal aluminum hydrides has become a matter of topical interest for hydrogen storage, after it was shown that one of the compounds, sodium alanate, is capable of storing reversibly 5.5 wt.% of hydrogen. As higher storage capacities are desired for mobile applications, other compounds have been investigated by researchers at the Karlsruhe Research Center, Institute of Nanotechnology. These compounds have a theoretical potential to store reversibly 7 wt.% of hydrogen or even more.

8.2.3 Low-Temperature versus High-Temperature Fuel Cells

With transportation as the DOE's long-term fuel cell goal, transfer of micro fuel cell technology to transportation fuel cell technology is important. In other words, the development of small fuel cells for portable applications must be applicable to the eventual commercialization of fuel cells for transportation applications. A focus on those areas that are most applicable is useful, as well as awareness of how these two industry segments differ.

Because of their low operating temperatures (80°C), polymer-electrolyte fuel cells are targeted for transportation applications. In particular, many researchers think DMFCs could prove to be the main source of vehicular power in the longer term. Operating temperature is a critical characteristic for transportation fuel cells due to crashworthiness and safety concerns, as well as the need for quick start and thermal insulation requirements. For successful commercial introduction of fuel cells, inexpensive membranes are needed that can operate at temperatures exceeding the 80°C typically used now.

In general, “high temperature” fuel cells (in general, above 500°C) are more efficient than low temperature ones in generating electrical energy. They provide high temperature waste heat that increases their efficiency, but this presents a problem for transportation applications. “Low temperature” fuel cells (in general, below 500°C) have quicker start-up times, compact volume and lower weight compared to high temperature fuel cells. More important, crashworthiness requires a low temperature system. As a result, most transportation fuel cell development have been of the low temperature variety.

The definitions of “high temperature” and “low temperature” are somewhat relative, and what is “high temperature” in one application segment is “low temperature” in another. Here are some general temperatures ranges for different fuel cell types:

• Proton exchange membrane fuel cells - 50 to 100°C
• Phosphoric acid fuel cells - 200°C
• Direct methanol fuel cells - 50 to 100°C
• Alkaline fuel cells - Below 80°C
• Solid oxide fuel cells - 800 to 1,000°C
• Molten carbonate fuel cells - 650°C

PAFCs, for example, are considered “low temperature,” although they are certainly not low temperature enough for mobile phone or notebook computer. SOFCs and MCFCs are considered “high temperature.” Today, PEM fuel cells typically operate at close to 80°C, although there is a desire to move to “higher” temperatures, close to 150°C, to mitigate the effects of carbon monoxide (CO) poisoning at the anode. The first polymers designed for temperatures in excess of 100°C are emerging. The McGrath Group at Virginia Tech have synthesized a series of poly-sulfonated sulfones for use as PEMs in fuel cells.

Since polymer-electrolyte fuel cells in general, and DMFCs in particular, are considered the most suitable for both transportation and portable power applications, DMFCs are further supported as the fuel cell of choice for portable devices. Both transportation and portable applications require low operating temperatures, high power densities and high energy-conversion efficiencies. Car manufacturers already use polymer-electrolyte fuel cells in electric vehicles and some bus fleets. The DOE’s goal is to develop membranes and MEAs for operation at 120 to 150°C.

Even though 150°C is still considered “low temperature” by vehicle fuel cell standards, such temperatures are “high temperature” for portable devices. When looking at ways to save costs in fuel cell development for portable products, temperature may be a moot point since this is not a transferable area of technology.

8.3 Consumer Experiences

An important element to consumer acceptance of fuel cells is low price and ease of use. Not only does the fuel cell have to meet certain price points, but the fuel and the means of replacing that fuel needs to be inexpensive. Currently, fuel cell cartridges are being considered in both replaceable and refillable forms. Consumers could prefer to use refillable cartridges rather than replacement cartridges. In other words, consumers might want to purchase the fuel separately, much as they buy butane fuel in canisters to refill cigarette lighters. In this case, costs would need to be the equivalent of just pennies per refill. Such fuels as methanol would need to be available anywhere in the world, just as cigarette lighter fuels are.

It is also useful to look at why other battery technologies have not made significant inroads into portable consumer applications. Rechargeable, refillable and reusable alkaline batteries have not successfully replaced NiCds, NiMH and lithium chemistries in notebook, cellular and other portable consumer devices, even though alkalines are cheaper. Motorola, for example, makes a "road warrior" cellular phone with a refillable alkaline battery pack, but these are considered "niche" products.

Alkaline batteries are best-suited for low-current applications, and they perform better in devices such as portable radios and MP3 players than in more demanding ones, such as handheld computers or digital cameras. Under lower-current draw conditions, more power can be obtained. Reusable alkaline batteries are also good for low-cost applications, and their limited cycle life are compensated by low self-discharge, making them good for portable entertainment devices and flashlights.

The longevity of reusable alkalines is a direct function of the depth of discharge: the deeper the discharge, the fewer cycles the battery can endure. In addition, the low load current capability of 400mA makes them insufficient for most cellular phones and transceivers. The purchase price is very low, but the cost per cycle is high when compared with some rechargeable batteries, such as NiCds. Also, there is danger in recharging ordinary alkalines because they pose the risk of generating hydrogen gas, which can lead to explosion.

Alkalines are not recommended for several of the applications discussed in this report. For example, PDAs can run on alkaline batteries, but when using ATA Flash cards in a PDA, alkalines are not recommended. This is because some alkaline batteries have a high internal resistance that prevents the battery from supplying the peak currents the cards require for writing. The problem occurs randomly, so the user could go months safely and then suddenly lose data. Rechargeable alkalines will also work in many digital cameras but are not recommended. These batteries typically have lower capacity than standard alkaline batteries and are consumed at a very quick rate in a digital camera application.

8.4 Recommendations for Successful Commercial Introduction of Fuel Cells for Portable Devices

This report has presented an analysis of the potential market for fuel cells for portable applications. Major competitors have been identified, including their products, partnerships and research and development. A comparison of fuel cells with the existing technology – portable, rechargeable lithium batteries – pointed out the price points that fuel cells will be competing against. Lithium battery pricing is a "moving target" and it is important to forecast ahead to where Li-ion and Li-polymer prices will be when fuel cells are commercially introduced – not where they are now. It is also useful to look at the introduction of Li-polymer and why it was not successful at displacing Li-ion in the marketplace. Fuel cells could face similar obstacles.

An assessment of the various fuel cell technologies and the product applications, along with forecasts of the served available market for fuel cells, provides some of the key issues involved with the successful introduction of fuel cells. This section presents what Darnell considers to be the "best" options, based on the various strengths, weaknesses, opportunities and threats for each application area and fuel cell technology.

An important consideration with fuel cells is that there is more than one factor driving adoption. High-value applications, new features of devices, less price-sensitive markets, and the ability to bring costs down will all play a part in whether this technology will be successful. At the same time, competing technologies, overcoming technical hurdles in the development of fuel cells, regulatory requirements for transport, small markets that would not produce economies of scale, and the business model of Japanese companies who already have a foothold in the market could pose threats sufficient enough to delay entries into this market.

So even though certain opportunities have been identified, each of them has balancing threats and weaknesses that could hinder their adoptability.

First Tier Opportunities

<u>Portable Power Units/Battery Chargers</u>

"Battery chargers," as used here, refer to lower-wattage units used for remote, industrial powering, not the battery chargers for portable consumer devices, discussed below. Portable power units/battery chargers are considered a small, but potentially good "market entry opportunity," which is why we recommend it in the first tier. These products could serve as a way to reduce costs for fuel cells in other portable devices, and provide a path to automotive fuel cells through the stationary market. This market is small, but relatively price insensitive.

Convergence Devices/Mobile Phones

Convergence Devices are considered a future subsegment of the Mobile Phone market, but sales are currently too insignificant to forecast. This is truly an opportunity that will be driven by future technologies, since current devices do not require the energy density of fuel cells. The adoption of 3G services and "wireless connectivity" would introduce features that batteries could be hard-pressed to support, and thus allow these devices to slowly take market share away from Mobile Phones (which is the largest market in these forecasts) and possibly even PDAs/Handhelds. So the potential market is very large. In addition, the cost of 3G handsets could absorb the increased cost of fuel cells, since fuel cells will compete against the combined price of the battery and charger.

Notebook Computers

Notebook Computers are the second-largest market in these forecasts, providing a good opportunity for fuel cells to reach manufacturing economies of scale and the requisite price points to compete with current battery technologies. They are also a "high-value" application, in that they are expensive enough to absorb the higher cost of a fuel cell. Darnell Group believes the problems with bringing fuel for fuel cells onto planes will be resolved, since the DOT has already shown willingness to meet on this issue and there is precedent for making exceptions with volatile battery chemistries, such as lithium. As with convergence devices, new features such as the Tablet PC and "always-on" computers could be enabled by fuel cells.

Second Tier Opportunities

Mobile Phones

Mobile Phones are a good opportunity for fuel cells when viewed within their evolutionary context. In other words, Mobile Phones are expected to evolve beyond their current form into the convergence devices discussed above. In their current form, they have little need for a fuel cell. But as an evolving, longer-term market, they will become a product segment that is likely to benefit from the advantages of fuel cells. Mobile Phones are by far the largest unit segment in our forecasts, and the fuel cell will compete against the combined price of a battery and a charger. "Road warriors" would be among the early adopters.

PDAs/Handheld Computers

PDAs/Handheld Computers are products that will not stay in their current form. Their features could end up in the so-called "convergence" devices discussed above, or in mobile phones and digital cameras. So, like the Mobile Phone market, their suitability for fuel cells depends on whether these products continue their evolution into more advanced features that require higher power. Already, this segment includes the higher-end devices that are capable of absorbing the higher cost of a fuel cell. Also, the fuel cell will be competing against the combined price of the battery and charger.

Battery Chargers for Consumer Devices

Some companies, like MTI Micro Fuel Cells, are looking at battery chargers as an "initial" product on the way to commercialization of fuel cells in other product applications. We do not see battery chargers as a good, long-term opportunity, but it might be a transitional point as fuel cell technology refines itself to other markets. Another advantage is that fuel cell companies can participate in the battery-powered applications market without displacing the battery. For longer-term opportunities, the Military and Industrial segments provide the best opportunities.

Portable Power Units (generators)

Portable power units typically use an inexpensive power source (gasoline or diesel fuel), and the market is dominated by Japanese companies that are competitive on price. But there are two segments in this market that might be good, initial points of introduction: the Military market and "High-Cost Environments" (such as photovoltaics). A commercial or residential site might be willing to use a quiet, less smelly fuel-cell-driven auxiliary power unit if they are already installing photovoltaics, which are expensive. And in the Military market, high initial costs are not a showstopper; total cost of ownership is more important.

Two-Way Radios (Military)

Like the portable power unit market, military two-way radios could be a good opportunity for fuel cells. These units are used in the field, where "emergency" products benefit from the high power and long usage that fuel cells provide. High initial costs are not a showstopper.

Third Tier Opportunities

Digital Cameras

Although a fast-growing market, digital cameras are not considered the best opportunity for fuel cells. The only portion of this market that can absorb the cost of a fuel cell is high-end, professional cameras, not consumer models. So the market is small, and the units do not necessary require more batteries or higher-energy-density batteries. Fuel cells would compete against the combined price of the battery and charger.

Camcorders

Like digital cameras, the only portion of the camcorder market that can absorb the higher cost of a fuel cell are high-end, professional units. In addition, most of this market is in

North America (about 51%), so it is limited internationally. The market is fast-growing, but it is not considered a good opportunity.

Portable Audio Devices

Portable audio devices, such as portable DVD players, are not considered good opportunities for fuel cells. Portable consumer devices typically use alkaline batteries, and the market is very price-sensitive. In addition, the portable DVD market in North America is small. Between the size of the market and its price-sensitivity, these devices are at the bottom of the fuel cell opportunity list.

Fuel Cell Recommendations

The fuel cell technologies being seriously considered for portable applications are direct methanol fuel cells, proton-exchange membrane fuel cells, metal-air chemistries and (to a lesser extent) solid oxide fuel cells. In the portable segment, **SOFC**s are only making headway in the APU market, around 1kW. So this technology is not currently under serious consideration for portable consumer devices.

Metal-air chemistries use a slightly different process than the typical fuel cell and are often considered more of a battery technology than a fuel cell technology. Chemistries such as zinc-air, therefore, are discussed in this report more as an example of a higher-priced battery alternative. But the experiences of companies like Electric Fuel are instructive, especially since they have targeted several of the markets fuel cells are targeting. These are discussed in further detail elsewhere in this report.

PEMFCs are the most widely developed fuel cell type. They have high power density and can vary their output quickly to meet shifts in power demand. They are considered more suitable for automotive applications.

The **DMFC** is not as developed as the PEMFC. The former is similar to PEM cells in that they both use a polymer membrane as the electrolyte. Since DMFCs operate in a relatively low temperature range, however, they are considered attractive for tiny to mid-sized applications. Issues related to cost and transportation regulation need to be addressed and are discussed in the above sections. But overall, Darnell Group believes the DMFC holds the most promise for use in portable, consumer-level devices.

Appendix A: SENSITIVITY ANALYSIS

The Fuel Cell Technology Adoption forecasts provided in this report are based on a complex business model. Five parameters (assumptions) are included in the model. Those parameters include: the learning curve associated with fuel cell production; the point on the learning curve represented by the introductory pricing for fuel cells (Start Quantity); the pricing premium that can be captured by fuel cells when they are first introduced to the “Innovators” and “Early Adopters” (the First Premium price); the pricing premium that can be charged to “Early Majority” users (the Majority Premium price); and the adoption rates for fuel-cell-powered devices.

The sensitivity of the model to changes in the assumptions varies from a very low 0.17 (relatively insensitive) to 3.10 (very sensitive). A sensitivity of 0 represents a completely uncoupled effect (a parameter that has no effect on the outcome of the model). A sensitivity of 1.0 indicates a one-for-one percentage change in the results of the model for a given change in the associated parameter. Sensitivities of below one and above one indicate that the prediction of the model changes more slowly, or more quickly than the associated parameter, respectively.

Exhibit 55
Parameter Sensitivities

Learning Curve	3.10
Adoption Rate	1.30
Start Quantity, >3%	1.00
First Premium Price	0.54
Start Quantity, <3%	0.41
Majority Premium Price	0.17

The single most critical assumption is related to the learning curve parameter. It is far more important than any other single parameter. For fuel cells to be successful, it is not necessary that the introductory pricing be directly competitive with existing battery technologies. However, the model assumes that fuel cells can capture sufficient market share to drive down the learning curve. That is expected to result in sustained and significant price reductions for fuel cells. Fortunately, the learning curve parameter for fuel cell production is based on empirical data obtained from a Princeton University study and is considered to be very realistic and reliable.

The second most-important assumption is related to the Adoption Rate. Changes in the value of that parameter can have a dramatic impact on the resulting forecast. For example, if the Adoption Rate falls below some critical level, the emerging Fuel Cell technology will not gain market share fast enough to keep up with price declines forecast for Li batteries. If Fuel Cell prices do not decline at a fast enough rate, Fuel Cells will be relegated to the status of a niche technology. On the other hand, the price premium that the Early Majority is willing to pay is the least important assumption. If fuel cell makers miss the target in that area, it could take a little longer to capture market share, but it would not necessarily be a fatal missed target. It is more important that fuel cells hit the First Premium pricing target. The importance of the First Premium pricing is a result of several factors: Having a First Premium price that is too high will result in a slower Adoption Rate, and a slow Adoption Rate can be fatal to success. On the other hand, the current First Premium pricing assumption is sufficient to ensure the success of fuel cells (if all other parameters are assumed to be at the given levels); it is not necessary that the First Premium assumption be reduced.

Finally, the Start Quantity presents an interesting dynamic. At Start Quantities below the assumed level of 3% (which represents improved performance by fuel cell makers), the model is relatively insensitive. However, at Start Quantities above the assumed level of 3%, the model is quite sensitive. In this case, the sensitivity analysis predicts that 3% is a critical threshold level. Improved performance will not dramatically improve the chances for success, but reduced performance could be a major stumbling block to the widespread adoption of fuel cells.

Appendix B: SEMICONDUCTOR ADVANCEMENTS

Successful commercialization of fuel cells is often predicated on the assumption that current battery technologies (i.e. Li-ion) are not “up to the task” of powering future portable electronic systems. This assumption is not necessarily correct. Portable electronic systems are, indeed, becoming more sophisticated, with features such as white LEDs to backlight keypads or color displays in mobile phones, PDAs, digital cameras, and so on. Depending on the application, constant current or constant voltage may be required.

Due to advances in semiconductor technology, however, these new portable systems do not necessarily require more batteries, or higher energy-density batteries. Semiconductor companies are developing ICs that use existing battery technologies more intelligently. They are designing power management products that push the energy envelope, and their overall philosophy is, “Don’t worry about the battery – we can find a way to deal with it.” In fact, the current electronics solutions to get the most out of battery chemistries have not been fully exploited yet. The industry is still using low dropout regulators (LDOs), which are not as efficient as switching regulators. The latter are expected to come into more widespread use in battery-powered devices in the future.

For example, ON Semiconductor recently announced its first power management Application Specific Integrated Circuits and expanded both its analog IC and MicroIntegration™ portfolios for the portable and wireless markets. The company says these system-level solutions will improve the power performance of cell phones, PDAs and other portable electronic equipment, while reducing the board space required to deliver the latest functionalities.

In September, 2002, Texas Instruments announced that it intends to deliver a single-chip cell phone with converged voice and multimedia capabilities by the end of 2004. The company’s CEO said, “…we will enable our customers to deliver wireless phones and PDAs with voice, data and multimedia without increasing size and power consumption.” In addition, TI unveiled in the same month power interface switches that they claim will reduce power consumption and extend battery life for notebooks, PDAs and other wireless devices.

In November, 2002, National Semiconductor Corp. and ARM Ltd. announced that they would jointly develop and market power-efficient systems that will increase the battery life of handheld portable devices by 25%, up to 400% in phases. The two companies plan to focus on developing an advanced technology that enables ARM Powered® system-on-a-chip (SoC) devices to dynamically adjust performance and power consumption to maximize energy conservation in portable devices. They are also collaborating to develop an open standard for advanced power savings in handsets and other portable devices.

Components of the Palm OS platform were recently licensed to MediaQ, a semiconductor manufacturer, to further support the development of Palm Powered products with advanced graphics and multimedia capabilities. MediaQ designs low-power, energy-efficient, multimedia-enabling chips. The company's core technologies enhance visual display capabilities, improve connectivity, and minimize power consumption. And apparently investors think highly enough of MediaQ's potential success in this area to provide $15 million in fourth-round funding. The funding was announced in late July, with news that MediaQ's "energy-optimizing chips will enable the next generation of smart mobile phones and PDAs to run multimedia-rich applications, while reducing overall system energy consumption."

These developments in semiconductor electronics will keep current battery technologies competitive, even with the increasing energy demands of portable electronic devices. In fact, semiconductor companies see fuel cells as "blue sky." They believe that any problem with battery power management can be addressed by semiconductor technology.

In addition, new electrode materials are being developed for rechargeable lithium batteries that could increase their power density by 10-20%. Researchers at Massachusetts Institute of Technology have developed a substance called lithium phospho-olivine that conducts electricity much better than the materials currently used as terminals in commercial batteries. And researchers at the University of Waterloo in Canada have come up with a method of generating lithium iron nitride cheaply and quickly as an anode material. Preliminary tests show that the lithium iron nitride compound stands up well to repeated charging and recharging. The material's capacity is also comparable to other leading candidate compounds.

Appendix C: INTERVIEW QUESTIONS AND RESPONSES

(1) As an OEM, how far into the future does your company plan products?

Mobile Communications and Computing Battery Pack, First-Tier OEM: 18 months, from plan to build (includes 60-90 days for beta testing, sometimes less). Longer for R&D. 2-3 years if there are problems.

Mobile Computing, First Tier OEM: 6 months, for changes to existing technologies. 2-3 years for new or emerging technologies.

Smart Fuel Cell: For laptops, 3-4 years.

Apple Computer: One year.

Director of Advanced Technology, Palm: 18 months. Development time: 18 months; 9 months for simple devices.

Manager, New Directions, Almaden Research Center, IBM: 3-4 years. That is, there is a projected product plan 3-4 years out that is very subject to change.

(2) What would be a reasonable introductory date for fuel cells used in portable applications: e.g. external charging unit, integrated charger?

Mobile Communications and Computing Battery Pack, First-Tier OEM: Industry introduction - 2004. But this could be a single company, and there could be problems of acceptance. For the market as a whole (at least 3-5 companies): 2006-2007.

Mobile Computing, First Tier OEM: Not restricted on the demand side, but on the supply side. System OEMs are ready now. For notebooks, there are fuel cell materials problems (reliability, quality). Starting with a charging unit for notebooks is good; pricing could be slightly higher.

Smart Fuel Cell: Company claims they have already shipped small, stationary products in 2002. External charging units will be introduced in 2003. For laptops: 2006.

Apple Computer: 2003-2004.

Director of Advanced Technology, Palm: A stationary charger would not be useful to them, so not ever. For mobile chargers, late 2004 or early 2005.

Manager, New Directions, Almaden Research Center, IBM: External charger: Never -- not attractive to our customer set. Wall plugs are too accessible, and free!

Integrated charger: 10 years, assuming breakthrough to 90% efficiency. If not, never.

(3) At what point do you see batteries putting hard limits on the system technology?

Mobile Communications and Computing Battery Pack, First-Tier OEM: Runtime is most important, not the battery technology per se. How frequently does someone need to buy a cartridge? The question is convenience versus (operating) cost.

Mobile Computing, First Tier OEM: Longer runtimes are an advantage. He doesn't think laptops will put limits on batteries, however. Intel would never design chips that push batteries beyond their limits, since they rely on batteries to run the products their chips go into. They would not assume that something new (like fuel cells) will replace batteries. Increase in clock speed is the main driver pushing battery technology.

Smart Fuel Cell: He considers laptops to be the only viable portable system (in our grid) for fuel cells. Below this energy point, fuel cells are not realistic. Limits will be reached around 2004.

Apple Computer: Today.

Director of Advanced Technology, Palm: Now. PDAs have a big display to power, and 802.11 has higher power requirements. They are making trade-offs in size already.

Manager, New Directions, Almaden Research Center, IBM: Now. Battery capacity already limits microprocessor speed (microprocessor speed decreases with the portability of the laptop). Competition between microprocessor and wireless power demands and battery energy content are driving the development of power management techniques.

(4) What percentage of your business do you expect to be (a) batteries; (b) fuel cells by (a) 2005 and (b) 2008? In 2005, what percentage of your business do you expect to be (a) wall charger; (b) fuel cell charger?

Mobile Communications and Computing Battery Pack, First-Tier OEM: For cell phones, 0% in 2005 (at $10 for fuel cell system). More attractive by 2007, but pricing is not an issue here. For chargers, it depends on the product. Chargers are very situation-specific. Customers will still buy wall chargers, which will be used more often. A portable charger is not really needed, and will be considered an "extra" device.

Mobile Computing, First Tier OEM: Notebooks - 10% fuel cells by 2005; possibly 30-40% by 2008. But this would include hybrid battery and fuel systems.

Smart Fuel Cell: By 2006, they expect 98% will still be batteries, with 2% fuel cells. Same ratio for chargers. He expects fuel cell chargers will have a faster introduction, but they will be limited in unit sales. They expect field testing of units for mobile office systems in second quarter of 2003.

Apple Computer: Declined to comment.

Director of Advanced Technology, Palm: 2005 - 80% battery-powered. Assuming fuel availability, by 2008 - possibly 50% battery-powered. The percentage for fuel cell chargers would be smaller, possibly 5% fuel cell chargers in 2004, increasing to 30% by 2007.

Manager, New Directions, Almaden Research Center, IBM:

Batteries - 100% (2005)	100% (2008)
Fuel Cells - 0% (2005)	0% (2008)
Fuel Cell Charger - 0% (2005)	2% (2008)
Wall Charger - 100% (2005)	100% (2008)

Fuel cell charger will never be the exclusive charging mode. It will be used as needed by wilderness remote users.

(5) How sensitive are you to system size and fuel capacity? If the fuel cell system size changed, what else would have to change?

Mobile Communications and Computing Battery Pack, First-Tier OEM: People won't buy it if it's too much bigger, so larger system size isn't necessarily good.

Mobile Computing, First Tier OEM: For laptops: Their research indicated that a 5x better runtime is important for customers to make a change to any new technology. A 10-15 hour runtime would be good.

Smart Fuel Cell: By weight, 3x to 4x increase is realistic. For volume, 1.5x to 2x is realistic. Smart Fuel said they already have achieved 2x increase by weight.

Apple Computer: They are very sensitive to size. The weight and cost of the system would have to change.

Director of Advanced Technology, Palm: For their products, they would need 50% more energy than a battery in the same size system.

Manager, New Directions, Almaden Research Center, IBM: At introduction, extremely. Must fit in battery space – same volume and shape. First products must have fallback possibility of substituting battery for fuel cell late in development manufacture. If fuel cells prove reliable, then other form factors can be considered. Probable contraints:

volume 0.1-0.2 liters; 0.3 liters possible if really 120Wh; thickness equal to DVD drive. Only about 1/3 or less of the space under the keyboard is available for energy.

(6) How price sensitive are you? If the fuel cell were 50% bigger, would given pricing be more (or less) reasonable?

Mobile Communications and Computing Battery Pack, First-Tier OEM: Price drops of 40-50% are not realistic, since you'd run into inventory problems. A drop of 15% per year is more realistic.

Mobile Computing, First Tier OEM: Customers will not spend $5-$10 on a cartridge (for laptops). $1.00/month is ideal.

Smart Fuel Cell: $5-$10 (for laptops) is too high, except possibly for professional users. $3-$4 is probably the highest you could go.

Apple Computer: Apple is very price sensitive. Size and weight come first, then price.

Director of Advanced Technology, Palm: No feedback on weight. Physical size is very important. 4-5mm is the limit for thickness. To Palm, worldwide fuel distribution is THE most important issue. There must be standardized cartridges, standardized fuel, and worldwide distribution of fuel. He said they would pay more for smaller sizes, as long as the loss of energy density was linear.

Manager, New Directions, Almaden Research Center, IBM: Price sensitive. But this is a matter of real debate. Marketing people think that customers will not pay for extra capacity. I disagree and think that the price in the table, if buried in the machine, would be acceptable. Customer will not buy separately, however. Experience is Electrovaya, which is about the same ($350 retail). Must not exceed battery of equivalent capacity. If cell were 180Wh, then price would be much more attractive, less than half the battery cost on a Wh/$ basis.

COMMENTS ON FUEL CELL GRID

Exhibit 56
Assumptions Used for Portable Fuel Cell Market Survey

Application	Fuel Cell Power	Battery Power	System Size & Fuel	Total WH	Runtime (hours)	Retail Fuel Cartridge Cost	Fuel Cell System Selling Price to OEM 2005	2007
Cell Phone/ Convergence Device	1W	2W	10-15cc	12	12	<$1	$10	$7
PDA	1W	none	20cc	20	20	$1.50	$10	$7
Digital Camera	2W	3W	20cc	10-15	5-7	$3	$25	$20
Laptop	15W	15W	300cc	120	8	$5-$10	$75	$50

<u>Mobile Communications and Computing Battery Pack, First-Tier OEM</u>: Overall, increasing size system and fuel is okay, but not much bigger, otherwise no one will buy.

Cell Phones - No one will pay $10 for 12 hours runtime (0% market penetration rate in 2005 at this price). $7 may be more attractive.

PDAs - 20 hours runtime is good. $1.50 for cartridge would last 1-2 days, so this is $270 per year operating cost. $10 in 2005 and $7 in 2007 for fuel cell system price to OEM is good.

Digital Camera (professional level) - $3 for cartridge will be steep for professional. These units can use primary batteries, which are cheaper.

Laptop - $10 for cartridge is getting expensive. Normally, street price is 3x-4x OEM price.

<u>Mobile Computing, First Tier OEM</u>: He answered questions relative to laptops only. 15W for fuel cell power and for battery power is low for peak power needs. 300cc not too bad for size, but would sell more at half this size. 8 hours runtime good, but 5x (10-15 hours) would be better. $5-$10 for cartridge is too steep. $75 for fuel cell system is not too bad. Refueling cost is the major issue.

Weight is important in laptops. The fuel cell system shouldn't weigh more than one pound. A fuel cell charger is good, since there would be 50W of heat dissipated in these systems, and that can't be inside the notebook. Have to have external charger.

<u>Smart Fuel Cell</u>: He answered questions relative to laptops only.

300cc is accurate. If volume is more, it will be too big and consumers won't accept it. An external unit is best, at first. $5-$10 for cartridge is too high, except for professional use. $3-$4 more realistic.

Apple Computer: No comments on grid.

Director of Advanced Technology, Palm: He answered questions relative to PDAs only. 20cc for fuel is higher than what is used today. Runtime is low; 25-30 hours would be ideal (these are the current runtimes). $10 for fuel cell system price is today's price, but at half the volume given in the matrix (i.e. 20cc).

Manager, New Directions, Almaden Research Center, IBM: Problem with your chart is that 15W is a bit light for a full-featured laptop (not sure whether this is average or peak. I always assume peak. 15W average power is about right, but need 30W peak for full features, e.g. IBM T2x line. 15W peak okay for lightweights, e.g. IBM X line, but then will have difficulty with 300cc. These machines are too thin for a DVD, even.)

Appendix D: GLOSSARY

3G - Third Generation wireless network.

AFC - Alkaline fuel cell.

Ah - Abbreviation amp-hour or AH, which is the result of the current times the number of hours to total discharge.

APU - Auxiliary power unit.

ASP - Average selling price.

Barriers to entry - Competitive factors that are likely to make it difficult for a company to enter a particular market, e.g. channels of distribution, manufacturing costs, and so on.

BOP - Balance of plant.

Business - Less price-sensitive end-use segment.

CAGR - Compound annual growth rate.

CCVD - Combustion chemical vapor deposition.

CDMA - Code division multiple access.

Channels of distribution - A company's means of distributing their products. These can consist of direct sales, value-added resellers, distributors, sales representatives, and so on.

CO - Carbon monoxide.

Consumer - Price-sensitive end-use segment.

Convergence devices - Electronic devices that combine the functionality of several different devices, such as cell phones and PDAs, handheld computers and digital cameras, and so on.

CPU - Central processing unit.

Cross Price Elasticity of Demand - The percentage change in unit demand for a product in response to a change in relative prices between the emerging/substitute product and an existing product.

Demand Curve - The sales volumes for an emerging product at a series of "relative" pricing levels compared with prices (or anticipated prices) for the existing substitute product.

DG - Distributed generation.

DMFC - Direct methanol fuel cell.

DOT - Department of Transportation.

Early Adopters - Pilot line and production line managers looking for a competitive advantage and comfortable with managing new technologies (Moore's Product Life Cycle).

Early Majority - Managers who are comfortable with new technologies but want guarantees, service infrastructure, maintenance contracts, manuals, training, user friendliness, and so on (Moore's Product Life Cycle).

Emergency/911 - Price-sensitive end-use segment; least likely to care about extended run-times for Mobile Phones.

Energy density - The amount of energy a battery stores per unit volume at a specified discharge rate. Lead-acid batteries have low energy density but high power density.

FAA - Federal Aviation Administration.

First Premium Price - The pricing premium that can be captured by fuel cells when they are first introduced to the Innovators and the Early Adopters.

GDL - Gas diffusion layer.

GSM - Global System for Mobile Communication.

IC - Integrated circuit.

Innovators - Individuals who are the first to adopt any new technology (Moore's Product Life Cycle).

Laggards - Buyers who do not want anything to do with technology, unless it is buried inside another product or has been accepted already. Decisions are based on margins; they are looking for the best deal.

Late Majority - Managers who are against discontinuous innovations and will cling to current technologies that have earned their trust (Moore's Product Life Cycle).

LCD - Liquid crystal display.

LCP - Liquid crystal polymer.

LDO - Low dropout regulators.

Learning Curve - The idea that every time cumulative production doubles, pricing declines by a given percentage.

LED - Light emitting diode.

Li-ion - Lithium-ion batteries.

Li-polymer - Lithium-polymer batteries.

Majority Premium Price - The pricing premium that can be charged to the Early Majority users.

MCFC - Molten carbonate fuel cell.

MEA - Membrane electrode assembly.

MEMS - Micro electro mechanical systems.

NiCd - Nickel-cadmium batteries.

NiMH - Nickel-metal hydride batteries.

NIST - National Institute of Standards and Technology.

OEM - Original equipment manufacturer.

PAFC - Phosphoric acid fuel cell.

PBT - Polybutylene terephthalate.

PDA - Personal digital assistant.

PDC - Personal digital cellular.

PEEK - Polyetheretherketone.

PEM - Proton exchange membrane.

PEMFC - Proton exchange membrane fuel cell.

PGM - Platinum-group metals.

PM - Precious metal.

Power density - The amount of power a battery can deliver per unit volume at a specified state-of-charge.

PPS - Polyphenylene sulfide.

PTC - Positive-Temperature-Coefficient resistor.

RAM - Random access memory.

RMFC - Reformed methanol fuel cell.

Road Warrior - Least price-sensitive end-use segment; depends on extended run-times of products.

SAM - Served Available Market.

SMC - Sheet molding compound.

SOFC - Solid oxide fuel cell.

Start Quantity - The point on the Learning Curve represented by the introductory pricing for fuel cells.

Stationary battery - A secondary (rechargeable) battery designed for use in a fixed location.

SWOT - Strengths, weaknesses, opportunities, threats.

TAM - Total Available Market.

TCO - Total cost of ownership.

TEM - Transmission electron microscopy.

TSA - Transportation Safety Administration

UNECE - United Nations Economic Commission for Europe.

UPS - Uninterruptible power supply.