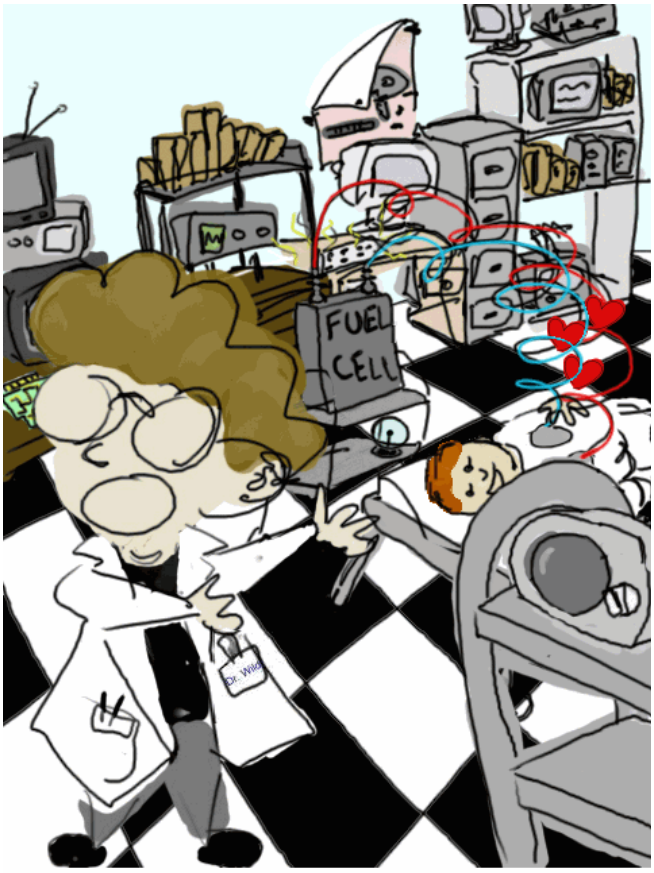
COMMERCIALIZING DISRUPTION & THE POWER OF PASSION

In the Emerging Fuel-cell Industry



I've achieved a breakthrough!! My regenerative fuel-cell runs off the very passion it inspires!

by

Amaury Laporte

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A dissertation presented in part consideration for the degree of *MA in Strategic Management*

In memory of my father, *François Laporte*,
who dedicated his life to the Third World's development.
May fuel-cells give these countries
the boost they sorely need.

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for their patience and their insistence that I not spend
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his insights on the question of passion.*

Summary

It is suggested that firms commercializing disruptive innovations must address six key needs (the need for merit, the need for government support, the need for champions & visionaries, the need for cooperation, the need for niches and the need for speed) in order to achieve success. The validity of this framework is analyzed using the fuel-cell industry as a case study. The author concludes that though the first five needs are indeed present in the fuel-cell industry, their importance varies, both in relation to one another and with time. The importance of the sixth need, the need for speed, cannot yet be determined, as fuel-cells have yet to be widely commercialized.

During his research, the author realized that passion, which is prevalent in the fuel-cell industry, could be considered a strategic resource. The second part of this dissertation thus focuses on elaborating a framework for the analysis of passion as a strategic resource. The author concludes that further empirical research is needed, and emphasizes the need for management scholars to undertake more research on the question of emotions in general, as these are chronically ignored although they are likely to play a crucial role in the business world.

TABLE OF CONTENTS

LIST OF APPENDICES

I. INTRODUCTION

1. The Promise of Fuel-cells

> **The Science of Fuel-cells**
>
> The scientific principles underlying fuel-cell technology have long been well understood. Indeed, the process that takes place within a fuel-cell is simply the reversal of the electrolysis of water. Instead of using electricity to separate water (H_2O) into its two constituent elements, hydrogen and oxygen (as occurs in electrolysis), hydrogen and oxygen are reacted together, by way of a catalyst, to produce water and energy (in the form of electricity and heat). And this is done very efficiently, to boot (70-80% fuel efficiency rates are possible if the heat generated by the cell is also exploited).
>
> The principal factor keeping the technology back has not been its inherent complexity (a student from Colorado won his high school's science fair by building his own fuel-cell -Kopicki, 2001), but its prohibitively high cost. But this is beginning to change, as we shall see.

"Fuel *sales*?"

This would almost invariably be my interlocutors' reaction when told the topic of my dissertation (that or they would simply nod approvingly, and then quickly change the subject, reluctant to admit that they had no idea what a fuel-cell is - assuming they'd correctly heard what I'd said in the first place!). When I myself first read about fuel-cells and their potential to become our leading source of energy, my reaction was little different. What are fuel-cells? Are they really the Next Big Thing? When will they appear on the market, and in what applications? My curiosity was definitely piqued, and I must admit that I set out to find a research topic that would give me the opportunity (or excuse, some would say) to study this fascinating emerging industry in more depth.

"And what do fuel-cells have to do with strategic management?" This slightly more awkward question would often immediately follow my initial explanation of fuel-cell mechanics and my exaltation of the technology's remarkable promise. Clearly, the fuel-cell, a technology that has yet to be widely commercialized, doesn't seem at first glance to be particularly relevant to business studies. After all, how can one study an industry whose product is in many cases still at the development stage? But there are in fact several issues here that of great import to the strategic management field.

First of all, how does one go about commercializing a (very) disruptive technology in the face of great uncertainty, massive investment requirements, and the entrenched interests of powerful rivals? Which industries are likely to benefit from the widespread adoption of fuel-cells, and which ones will be threatened, sometimes to the point of outright extinction? And what will all this mean to firms in general? Indeed, one must not underestimate the potential impact of fuel-cells on the business world and on the global economy. Fuel-cells, by making widespread distributed power possible, could facilitate the exploitation of remote areas (making previously uneconomic ventures viable) and could greatly accelerate the development of industrializing countries (which, because they would not have to set up expensive electrical grids, could skip a development stage). In addition, fuel-cells, being more powerful than comparably-sized batteries, may allow the conception of new, energy-hungry products that are currently impractical. In other words, fuel-cells could usher in a cornucopia of new markets and new products. It is thus safe to say that, should fuel-cells live up to their promise, few businesses will be left unaffected.

"How a fuel cell works"
*Source: The Economist, July 22nd, 1999, p. *1*

"IT GETS wet and hot and that's all. This, in short, is the attraction of a fuel cell. In simple terms, it gobbles up hydrogen and combines it with oxygen from the air to generate electricity, avoiding combustion and by-products any nastier than water and heat.

Although there are rival varieties of fuel cell [see appendix 14], the most promising is the proton-exchange membrane. This is a sandwich of two electrodes, a cathode and an anode, with an electrolyte stuffing called a polymer membrane placed in between.

At the anode, hydrogen gives up its electron with the help of a platinum catalyst. While the hydrogen passes across the membrane in the form of positively charged ions, its electrons, which cannot cross the membrane, instead stream around an external circuit, rather as electrons do if you connect the poles of a battery. And as with a battery, this current can power a car or a computer. When the hydrogen ions reach the cathode, they are reunited with electrons and combine with oxygen to create water and heat.

If the fuel that is used is pure hydrogen, then the process will live up to its clean image. But if the hydrogen is made on board by a reformer that consumes hydrocarbon fuels, such as methanol, natural gas or petrol, the whole process will be slightly

And so it behooves us, as researchers, to consider these questions. Indeed, I firmly believe that academics, unless they are willing to be seen as irrelevant, must strive to make their research useful for practitioners (see Stoecker, 1999). The considerable and far-reaching implications of the (probable) advent of fuel-cell technology need to be studied and, especially, brought to the attention of company executives. Energy is a key input in all human activities, and its role in strategy-making should not be treated casually.

However, researchers must also take care not to impinge too much on the functions of executives. We are not consultants, as my supervisor pointed out. Nor are we futurists. So although I will, to a limited extent, discuss many different aspects of the commercialization of fuel-cells, I have elected to focus on the strategies that can be used in an emerging industry. Since the study of emerging industries has already generated a wealth of theory, this gave me the opportunity to test many hypotheses and so help to validate (or discredit) the theories in question.

2. Fuel for Thought

The Emergence of Welfare-Maximizing?

But I also felt that I might be able to derive some valuable insights, leading perhaps to a new theoretical framework, by studying the fuel-cell industry. I was particularly intrigued by the possible role played by strong environmental and social motivations. I wondered if many of the people involved in the industry (including founders and top executives) were greatly and maybe even primarily inspired by such considerations. This would have important implications concerning much of strategic management's traditional frameworks.

Indeed, the discipline of strategic management has been very heavily influenced by economics and its various branches, such as agency theory (Jensen & Meckling), industrial organization (Porter) and transaction costs analysis (Williamson). One could in fact argue that strategic management is basically the application of economic theories to the business world. Now one of the major assumptions of mainstream economics (derived in large part from neo-classical theory) is that in a capitalist system, firms are profit-maximizing. Or, as Milgrom and Roberts (1992, p. 40) explain, "the goal most commonly ascribed to firms in economic analysis is profit maximization." Presumably, if most, or even a significant minority, of the firms in an industry are driven by objectives that don't necessarily involve profit-maximization and may even be incompatible with it, this would lead to unusual industry dynamics requiring a whole new set of strategies. How does one compete with a firm that is prepared to make minimal or no profits in order to achieve certain social or environmental goals?

Such concerns are not confined to extremely unusual situations like the emergence of a disruptive technology. Companies are increasingly under pressure to forego profits in the name of social or environmental considerations. This is especially true of pharmaceutical companies, for example. They must spend enormous sums to research and develop their drugs (often fruitlessly), and so are naturally inclined to sell them at premium prices to make their investments worthwhile. This makes the drugs beyond the reach of many people in the developing world, who are often most in need of them. The result is public outcry, and embarrassed companies. Although it is very unlikely that profit-maximizing will lose its primacy in the capitalist world, it may be necessary to elaborate new strategic frameworks that can deal with and accommodate non-profit maximizing behaviors (which I call "welfare-maximizing").

The Influence of Individuals

In addition to studying the extent of welfare-maximizing motivations, I was also intrigued by the role of visionaries and champions in emerging industries. In part, this was because I assumed that these individuals would be the ones most driven by environmental and social considerations, and would in turn inspire their employees and colleagues. Also, I found that the literature on visionaries was sparse, and tended to focus too much on the "how" and not enough on the "why." Finally, and most importantly, many of the popular theories in academia today tend to disregard the role unique individuals can play in shaping an organization, and even an entire industry. Instead, these theories focus on population dynamics and environmental conditions (organizational ecology), internal resources (the resource-based view)[1], or external competitive forces (Porter's 5 Forces framework), etc...

Yet, it would seem that the complex unfolding events that occur during an industry's emergence can be extraordinarily sensitive to their initial conditions. So much so that Bygrave and Hofer (1991) suggest that chaos theory, which can mathematically model such situations, may have something to offer to entrepreneurship studies. For example, "if Fred Terman had not fallen ill with tuberculosis when vacationing in Palo Alto, there might not be a Silicon Valley today," (Rogers and Larsen, 1984 *in* Bygrave and Hofer, 1991, p. 20).

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[1] Certainly, the RBV does emphasize the importance of human resources, but rarely on an individualized basis.

3. Research Objectives

First Research Objective: Demonstrating the Six Needs

So, to summarize, my research had two primary objectives. First, to analyze what strategies are being implemented in the emerging fuel-cell industry, and whether these are in accordance with the strategic management literature on the subject. Specifically, my literature review led me to identify six crucial needs that firms in an emerging industry must address in order to successfully commercialize a disruptive innovation. They must first determine whether their technology does indeed have potential, which makes its development worth pursuing (*the need for merit*). They must take advantage of, and indeed push for government help during the often very long pre-commercialization period in which R&D costs are high and revenues low or non existent (*the need for government support*). They must have a worthy objective that can sustain their determination during this arduous pre-commercialization phase, as well as forceful individuals who will egg them on when the going gets rough (*the need for champions and visionaries*). They must collaborate, for one company alone cannot hope to bring a disruptive innovation to market (*the need for cooperation*). They cannot tackle the mass market head-on, for a variety of reasons, but must instead identify suitable customers for their first products (*the need for niches*). Finally, they must be fast. Or must they? I must admit, I was unsure myself, as the literature on the subject is quite equivocal (*the need for speed?).*

This analysis will constitute part III of my dissertation, its main thrust. Although my findings, based on an in-depth study of the fuel-cell industry, confirm the existence of the first five needs, and indeed their fulfillment by most of the companies in the industry (certainly all the better placed ones), they also suggest that some needs are more important than others. Indeed, the needs' relative weights vary over time, and from company to company, depending on a variety of factors. Moreover, the evidence for the sixth need, the need for speed, is mixed and somewhat inconclusive, although perhaps it does indicate the wisdom of prudence rather than haste.

Second Research Objective: Exploratory Research - The Power of Passion

Second, I undertook some exploratory research around the theme of welfare-maximizing motivations in the hope of gleaning some new, useful insights. This half of my research project quickly led me to the conclusion that welfare-maximizing motivations do not override profit-maximizing ones, but instead the two kinds of motives reinforce one another (in most cases). Many firms in the fuel-cell industry are strongly driven by welfare considerations, but few, if any, place these before the desire (indeed, the need) to make profits. Though my initial instinct proved a dead end (profit is as preeminent as ever, so the foundations of strategic management remain sound!), it did inspire another insight. Indeed, it brought me to realize the considerable importance of passion in business, and particularly in emerging industries. This is turn exposed what I believe is a grave flaw in current strategy formulation and implementation: the neglect of emotion. Humans are, for better or for worse, emotional creatures, and this can have important implications when it comes to management. My analysis of the role of passion in business forms part IV of this dissertation, in which I will argue that passion is critical to achieve excellence, but that more research will be needed to demonstrate this conclusively.

But first, part II is the overview of my methodology, which forms the foundation of my analyses and so merits some attention.

II. METHODOLOGY

1. Research Focus

I considered focusing above all on the companies developing fuel-cells for automobile applications. These firms are generating the most media interest, so I believed there would be more than enough information available. In the end, I decided this would be too limiting. One of the key appeals of fuel-cell technology is the fact that it is very scalable. Fuel-cells can power mobile phones or power plants, and anything in between. I felt this aspect was too important to ignore. Later, I also realized that many of the companies in this industry are not restricting themselves to particular applications.

Similarly, I initially adopted a rather restricted definition of the fuel-cell industry as consisting of only those firms which are developing actual fuel-cells (in view of mass producing them for consumer and intermediary markets). But I found it expedient to approach companies that were not involved in the production of fuel-cells per se but rather in the selling and designing (often in close collaboration with their customers) of the necessary electrical systems, reformers and catalysts required for an operational fuel-cell. I also contacted a few of the major associations in the field, such as Fuel-cells 2000, the US Fuel-cell Council and the World Fuel-cell Council (see appendix 1). In this way, I was able to build a slightly more balanced view of the industry and its dynamics.

2. The Exclusive Use of Qualitative Research.

I elected to use qualitative research methods for several reasons, not least being the fact that quantitative methods are not my forte... Qualitative methods are particularly well suited for the type of research I undertook, which was in large part exploratory. It is hard to measure something when you don’t yet know exactly what you want to measure. Moreover, Conger (1998) argues persuasively that qualitative research methods should be the methodology of choice for topics that have a strong symbolic and subjective component, and that are dynamic in nature. She refers to her particular field of study (corporate leadership), but her reasoning is just as applicable to research regarding motives, passion, visionaries and champions. Indeed, these issues are clearly extremely subjective, and are liable to change significantly over time.

Although one could conceivably have designed a questionnaire addressing these questions so as to employ quantitative methods (indeed, many researchers have approached the study of entrepreneur motivations in this manner -please refer to my literature review on the subject), surveys are not necessarily particularly accurate. Philips (1973, in Conger, 1998) points out that surveys often measure respondents' attitudes about the behaviors being studied rather than the actual behaviors. This is because people are often reluctant to admit to their true motives, desires or goals if they fear these will not be deemed socially acceptable. Of course, this difficulty also surfaces when qualitative research techniques such as interviews are employed. But in this case, the researcher can attempt to rephrase his or her questions, to establish a certain *rapport* with the interviewee so that he or she will be more willing to speak frankly.

My research on corporate strategy was perhaps more amenable to quantitative analyses (although this is debatable). But there were also practical obstacles to take into account. Since fuel-cells are only just now on the verge of widespread commercialization, there is a lack of available market data. To compound matters, many of the companies in the industry are privately owned, and so do not readily divulge information regarding their activities.

3. Interviews

My research objectives clearly called for the extensive use of interviews. Speaking to the company founders and the executives in charge of elaborating corporate strategy (sometimes, but not always, one and the same), was, after all, the best way to learn about their motivations and strategies. Unfortunately, there was the distinct risk that, due to their important responsibilities and busy schedules, they would decline to grant me an interview. Researchers in strategic management are often confronted by this difficulty. This consideration brought me to draw up a rather limited set of questions (see appendix 2), so that I could assure potential interviewees that I would only require 30 to 60 minutes of their time (on average about 45 minutes).

Necessary Trade-offs

Ideally, I would have liked to conduct my interviews in person, as this would have enabled some degree of interaction (an immeasurable advantage in qualitative research), and would have perhaps formed the basis for a more in-depth and open discussion. But many of the companies studied are based throughout North America (the United States and Canada), which ruled out face-to-face meetings because of budgetary and time constraints. The obvious alternative was to conduct the interviews by telephone, which although somewhat impersonal, and less conducive to prolonged discussions, still provides many of the advantages of interactivity and spontaneity. On the other hand, giving the respondents as much flexibility as possible would probably encourage their participation. I therefore made it clear in my requests (see appendix 3) that, although I would like to speak to a top executive if at all possible, I would also be quite happy to receive his or her e-mailed (or mailed) responses. There were thus a few trade-offs involved in my research, as is often the case. Basically depth was sacrificed for breadth.

Contact Procedure

Seven associations, councils, institutes and publications, as well as forty-two companies were contacted in all, including all the major players in the industry -such as Ballard, International Fuel-cells, Plug Power... (see appendix 1). The chosen companies were identified principally through the use of publicly accessible directories on the Internet (notably on the Fuel-cells 2000 website), as well as during the preliminary industry research phase. Contact was always initiated by email, but if no response was received within a week or so, a letter would also be addressed to the company. The requests sent were personalized as far as possible, as I had learned from my experience as an intern that this was the best way to elicit a response.

Results

Five companies politely declined to participate (this unfortunately included most of the major players) and instead directed me to other sources of information or sent me their annual reports and other relevant literature. But 15 organizations (13 companies, 1 publication, and the US Fuel-Cell Council) were kind enough to grant me an interview (see appendix 4). Of the resulting 17 interviews, 9 were conducted by phone, and the remaining 8 by email (see appendix 4). The other twenty-nine firms and associations did not respond.

The final, positive, response rate was thus close to one third (30.6% to be precise) which is rather high for such a study. Indeed, many of the respondents were eager to participate, and a significant number indicated they would be willing to answer any additional questions I might have later on. The enthusiasm demonstrated in this fashion was, I believe, what first brought me to consider the role passion could play in the business world. My timing was also rather fortuitous. As Mr. McNeill, from H Power, explained, the industry is just beginning to emerge, so its companies' executives are still relatively approachable (interview - McNeill).

4. Press Reviews

Although the interviews were an indispensable part of my research, it is important to vary one's sources in order to achieve what Conger (1998, p. 110) calls "between-method triangulation," in which "the shortcomings of one method are balanced by the strengths of the other." Participatory research, although it would have been particularly well suited to my research objectives, was unfeasible in practice. Instead, I gathered as much information as possible from the websites of the organizations I contacted and undertook an extensive review of any secondhand accounts I could track down. In this, the Internet was absolutely invaluable, as it made unearthing relevant academic and journalistic articles (including those in the specialized press) straightforward and speedy.

In addition, exploiting digital data brings with it a key advantage: taking notes becomes a simple matter of copying and pasting the text into relevant files (see appendix 5). Indeed, all my major themes were assigned a text file, where I scrupulously kept track of the information's source. Whenever a new theme was identified, I simply created a new file. I was thus able to analyze and dissect a considerable amount of information (this dissertation has over 200 references, which only represent a portion of all the articles and papers I actually consulted). The information collected could then be relatively easily processed and distilled. Although my research was wide-ranging (see appendix 6 and the list of references), it remained manageable.

5. Caveat: Researcher Bias

Inevitably, a researcher will influence his or her findings, as he or she mediates and attempts to interpret reality (Watson, 1994). "Research is *shaped* in the process of its being carried out, as opposed to resulting from a perfectly formed and pre-planned research design" (Watson, 1994, p. S86). This is true both for qualitative and quantitative research, but since qualitative research tends to deal with very subjective and complex phenomena, it is often particularly affected by researcher bias. This can be mitigated, but never entirely eliminated. The researcher thus has a certain obligation to acknowledge his or her partialities and/or prejudices so that the reader can better evaluate the author's conclusions and analyses.

Regarding my study of the strategies implemented in the fuel-cell industry, I was of course keen to demonstrate my hypotheses, and this may have somewhat colored my data analysis. This is not likely to have greatly altered my findings, however. More problematical is my exploratory research concerning motivations and passions. I am myself quite passionate about fuel-cells and their potential, which could have influenced the people I interviewed and how I interpreted my readings. For example, my questions may have been phrased in a way that elicited certain responses that would not normally have been forthcoming. Basically, I was perhaps too enthusiastic about my research on enthusiasm... However, I did strive to remain as objective as possible. In the end, my readers will have to decide for themselves just how valid my conclusions are.

III. COMMERCIALIZING DISRUPTION & THE SIX NEEDS

Strategic management research has traditionally focused on relatively mature industries, as there is more data available to study them. It has been assumed that the resulting theoretical frameworks could relatively easily be adapted to emerging industries. To a certain extent, this is true. But emerging industries also present many very specific challenges, and thus require a different set of strategies than those which are frequently employed in more developed industries. This and the fact that emerging industries play a critical role in economic growth, through the process of "creative destruction" (Schumpeter), has recently encouraged researchers to redirect their focus, so that the commercialization of new technologies have now become a popular topic.

Of course, certain technologies are drawing more attention than others. The Internet, and other developments in telecommunications, have proved especially popular, and biotechnology is also a frequent choice. These studies have generated useful insights regarding what strategies should be used, and what strategies should be avoided, during this very precarious and volatile stage of an industry's evolution. But because emerging industries often involve radical and unique technologies, because they are subject to a myriad of factors (ranging from social acceptance to government policy), and because they are particularly sensitive to the contributions and decisions of single individuals (nothing is yet etched in stone, and the initial communities are usually small enough so that an individual can still have a major impact), it is possible, and even likely, that the insights obtained through their examination will not be very generalizable. This is what I sought to determine by researching the fuel-cell industry, which is by comparison understudied by the academic community.

First, we will consider why radical innovation calls for very specific strategies in order to be commercialized successfully. To do so, we will begin by defining the concept in detail, which will then lead us to identify appropriate strategies for dealing with radical innovation's distinctive challenges[2].

1. What is radical innovation?

A Variety of Ways to Consider a Complex Phenomenon

Basically, "a radical product innovation is a new product that incorporates a substantially different core technology and provides substantially higher customer benefits relative to previous products in the industry" (Chandy and Tellis, 2000, p. ~4). But this definition merely scratches the surface of what lies behind the words "radical innovation." Indeed, radical innovation is just one of several forms that have been identified and which include incremental, architectural, modular and niche innovation (Afuah and Bahram, 1995). Actually, originally, Robertson (1967) recognized only three classes of innovations, based on how they affect patterns of consumption. Thus, a continuous innovation hardly disrupts these patterns, a dynamically continuous product causes limited (but not substantial) disruption, and a discontinuous innovation requires entirely new consumption behaviors (Strutton and Lumpkin, 1994). This typology is clearly heavily "marketing-oriented," and so is perhaps not entirely satisfactory for the present study.

Business strategy scholars prefer to determine which category a particular innovation belongs to by considering its effects on the "competence, other products, and investment decisions of the innovating entity" (Afuah and Bahram, 1995, p. ~56). Simply put, radical innovation differs from incremental innovation in that it forces the innovating firm to undergo strategic and structural change in order to adopt and/or commercialize the new technology (Cooper, 1998). So where incremental innovations "enhance and extend the underlying technology and thus reinforce the established technical order" (Tushman and Anderson, 1986, p. 441), radical innovations require "revolutionary alteration of the organization and its support networks [...] to accommodate and implement change" (Cooper, 1998, p. 497).

[2] I will use the terms "radical," "disruptive," "breakthrough," and "discontinuous" interchangeably, although some rigorous academics would undoubtedly object to this.

Competence-Destroying Innovation

Unfortunately, companies are often reluctant to carry out such changes because, in the case of disruptive innovations, they tend to be competence-destroying (Tushman and Anderson, 1986). That is, they require fundamentally new skills and abilities and make existing ones irrelevant or, even worse, harmful (Chandy and Tellis, 1998). Thus, disruptive technologies are usually commercialized by new firms, that have nothing to lose and everything to gain from radical industry restructuring. In fact, it would seem that the very nature of knowledge (ie the inertia a knowledge base can create) hinders the development of radical technology by incumbent firms (Saviotti, 1998 *in* Lemarié et al, 2000). Oldness is definitely a liability in these situations. On the other hand, competence enhancing technologies are usually initiated by incumbents. In these cases, newness is a liability, and the rich tend to get richer (Tushman and Anderson, 1986).

The distinction between competence-destroying and competence-enhancing innovations is actually remarkably reminiscent of the two forms of innovative activity first described by Schumpeter (Lemarié et al, 2000). In the "Theory of Economic Development," Schumpeter presents the process of creative destruction, in which start-ups and entrepreneurs play a key role, and through which the competitive and technical advantages of incumbents can be rapidly eroded (Lemarié et al, 2000). By contrast, in "Capitalism, Socialism and Democracy," Schumpeter emphasizes the role of “industrial R&D laboratories” run by large firms. These incumbents can safely carry out creative accumulation, as their privileged position is protected by entry barriers (Lemarié et al, 2000).

The question of whether incumbents or start-ups are advantaged when it comes to commercializing innovations is actually a very interesting one. But since it does not truly fit into the flow of my argument, I chose to discuss the issue separately, in an appendix (see appendix 7)

Synthesizing it All

Chandy and Tellis (1998) seek to combine the marketing and corporate strategy definitions of radical innovation by considering both their market and technology dimensions. Thus, they come up with a matrix, in which they identify four types of product innovations, depending on whether they involve minor or major changes in both customer benefits and underlying technology.

CHANGES IN CUSTOMER BENEFITS	CHANGES IN TECHNOLOGY	
	LOW	*HIGH*
LOW	Incremental Innovations	Technological Breakthroughs
HIGH	Market Breakthroughs	Radical Innovations

Clearly, the concepts of radical innovation, competence-destroying innovation and creative destruction are all closely related, and these terms can all be applied to the same underlying phenomena. Of course, it isn't that simple (things never are in academia). One must also distinguish technological innovation from administrative innovation, and product innovation from process innovation (Cooper, 1998). In addition, the same innovation can very well be modular, for example, at the manufacturer level but quite radical as far as the customers are concerned, and yet simply incremental from the suppliers' point of view (Afuah and Bahram, 1995). But such distinctions are beyond the limited scope of this dissertation.

Radical Innovation is Different and Neglecting it is Downright Foolish

The key point that all researchers agree on is that radical innovation is very much unlike continuous or incremental innovation, and thus requires very different corporate strategies and management styles. Indeed, conventional managerial goals (such as speed to market and rapid cash recovery) could "actually hamper the radical innovation's progress" (Rice et al, 1998, p. ~53). Unlike incremental innovation projects, discontinuous research is long-term (10+ years), extremely uncertain and unpredictable, sporadic, non-linear and haphazard (Rice et al, 1998). And yet, firms that, deterred by these hurdles, neglect radical innovation, are asking for trouble.

Indeed, "Christensen (1997) provides many examples of how outstanding companies that listen to their best customers and invest substantially in new technologies are blindsided by discontinuous innovations and ultimately lose their markets" (Cooper, 2000, p. ~3). Radical innovation can "permit entire industries and markets to emerge, transform, or disappear" says Kaplan (1999, p. ~17). Indeed, the history of business is littered with the gravestones of entire industries that were destroyed by radical product innovations because, once a new product provides a better performance per dollar than current products, fickle customers will not hesitate to desert incumbents (Chandy and Tellis, 1998).

Alternatively, neglecting radical innovation is also foolish because it can mean failing to take advantage of a wonderful opportunity. In their 1986 study of the evolution of three industries from their births until 1980, Tushman and Anderson observe that breakthroughs, which tend to be driven by individual geniuses, increase industry uncertainty and munificence (that is, the extent to which the industry can support additional firms, or support increased production by existing firms). So in other words, radical innovation provokes drastic changes and offers great opportunities, often by sharply improving the product's price-to-performance ratio (Tushman and Anderson, 1986). And, crucially, firms which initiate major technological changes grow more quickly than those that do not (Tushman and Anderson, 1986). Geroski, Machin, and Van Reenen (1993 *in* Chandy and Tellis, 1998) agree that radical innovation can potentially have a very positive and durable effect on the innovating firm's profits and market share. Clearly, it is worth one's while to identify which strategies need to be implemented in order to successfully commercialize a disruptive innovation.

2. Obstacles Abound on the Path to Commercializing Disruption

Unfortunately, the obstacles in the path of companies wishing to "commercialize disruption" are formidable. To take one edifying example, in the 1970s, many experts predicted electric cars would soon make big inroads into the automobile market. Predictions ranged from 0.3 to 100% of the 1995 market, with the average hovering around 6.7% (Cowan and Hultén, 1996). Predictions made in 1995 for the 2005 market were even more optimistic. And yet, in 1996, the total stock of electric cars was about 10,000 strong (Cowan and Hultén, 1996), a far cry from any of these predictions.

The Lock-In Phenomenon

So how does one market radical technology in the face of pervasive uncertainty, massive investments, and powerful entrenched interests? The latter are especially effective at deterring breakthroughs when there is a "lock-in" phenomenon in place. This describes a situation in which a technology that has been able to gain an initial advantage (even a moderate one) over its rivals quickly dominates the market through a "snowballing effect" (Cowan and Hultén, 1996). The technology's uncontested dominance favors the development of support networks (eg gas stations, auto mechanics and car dealerships in the case of the internal combustion engine), which further ensures the technology's primacy in what becomes a, depending on your point of view, virtuous or vicious cycle.

So, for example, the internal combustion engine (ICE) benefitted from the invention of the starting-lightning-ignition key in the early 1900s, and from the rapid introduction of mass production techniques in the firms, such as Ford, involved in its early commercialization (Cowan and Hultén, 1996). These advances were enough to give IC engines a decisive advantage, and electric cars quickly disappeared (although they'd had promise and were even considered at one point to be the superior technology of the two because of their quietness, immediate start-up and lack of fumes -McNicol, 1999). Now, both manufacturers and consumers are to a large extent "locked-in" ICE technology, and they will be reluctant to adopt a new technology if the switching costs are too high relative to the innovation's benefits. Thus, it is not enough for a competing technology to be superior. It must also escape the lock-in effect (Cowan and Hultén, 1996).

The Lack of Legitimacy

Another barrier that often stands in the way of successfully commercializing a new technology is the difficulty of acquiring legitimacy (Aldrich and Fiol, 1994). Almost always, emerging industries lack both cognitive and sociopolitical legitimacy. That is, they are not taken for granted, and they often do not conform to "recognized principles or accepted rules and standards" (Aldrich and Fiol, 1994, p. ~646). This doesn't sound particularly worrying, but it can have dire consequences. "Access to capital, markets, and governmental protection are all partially dependent on the level of legitimacy" achieved by an industry (Aldrich and Fiol, 1994, p. ~648). And, if anything, legitimacy is even more crucial in the early stages of a new industry's inception. This is when firms must persuade skeptical investors, creditors, public officials, suppliers, and of course customers to trust them, but eliciting trust is a tricky proposition if one's technology is unfamiliar and maybe even not credible. Indeed, the president and CEO of Ballard Power Systems, Firoz Rasul, recalls that, when he was touring the States in 1989 to round up funding for fuel-cell research and development (R&D), he was treated like a charlatan by a Chicago venture capitalist who did not hesitate to show Mr. Rasul the door (Verburg, 1998).

The Six Needs

The "lock-in" phenomenon and the need for legitimacy are basically the two main obstacles that emerging industries, particularly when they are commercializing radical technologies, need to surmount. Now we shall consider how this can be done in practice. There is little research that investigates, in its entirety, the issue of commercializing disruptive technologies. Instead, the different aspects are often considered apart from one another. Or, more often, practitioners are given advice on how to foster discontinuous innovations (Kaplan, 1999[3]), but they are rarely told what strategies they should apply in order to successfully bring these radical innovations to market. It was therefore necessary to consider several different strands of the strategic management literature in order to uncover the research community's insights on this critical question.

In the end, I identified 6 needs that company's must address in order to successfully commercialize a disruptive technology. These are, more or less in chronological order (although it would be incorrect to infer that they must always be addressed in this exact sequence: in truth, companies must take them into account almost simultaneously): the need for merit, the need for government support, the need for champions and visionaries, the need for cooperation, the need for niches and the need for speed. Each of these needs is important in and of itself, and some are not

[3] Kaplan (1999) mentions the creation of "ambidextrous organizations" (Tushman, 1997), engaging in "discovery-driven planning" (McGrath and MacMillan, 1995), and "probing and learning" (Lynn, Morone, and Paulson, 1996).

confined to industries developing radical innovation. However, I believe such industries are unique in that they call for all six needs to be dealt with decisively in order for their firms to survive and then thrive. As we shall now see, many of these needs are linked to one another, and they are not all equally crucial.

3. The Need for Merit.

For a disruptive innovation to succeed in the marketplace, it needs to have some merit. This is almost painfully self-evident. Unfortunately, merit isn't something an executive can conjure up on his or her own. An innovation's merit (or lack thereof) lies partly in the hands of the researchers and technicians developing it, and is of course largely determined by factors beyond the control of anyone (sometimes, a technology's time just hasn't come yet, and, sometimes, it never will). Therefore, it would seem management can only hope for the best: merit is something an innovation will either have or not have (or, as they say in France, *que sera, sera*). However, managers do have a role to play when it comes to assessing whether an innovation has any merit. To do so, it is useful to consider the different forms of merit White and Graham (1978) have identified.

Inventive merit, first of all, is the merit that stems from the innovation's intrinsic capabilities, its potential to "relieve old restraints," although of course the new technology usually carries its own particular limitations (White and Graham, 1978). Embodiment merit arises from the engineering and design which surrounds the innovation, or how the technology is actually materialized. Often, increasing an innovation's embodiment merit may require the curtailment of one of its main advantages in order to increase the product's overall value (for fuel-cells, this could for example be the use as a fuel -initially at any rate- of gasoline, which is widely available, instead of hydrogen, which produces no emissions but is more difficult to handle). The new technology's operational merit lies in its beneficial effect on the firm's business practices. For example, if the innovation is more reliable than the technology it replaces, there will be less of a need for service centers. Finally, an innovation's market merit is a function of its appeal to the final (as opposed to the intermediate) customer. Market merit will be high if the new technology offers similar or better performances at a similar or lower price. Executives should consider all these different aspects and, if they come to believe that the innovation does indeed have potential, they should firmly and explicitly back the technology's continued development (White and Graham, 1978).

Research Objectives

In my research, I therefore considered what exactly are fuel-cells' merits. Do fuel-cells really have the potential to successfully compete against IC engines, gas turbines, batteries, solar panels, hydro-power (etc...)? Or would fuel-cell companies be better off finding other pursuits on which to spend their money and exert their efforts? The question isn't as senseless as it may seem: many an innovating company has floundered because its founders did not properly consider whether the technology they were developing was actually worth developing in the first place.

4. The Need for Government Support.

Once the technology is deemed to have potential merit (and indeed often before its merit has become fully apparent), there is a need to secure the necessary financing for the initial R&D. This is when the technology's commercial potential is still very much unproven, and any research undertaken could easily turn out to be fruitless. Moreover, the investments involved are often substantial in the case of radical innovations, since these require entirely new competences, skills and knowledge. Even in the event that the technology's commercialization is deemed feasible, the time between the initial R&D expenditures and the product's actual launch can easily amount to several years, or even decades. In other words, it is a particularly risky investment, and the returns (if there are any) will only materialize in the long-term. These are the types of investments generally shunned by the private sector. Therefore, it would seem that public funds have a key role to play in the initial stages of a radical technology's commercialization process.

This is confirmed by Norberg-Bohm's (2000) very interesting study of the US government's role in the initial commercialization of four technologies for stationary power generation. She observes that all four technologies studied (atmospheric fluidized bed combustion, gas turbines, solar photovoltaics and wind turbines) benefitted from government funds and policies. Indeed, she concludes that "government activities to promote environmentally enhancing technological development must include both supply-push and demand-pull policies during the period spanning precommercialization, first commercial use, and lead adoption" (Norberg-Bohm, 2000, p. ~125). In other words, government support must be both multi-pronged and long-lasting.

The Rationale for Government Intervention

Such a recommendation runs counter to the prevalent philosophy in the United States, which is that the state should play as small a role as possible in the economy. Most would accept the need for government to undertake basic research (whose commercial applications are uncertain at best), but helping private companies to commercialize their technology is another matter entirely. Yet Norberg-Bohm (2000) argues that government action is warranted in this case because energy production has both negative externalities (environmental and security risks) and positive ones (its contribution to the economy and to social progress) which are not properly taken into account by the private market. And, fortunately, though "conventional business wisdom has repeatedly claimed that environmental regulations are detrimental if not disastrous for business and economic development. We have concluded that just the opposite is true" (Clark, Jr. and Paolucci, 2001, p. 567).

In addition, all emerging technologies are confronted with two fearsome hurdles, the "valley of death" and the "mountain of death"[4], which companies will have trouble facing without some kind of government support (Norberg-Bohm, 2000).

> "The mountain of death is a concept used to explain the difficulty in commercially providing the first-of-a-kind capital good. For technologies such as power plants, which may be standardized but not mass produced, the initial plant is much more expensive than the 5th or 10th plant. The valley of death is applicable for mass-produced goods. In this case, most businesses based on a technological

[4] The sources cited by Norberg-Bohm (2000) are the Electric Power Research Institute for the "Mountain of Death" expression and Helena Chum, NREL, and Irvine Barash, VenCom Management, Inc., for the "Valley of Death" expression.

innovation fail due to an extended period of negative net cumulative cash flow" (Norberg-Bohm, 2000, p. ~127).

Two Possibilities: Supply-push

In practice, governments can pursue both supply-push, which is the stimulation of specific technological innovations, and/or demand-pull, which is the creation of a market for emerging technologies (Norberg-Bohm, 2000). In the case of supply-push, for example, the US government initiated much of the research on gas turbines (for military applications) and on solar photovoltaics (for the space program). Public investment was crucial for the initial development of these two technologies, and continues to be the main source of funds for research on solar panels (Norberg-Bohm, 2000).

And Demand-Pull

As for demand pull, the government's role is more indirect, but can have far greater effects. The government can create a favorable setting for certain technologies through its tax and regulatory policies, by exhibiting a supportive attitude towards the innovating firms (Loiter and Norberg-Bohm, 1999), or even more actively, by purchasing significant quantities of the innovative product itself. In effect, it can create a market for emerging technologies. This can be the difference between life and death for these technologies during their early stages of commercialization. To take a practical example, once again provided by Norberg-Bohm (2000), regulations that set stricter environmental standards gave solar photovoltaics, gas and wind turbines a considerable boost (commercially speaking), which, in the case of gas turbines, encouraged the private sector to further invest in the technology's improvement. Similarly, Clark, Jr. and Paolucci (2001) find that research in cleaner, alternative automobile engines was initiated because of government regulation, not for economic reasons.

Dalpé (1994) emphasizes the government's role as the initial purchaser of new technologies. He points out that in the mid eighties, an OECD government's procurement represented 10-15% of its country's total production, and often involved very high-tech products. This is a significant market. It is also a particularly attractive one, as the government can group its purchases (and thus place very large orders) and is often primarily performance-oriented (in other words, cost in not always an issue). Because the government is often the first buyer of emerging innovations, it ends up playing a very strategic role: first by assuming the risks inherent in using a new technology and second, by taking on part of the fine-tuning costs (Dalpé, 1994). A state's specific needs will also stimulate innovation: "if no product on the market matches [its] requirements, [it] may encourage suppliers to innovate and, using [its] monopsonistic position, induce them to develop new products" (Dalpé, 1994, p. 71).

Finally, government-led demand-pull can be quite subtle, and yet just as critical for an emerging technology. As Rothwell and Wissema write (1986, p. ~92), "the importance of culture in innovation suggests that public policy can be a strong influence on public acceptance of new technology." Public information programs, for instance, can help to fashion favorable public perceptions of a new technology, and thus encourage its adoption. Thus, some governments are now extolling the virtues of genetically engineered plants, in an attempt to defuse public hostility towards them.

In their study of the development of wind power in the US, Loiter and Norberg-Bohm (1999) conclude that both demand-pull and supply-push are important, although consistent and durable demand-pull is especially crucial at the pre-commercialization stage. Here, by ensuring that the new technology will find a market, the government can give it an opportunity to test itself in a commercial environment, before it actually has to face the rigors of full competition. Finally, Clark, Jr, and Paolucci (2001) point out that it is not enough for the state to fund research, it must also coordinate research. But we will consider this in more detail in the *need for cooperation* section.

The Dark Side of Government

Of course, government action is not always positive, as both Dalpé and Norberg-Bohm readily admit. To practice effective supply-push, a government must accurately "pick winners" (ie, select technologies it believes can succeed commercially), which is something that bureaucratic government agencies have often been notoriously bad at (Norberg-Bohm, 2000). Moreover, if subsidies and incentives are too generous, private investors may become complacent and will not seek to develop the technology to its full potential (Norberg-Bohm, 2000). In other words, they may become excessively dependent on government support, and thus unable to compete on equal terms with rival technologies. As for demand-pull, well, regulations can just as easily make it harder for new technologies to emerge. For instance, “the regulation of electric utilities as natural monopolies prevented the penetration of technologies that were more efficient and smaller scale than the power plants typically adopted by electric utilities” (Norberg-Bohm, 2000, p. ~139). Indeed, sometimes a technology (such as gas turbines) will succeed in spite of government actions, not because of them.

Research Objectives

But, once again, the government can play an extremely important (perhaps indispensable) role in the early stages of a breakthrough’s commercialization, even if it can be a bit clumsy at times. Many studies confirm this, in particular Woiceshyn’s (1995), who studied five firms in the emerging biotechnology industry. In consequence, I expected to find that public authorities (particularly, but not only, the US Federal government) have been, and still are, key participants in the development and early commercialization of fuel-cells. In addition, I expected to find that firms in this emerging industry are actively lobbying the government for favorable legislation, and have benefitted in the past (and perhaps still today) from the fruits of publicly-funded research in fuel-cells.

5. The Need for Champions and Visionaries

The literature on innovation is almost unanimous in its emphasis on the importance of visionaries and champions. Schon (1963, p, 84), perhaps the first to note the importance of champions, writes trenchantly: "the new idea either finds a champion or dies." Frey (1991, p. ~47), describing his own past as a product champion, agrees that “innovations are lost without champions.” Indeed, “in a 1974 study of 45 cases of product innovation, Chakrabarti found that 94 percent of the innovations that progressed to adoption had champions; in contrast, 96 percent of the projects that stalled did not have champions” (Chakrabarti, 1974, *in* Markham and Aiman-Smith, 2001, p. ~47). Other studies arrive at similar conclusions, so that in their exhaustive review of the “championship” literature, Markham and Aiman-Smith (2001) confirm that a considerable majority of innovative projects have champions (indeed, a significant percentage have multiple champions).

Champions & Visionaries: Sharing the Same Spirit but not the Same Goals

But, despite this consensus, papers focusing on champions or visionaries are few and far between. Markham and Aiman-Smith (2001, p.~45) “uncovered fewer than 40 articles discussing champions, and in many of them champions were a side interest.” Only nine empirical studies on the question have been published since 1986. If my own, much less comprehensive, research is any guide, it would seem that the literature dealing with visionaries is even more limited. Thus, I have decided to combine the two concepts, although they are of course distinct, to make the most of what research is available. I believe champions and visionaries share enough key elements to warrant their amalgamation in the context of this dissertation.

Basically, both champions and visionaries can be described as driven individuals who have grasped the value of an idea and who do their utmost to see it into fruition. But whereas champions are often associated with specific products or processes, and are often assumed to be part of a large organization’s middle management, visionaries are usually founders or top executives and tend to deal with radical, potentially very disruptive ideas that may only become practical in the mid-to-long term. Visionaries are also more “hands-off” than champions and may not even play a particularly active role in their vision’s realization.

In fact, these distinctions are often blurred in the literature. In particular, some authors argue that champions, and not only visionaries, can advocate radical ideas that have the potential to revolutionize their firm’s business. Howell and Higgins (1990, p. 336), for instance, write that champions appeal “to larger principles or unassailable values about the potential of the innovation for fulfilling an organization's dream of what it can be." In the main, though, champions are the preserve of marketing research, and so tend to be associated with the development of products that are usually not radically innovative.

Three Flows for the Emergence of a Vision

Howell and Higgins (1990, p. 336) then go on to emphasize that one of “the fundamental components of a champion's capacity to introduce innovations successfully [is] the articulation of a compelling vision of the innovation's potential for the organization" (once again, it is interesting to note that the distinction between a champion and a visionary is slightly blurred). Fortunately, O'Connor and Veryzer (2001) identify at least three different ways in which a vision can emerge in an organization. The first way, or "flow," is proactive and starts with the vision per se. The firm anticipates future developments, or determines itself what the future should be like, and then develops or acquires the competencies necessary to seize the predicted opportunities or to turn its vision into a reality. The second flow is reactive, and is in fact the first flow turned upside down. The firm fortuitously realizes is has acquired or developed a valuable competency, and promptly seeks to envision how this competency might be taken advantage of. Thus, the vision emerges from already existing resources. Finally, the third flow also "involves a technical discovery in search of an application" (O'Connor and Veryzer, 2001, p. ~241), but it differs from the second one in that the process is much more flexible. The firm begins "with a desire to employ a particular technology, sometimes with a specific application in mind, and yet [ends] up either at a different destination (...) or along the way [switches] to (...) a different technology from the one that initiated the process in order to achieve the original product goal" (O'Connor and Veryzer, 2001, p. ~241).

What is a vision?

So what exactly is a vision, since it seems to be such an important part of the process, both for champions and of course for visionaries? Well, the (limited) literature on visionaries is not very explicit on the subject. Veryzer (1998) explains that a vision is an insight on "how all the pieces fit together," and thus requires a good sense of both the technology and the market (which a single individual might possess, or which might be shared among two or more people). O'Connor and Veryzer (2001, p. ~233) phrase it differently, explaining that visioning is "the ability to link advanced technologies to market opportunities." It involves three elements, which they call Motivation, Insight, and Elaboration. "The motivation component serves to focus attention and energy (...). The insight represents that critical "gap" or connection in thinking that must be made for progress to occur (...). Once the insight has been grasped, ways of operationalizing it must be found. While this component might seem to follow the visioning process, in actuality it is a vital part of it" (O'Connor and Veryzer, 2001, p. ~242). Thus, a vision is multi-faceted, and it does not suddenly materialize one morning after a good night's rest, but "develops over time and requires focus, discipline, energy, and the involvement of many people" (O'Connor and Veryzer, 2001, p. ~232).

Overcoming Inertia

Coming up with a vision is all fine and good, but that is only part of the process. Indeed, a champion not only "recognizes a new technology or market opportunity as having significant potential," he or she also "adopts the project as his or her own;

commits personally to the project; generates support from other people in the organization; and advocates vigorously for the project" (Markham and Aiman-Smith, 2001, p. ~45). In practice, their most important function is to challenge their organization's inertia. Indeed Schon (1963) explains that champions, by enthusiastically promoting an idea, are necessary to overcome the indifference or even resistance almost always encountered by innovations when they are first proposed[5] (in general, humans instinctively oppose new things). This leads me to suggest that entrepreneurs in emerging industries need to be champions in order to be successful. After all, when Aldrich and Fiol (1994, p. ~651) insist that entrepreneurs in emerging industries "must engineer consent, using powers of persuasion and influence to overcome the skepticism and resistance of guardians of the status quo," they seem to be saying, in effect, that entrepreneurs must be champions!

Unfortunately for the individuals involved, overcoming this inertia is not a one-off process, but rather a continuing endeavor. Champions must constantly struggle to keep their projects alive in the face of opposition (Markham and Aiman-Smith, 2001). In order to rally supporters, and silence skeptics, champions employ a wide selection of tactics, which include "bargaining, appeals to higher authority, ingratiation, coalition building, clandestine fait accompli, and assertion" (Markham and Aiman-Smith, 2001, p. ~47). But despite all their efforts, champions cannot guarantee the success of their projects. They are not miracle-makers, and though they can indeed significantly prolong a project's life, they are "just as likely to support market failures as they are successes" (Markham and Aiman-Smith, 2001, p. ~45).

Nurturing Champions and Visionaries

Truly, being a champion, and a fortiori a visionary, is not easy. They must believe in their innovations, but also "understand the gritty tasks of actually building them" (Frey, 1991, p. ~47). Fortunately, there are some things managers can do in order to facilitate and encourage visioning, and to support champions. The explicit and clear articulation of strategic intent and of "holy grails" to focus the visionary's mind

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[5] Chandy and Tellis (1998) thus draw the conclusion that champions are particularly critical in incumbent firms, as they are the ones who must overcome their firm's usual staunch resistance to product cannibalization.

(Rice et al, 1998); the understanding of what motivates the champion (so as to better motivate and encourage him or her); the appointment of a devil's advocate (to provoke "creative conflict"); the granting of access to varied information sources (such as trade conferences and professional journals) for the champion to find inspiration and form networks; the provision of training in interpersonal skills (Markham and Aiman-Smith, 2001)... all these are of great help. Managers must also strive to mitigate the paradox identified by Kaplan (1999, p. ~16) namely that on "the one hand, visionary opportunity identification is essential to the long-term growth of the enterprise. On the other, operational challenges and quarterly revenue objectives mandate a focus on short-term results." Thus, a corporate culture conducive to long-term thinking, to creativity and experimentation, plays a key role in nurturing visioning and championing.

Research Objectives

I expected to find that all fuel-cell companies have a resident visionary, in the case of start-ups, or fuel-cell champions, in the case of larger incumbents. I further anticipated that champions and visionaries have been critical in sustaining the prolonged, uncertain journey towards the commercialization of fuel-cells. I surmised that the companies with the most enthusiastic and persuasive champions/visionaries would also tend to be the ones most driven to succeed. Finally, I was interested to learn more about the process of visioning and championing, and in particular whether certain visioning "flows" are more common than others.

6. The Need for Cooperation

Alliances and networks are an extremely popular topic in management scholarship today (Cooper, 2000), possibly because researchers have traditionally focused on the more competitive aspects of business and now welcome the chance to consider its more cooperative sides. Moreover, two relatively recent and already highly influential frameworks, resource-dependency theory and the resource-based view (RBV) of the firm, both make a strong case for collaboration. For the former, cooperation is essential as companies depend on one another for resources. As for the RBV, it recommends that firms engage in partnerships and alliances in order to contract out their excess resources and, inversely, in order to obtain access to other companies' resources. But though the literature on the topic of collaboration is now extensive, few papers specifically focus on alliances (or other forms of cooperation) in industries affected by disruptive innovations (Lambe and Spekman, 1997). This is surprising, because alliances -which can take the form of joint ventures, technology licensing agreements, or R&D consortia- are particularly appropriate in such circumstances, both for the incumbents and for the innovating firms[6]. In both cases, the "if you can't beat them, join them" philosophy can be extremely appealing.

A. Incumbents Need to Cooperate

Three Ways for Incumbents to Deal with Radical Innovation

Clearly, incumbent firms risk cannibalizing the sales of their existing products should they get involved in a radical innovation's commercialization. Indeed, such cannibalization is almost assured. On the other hand, "if you don't eat your own lunch, someone else will!" (Kaplan,1999). It is in the incumbent's interests to join the flow early on, rather than resist it, often futilely, and end up marginalized. As Levitt (1975) made all too clear, companies that do not react or anticipate radical product developments in their industries usually face dire consequences... Thus, "if you can't beat them, join them." But how can this be done in practice?

Well Lambe and Spekman (1997) note that there are three major ways for incumbents to deal with radical innovations. They can engage in mergers & acquisitions (M&As) to get hold of the technology in question and thus control, to a certain extent, how it is commercialized (but M&As are notoriously expensive, and can be extremely difficult to manage successfully). They can attempt to develop the technology in-house, though this is not always practical or even feasible. Or they can

[6] It is worth noting that cooperation (via various forms of alliances and partnerships) does not exclusively concern private firms, whether they be incumbents or challengers. The innovating companies studied by Rice et al (1998) teamed up with large firms, other small innovating firms, but also with universities and government laboratories. Indeed, Lynn et al (1996) emphasize the importance of non-market relationships in the commercialization of innovations. They coined the term "innovation community" to capture the fact that one must consider all the organizations (whether they be public or private, profit or non-profit) that are significantly involved, directly and indirectly, in the commercialization of a new technology.

enter into an alliance with an innovating firm, which would give them access to the technology, although without the level of control they might desire. Each of these alternatives has its own strengths and weaknesses, and so will be appropriate during different stages of the emerging industry's evolution.

Alliances Are Most Attractive When Commercialization is Just Beginning

Lambe and Spekman (1997) proceed to identify four different such stages, according to the level of uncertainty and urgency present. When the new, radical technology is just beginning to emerge, uncertainty is extremely high, but urgency is still relatively low (in part because the uncertainty revolving around the technology favors inertia). But when the technology begins to take hold, when its potential becomes clearer, urgency becomes a much graver concern (because of first mover advantages, which we will consider later on) while uncertainty remains high (the technology is better understood, but its potential business implications are still anyone's guess).

This is when alliances are most attractive, as they are much faster to implement than in-house research or M&As, they are significantly cheaper than outright acquisitions (there is no need to purchase superfluous assets) and they are more flexible as well. Thus, a firm can negotiate alliances with several innovating firms, and so avoid putting all its eggs in the same basket. Alliances are also easier to end, should the technology not live up to its promise... It is only once uncertainty and urgency have begun to decrease (with the advent of dominant designs and mass production) that in-house R&D and M&As will become more appealing, as they allow increased control, better economies of scale, and are not marred by coordination problems. Finally, once the industry is no longer emerging, but truly mature, alliances, should they arise, will do so for market related reasons rather than technology-related ones (Lambe and Spekman, 1997)

B. Innovating firms need to cooperate

Acquiring Legitimacy

Innovating firms are also likely to come to the conclusion that alliances and other forms of cooperation are necessary for their own survival. Both the need for legitimacy, and the difficulty of challenging incumbents benefitting from technological “lock-in,” will encourage them to find partners and nurture networks. We have already considered the importance of legitimacy for an emerging industry. An important point that remains to be made, however, is that acquiring legitimacy is exceedingly difficult for a firm to do on its own. Indeed, it is quite easy to ignore the implausible ravings of a single individual, or even of a handful of unknown firms. But once more and more people and firms start to pull in the same direction, it becomes harder to discredit them.

So in order to gain credence as an industry, some form of collective action will be necessary (Aldrich and Fiol, 1994). This cooperation can include the creation of trade and technical committees, industry councils, trade associations, trade journals, marketing campaigns, trade fairs... all of which help to give the emerging industry some visibility, help to enhance its standing and help to demonstrate its stability and reliability to customers and suppliers (Aldrich and Fiol, 1994; Chen, 1997).

Often, this cooperation starts very informally. Van de Ven and Garud (1991 *in* Aldrich and Fiol, 1994) surveyed several different studies of high-tech industries, and noted that radical innovations “tend to be pursued by a handful of parallel, independent actors who come to know one another rapidly through personal interaction and through traveling in similar social/technical circles, such as attending the same industry conferences and technical committee meetings” (Aldrich and Fiol, 1994, p. ~654). In this manner, networks are created which, over time, legitimize the new industry (Aldrich and Fiol, 1994). But incumbents can undermine this process. They are quite capable of throwing doubt onto an emerging industry’s legitimacy, by spreading rumors that the new technology in question is dangerous, expensive or unreliable (Aldrich and Fiol, 1994).

Enlisting Incumbents

Indeed, though incumbents may be slow to react to change, they are a force to be reckoned with once they’ve set their sights on obstructing a new technology’s commercialization. Desperate to avoid seeing their own technologies and competences rendered irrelevant and obsolete, they can marshal their vast resources and superior market position to deadly effect. In such cases, teaming up with other challengers is unlikely to prove very effective. Instead, it is time to consider the “if you can’t beat them, join them" tactic.

Because, just as large incumbents can be formidable opponents, they can also be extremely valuable allies. Chandy and Tellis (2000) helpfully provide an exhaustive list of all the advantages held by large incumbents when it comes to commercializing radical innovations. These include, first of all, market capabilities, namely customer knowledge, customer franchise, and market power (Chandy and Tellis, 2000). Incumbents know their customers well, having often amassed detailed records regarding their preferences and behaviors; they benefit from their clients' trust, a crucial factor when trying to sell a radical innovation (which are often perceived as risky purchases -Gregan-Paxton and John 1997*in* Chandy and Tellis, 2000); and they have privileged access to distribution channels (Mitchell 1989 *in* Chandy and Tellis, 2000). As if this weren't enough, large firms have considerable financial, technical and scientific resources (such as state-of-the-art labs and first-rate researchers), and can benefit from economies of scope and scale to reduce the risk inherent in commercializing disruptive technologies. Indeed, incumbents can provide innovating firms with the "depth of technological capability and complementary assets [necessary] to weather the long climb to unsubsidized commercialization" (Norberg-Bohm, 2000, p. ~143). Thus, there are many incentives for innovating firms to team up with incumbents.

C. Everyone needs to cooperate

Technology Can No Longer be Developed by a Single Firm

Finally, alliances aren't just a matter of survival, of reacting to an innovation in order to avoid being caught off-guard or in order to deal with powerful incumbents. They can be a necessary prerequisite, a sine qua non of the radical technology's development. These technologies are often so complex and expensive that it is simply unthinkable for a firm to develop them on its own (Clark, Jr. and Paolucci, 2001).

Indeed, innovation is an increasingly complex undertaking. Most technological advances depend on the progress made in other, sometimes apparently very unrelated, domains (Frey, 1991). In fact, many breakthroughs now occur at the interface of very different scientific disciplines (Chen, 1997). So, the implementation of an innovation will frequently be dependent on research that has been carried out for other applications and technologies[7]. And, usually, the innovating firm does not hold the patents to this necessary but tangential research. So cooperation becomes necessary in order to coordinate the development of any necessary complementary technologies and assets (Clark, Jr. and Paolucci, 2001).

Of course, technological research is just one aspect of a technology's development. Many other intricate interdependencies require increased collaboration between all the companies involved in an innovation's commercialization, as well as between the industry's firms and a multitude of other organizations. Indeed, cooperation is useful or outright indispensable for all kinds of things. As Lynn et al (1996, p. 95) write "professional societies, trade associations, various forms of industry consortia and university-industry relationships can facilitate diffusion of technical information, help identify bottlenecks, coordinate investment, [and] help provide infrastructural support."

The Tension Between the Need to Cooperate and the Need to Protect One's IP[8]

Strategists "have long prescribed uniqueness and imperfect imitability as means of gaining a sustainable competitive advantage" (Aldrich and Fiol, 1994, p. ~663). Thus, firms have been aggressive in ensuring that their intellectual property, often their most valuable resource, is safely kept inside the firm's confines, to prevent rivals from gaining access to their knowledge. The resource-based view, in particular, has been very keen on recommending that firms focus on developing resources that can be legally protected (through the use of patents, copyrights and trademarks) or that are otherwise difficult if not impossible to imitate (Chen, 1997).

But such behavior may no longer be appropriate, especially in "emerging high-technology industries" (Chen, 1997). Basing one's strategy on isolation and on the jealous protection of scarce knowledge may actually be quite counterproductive, for the

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[7] This is very true for fuel-cells, which have only recently become commercially viable in large part thanks to impressive improvements in catalytic systems for automobiles. The two seemingly unrelated technologies actually share some key features, in particular the use of platinum as a catalyst (Interview - Jaffray).

[8] IP = Intellectual Property

very reasons considered above. Thus, Nalebluff and Brandenburger (1996, *in* Chen, 1997) suggest that firms stop thinking in exclusively competitive terms, but instead recognize and indeed embrace the need for cooperation: instead of practicing competition, they need to practice coopetition (simultaneous cooperation and competition -a term coined Nalebluff and Brandenburger). In fact, it would seem that firms had already realized this a while ago. Indeed, the number of alliances has increased by 25% every year since 1985 (Booz, Allen & Hamilton, 1994 and 1995 *in* Chen, 1997). At present, approximately half of the alliances involving the top 2,000 American companies are with competitors (*idem)*. Meanwhile, strategies based on open systems and licensing are becoming ever more commonplace. Clearly, cooperation is increasingly the name of the game throughout the business world. Of course, it is not without risks, notably that of creating excessive dependencies, “hold-up” situations or deadly competitors!

Research Objectives

In view of all this, it is not at all surprising that in his study of 15 radical technologies, Souder (1989) found that cooperation is indispensable, not only between firms (and particularly between firms and their customers) but within them as well. I myself expected to find a dense tissue of networks and alliances in the emerging fuel-cell industry (indeed, I assumed that there would be a tight-knit fuel-cell community with a strong sense of solidarity). And because fuel-cells now seem poised for widespread commercialization, I believed incumbents would be particularly eager to link up with innovating firms. On the other hand, I thought that start-ups would be focusing above all on cooperating with their direct rivals, to legitimize their emerging industry and share critical knowledge, thus accelerating the development of commercially viable fuel-cells.

7. The Need for Niches

Catch 22

New technology is often very expensive (relative to its benefits) when it is first commercialized. And unless an innovation addresses a previously unsatisfied consumer need, it will only become widespread if it can be sold at a reasonable price compared to the technology it seeks to replace. Or, put differently, an innovation needs to offer more value for money than its rivals (Pitelis and Taylor, 1996). Fortunately, economies of scale can rapidly reduce a new product's cost, giving it access to a wider market. But there is a catch, a catch 22 as it were: to be competitive and thus have a chance at making inroads in the consumer market, the product's costs must come down, but to bring the costs down, the product needs to be produced in large quantities, which will only be possible once significant market penetration has occurred (Bos, 1996). In other words, one needs to have a sizeable market share in order to have access to the market... The solution to this quandary is, of course, to initially target niche markets, where cost is not a major issue. Hopefully, the demand in these early markets will be enough to warrant sufficiently large production runs, which will lead to some initial scale economies scale. The innovating firm will then be able to progressively tackle markets that are slightly more price conscious, until it finally breaks into the mass market.

An Abundance of Definitions but an Absence of Empirical Research

This niche-targeting strategy is well known, and is frequently cited in marketing, and, to a lesser extent, in business strategy literature. Strangely enough however, there is little academic research on the topic, although definitions abound (Dalgic and Leeuw, 1994). Basically, "niche marketing is a bottom-up approach where the marketer starts from the needs of a few customers and gradually builds up a larger customer base" (Chalasani and Shani, 1992 *in* Dalgic and Leeuw, 1994, p. ~41). Usually, a niche (derived from the French word meaning "alcove") is a small market segment consisting of consumers whose need for some kind of special treatment has been relatively ignored by firms currently in the market. Ideally, a niche should be large enough to be profitable (and/or should have good growth prospects), and the consumers it includes should have sufficient buying power as well as be receptive towards innovations that try to meet their requirements (Dalgic and Leeuw, 1994). Let us consider each of these points in turn.

The Attributes of an Ideal Niche: the Importance of Indulgence

First of all, though a niche is usually conceived of as a small market segment, care must be taken not to target niches which are too small. Wind turbines and solar photovoltaics, for example, are presently only attractive for low-density remote usages, a market which is not big enough to bring about the necessary economies of scale that would enable market expansion (Norberg-Bohm, 2000). Consequently, both technologies remain confined to very specific applications, and are unlikely to become widespread without additional technological advances. Moreover, people who need low-density and remote power generators live primarily in developing countries, so they are unable to afford solar panels or wind turbines, even though these are cost-competitive compared to rival technologies (Norberg-Bohm, 2000).

Finally, the niche's members must be open to new technologies, and indeed relatively indulgent. Indulgence is required on their part because, for a radical innovation, the transition between its laboratory phase and its commercialization phase is often very delicate and not without difficulties. This is because the research relating to a discontinuous innovation is often initially technology-driven (Norling and Statz, 1998). It is frequently only when the innovation nears commercialization that the innovating firm searches for market opportunities, meaning that the first embodiment of the technology is not always very adapted to the market is ends up addressing. Certainly, as these first markets are served, the customer's needs become better understood, and any subsequent innovation-related research thus tends to become market-driven (Norling and Statz, 1998). But until then, it is likely that there will be a few growing pains, so it is important that the first clients be very keen on new technology, and so willing to tolerate its initial flaws and imperfections.

The Importance of Careful Market Selection & Discipline

All in all, to avoid expensive delays, or even, at worst, a disastrous failure, it is necessary to select one's initial markets very carefully. In addition, careful selection can greatly accelerate the innovation's market penetration: in his study of 15 radical technologies, Souder (1989, p. 21) notes that all those he interviewed agreed that the best way of generating strong user demand is "by demonstrating the technology in some clever application." The need to identify niches is particularly pressing when existing rival technologies benefit from a "lock-in" effect. The IC engine, for example, can not be attacked head-on, because it benefits from too many support networks and vested interests. Instead, it will be necessary for fuel-cells to focus on certain more amenable early adopters, which will hopefully provide the learning and scale economies needed to generate externalities (Cowan and Hultén, 1996). In a way, niche marketing is akin to guerilla warfare, leading Dalgic (1993, *in* Dalgic and Leeuw, 1994) to speak of "Guerillas against Gorillas." Indeed one seeks to attack one's opponents not where they are the strongest, but where they are the weakest, and to avoid open and orderly confrontation.

As we have seen, it is possible for the government to provide the first niche markets. Indeed, the electric cars in circulation today are mainly owned by public organizations and nationalized companies, with Electricité de France's[9] fleet, for example, being the largest in Europe (Cowan and Hultén, 1996). But eventually the innovating firms will have to gain a foothold in private sector markets as well, or else they risk being lastingly marginalized. Thus, firms will have to make an active effort to identify niches, and not simply rely on fickle and uncertain government assistance. They will also, and most importantly, have to stay focused. Indeed, niche marketing requires a certain amount of discipline, especially when the radical technology being developed has very broad applications. When this is the case, it can be all too tempting to get carried away by the technology's awesome potential, and thus lose one's focus (Woiceshyn, 1995). Indeed, though the wisdom of targeting niches is almost self-evident, and certainly appears to be universally recognized by innovating firms, many cannot in the end resist going after the glamorous markets first, often with very dire consequences (Souder, 1989).

Research Objectives

I wanted, first of all, to consider whether fuel-cells are one of those rare innovations that can be directly commercialized on a wide scale, or whether they will need to be targeted at certain niche markets at first (as I assumed they would be). Should the latter be true, I wished to identify the most attractive niches, and determine whether these were indeed the ones being selected by fuel-cell manufacturers. Finally, I set out to uncover whether niche-targeting is an integral part of these firms' strategies, or more of an afterthought tacked onto them only after they've deemed their technology

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[9] EdF, France's sole electric utility company, is controlled by the government.

ready for commercialization.

8. The Need for Speed?

Rather than "The Need for Speed", this section could have been entitled, "The Need to be Number One" (but it didn't ring as well). Indeed, in it, we will primarily consider the literature pertaining to first-mover advantages (FMA), which can arise when a firm is the first to commercialize a new product, the first to implement a new process, or the first to penetrate a new market (Kerin and Varadarajan, 1992). When it comes to new technologies, the technological pioneer, ie the first firm to commercialize the innovation, is deemed to be the beneficiary of any potential first mover advantages. Thus, assuming these FMA are sufficiently attractive, we would expect firms to be engaged in a race to be the first to commercialize particular innovations. However, many academics note that being the first isn't always what it's cracked up to be.

A. First-Mover Advantages

Barriers to Entry

So what are these FMA? Well, in the main, they are barriers to entry that the first-mover generates and which make it hard for subsequent firms to enter the market, and then to catch up with the pioneer. When it comes to technological pioneering, the barriers to entry in question arise from the pioneer's possession of crucial patents, and the benefits it can extract from proprietary learning, experience curve effects, product acceptance (Lowe and Atkins, 1994), scale effects, reputational effects, the preemption of scarce resources (such as the best niches and segments, where the greatest profits are to be had -Zahra and Nash, 1995), and buyer switching costs (Kerin and Varadarajan, 1992). Last but not least, speed to market could enable the pioneer to establish an industry standard, which can be a decisive advantage (Lambe and Spekman, 1997). All these serve to strengthen the pioneer's position relative to its potential rivals.

Either competitors cannot even commercialize the innovation themselves, if it is sufficiently well protected by patents, in which case the pioneer enjoys, in effect, a monopoly (Kerin and Varadarajan, 1992). Or, once the patents expire (or should they be circumvented), the pioneer still benefits from a dominant market position and so new entrants may simply find themselves forever lagging behind the leader, who will be too far advanced in the experience curve (Kerin and Varadarajan, 1992) and benefit from too many scale economies to make catching up possible.

Branding & Network Effects

To this very economic interpretation of FMAs, one can also tack on the conclusions from consumer behavior research regarding the benefits enjoyed by a pioneering brand (Kerin and Varadarajan, 1992). Briefly, the first product to reach the market becomes the "prototype against which all later entrants are judged" (Alpert 1987 *in* Kerin and Varadarajan, 1992, p. ~35). This can lead to strong customer loyalty, provided the product is judged satisfactory. And since the innovation is radical, it is often perceived as relatively risky for quite some time, so that customers will tend even more than usual to stick with a proven brand (namely the first one) and will only reluctantly try rival ones (Schmalensee 1982). Basically, imperfect information gives pioneering brands a lasting advantage.

Of course, the extent of these first-mover advantages will vary greatly depending on the product's actual characteristics. "For example, when a product is technically complex, or bulky, or a distributor must stock large product inventories and complementary items or spare parts, channel members might be reluctant to carry second or third brands" (Kerin and Varadarajan, 1992, p. ~42). And some types of innovations benefit from network effects, which can prove a critical boon to a pioneer. In this case, part of the product's value lies in its community of users: the larger this community, the more valuable the product. Thus, the first firm to reach the market can initiate an almost exponential build-up of clients, making its dominant position almost impregnable[10].

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[10] Good examples of markets with strong network effects include the one for operating systems, where Microsoft's Windows has achieved a quasi-monopoly, and the one for instant messengers, where ICQ currently boasts more than 100 million accounts.

B. First-Mover Disadvantages

Taking on Most of the Initial Risk and Uncertainty Leads to Pioneer Burnout

Empirical research does tend to demonstrate the existence and importance of first-mover advantages (Kerin and Varadarajan, 1992). In particular, firms that are the first to recognize and exploit a technological disruption often make spectacular returns (Tushman and Romanelli, 1985 *in* Tushman and Anderson, 1986). But Bryman (1997) suggests that most of the studies on FMA suffer from methodological flaws. Using a more rigorous methodology, he concludes that pioneers are actually more likely to suffer disadvantages, in particular because of the "liability of newness" effect (Stinchcombe, 1965 *in* Bryman, 1997). This liability includes, for instance, the lack of legitimacy, which we have already referred to and which can be a difficult hurdle to overcome. Kerin and Varadarajan (1992), surveying the findings of thirteen papers, also note that there is no unequivocal evidence supporting the existence of FMAs.

Olleros (1986), for example, suggests that a pioneer's advantages are often outweighed by its disadvantages. He emphasizes the great market and technological uncertainty pioneers face, and coins the term "pioneer burnout" to describe their frequent inability to survive in such difficult circumstances. Pioneers face particularly daunting obstacles if they are attempting to replace an industry's well established standards with new ones (Zahra and Nash, 1995). Other drawbacks include the large, asset-specific R&D investments a pioneer must disburse (such investments are usually not transferable to other activities and are therefore particularly risky); the need to satisfy complex, often inappropriate and obsolete regulatory requirements that have yet to be updated (hopefully!); and the need to educate consumers about the new, radical technology being commercialized (Zahra and Nash, 1995).

The Precariousness of First-Mover Advantages (No Guarantees)

In times of turmoil, even some of a pioneer's undeniable advantages can be temporary at best, deceptive at worst. Clearly, the longer it takes rivals to commercialize competing products, the more opportunities the pioneer will have to secure a strong market position (by widening the experience gap, for instance) and the longer it will be able to reap the benefits of being the first-mover (Kerin and

Varadarajan, 1992). But Agarwal and Gort (2001), in their study of forty-six major product innovations, found that in the 1976-1986 period, a mere 3.4 years separate pioneers from their nearest rivals (down from almost 33 years at the turn of the century). Mansfield, Schwartz, and Wagner (1981 *in* Kerin and Varadarajan, 1992) arrive to similar results, and conclude that about 60% of successful innovations are imitated within four years. This is hardly long enough to truly profit from one's status as a pioneer. And, more worryingly, it indicates that patents are perhaps not as effective as they are made out to be. Indeed, Bryman's (1997) study confirms that patents aren't a foolproof form of protection, especially when staff mobility is high. In fact, patents often actually leak vital information, making it easier for rivals to "invent around" them (Zahra and Nash, 1995). And of course, technology diffusion also occurs through reverse engineering and the publication of research findings (Lowe and Atkins, 1994).

Finally, even when FMAs exist and outweigh first-mover disadvantages, it is of course necessary for the pioneer to pursue an appropriate competitive strategy in order to obtain them -and having a high quality product doesn't hurt either (Kerin and Varadarajan, 1992). FMAs aren't a given, they must be deserved. Indeed, speed to market may end up being counterproductive if it is achieved by sacrificing quality and reliability. A shoddy product won't win the hearts of many customers, no matter how innovative it is... By extension, maintaining any advantages obtained requires sustained efforts on the pioneer's part to ensure its product continues to be perceived as superior to rival offerings (Kerin and Varadarajan, 1992).

C. The Need for Speed or Patience's Payoff?

Free-riding

Considering all these caveats and limitations, it is not all that surprising that a significant subset of the literature on emerging industries deals with later-mover, as opposed to first-mover, advantages. For example, in a very interesting study of the US animation industry, Bryman (1997) demonstrates that being a late entrant was a definite advantage for many of the firms involved. Indeed, later-movers can sit back and watch as the pioneer and other early-movers deal with all the initial market and technological uncertainties, strive to educate the consumer, and struggle to develop an infrastructure for the new product (should one be necessary). Later-movers can then enter the market once things have become a bit more stable, once a dominant design and standards have emerged (Abernathy & Utterback, 1977 *in* Lowe and Atkins, 1994). Late-movers can in effect free-ride on many of the pioneer's initial investments and efforts (Lowe and Atkins, 1994).

Finally, late-movers can, rather ironically, benefit from the pioneer's incumbency. Indeed, pioneers are often tempted to rest on their laurels, and to succumb to the same inertia which may have proved so fatal to the previous generation of incumbents (see appendix 7). This gives new players an opportunity to identify and address changes in customer needs (Lowe and Atkins, 1994).

Research Objectives

The question of first-mover advantages, their existence and their extent, is clearly unresolved and subject to controversy. Mitchell (1989) provides a good summary when he writes that first-movers can benefit from the achievement of technical leadership, the capture of scarce resources, and the creation of buyer switching costs. But they must also face the full brunt of technology and market uncertainty, and their advantages may end up being rapidly eroded as followers free ride on their pioneering efforts. Basically, firms must decide whether, if they move fast, they stand a chance of recovering their initial investments before rivals come up with competing products and, should they decide to wait, whether they will be able to enter the market later on before their rivals gain a strong market position (Mitchell, 1989).

Thus, much of my research focused on determining whether first-mover advantages or late-mover advantages are likely to be prevalent in the fuel-cell industry. Are barriers to entry going to be substantial for late comers, or is free-riding just too seductive? Fuel-cells, being such a disruptive technology, and being up against particularly entrenched competition, appeared to be the type of technology offering tremendous appeal to free-riders. I thus expected that firms involved or interested in this emerging industry would not be racing to be the first to market, but would instead be biding their time.

IV. A CASE STUDY:
THE FUEL-CELL INDUSTRY

Having considered the conceptual case behind each of the six needs, let us now analyze how relevant they are to the fuel-cell industry. Have all six needs been recognized by the industry's players? Are some perceived as more important than others? Basically, is this framework any good? But first, we must consider whether fuel-cells are indeed disruptive innovations.

1. A Disruptive Technology Seeking to Conceal its True Nature.

According to Chandy and Tellis's (1998) typology, fuel-cells are, at the moment, technological breakthroughs. Indeed, fuel-cell technology is substantially different than that underpinning existing products, but fuel-cells are not yet capable of providing much greater value for money than their rivals, as they remain much more expensive (for most applications). However, as we shall see, there are many reasons suggesting that this price differential is merely temporary, and that soon fuel-cells will be able to pack a much bigger bang for the buck than either batteries, internal combustion engines or even gas-powered generators. Thus, fuel-cells have the clear potential to become truly radical innovations.

The Radicalness of Fuel-Cell Technology From a Manufacturing Point of View

First of all, fuel-cells are clearly a radical technology, from the manufacturer's perspective, no matter what potential application is considered. For miniature and portable equipment, for example, they will compete against rechargeable batteries. And although a fuel-cell is in many ways simply a battery that can be refueled, the technologies are sufficiently different to require entirely new production processes and competences. Makers of batteries cannot simply upgrade their factories to produce fuel-cells. The radical nature of fuel-cells is even more flagrant when compared to the internal combustion (IC) engine, its rival for mobile applications (cars, buses) and some types of portable equipment (gardening equipment...). Many of the competences that automobile manufacturers, for example, have gathered over the past hundred or so years in the construction of IC engines (such as how to deal with the vibrations they produce, and how to design transmission systems) have little relevance to the process of designing and building fuel-cell powered vehicles. Finally, for stationary applications, fuel-cells will be up against gas turbines, diesel-powered generators, even solar panels (etc...), which are, once again, all very different technologies.

However, fuel-cells are not a stand-alone product. After all, they are little better than (very) expensive paper weights without a device to power! Fuel-cells must indeed usually be integrated into more or less complex electrical systems and products. This gives incumbents an opportunity to cash in on some of their competences. Ballard, for example, was eager to team up with car manufacturers so that it could benefit from their experience regarding the design of electrical systems for automobiles (Ballard Power Systems, 2001a). In other words, fuel-cells are perhaps not quite as disruptive as they might initially appear to be.

The Radicalness of Fuel-Cells From a Consumption Point of View

The same is true from the consumer's point of view. Fuel-cells are without a doubt a discontinuous technology when it comes to miniature applications, as they will require (or enable) entirely new behaviors. Instead of recharging one's battery by plugging it into an electrical socket for a prolonged amount of time, one will simply swap an empty fuel cartridge for a new one. No more careful rationing of laptop or cell-phone usage. On the other hand, the change in behavior caused by fuel-cells in mobile applications may very well be rather limited, making it a dynamically continuous technology. Indeed, if GM has its way, motorists may hardly realize their IC engine has been replaced by a fuel-cell: their vehicles will be much more quiet, and may be more responsive, but they will still run on gasoline (Butters, 2001). Even if methanol is eventually adopted, it will be sufficiently like gasoline not to engender very different behaviors. One will still need to regularly stop at a gas station (less frequently though) to refuel, and refueling will still involve filling a tank with a liquid. The use of pure hydrogen as a fuel, however, would probably require significant changes in behavior, but its use is unlikely in the mid-term.

When it comes to stationary applications, fuel-cells are likely to have a very pronounced effect on the behavior of certain end-users. Indeed, fuel-cells are likely to generalize distributed power, which opens up many possibilities: exploiting isolated resources, or simply living in a remote area, will become significantly more practical. More conventional consumers, however, may hardly notice the advent of fuel-cells. Even if they should elect to equip themselves with the new technology, they will simply replace their dependence on the grid for electricity by a dependence on the grid for natural gas[11]. In the end, most consumers don't usually care where or how their electricity is generated, as long as it's reliable and requires minimal attention on their part. But should fuel-cell cars become widespread, using one's car to power one's house becomes a serious possibility, and could result in substantial behavioral changes. Indeed, a fuel-cell powered car would have enough energy-producing capacity to run all of an average household's electrical appliances (see appendix 8). Since cars are idle 96% of the time (Lovins and Williams, 1999), using them to generate electricity for other uses might turn out to be their main function! This would certainly involve changes in consumer habits.

The Need to Wear Sheep's Clothing

It is of course difficult to predict what effects fuel-cells will have. Uncertainty is the essence of emerging industries after all. What is certain is that consumers will be less reluctant to adopt this new technology if it doesn't require major changes in their behavior, unless they feel the benefits are worth it. Specifically, consumers will consider the following points when evaluating a discontinuous innovation's appeal:

> "Relative advantage - The degree to which the innovation is perceived to be superior to that which it replaces. Compatibility - The degree to which the innovation is perceived to be consistent with the innovator's existing values, past experiences and needs. Complexity - The degree to which the innovation appears difficult to understand and use. Divisibility (trialbility) - The degree to which one can experiment on a limited basis with the innovation.

[11] In all likelihood the fuel that will initially be used with stationary fuel-cells.

Communicability (observability) - The degree to which the results of using the innovation are visible to others." (Rogers and Shoemaker, 1971 *in* Strutton and Lumpkin, 1994, p. ~119-120).

Thus, fuel-cell makers, which are in the main preparing to commercialize a discontinuous innovation, are striving to present it as a continuous, or at most a dynamically continuous, one. This is to facilitate acceptance of the new technology by consumers. In a way, it pays not to be too radical. And this is an extra complication in the already very difficult process of commercializing a new technology.

2. THE NEED FOR MERIT: Do Fuel-cells Merit Commercialization?

As we have just seen, if fuel-cell firms want the general public to adopt their technology, they will have to address the concerns people have regarding discontinuous innovations. In particular, they will need to make the case that fuel-cells have clear advantages over other energy-generating devices, that they are compatible with current needs and values, and that they are not too much of a pain to use. Determining whether all this is feasible should be priority number 1 for fuel-cell firms. Indeed, the sooner one knows whether a technology has a chance at being commercialized successfully, the better. Failing to meticulously and objectively analyze a technology's potential can lead a company to espouse a lost cause, which can have disastrous consequences, both in terms of wasted resources and lost opportunities[12]. So let us now consider if fuel-cell technology can indeed be made palatable. First, we shall consider all its strengths and weaknesses relative to current technologies. Based on this initial analysis, we will then use White and Graham's 1978 framework to determine how "meritorious" fuel-cell technology is.

[12] The car-makers who pursued battery technology, for instance, could have saved themselves a lot of money, time and effort had they evaluated the technology's pros and cons before embarking on their R&D programs. They would probably have realized that batteries just can't realistically compete any time soon with internal combustion engines, because of their many limitations. In particular, whereas gasoline stores the equivalent of 13,000 watt-hours per kg, lead-acid batteries can only pull off a pathetic 40, and the most advanced zinc-air batteries manage a mere 120 (Cowan and Hultén, 1996).

A. Strengths and Weaknesses of Fuel-Cell Technology

One could write pages and pages on the subject. Indeed, I did. But what follows is merely a brief summary of my in-depth analysis. The full analysis, including all relevant references, can be consulted in appendix 9.

Strengths

Compared to rival power-generating technologies, fuel-cells enjoy several critical advantages. First of all, and perhaps best known, is their environmental friendliness. Although no panacea (they don't take pollution entirely out of the picture, although they do have the potential to do so eventually), they are much cleaner than all other comparable technologies[13], no matter what fuel they are fed with. Their "green" credentials are further accentuated by the fact that fuel-cells are very energy efficient, quite simply because they have no moving parts, thus, unlike other power-generating systems, no energy is needed to create energy (Darbonne, 2001). In theory up to 90% of a fuel's energy content can be converted into useable power by a fuel-cell, which is better than the 30-40% achieved by gas or coal burning plants (Dukart, 1999), and beats ICEs hands down (these are currently 15% efficient -Renzi and Crawford, 2000). The lack of moving parts also makes fuel-cells inherently simpler, and more reliable, than these other technologies (which may make manufacturing them significantly less expensive).

Fuel-cells benefit from high energy densities which means, in effect, that they are highly energetic for their size. Indeed, a fuel-cell equipped car will be able to power all sorts of electrical accessories, not to mention an entire household (see appendix 8). In particular, fuel-cells are much more powerful than similar-sized batteries (The Economist, 2001i): in theory, a fuel-cell powered cellular phone could be left on standby for six months, instead of the mere week possible with existing batteries (Libin, 2000). This brings us to the technology's scalability: fuel-cells can power cities, just as they can, in theory at least, power hearing aids (Arnst and Port, 1998). And because a fuel-

[13] Apart of course from renewables such as solar and wind power, but these are impractical for many applications.

cell's efficiency and power density are not significantly affected by its size (in other words, a large fuel-cell is not more efficient than a small one), the technology is inherently modular, making it quite flexible. Finally, another source of flexibility is the possibility to feed fuel-cells with just about any hydrocarbon, or indeed any hydrogen rich substance, which would finally put an end to our dependance on petroleum.

Weaknesses

So what's the catch? If fuel-cells are so great, and considering the first one was built in 1839 (see appendix 10), why aren't they already in our cars and laptops? Well, fuel-cells have been extremely costly to build, in large part because of their need for expensive materials, such as platinum. In addition, companies will have to incur gigantic costs in order to build the infrastructure required by fuel-cell-powered vehicles. Considering that energy firms are unwilling to simply write off their past investments in the existing gasoline infrastructure, especially when there are no fuel-cell cars to refuel yet, and that no one is prepared to commercialize fuel-cell cars without an infrastructure to fuel them, we are confronted with a chicken and egg problem (a problem that is particularly difficult to crack).

Another weakness lies in most fuel-cells' dependence on platinum, a relatively rare metal. Indeed, it is uncertain whether enough of the metal can be mined to meet the expected increase in demand resulting from the commercialization of fuel-cells (see appendix 9). Finally, perhaps the greatest obstacle to the successful commercialization of fuel-cells is the fear hydrogen inspires. Indeed, the word hydrogen usually brings to mind the Hindenburg disaster and nuclear bombs, hardly the most reassuring images. In truth, fuel-cells are not inherently more dangerous than rival technologies (see appendix 9), but it will certainly be necessary to change peoples' perceptions of hydrogen.

The Future is Bright

These weaknesses certainly seem daunting. If one were simply to compare them to the technology's strengths, one would be hard-pressed to conclude that fuel-cells are definitely worth developing aggressively. However, one must also consider how entrenched these weaknesses are, for they are not necessarily insurmountable.

Indeed, they would appear to be well on their way to being resolved. For example, companies like Ballard have found ways to significantly reduce the quantity of platinum required to build a fuel-cell, or even to replace the metal altogether with cheaper alternatives (easing fears that there won't be enough platinum to meet growing demand). So though fuel-cells continue to be expensive, further progress in cost-cutting and, mostly, the scale economies that will almost certainly be obtained once fuel-cells are mass-produced (and so no longer have to be assembled by hand by highly skilled technicians and researchers...) give reason to hope that cost will not be an issue for much longer. Similarly, there would appear to be ways of introducing an alternative fuel infrastructure so that it would be relatively affordable, and maybe even profitable (see appendix 9). Finally, it is likely that hydrogen won't be the fuel of choice in the near to mid term, making it less pressing to reassure the public about this new source of energy.

B. The Merit Test

Inventive & Embodiment Merit

We can now evaluate these diverse advantages and disadvantages using White and Graham's (1978) framework. First of all, do fuel-cells have inventive merit? They most certainly do, as they can potentially reduce, perhaps eliminate altogether, our dependance on petroleum, and most importantly, they can greatly limit the pollution emitted by our power-hungry societies.

Do they have embodiment merit? Well, this remains to be seen, as embodiment merit stems from the technology's actual materialization, and thus will vary from company to company and from product to product, as they each accept their own set of trade-offs. What can be said is that since fuel-cell technology is quite flexible and adaptable, there is much scope for customizing fuel-cells for very different applications. Or in other words, engineers have the necessary leeway to achieve embodiment merit: their raw material, fuel-cell technology, is quite malleable.

Operational Merit

Will fuel-cells have operational merit, as far as their manufacturers are concerned? We have seen that fuel-cells are reliable, which will hopefully cut down the costs associated with repairing or replacing products still under warranty. In addition, they will probably be relatively easy to mass produce, which could have several beneficial implications, such as the need for fewer suppliers and simplified quality control. Finally, and perhaps most interestingly, makers of fuel-cells for portable applications may be able to earn ongoing revenues from their sales of refueling cartridges. This may indeed become their main profit-source, if they choose to sell the fuel-cells themselves at or below cost, or simply very cheaply, in order to spur market growth. Such a business model would be very similar to Gillette's: "sell the razor (or fuel cell) cheap and reap profits from hooking customers on a proprietary type of blade (or refill cartridge)" (The Economist, 2001i, p. *1). Medis Technology, for example, is planning to cell its refills for about $1, resulting in a 30% profit (Kopicki, 2001). Unfortunately for the company, one refill will last about 3 months!

Market Merit

Finally, and most crucially, do fuel-cells have market merit? At the moment, it would appear that they do not as far as mobile applications are concerned, but that they do, or soon will have, in the stationary and portable power markets (see appendix 9). The key here will be to continue to work on overcoming the three main obstacles on the road to the successful commercialization of fuel-cells: expense, infrastructure development and negative public perception. If these can be surmounted, then the future of fuel-cells seems assured, as they clearly offer a superior performance relative to their rivals. Clean, reliable, decentralized energy for stationary applications; power and duration for portable applications; and clean energy as well as a smooth, enjoyable ride for mobile applications[14].

All in all, fuel-cell technology definitely has a good chance of becoming a success on the marketplace, especially if Dr. Panik, one of DaimlerChrysler's senior

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[14] Indeed, the users and drivers of trial fuel-cell buses were very pleased with the experience, citing how the buses were quiet and smooth, not to mention simple to operate and maintain (Anonymous, 2001c). Mr. Jaffray, from Johnson Matthey, told me that he'd been given the opportunity to drive an electric car, and that it'd been a very pleasurable experience. The car was more responsive, "zippier," more exciting than a conventional automobile, as it responds instantly and maximum power is possible even at a low torque (Interview - Jaffray). Even the more intrepid among us have no need to fear, as fuel-cars are in theory capable of Porsche 911-like performances (Eisenstein, 1999b).

vice-presidents, is proved correct in declaring that "in the end I believe the fuel cell can be done for the same price as the piston engine, or lower. And I believe it can let the owner travel 50% farther for the fuel used, with an engine that will be truly maintenance-free."

Conclusion: Undeniable Merit

Therefore, the first phase necessary in the commercialization of a disruptive innovation, the need to ascertain its potential merit, seems to have been satisfied. The companies currently involved in developing fuel-cell technology, which are often spending considerable amounts of money in the process, have accurately assessed their research's potential (or perhaps they have not even undertaken such an analysis, in which case they are quite lucky!).

3. THE NEED FOR GOVERNMENT SUPPORT: Are States Playing their Part?

It is undeniable that governments, and particularly the American government, played a critical role in the development of fuel-cells. States have both pushed and pulled fuel-cell research, and continue to be a key impetus, even now that fuel-cells are beginning to reach the market. Governments have also played an important role in encouraging fuel-cell developers to cooperate. We will consider each of these points in turn, before concluding that not only is there a universally recognized need for government support in such emerging industries, but many insiders and analysts are actually complaining that public authorities aren't doing enough to promote fuel-cells.

A. Pushing Fuel-Cells

The Early Days: Submarines and Space Shuttles

Much of the initial research in fuel-cells was funded in totality by public agencies, with very specific aerospace and military applications in mind. The military uses of fuel-cells have not been well publicized. They seem to have been installed on certain non-nuclear submarines in order to produce quiet, emission-free electricity (German submarines have been equipped with PEM fuel-cells since the 1970s in order to achieve air-independent propulsion -Sattlet, 2000). Better known are fuel-cell technology's applications in the fascinating realm of space exploration and exploitation. When NASA first studied the feasibility of manned missions, it looked for a reliable way to provide its astronauts with electricity. Batteries were simply too short-lived. Nuclear and solar power were both considered, but soon rejected: nuclear reactors were deemed too dangerous, and solar panels too cumbersome (Bellis, 2001). That left fuel-cells, which as an added bonus could produce drinkable water. NASA therefore decided to heavily fund fuel-cell research, and it paid off: fuel-cells have powered every manned flight since Apollo, and continue to supply the space shuttles with electricity and water (United Technologies, 2000).

In those early, heady days, fuel-cells were simply too expensive to have any viable commercial applications, so, basically, any fuel-cell related research had to be government funded. And so many of the first fuel-cell companies were actually founded specifically to pursue government-funded research[15]. Ballard, for example, initially won a contract in 1983 from the Canadian Department of National Defense to develop PEM fuel-cell technology (Ballard, 1999). H Power, founded 10 years ago, also started out as a very research-oriented government contractor (Interview - McNeill). Sometimes, the government's role was more roundabout. Jeffrey Bentley for instance, first learned about fuel-cell technology while working for Arthur D. Little because he'd been hired to do some consulting work on the subject by the government. Intrigued by the technology's potential, he founded Epyx in a bid to play a part in its commercialization (Interview - Bentley).

Heavy Funding Continues in the US...

Without public funds, it is thus very unlikely that fuel-cells would have reached

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[15] Alternatively, the 1974 Federal Nonnuclear Energy Research and Development Act (P.L. 93-577) sought to encourage private initiative by offering grants to companies developing non-nuclear inventions with the potential to save or produce energy (Livesay et al, 1996). In this case, the companies (particularly smaller ones, as they were favored under the program) came to the government with proposals, rather than the other way around. Their submissions are assessed, secretly and for free. Promising projects received Department of Energy grants. But it is unclear whether fuel-cell research benefitted from this particular program.

their present level of development. And though private companies now invest considerable sums as well, government spending remains very significant. Indeed, according to Johnson (2000), much of the $1 billion being spent annually on fuel-cell R&D is provided by government agencies in the US, Japan and Europe. Harding (2000) states that, in general, most of the R&D spending for alternative fuels comes from the public purse.

In practice, government spending on alternative energy research varies a lot, depending on the administration's political philosophy (under President Reagan, for example, research was cut back) and on oil price fluctuations (high prices stimulate the quest for new energy sources). As a fraction of GDP, energy research's heyday was in the 1970s, whereas a 30-year low point was reached in 1997 (Norberg-Bohm, 2000). At present, although George W. Bush's administration has been suspected of being a bit too cosy with the traditional energy industries[16], the President took pains to announce $85.7-million in grants to accelerate fuel-cell development on the day he sent his energy plan to the Capitol (Dunne, 2001b). The Department of Energy alone plans to spend $90-$100[17] million funding fuel-cell research in 2002 (Dunne, 2001b), and it disbursed a similar sum in 2001 (Anonymous, 2001d), including $58 million specifically for stationary applications (Rosta, 2001).

The totals are encouraging, and so are the trends: the amount of money allocated to fuel-cell research increased by 55% from 2000 to 2001, and as a matter of fact, the 2001 budget was "the first time in recent memory that Congress [has] fully funded the [DOE's] fuel cell research budget," according to Robert Rose, founder of Fuel Cells 2000 (Anonymous, 2000c). Actually, Congress granted $10 million more than what the Clinton administration had originally asked for (Anonymous, 2000c). Finally, it is important to point out that some of the assistance offered by the government is in kind. For instance, the US military has conducted widespread testing of fuel-cells in many different environments (including some particularly inhospitable ones), which has provided fuel-cell researchers with extremely valuable information.

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[16] Coal, gas, nuclear, and particularly Big Oil.

[17] It is unclear whether the $85.7 million announced by Bush are included in this total.

...And in the Rest of the World as Well

The US are not alone in their interest for fuel-cell technology. The Japanese government has perhaps been even more generous, as it is keen to put an end to Japan's heavy dependence on oil. Indeed, fuel-cell R&D is 100% subsidized in Japan. The government also covers half of any demonstration expenses, and one third of the cost of field tests (Nurdin, 1996). Canada, birthplace of Ballard, the leading PEM fuel-cell company, has pledged $500 million to help develop technologies, such as fuel-cells, that reduce greenhouse gases (Ballard Power Systems, 2001a). Britain's Department of Trade and Industry, belying the country's traditional "wait and see" attitude, established its Advanced Fuel Cells Programme back in April 1992. Meanwhile, French members of Parliament, worried that France will be irremediably overtaken by its rivals, have recently called for drastically increasing fuel-cell research (Le Hir, 2001). They want major French research centers and industrial groups to combine their efforts and launch an ambitious and aggressive fuel-cell development program. Already, the Commissariat à l'Energie Atomique (Atomic Energy Agency) has intensified its research efforts (Le Hir, 2001).

On a grander scale, the European Union has also consistently provided support for fuel-cell research, provided it is undertaken by companies from at least two different EU states (Borthwick, 2000). Actually, the EU doesn't target specific technologies for assistance, but rather sets out certain research objectives, which companies can then attempt to achieve using their choice of technologies. Not unlike Japan, the EU then covers 50% of the R&D costs, and 35% of the demonstration costs of any projects deemed worthy (Borthwick, 2000). Although the EU doesn't specifically earmark funds for fuel-cells, it has recognized their importance pretty much since the inception of the European Union Framework Programme for Research (Borthwick, 2000). Indeed, the publishing by the European Commission, in 1995, of the "Ten year fuel-cell research, development and demonstration strategy for Europe," confirmed Europe's strong interest in this technology, and its determination to rationalize research in the sector by defining common goals (Ponthieu, 1998)[18].

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[18] More concretely, fuel-cell research received €8 million during the Second Framework Program (1988-1992), €32 million during the Third Framework Program (1992-1995), and €54 million during the Fourth Framework Program (1994-1998). Since the selection of particular projects to fund takes place

All the Companies Studied Have Benefitted from These Funds

All the companies I studied seem to have benefitted, at some point or another, from government funds. Indeed, during our talk together, Mr. McNeill took care to emphasize the importance of government contracts in the industry (Interview - McNeill). Unfortunately, exact figures were hard to come by. The best I obtained were from H Power, which stated that, since its inception, it has received about $19.5 million from federal and state government contracts to produce fuel-cell vehicles, stationary units or communications backup generators (H Power, 2000). In particular, a Department of Energy program represents a significant portion of their revenues. Most of the companies, including H Power, continue to be awarded government contracts.

B. Pulling Fuel-Cells

Government Procurement is Minor at Present, but the Potential is There

We have already mentioned how government agencies, particularly NASA, constituted the first "market" for fuel-cells. But now that fuel-cells are about to be commercialized, it is perhaps not surprising that government procurement has become almost irrelevant. Almost, but not quite. After all, the government still represents a huge potential customer of fuel-cells. The military will certainly want to equip its new, highly advanced and power-hungry forces with these energetic little devices. And military bases could benefit from the autonomy and reliability of stationary fuel-cells. Public hospitals, key government buildings (embassies perhaps?) may be early customers as well. The potential is perhaps greatest when it comes to mobile fuel-cells, as governments and public companies throughout the world tend to have very sizeable fleets of vehicles.

For the moment, it would seem that no government has placed significant orders for fuel-cells of any kind (at least I was unable to unearth any evidence to this effect). But certain regulations, that have already been enacted, could give the initial

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after a global budget envelope has been agreed on, it is impossible to say exactly how much money fuel-cell research will obtain during the Fifth Framework Program (adopted in December 1998 for the 1998-2002 period -Borthwick, 2000). But considering fifteen billion euros are up for grabs, it is very probable that the upwards trend in spending on fuel-cell R&D will continue.

commercialization of fuel-cells an impetus. The Alternative Motor Fuels Act of 1988, for instance, calls for the American government to purchase as many alternative-fueled vehicles as is practical (Harding, 2000). Indeed, by 2005, 100,000 government vehicles must be using alternative fuels (Ballard Power Systems, 2000). In addition, the law mandates that the Department of Energy must help state and local authorities to develop alternative-fueled buses (Harding, 2000). This law, as well as Executive Order 12844 (which seeks to increase the government's acquisition of alternative-fueled vehicles -Cooper, 2000), could be a boon for the industry. Some states have joined in as well: New York's governor, George E. Pataki, has recently signed a law requiring "state buildings and quasi-independent agencies to use 10% of renewable electric power by 2005," which will rise to 20% by 2010 (Anonymous, 2001d). In this case, stationary fuel-cells may well end up with a sizeable chunk of this market.

Generous Subsidies

In practice, most government assistance took the form of subsidies, rather than of outright purchases[19]. For instance, in 1996, under the Clinton administration, the American government launched the Climate Change Fuel Cell Program (a.k.a the Fuel Cell Rebate Program), under which it granted rebates to any organizations purchasing fuel-cells ranging between 100 and 3,000 kW in size and manufactured by US companies (Kirlin, 2000)[20]. The buyers (companies, but also universities and state agencies) received $1,000 per kW from the Department of Defense, which corresponded to approximately 1/3 of the total price and made the fuel-cells competitive with rival technologies (Hoffman and Paulson, 1997). In addition, the government would pay for up to a year of testing, so as to reduce the uncertainty and risk involved (Hoffman and Paulson, 1997). The big beneficiaries of this subsidy have been UTC's International Fuel Cells and its partner, Toshiba. Of the more than two hundred orders

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[19] Most economists flinch at the word "subsidization," but many would probably concede that such government "meddling" is warranted under certain circumstances. Care must be taken, however. Subsidies can often be too generous, causing complacency and inefficiency, and discouraging innovation and competition. If badly designed, subsidies can have unpredictable, pernicious effects, and even plain and simply backfire, like an Arizona initiative that ended up favoring the purchase of gasoline-guzzling SUVs (Green, 2000)!

[20] Although defense-related projects or those demonstrating "first of a kind" applications were privileged (Anonymous, 1997)

for UTC's 200-kilowatt PC25 since 1991 (United Technologies, 2000), most were contingent on receiving this subsidy (Hoffman and Paulson, 1997). Indeed, UTC's executives openly recognize that their sales would have been significantly less impressive without the government's helping hand.

As of 1998, more than 100 rebates of $1,000/kW had been awarded by the Department of Defense, and five million dollars' worth were projected for 1999 (Kirlin, 2000). These figures give but an inkling of the true sums involved, since the Japanese, Canadians, and Europeans, not to be outdone, run subsidy programs of their own. The Japanese government subsidizes the sales of PC25s by Toshiba (The Economist, 1997), Germany is aggressively pushing fuel-cell technology (perhaps at the behest of DaimlerChrysler), and a $30 million investment by the Canadian government[21] helped found the Ballard-GPU partnership for the commercialization of fuel-cell co-generation units (Kirlin, 2000). Moreover, very substantial subsidies are being aimed directly at the final consumer, individuals. Just recently, the Bush administration called for 4 billion dollars' worth of tax breaks for consumers who buy super-efficient cars, in particular ones using fuel-cell technology (The Economist, 2001h).

Giving The Invisible Hand a Nudge in the Right Direction

Apart from financing the early R&D, government's main role in the commercialization of fuel-cells has undoubtedly been through its regulatory power. This is not surprising, considering the importance of government intervention in anything pertaining to energy production and distribution (Harding, 2000). After all, many people think that energy is simply too important to be left to the markets: the economy depends on reliable power, national defense is contingent on energy autonomy, and ensuring a sustainable environment (which we all depend on!) means figuring out ways in which to produce cleaner power. Can the invisible hand steer us in these directions? Yes and no. Free market capitalism is much more resilient and efficient than most people give it credit for being, but sometimes, positive or negative externalities warrant some kind of government intervention. Fuel-cells, for example, hold much promise, but their

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[21] Which limits its subsidies to about one third of the cost of a project, according to Mr. Faul from Greenvolt (Interview - Faul)

commercialization would not have been so rapid had the business world's interest not been egged on by increasingly stringent environmental regulations. Inversely, it is only because states have gradually liberalized the energy industry that a very important market for fuel-cells, distributed power, is becoming accessible. Less us consider these two opposing trends in turn.

Environmental Regulations

Concern for the environment has been growing steadily since the 1970s, and has led authorities, both local and national ones, but also those at the global level, to set ever higher standards for its safeguard. At the local level, first of all, many US states, including New York, Massachusetts, Maine, Vermont and the District of Columbia, have adopted very tough standards for automobile emissions (Ballard Power Systems, 2000). But the state that started it all, and that continues to have the most stringent standards, is California, with its LEV (Low-Emission Vehicles) and ZEV (Zero-Emission Vehicles) program. Basically, 4% of all new cars sold in the state must be ZEVs by 2004, and 6% must be LEVs. This is not just empty bluster. The California Air Resources Board, which oversees this program, has recently reaffirmed its determination to see it implemented on deadline, and will probably not hesitate to levy substantial fines to punish car-makers that fail to meet its standards (Lloyd, 2000).

Because California, with about 30 million inhabitants, is an extremely important market for the main car manufacturers, it cannot simply be ignored. Indeed, according to Mr. Hoffmann, Editor-in-chief of the Hydrogen & Fuel-Cell Letter, California is in effect setting the nation's, and by extension the world's, standards (Interview - Hoffmann). As a matter of fact, 12 US states have already followed California's lead, and 11 others are likely to do soon (Clark, Jr. and Paolucci, 2001). But the US Federal government is not leaving all the initiative to its component states. Starting in 1971, with the Clean Air Act, a long series of environmental laws have been enacted (please see appendix 11 for a list). Few of them have directly promoted fuel-cell technology, but most have contributed to a "green" mind-set and encouraged companies to seek more environmentally-friendly solutions, including of course fuel-cells. And, once again, though most of the English-language sources I exploited focused on the US, environmentalism is a growing force throughout the world, and perhaps even more so in Europe than in America. Two examples illustrate this quite vividly. In the UK, electricity suppliers will be required to obtain at least 10% of their power from renewable sources by 2010 (Thomas, 2001). And in Germany, conventional cars are no longer allowed to remain idle for longer than 45 seconds[22] (Ballard Power Systems, 2000).

Finally, because the protection of the environment is by nature a global undertaking, global agreements are an increasingly important part of the picture. The 1992 Rio Summit's Agenda 21, for instance, calls the world's nations to enact and enforce environmental regulations, and for companies to develop technologies that can help clean up the environment (Clark, Jr. and Paolucci, 2001). Most notable, however, is the 1998 Kyoto protocol, which commits the industrial powers to reduce their greenhouse gas emissions to 1990 levels, although the EU is even more ambitious and is aiming to cut its emissions by 8% relative to 1990 levels in the 2008-2012 horizon (Borthwick, 2000). Of course, now that the US have pulled out of the Kyoto agreements, their impact will be greatly diminished, since America currently emits one quarter of the world's greenhouse gases (The Economist, 2001l). Nevertheless, it would appear that most countries will stick with the protocol. And, according to Kock (2000, p. ~5), meeting the Kyoto targets means thay by 2008-12, "energy-related CO2 emissions would have to fall to almost 30% below the level projected for a Business-As-Usual scenario." Cutting emissions by 30% is quite significant, and will certainly require the widespread use of cleaner technologies, such as fuel-cells.

The Deregulation of Electric Utilities

Inversely, some government deregulation will also be critical for the success of fuel-cells, at least when it comes to stationary applications. Until rather recently, the production and distribution of electricity were considered natural monopolies (The Economist, 1998a). Bigger was better: gigantic power stations were clearly more efficient, and only huge companies could afford the considerable capital costs involved in building them. Moreover, by granting monopoly rights to these firms, governments ensured that all their citizens would have access to the grid (the high cost of providing

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[22] This, incidentally, gives fuel-cells a big boost: because they can provide clean energy for electrical accessories, they will not be covered by the 45 second limit.

electricity to remote communities could be offset by higher rates elsewhere). In Europe especially, "complex reasons having to do with historic regulations, attitudes about national identity, and the risk of market failure made each country develop large national or regional utilities that owned every part of the process of producing and distributing electricity" (Leslie et al. , 1999, p. 39-40).

But now, technology has made small generators just as efficient, if not more efficient, than large ones, and political thinking has evolved, becoming more market-friendly (The Economist, 1998a). Though the transmission of electricity remains a natural monopoly, its production is now economic even at relatively small scales. Indeed, according to the Economist (1998a, p. *1), "in enterprises with stable demand, it is almost always cheaper to generate on-site because there are no charges for transmission, distribution or billing." Thus, state-owned monopolies are out, and competition is in. This is true in America, where deregulation began with the Public Utilities Regulatory Act (PURPA) of 1978 that instructed public utilities to purchase power from small-scale producers (Loiter and Norberg-Bohm, 1999), and where at least 21 US states and 2 Canadian provinces now allow retail electricity competition (Gatlin, 2000). It is also true in Europe, where the electricity market is being progressively liberalized[23], despite fierce resistance from the French.

C. Government-led or initiated cooperation

Finally, the government also played an important role by promoting cooperation within the fuel-cell industry (which, is as we will see later, is essential). One of the first, and still one of the best known, government initiated fuel-cell coalitions was the California Fuel Cell Partnership. Founded in April 1999, it consists of Ballard Power Systems, International Fuel Cells, most of the world's major automobile manufacturers (DaimlerChrysler, Ford, GM, Honda, Hyundai, Nissan, Toyota and Volkswagen), oil companies (BP Amoco, ExxonMobil, Shell and Texaco), industrial gas producers, government agencies (the California Air Resources Board, the California Energy

[23] The process started on February 19th, 1999, when one fourth of the market was opened to competition (Leslie et al. , 1999).

Commission, the United States Department of Energy, the US Dept. of Transportation, and the South Coast Air Quality Management District) and utilities (Interview - Hoffmann). Their overriding objective is to ensure that fuel-cells are ready in time for the implementation of California's strict emission laws.

Other examples of government-led alliances include the Partnership for a New Generation of Vehicles (a 1993 initiative by the Clinton administration), whose goal is to develop a car that can achieve 80 mpg (and still carry up to 6 passengers and 200 pounds of luggage); the Solid-State Energy Conversion Alliance, a consortium led by two Department of Energy labs (Anonymous, 2000b); and a joint-venture between the US government, Plug Power and Arthur D. Little to develop a fuel-cell that can run on gasoline (Verburg, 1998).

In other parts of the world, governments are even keener on promoting cooperation. In Japan, especially, there exist close relationships between public agencies, fuel-cell manufacturers and utilities (Nurdin, 1996). But Europe is by no means a laggard in this respect. Borthwick (2000), mentions four programs that were launched by the EU: the HYDRO-GEN project (led by Peugeot SA), which is developing a fuel-cell powered monospace, the CAPRI project (led by Volkswagen) which is developing a fuel-cell/battery hybrid based on the chassis of the Golf model, the FCBUS project (led by Air Liquide) which is developing a fuel cell/battery hybrid bus, and the JOULE program (led by a German organization called LBST), which has been charged with examining how best to regulate hydrogen-fueled vehicles to ensure an adequate level of safety. Meanwhile, in France, faithful as ever to its statist traditions, Peugeot SA recently announced an agreement with the Centre National de la Recherche Scientifique (CNRS) and the Commissariat à l'Energie Atomique (CEA) to develop a fuel-cell car (Anonymous, 2001).

D. Government Support Was Crucial - And the State Could do More.

The industry insiders I interviewed were unanimous in recognizing the importance of government spending in the early stages of fuel-cell technology's development. And to this very day, state agencies continue to be an important source of funds for fuel-cell R&D. Dr. Stannard, to take just one example, told me his company had just been awarded a major program by the US Department of Energy (Interview - Stannard). And he believes that government assistance in some form or another is likely to continue over the next few years.

Extended Hands

Many, however, also called for increased support. Bob Rose, of the US Fuel-Cell Council, wrote "I would also say that coercive regulation in emissions, energy efficiency or both would help. Governmental support (research dollars, early purchases, purchase subsidies, tax credits) would also be valuable (...)" (Interview - Rose). Mr. Hoffmann concurred: "government help is very much needed, not only financial help and tax breaks, but also reassessing and removing regulatory barriers." (Interview - Hoffmann). He is of the opinion that government assistance hasn't really been all that abundant until now. Andrew Flicks, principal fuel-cells scientist for BG Technology, is more generous in his assessment, but would also agree that more can be done. "The government has been good at funding the R&D, but now there's more of a need to fund the companies demonstrating the technology; to try to help them get off the ground," (Flicks in Buchan, 2001, p. *1).

Of course, most industrialists, no matter what their field of business, can cite a number of reasons demonstrating their need for special government treatment... Subsidies and regulations are an excellent way of minimizing competitive pressures, after all. But the reasons advanced in the case of fuel-cells do seem to hold up well under scrutiny. As Bob Rose points out, there are definite positive externalities to be had: "the United States [will reap] the benefits of reduced greenhouse gas emissions, new high-technology jobs and cleaner air" (Anonymous, 1997). Taking a more global perspective, Vaitheeswaran (2001, p. *1) sees government support for renewable and alternative energies as an "insurance policy against the possibility of distant hazards such as global warming and oil depletion."

What the Government Must Still Do: Five Worthy Policies

In practice, there are five, relatively inexpensive things most commentators agree governments should do in order to help the emerging fuel-cell industry. Most importantly, governments should end all the subsidies that currently benefit fossil fuels

(The Economist, 2000f). These subsidies are both direct and indirect, but almost always hidden, and they tip the scales in favor of coal and gasoline, hardly the cleanest fuels (Vaitheeswaran, 2001). Instead, so as to better reflect these fuels' negative externalities (ie the harmful effects they have on the environment and on human health), carbon taxes need to be introduced (Vaitheeswaran, 2001).

Secondly, governments will need to play an active role in the newly liberalized energy markets to ensure a level playing field (Vaitheeswaran, 2001). Indeed, distributed power, which is now conceivable thanks to deregulation, will only take-off if, ironically enough, some government regulation is imposed. On the one hand, incumbents will, rightfully, insist on being able to set interconnection rates that allow them to recoup some of their past, very substantial, investments. On the other hand, these rates cannot be too high, or they will discourage new comers from offering alternative power sources (such as fuel-cells). Standards will also be necessary to make distributed power technologies "plug and play" (to borrow an IT expression), and the complicated matter of metering the consumption but also the output of individual homes will need to be ironed out[24] (Williams, 1998). Thirdly, and related to the previous point, governments should more vigorously promote collaboration within the industry, and in particular across borders. This would "contribute to more effective deployment of the result of research and development by sharing costs, pooling information and avoiding duplication of efforts (Kock, 2000, p.~2). It would also, hopefully, accelerate the development of common regulatory and safety standards and the establishment of common technology and infrastructure platforms (The Economist, 1999c).

Fourthly, rich countries should do their utmost to ensure that developing nations adopt clean power-generating technologies, in particular fuel-cells, to meet their skyrocketing energy needs (Vaitheeswaran, 2001). Providing financial and technological assistance to developing countries would enable them to skip a generation of cheaper but much dirtier technologies, which would be to everyone's benefit. Mr. de Groot, PowerTek International's chairman of the board, also pointed out that the sale of stationary fuel-cell systems to developing countries (potentially a huge

[24] Since one of the attractions of distributed power is the prospect of selling one’s surplus electricity to one’s utility.

market) will almost definitely require some form of government subsidization. Most of the people in these countries could otherwise not afford to pay their electricity bills (Interview - de Groot). Finally, at the moment governments are doing very little (in fact, apparently nothing) to educate the public about fuel-cells. This will have to change if this technology is to gain widespread acceptance.

The Need for Self-Reliance Will Prevail

Though they are grateful for past government aid, and would like to receive more, the people I spoke to were adamant that, in the end, the success or failure of fuel-cells will be determined by the marketplace and only by the marketplace. As Dr. Stannard puts it (in Libin, 2000, p.~96), "environmental regulations will make it so that manufacturers have to make products available; they will not make it so people have to buy them." Bob Rose was particularly emphatic that the technology will have to succeed thanks to its own merit, and not because the decks are stacked in its favor by the state (Interview - Rose). Indeed, he and the members of the US Fuel-Cell Council have ruled out lobbying Congress for hand-outs (Interview - Geyer). Even the main winner of government largesse, UTC's International Fuel Cells, is not planning to receive subsidies ad infinitum. Already back in 1997, it was confident that by the turn of the millennium, its fuel-cells could compete unaided, thanks to scale economies and technical improvements (Hoffman and Paulson, 1997).

Sir Moody-Stuart (2000, p. *1) probably best summarizes the industry's position when he says that "There is a legitimate political interest in cleaning up the environment and limiting CO2 emissions - which we share (...). Targets should be set and then industry should be allowed to get on with experimenting and developing different technologies. Provided the freedom to experiment is maintained, and conditions favourable to the introduction of more environmentally friendly products are created, customers will make the right choice (...). That is the way to make rapid progress and to introduce hydrogen technologies - through a broad market focus, guided, but not controlled, by benign government regulation."

Conclusion

Clearly, there is an undeniable need for government support in emerging industries, as was demonstrated extensively in the case of fuel-cells. Government supply-push was absolutely critical to start out with, and its demand-pull has been growing in importance. Indeed, in many ways, the development of fuel-cells for mobile applications was primarily spurred by environmental regulations, particularly California's. Rather than dismissing the importance of government support, many of the industry's actors are calling for more of it. However (and this surprised me to some extent, I must admit), an even greater amount of respondents affirmed the need to avoid being excessively dependent on the government's support. In the end, fuel-cells will have to prove themselves on their own merit.

4. THE NEED FOR CHAMPIONS AND VISIONARIES: A Driven Industry.

I first wanted to determine whether visionaries (and champions) are indeed important in the fuel-cell industry. It would seem that they most definitely are, and, interestingly enough, the leaders of large incumbents (but by no means all of them) are some of the industry's most influential visionaries. I then focused on how these visions came to pass, using O'Connor and Veryzer's (2001) flows of visioning framework. In the end though, I found some evidence suggesting that the need for visionaries isn't quite as universal as I may have assumed.

A. The Prevalence & Importance of Visionaries in the Fuel-Cell World

Sprouting Up All Over the Place

When I first set out to study the fuel-cell industry, I expected to find it rife with visionaries and champions. I was not disappointed. The industry seems to have a knack at attracting "dreamers such as Nick Abson, a committed environmentalist who gave up a career as a television and video producer to take over a struggling Belgium company, which became ZeTek Power" (Dunne, 2001a, p. *1). Mr. Abson "sees [fuel-cell] technology running everything - from cars to aircraft, to malls and skyscrapers - while saving the planet" (Dunne, 2001a, p. *1). More to the point, out of the 12 respondents I asked, only two declined to be described as visionaries (or to describe their executives as such), one because he was not comfortable with the label, and the other because he wasn't sure he could indeed be called a visionary, although, as he puts it, he "saw the handwriting on the wall, as it were" back in 1972/73 (Interview - Hoffmann). On the other hand, the CEO of Hydrovolt, John Lucas, was not reluctant in the least to call himself a visionary. When I asked him whether he would describe himself as such, he replied: "Sure I would. How many people can envision a society where we drive ultra efficient non polluting vehicles, and use our garbage as fuel to create our own electricity? Not too many I think" (Interview - Lucas).

Consensus on the Importance of Visionaries in the Industry

A strong majority of those interviewed, both company founders and their employees, also agreed that visionaries have played a very important role in the industry's development, particularly before fuel-cells truly became serious contenders and attracted the attention of established businesses. Peter Hoffmann, who as Editor-in-chief of the Hydrogen & Fuel-Cell Letter since 1986, is a shrewd observer of the industry, wrote " I think there were/are a lot of visionaries - many scientists, but also environmentalists and others - who played a key role in pushing hydrogen before it became fashionable" (Interview - Hoffmann). He himself, back in 1972-73, wrote one of the first pieces on the possibility of using hydrogen as a fuel for Business Week, and his first book on the subject, The Forever Fuel - The Story of Hydrogen, was published by Westview Press in 1981, long before fuel-cells became trendy (Interview - Hoffmann).

A Selection of Key Visionaries

Perhaps the best way to demonstrate the important role of visionaries in this emerging industry would be to consider some of the key individuals who, over the years, have struggled to make fuel-cells a commercial reality. Without a doubt, one of the better known and most influential of these would have to be Geoffrey Ballard. Now 68, he and his two partners, Paul Howard and Keith Prater, first began working on fuel-cell technology in 1983, at the behest of the Canadian military (Ballard, 1999). As their research progressed, Ballard realized that PEM fuel-cell technology could eventually be used to power cars and, in the summer of 1989, he persuaded a Vancouver official[25] to back the development of a municipal fuel-cell bus (Ballard, 1999). The rest, as they say, is history.

Another long-time proponent of fuel-cells for vehicles is Amory Lovins, co-founder of the Rocky Mountain Institute (a think-tank) and, according to the Economist, “one of the world’s most energetic visionaries” (The Economist, 2001b, p. *1). Indeed, he wants to redesign the car from scratch, to make it as environmentally friendly as possible (The Economist, 2001e). And he seems to have succeeded, after almost a decade of work. The concept car his institute has recently unveiled, christened the Hypercar, “features all-electric propulsion, a 100% composite body, highly sophisticated electronics and software, a radically simplified and integrated design and, crucially, a fuel-cell stack to power the whole thing” (The Economist, 2001b, p. *1). Lovins’s vision is ambitious and radical: he sees Hypercars becoming widespread in 5 years, and dominant in 10 (DeJong, 2001). He even predicts that the automobile industry, in its current form, will no longer exist twenty years from now, because “it will buckle under the weight of being (...) enviro-political, slow-moving [and] business-as-usual” (DeJong, 2001, p. ~42).

Still, this vision almost pales in comparison to Professor Bragi Arnason’s, who is affectionately known as “Professor Hydrogen” in his native Iceland (The Economist, 1999b). For the past two decades, Professor Arnason has been waging an uphill battle to convince his countrymen to turn their small, nordic nation into the world’s first hydrogen-powered economy[26]. Iceland is already by far the world’s greatest user of renewable energy sources: 99% of its electricity is produced with geysers and hydroelectric dams[27] (Davidsdottir, 2001). And yet, it is also one of the word’s greatest per capita emitters of carbon gasses, and it has to import large quantities of oil to cover 40% of its energy needs (Davidsdottir, 2001). This is because its substantial fishing fleet (on which 85% of its economy depends), runs on diesel fuel, producing one third

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[25] "Can you get me a green photo op?" he’d asked Ballard (Ballard, 1999).

[26] Canada may also be one of the first countries to widely use hydrogen as an energy source. Indeed, “Canada enjoys 2 primary advantages: 1. cheap power for electrolysis of water, and 2. abundant hydrocarbons for upgrading (Anonymous, 1984, p. ~28).

[27] And only about 16% of the country’s potential is currently being exploited (Davidsdottir, 2001)!

of the country's CO_2 (The Economist, 1997a). Equipping these 2,000 boats with fuel-cells would significantly reduce the country's emissions and help it meet is obligations under the Rio agreements. So, in 1999, "Professor Hydrogen" finally got his way when Iceland pledged to become a hydrogen economy by 2030-2040 (The Economist, 1999b). The Icelandic Hydrogen and Fuel Cell Company Ltd[28], was established soon after this announcement. It brings together Vistorka hf., DaimlerChrysler AG, Norsk Hydro ASA and Shell International BV, who together will implement a six phase plan that will gradually convert the country's entire fleet of cars, buses and, most importantly, boats, into fuel-cell vehicles (Árnason and Thorsteinn, 2000).

The Heavy-Weights

Even more influential, I believe, than these key individuals are what I call the "Heavy-Weights," namely the leaders of powerful incumbent firms who can also be described as visionaries and who, more than most, can ensure that their vision is actually achieved. Intuitively, one would think that incumbents will be much more dispassionate about fuel-cells than dedicated start-ups, and indeed many are. But there are some very notable exceptions. Sir Moody-Stewart (the recently retired chairman of Shell) was personally a strong advocate of the hydrogen economy (Interview - Bosch). Indeed, in his speech at the International Hydrogen Energy Forum (2000, *1), he declared: "I have, for quite some time, taken a personal interest in the development of hydrogen energy technologies. I find current developments in this field truly exciting; we may be part of the creation of a significant new industry, a great new business that will be able to deliver even cleaner and cheaper energy." He and other board members (such as Don Huberts, head of Shell Hydrogen -The Economist, 1999b) were truly visionary in that they glimpsed what the future would (or should) be like, and then strived to turn their vision into a reality. Yet, being after all the leaders of a publicly own company, they did so "from a clear business perspective and always with shareholders in mind" (Interview - Bosch).

Perhaps the two greatest fuel-cell proponents in the world of Big Business are, ironically enough, the chairmen of DaimlerChrysler and of Ford, the two companies that

[28] Later to become The Icelandic New Energy Co. Ltd.

were respectively the first to build and mass-produce internal combustion engines. Jürgen Schrempp, chairman of DaimlerChrysler, is without a doubt very enthusiastic about fuel-cells. He is quoted as saying: "we are investing in fuel cells because we are committed to sustainable mobility and because we believe this investment will pay off. Fuel cells have the potential to be the most attractive alternative propulsion system for the long term" (*in* Renzi and Crawford, 2000, p. 41) and: “the problem of how to ensure sufficient supply of energy that is environmentally friendly is the key challenge of the future, and we see fuel cells as the solution” (*in* The Economist, 2001b, p. *1).

If possible, Billy Ford Jr., Ford’s co-chairman (and its founder’s great-grandson), is an even more fervent believer in fuel-cells, which is an impressive feat, considering “Ford executives scarcely knew what a fuel cell was” back in 1996 (The Economist, 1998c, p. *1). He has declared that "fuel cells could end the 100-year reign of the internal-combustion engine. In 25 years, fuel cells could be the predominate automotive power source” (*in* Popely, 2001a, p. *1). Indeed, he believes fuel-cells “will be the driving force behind his company in the next century” (The Economist, 1999b, p. *1). So though some of the car company’s executives saw the move into fuel-cells as defensive (to keep up with Japanese rivals), Billy Ford, Jr. is a “true believer” (The Economist, 1998c).

B. All Three Flows of Visioning are Present in the Industry

Now that we have determined that visioning is in fact widespread and indeed critical in the fuel-cell business, let us consider how some of the industry’s visionaries elaborated their visions, and how these in turn took hold in their organizations.

The Second Flow of Visioning: the Vision Comes From Initial Involvement

Many of the industry’s pioneers, who can now be described as visionaries, simply started conducting fuel-cell research for the government long before anyone thought fuel-cells would actually become commercially viable by the turn of the century. H Power, for instance, was formed by half-a-dozen scientists back in 1990 and was originally a very modest, research-focused company. Its founders only started to see the commercial potential of their research in 1995-1996 (Interview - McNeill). Similarly, Bob Hockaday's interest in fuel-cells started out as a passion and only later became a commercial project. He first dabbled with fuel-cells in 1974, when he was still in high school. His first prototype caught fire in his mother's oven, but his Hockaday fuel-cell is now one of the more advanced models available (Chase, 1998).

The First Flow of Visioning: the Initial Vision Leads to Involvement

Though many in the industry were thus involved with fuel-cells before envisioning its commercial potential, others decided to join it after they'd realized the potential the technology had. For instance, Jerry Leitman, FuelCell Energy's CEO, explains that "I was looking for a business to start up or take international. What intrigued me was the idea you could build a 3-megawatt power plant the size of a tennis court that can generate power at the 5-6 cents per kilowatt hour range that is absolutely clean and quiet. And you can put it anywhere. That's what brought me here. That's a killer app, that's an absolutely killer app" (Kopicki, 2001, p. 76).

John H. Perry Jr, who formed Energy Partners in 1990, also entered the industry after having identified its promise (although he'd begun devoting his energies to the development of renewable energy over a quarter century ago). He could even be described as a professional visionary: "John H. Perry, Jr. (...) has a long, rich history of identifying emerging markets and successfully seizing the opportunity in several industries. Mr. Perry has been instrumental in computerizing the typesetting industry, predicting the success of the cable industry, developing some of the first underwater laboratories and robots" (Energy Partners, 2001).

Of those I personally interviewed, Mr. Bentley describes how he serendipitously learned about fuel-cell technology when asked to conduct some consulting work on the subject by his firm, Arthur D. Little, on behalf of its client, the US Government. He quickly became very intrigued by the technology, and convinced his firm to start its own fuel-cell research (Interview - Bentley). By 1992/93, he saw that the window of opportunity for commercialization was on the verge of opening, and he thus decided to focus on fuel-cells from then on. Eventually, his company Epyx was founded as a separate unit of Arthur D. Little[29]. Ironically enough, though Mr. Bentley had been

[29] It eventually merged with the Italian firm De Nora to form Nuvera in 1999.

interested in finding alternatives for petrol and diesel since 1985, he was the first to suggest that fuel-cells should run on gasoline (Interview - Bentley). Initially denounced by his more environmentally-minded colleagues in the industry, but at present, both GM and Toyota have decided to focus their R&D efforts on developing fuel-cells capable of being fed gasoline.

Finally, another example of this first flow of visioning is provided by Sure Power. Arthur Mannion, one of the company's cofounders, had been trying to figure out a way to keep energy costs down for a school (a client of his strategic consulting and capital formation firm, Bedrock Consulting & Capital), when he came across fuel-cell technology (Interview - Mannion). He and his future partner, William Cratty (presently Sure Power's President, and previously working for IFC's Onsi Corporation to market its PC25 unit) thought the technology was really wonderful, and were convinced that IFC's uninspired marketing wasn't up to its potential (the venerable firm was only selling 10-15 PC25 units a year in the early 1990s). So they decided to set up their own fuel-cell business. In other words, here was a great technology, now they just needed a market to sell it to. Eventually, they hit upon the idea of tackling the premium power market (please see the section on niches for more information), envisioning "reliable, long-lasting, cheap power independent of grid" (Interview - Mannion).

The Third Flow of Visioning: Flexibility in Action

Few of the companies I studied could be said to have followed the third path of visioning, according to O'Connor and Veryzer's (2001) framework. The ones that did are invariably incumbents. For example, DTE, a traditional utility, realized that electricity deregulation would change the rules of the game in the energy industry. In order to be able to keep meeting its customers' needs, it set off to identify technologies that could give it an edge in the distributed power business that will likely emerge. Fuel-cell technology was one of the technologies deemed promising, and so DTE formed Plug Power with Mechanical Technology of New York (Interview - Rollins). But DTE is keeping its options open, and is also developing other technologies that could be applied to distributed power.

Global Thermoelectric is an even clearer example of this third flow of visioning. The company had 95% of the world thermoelectric generator business, leaving little room for expansion... (Interview - Kryzan). It realized that its current clients in the oil and gas industries, and also potential clients in the telecommunications business, would increasingly be needing cheap, reliable sources of power in remote locations. But, according to Mark Kryzan, the firm's "thermoelectric generator technology, while highly, highly reliable is too dear for these markets and is cumbersome to develop into large systems of + 5 kW." Therefore, they "conducted a worldwide search to find a synergistic technology .... synergistic in the sense that it both offered a solution to our clients needs as well built on the know-how we had in developing systems that operate at high temperature and involve electricity. Our clients primarily used propane or natural gas as a fuel" (Interview - Kryzan). Solid oxide fuel-cell technology seemed promising, as it could run off hydrocarbons and be scaled down to 1-25 kW applications, and Global Thermoelectric thus decided to become a player in the fuel-cell industry, although this was a technology it had no experience with.

C. When Vision is Replaced by Reason

Though the fuel-cell industry is especially adept at attracting and producing visionaries, some of the people I interviewed did not approve of the term, or rather did not wish to be described as visionaries. Explaining this mind-set, Bob Rose wrote that, though "there is a visionary aspect to every unconventional venture," "there are hard-headed businessmen who have devoted more than 40 years to pursuing the vision of commercial fuel cells. That makes them visionaries though not all would be pleased with the title." He went on to point out that "in the fuel cell industry, the influx of billions of dollars in capital has dramatically expanded the number of people working in the industry and probably as a result has reduced the percentage of visionaries, but not the absolute number" (Interview - Rose).

Followers are Becoming More Frequent

Indeed, I found that many of the newer entrants in the fuel-cell industry, particularly when they are big incumbents in other related industries, couldn't really be described as visionaries, but more as prudent followers. Their interest in fuel-cells was motivated not so much by a proactive vision but by a combination of calculation and fear. They are often (not always) acting defensively in order to ensure their survival, just in case fuel-cells do become a major force to be reckoned with. Because they have considerable resources at their disposal, they can afford to invest in fuel-cell development on the side, as if they were taking out an insurance policy. Many of the car-makers illustrate this sensible mind-set very nicely. As Dr. Stannard (cynically?) points out, though they are devoting billions of dollars to fuel-cell development, "ask yourself how much they're spending on advertising. If fuel cells pay off, then they're way ahead technologically. If not, they've spent very little money to get the government off their backs. The average auto executive is a very canny beast" (Libin, 2000, p. ~97). Energy providers and electric utilities are also quite eager to cover all their bases, and thus avoid leaving themselves vulnerable to a potential fuel-cell breakthrough. Shell's recently retired boss, Sir Mark Moody-Stuart (although himself a visionary), sums up this very sober and pragmatic business philosophy by insisting that his company wants to meet its customers' energy needs, whatever they may be and even if it means leaving hydrocarbons behind (The Economist, 2001c).

The Search for Synergies

Some enterprising incumbents seem to have simply bypassed vision altogether, and have instead determined that there are important synergies to be had should they associate a fuel-cell program to their present businesses. For example, when Mr. Tangeman, from Dupont, described how his company had decided to enter the fuel-cell business as a component and materials supplier, he emphasized the fact that it was already involved in many relevant industries (namely polymers, coatings and electrochemicals). Even so, the firm proceeded very cautiously: a work group assigned to study the question labored for about a year before delivering its recommendation (Interview - Tangeman). Dupont wanted to make sure the technology was proven and had good credentials before allocating any resources to the field.

Johnson Matthey also decided to enter the emerging fuel-cell industry because it would be a good fit with its existing businesses, namely its leading position in the commercialization of platinum and related metals (Dandy, 2001) and most importantly its expertise in auto catalysts which, according to Mr. Colin Jaffray, are very similar to fuel-cells (Interview - Jaffray). Thus, Mr. Jaffray describes Johnson Matthey's move into the fuel-cell business as “organic.” The firm first supplied platinum to other companies[30], in particular Ballard Power Systems, with which it has a close partnership, but also International Fuel Cells (for the space program)[31]. But it soon realized that its strength in precious metal catalysts could be mustered to significantly improve fuel-cell technology (Interview - Jaffray). Indeed, “in order to better understand the workings of a catalyst in a fuel cell system and thus improve them continually for competitive advantage we make-up effectively mini-fuel cells and test the catalyst as part of, and interactions within, a system. In so doing we start to develop our way up the value chain” (Interview - Jaffray). Yet the venerable British company is not planning to actually commercialize complete fuel-cells, but rather their key components such as Membrane Electrode Assemblies (which are in effect single cells). As Mr. Jaffray writes, “JM isn’t going to make fuel cells, but rather the key components, sub-systems and advanced materials that go into them (the 'JM inside' approach). Thus we expect to be a Tier 1 development partner but Tier 2 or 3 in the supply chain. Even so, the JM materials may well comprise 40% of the cost of a fuel cell system” (Interview - Jaffray).

D. The Importance of Visionaries Should not be Exaggerated

My research certainly confirmed the pervasiveness of visionaries in an emerging industry such as fuel-cells. Indeed, and partly to my surprise, even some large incumbents can boast that they are led by such prescient individuals. Perhaps this ubiquity of visionaries in an emerging industry is to be expected, if what Wayne Hartford, CEO of Energy Ventures[32] writes is true: “I think that anyone who is contemplating next generation needs is visionary” (Interview - Hartford).

Visioning is a Complex Process but can be Guided by the Analysis of Merit

Though apparently widespread, I found that visioning is exceedingly difficult to divide into distinct categories, such as those suggested by O’Connor and Veryzer

[30] Not to mention Sir William Grove himself, back in 1838! (Interview - Jaffray).

[31] Other partners include H-Power, DeNora, Siemens, Energy Partners and Plug Power.

[32] Which appropriately enough recently changed its name to Energy Visions.

(2001). In truth, one usually can't point to an exact time and place and assert that this is when and where the vision occurred. It is a complex, dynamic, activity that takes place over time. As Mr. Mannion explained, the important thing is to envision the technology's killer application, which all new disruptive technologies need in order to break into the limelight, but most people, when they first get involved with a technology, have absolutely no idea what this killer application will be. Visioning is thus an evolutionary process, and has to carefully take into account the market's needs and the technology's capabilities if it is to be successful (Interview - Mannion). This actually suggests a link between the *need for merit* and the *need for champions and visionaries.* Indeed, the very process one engages in to determine whether a particular technology is worth developing can lead one to elaborate a vision of what the technology can and should achieve.

The Importance of Visionaries Varies in Time

My research also seems to have demonstrated, to a certain extent, the importance of visionaries in an emerging industry. Indeed, if the fuel-cell industry is any guide, emerging disruptive technologies depend on visionaries to bring them to the fore. But visionaries are not always needed, nor even present. For instance, when fuel-cell development first started in earnest, it seems that most of those involved in the industry were not visionaries[33] but simply researchers intrigued by the technology, and content to be paid by the government to study it. Inversely, now that fuel-cells are almost universally recognized as being a very promising technology in the near to mid term, the importance of visionaries has once again dwindled, quite simply because they are no longer needed to drive fuel-cell development forwards. The commercialization of fuel-cells has, in a way, acquired a life of its own.

Mr. McNeill, of H Power, described this evolution well. He explained that companies in emerging industries usually go through a number of phases, and that the initial visionary-entrepreneur often doesn't see this process all the way through, simply because he or she doesn't have all the requisite skills to do so (Interview - McNeill).

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[33] Or, if they were, they reasoned in the very long term and did not think it likely that fuel-cells would be commercialized any time soon.

For instance, H Power had been the creation of half a dozen researchers who'd felt that fuel-cells would be big someday, and that they should therefore work on them, but they had not realized how quickly fuel-cells would become practical. When it became clear that the technology could soon become commercially viable, a new management team (including the firm's current CEO, Dr. Frank Gibbard) came in and rationalized their efforts so as to focus on developing practical prototypes. Now, all but one (Dr. Arthur Kaufman) of the early founders have left, and H Power has just entered the third phase, which is when the company can and must be geared up for actual production, and change its mind-set accordingly.

So though the company continues to be led by a visionary, namely Dr. Gibbard, other skills have become just as, if not more, important, and his visioning isn't enough to ensure H Power's success. The company also needs someone who knows the technology's capabilities (Dr. Art Kaufman, Chief Technology Officer), someone who understands the market's needs (Paul McNeill, VP of Business Development), someone who grasps the intricacies of mass-production (the new COO), and someone who can find the cash to finance all of this (William Zang, Chief Financial Officer). (Interview - McNeill). Basically, it would seem that to achieve greatness, a company will need a powerful and appealing vision, but also a coherent and practical plan to achieve it.

The Need for Visionaries can be Ignored by Individual Firms

No doubt the industry as a whole needs visionaries, but single firms can do quite well without them. Not every company currently developing fuel-cells was founded or is led by a visionary. Many firms, including most of the large incumbents, decided to develop fuel-cell technology in order to make sure all their eggs weren't in the same basket, or for other conventional strategic reasons (the search for new growth opportunities, the desire to profit from synergies...). And now that many big companies are actively involved in commercializing fuel-cells, followers are joining the industry in ever greater numbers, confident that, if Ford and GE are into fuel-cells, then they must be worth something. Indeed, Mr. Hoffmann writes that "I think Daimler-Benz's early decision to build fuel cell prototypes in 1993/94- their alliance with Ballard then and shortly afterwards with Ford - were probably among the main seminal impulses jump-starting the stampede [of firms into the industry,] on the assumption that if big guys like these are moving into this area, there must be something to it. There are still a lot of visionaries, but there are also a lot of people who jumped on the band wagon to make the next big buck" (Interview - Hoffmann).

Passion and Vision

Finally, it is by studying the role of visionaries in the fuel-cell industry that I came to the insight that passion can be a very important strategic resource. Indeed, it is the visionaries who, passionate about the technology and its potential, infuse their passion into their colleagues and employees and so drive their progress along the slow and arduous path towards commercialization. Vision and passion are intimately linked, as I will argue in this dissertation's second part.

5. THE NEED FOR COOPERATION but Cut-throat Competition Endures

I will first briefly consider in what ways the approach of commercialization has modified relationships within the industry, by accentuating rivalries and discouraging the sharing of information. However, cooperation remains vital, and is recognized as such by the firms in the industry. Indeed, cooperation is widespread, and takes many different forms, although it is possible to identify three basic ones: horizontal cooperation (between immediate rivals), vertical cooperation (between suppliers and their customers) and finally associations and councils, which attempt to bring companies with very varied backgrounds together in order to accelerate the commercialization of fuel-cells. We will consider each in turn before concluding.

A. Times They are a Changin'

A Previously Close-Knit Community

Before beginning my research, I'd imagined the fuel-cell community to be rather small and close-knit, and to consist mostly of idealistic researchers and businessmen who were eager to share information with each other (within limits of course!) in order to facilitate and accelerate the commercialization of fuel-cells. But I quickly realized that this, rather naive, preconception of mine was a few years behind the times. According to Paul McNeill, of H Power, most of the people in the industry do indeed know each other well, principally because they used to work together in government labs (Interview - McNeill). He describes the fuel-cell community as still being quite incestuous, with a lot of personnel swapping taking place (Interview - McNeill). Thomas Bosch, of Shell, agrees that there is a "strong fuel-cell oriented community" (Interview - Bosch). So, when fuel-cell technology still had to overcome many technical challenges, the members of this community were quite willing to help one another out (Interview - Bentley).

Imminent Commercialization Discourages Cooperation

But now that commercialization is looming, there is much less cooperation, much less sharing of information (Interview - Bentley). This is to be expected, as the distinct prospect of profit discourages the revelation of anything that could prove helpful to one's rivals. Moreover, many fuel-cell companies are now public, and so are accountable towards their shareholders, which limits their room for maneuver (Interview - Bentley). After all, shareholders tend to frown upon any activities that could smack of nepotism, or weaken their firm's competitive position. Therefore, the only information currently shared is contained in the papers that are published (Interview - Lucas), which often reveal very little.

Peter Hoffmann, editor of the Hydrogen & Fuel Cell Letter, agrees that "fuel cell technology advances used to be fairly widely shared at seminars and conferences, but I'd say [that] in the last 2-3 years it has become much more competitive and secretive -projects have become increasingly "black," and it's getting harder to get information out of companies; the PR guys are increasingly in the act, and they carefully parcel out information. (...) They aren't letting the other guy know how far along they are, and with what specific technology and efficiencies" (Interview - Hoffmann). Practically all those I interviewed confirmed this state of affairs. Mr. Faul, of Greenvolt, was particularly dismissive of any kind of solidarity in the industry: there are no "helping hands," and everyone is "keeping everything close to their chest" (Interview - Faul).

Cut-Throat Competition

Indeed, there would seem to be much less communication, let alone cooperation, between rival fuel-cell companies than I'd originally suspected. When asked whether they often come into contact with their colleagues from rival firms, both John Lucas and Thomas Faul affirmed they did not (Interview - Lucas and Interview - Faul). Actually, avoiding contact doesn't seem unreasonable, if what happened to PowerTek is any guide to typical practices in the industry! Mr. de Groot told me that, just a few months ago, his company had had to take legal action against a rival who'd managed to take pictures of sensitive equipment and manufacturing processes during a visit (Interview - de Groot).

In general, according to Mr. Kryzan, "the sector is very competitive. All companies are very busy protecting their intellectual property, securing and locking up supply partners etc..." (Interview - Kryzan). Everyone has their secrets, particularly when it comes to their membranes. PowerTek alone has over 47 different items of intellectual property, mostly in the form of trade secrets (Interview - de Groot), and Ballard has over 500 patents issued or pending worldwide (Ballard Power Systems, 2001a). As Bernadette Geyer, of the US Fuel Cell Council, was keen to point out, this proliferation of patents and the intense competition that drives are a good thing. Rivalry helps to spark progress (Interview - Geyer). Nevertheless, as Mr. Matthey writes, "protectiveness of [intellectual property] is a big feature of this industry, everybody is incredibly protective of information. So much so it may actually inhibit the commercialisation of fuel cells.............'if a company A won't share information, be it marketing, cost, timings or whatever with a supplier, how is supplier B supposed to develop its own plans?' - a crude example but not a million miles from some situations" (Interview - Jaffray)

B. But some form of cooperation remains vital

Cooperation is Necessary and Will Undoubtedly Occur

Despite a clear consensus that the industry is very competitive, and that secrecy within it is endemic, none of the companies I studied is planning to go it alone. Indeed, Jacques de Groot believes that cooperation will necessarily spring out, no matter how intense the competition. It is in everyone’s interests to see fuel-cell technology succeed: industrialized and developing countries, international organizations and fuel-cell companies... All will want to promote cooperation so that standards (especially regarding security) can be established (Interview - de Groot). Mr. Kryzan also agrees that self-serving motivations will eventually “[bring] about cooperation to an otherwise very competitive industry,” since “companies do need to cooperate to get interconnect requirements (with the grid), regulations and other standards adopted and everyone would welcome tax incentives for fuel cell products” (Interview - Kryzan). Thomas Bosch, of Shell, points out that it is already “clear to most parties involved that 'we need each other' to put all the pieces of this new economy together” (Interview - Bosch). Again, he emphasizes the need for standards and regulations, for common practices and rules, in order to accelerate the arrival of a hydrogen economy (Interview - Bosch).

Why this preoccupation with cooperation? Well, as Mr. Schrempp, DaimlerChrysler’s chairman puts it, “we need partners in government and in the oil industry” (*in* Renzi and Carwford, 2000, p. 46), because one company acting alone cannot hope to transform an entire industry. Dr. Panik is just as adamant that “in order to be successful in introducing new technologies on the market, business, government and science must work in closer collaboration... Automakers must develop affordable, practical vehicles that meet customer needs, and the fuel providers should work on availability, affordability and volume production of methanol fuel. Government agencies should take this opportunity to promote and support environment-friendly mobility" (*in* Renzi and Crawford, 2000, p. 46). Both insist on the need to enroll the oil companies in any serious commercialization effort, since they” know that their plans to introduce fuel-cell vehicles will succeed only if a fuel is available. And that means persuading oil bosses that fuel cells are both a serious technology and a potentially profitable one” (The Economist, 1999b, p. *1). They are also aware that government help will be critical, as we have already seen.

Nobody has Everything it Takes to be Successful

And the car companies aren’t the only ones to see this need. According to Bob Rose, the US Fuel Cell Council’s executive director, "about every fuel cell company I know is either seeking a partner, has a partner, or would like to have one” (*in* Johnson, 2000, p. ~28). Indeed, H Power is not alone in listing the establishment of partnerships as one of its key strategic goals in the short term (H Power, 2000). This obsession with finding partners is quite simply caused by the fact that "it's relatively unusual for a company to go from soup to nuts on its own. A company like United Technologies might be able to do it, but that's only because it has Carrier in-house, whereas a company like Plug Power needs a GE Fuel Cell Systems in order to get access to not just the GE badge, but also the market that GE already sells into" (Rose, *in* Johnson, 2000). Thus access to distribution channels is one key reason driving this frenetic match-making, as are the search for investment and technological expertise (Johnson, 2000).

C. Horizontal cooperation

Not as Prevalent as Suspected

Reasoning that there is strength through unity, I expected to find that many fuel-cell companies had teamed up in order to face their larger rivals. In truth, however, horizontal link-ups (ie link-ups between firms that are at the same level in the value chain) are not extremely frequent. Some do happen though, and these tend to involve actual mergers or acquisitions or, more often, joint-ventures. Thus, Mr. de Groot informed me that PowerTek International has already purchased other fuel-cell companies in order to obtain access to their research, and other acquisitions are likely in the near future (Interview - de Groot). For similar reasons, Fuel Cell Technologies did a reverse takeover of ThermicEdge Corporation in 2000, and H Power set up a joint-technology development program with Epyx (which later merged with de Nora to form Nuvera Fuel Cells) in January of 1999 (H Power, 2000).

Large Companies Favor Joint-Ventures

Meanwhile, larger companies generally prefer joint-ventures, as they are only interested in combining their fuel-cell activities, not their entire businesses, and they want to avoid the large expenses incurred through M&As (basically, big firms tend to avoid exclusive deals, as they are very reluctant to lock themselves in -Interview - McNeill). So, for instance, UTC and Toshiba, which already jointly own International Fuel Cells (with 88% and 12% of the shares, respectively), set up a joint-venture last year to market stationary fuel-cells in Japan. By combining their research efforts, both companies will eliminate duplication and UTC will benefit from Toshiba's experience concerning the Japanese market (UTC, 2000)

But the two alliances that have received the most media coverage are without a doubt those of Ballard, DaimlerChrysler and Ford on the one hand, and GM and Toyota on the other. I will consider the first one in some detail in a separate case study (see appendix 12). In the meantime, why have GM and Toyota, which together manufacture 25% of the world's cars, agreed to jointly develop fuel-cells, as well as battery-powered and hybrid cars (The Economist, 1999a)? Well, GM's Vice-chairman, Harry Pearce, sums up their reasons when he says that "both companies are capable individually of doing their own alternative fuel vehicles. But our joint efforts will yield the best solutions, in the fastest timeframe, at the lowest cost, to reach the most people" (*in* Eisenstein, 1999b, p. ~14). The two giant car-makers, who are particularly interested in refining petrol-reformers, so that gasoline could become a viable fuel for fuel-cell equipped cars, have recently added Exxon Mobil to their alliance (The Economist, 2001f). They believe, probably rightly, that this would significantly improve the feasibility of fuel-cell technology's widespread commercialization.

Other car-makers have also forged ties. BMW, Delphi and Renault are jointly working on solid oxide fuel-cell technology, not to power their cars per se, but to incorporate into light and heavy-duty diesel trucks. By replacing their battery systems with fuel-cells, these vehicles will be able to run their electrical and electronic systems, and most importantly, auxiliary electrical devices, independently of the engine (Anonymous, 2000a).

D. Vertical cooperation

The Importance of Cooperation Along the Value Chain

Whereas there is much less horizontal cooperation in the fuel-cell industry than I'd expected, there is widespread vertical cooperation. The vast majority of the people I interviewed insisted on the importance of teaming up with suppliers and distributors. Mr. Tangeman was particularly insistent on the need for cooperation along the entire supply chain, ie including customers as well (Interview - Tangeman). Indeed, most of the companies I studied are above all fuel-cell designers and manufacturers. They do not produce the fuel-tanks, fuels or reformers that fuel-cells require. Nor, in many cases, do they build the systems that will regulate and control their units. Thus, forming partnerships with all these complementary industries is critical, in order to ensure that the fuel-cells will run optimally (Interview - McNeill).

Ballard's boss, Firoz Rasul, is very much aware of the fact that "fuel cells need more than just the basic stacks and electrodes to earn their keep. They need whole systems, for control and so on, that are adapted to the particular application they have been designed for. Thus it takes a power company to see how best to adapt them into electricity generation. And it takes a car company of the stature of Daimler to work out how to tailor them to best effect in cars or buses" (The Economist, 1997b, p. *1). The need for all this various expertise suggests that there is no blanket solution: fuel-cell companies (at least those which are not focusing on very specific niches) will need to establish several strategic alliances and partnerships, at the very least one for each market they are targeting (Interview - Stannard).

Examples of Vertical Cooperation

Examples of such partnerships abound, especially in recent years, as fuel-cell technology has finally matured enough to become truly credible. Thus, after more than two decades of research, Medis Technologies has just formed two major alliances, with Sagem SA and General Dynamics Communication Systems (Medis Technologies, 2001). Sagem SA wants to use Medis's fuel-cells to power its mobile devices, in particular its cell phones, whereas General Dynamic's subsidiary is planning to manufacture fuel-cell powered equipment for the US Department of Defense (Medis Technologies, 2001). And Medis Technologies is hoping to sell or license its technology to, as well as enter into joint-ventures with, several other large multinationals (Medis Technologies, 2001).

Meanwhile, PowerTek has struck an agreement with Anton Bauer, the leading producer of batteries for professional cameras, which will be in charge of commercializing its fuel-cells (Interview - de Groot). PowerTek is also teaming up with database management companies, such as Enron. Indeed, Jacques de Groot told me that their strategy is very alliance-oriented, since they not only want to focus on the manufacturing side of the business, they also plan to out-source much of the production of their fuel-cells' components, leaving them free to concentrate on final assembly, design and quality control (Interview - de Groot).

Just last summer, GM announced it was acquiring a 15% stake in General Hydrogen Corp (which was founded by Geoffrey Ballard, who remains the company's chairman), as part of their agreement to cooperate regarding the development hydrogen-related technologies (Garsten, 2001). At the same time, GM also revealed the purchase of 20% of Quantum Technologies shares, which is "developing a tank that can withstand hydrogen stored at 10,000 pounds per square inch, making it possible for a fuel cell vehicle to travel up to 800 kilometres on a fill-up, about four times the distance current hydrogen-storage tanks permit" (Garsten, 2001, p. *1).

Of course, not all such partnerships are brand new. Early in 1999, Black & Veatch, a global engineering and construction company signed a memorandum of understanding with Avista Labs (some of whose stocks are owned by none other than Bill Gates). Black & Veatch will market and distribute, and help to install, Avista's fuel-cell units which are targeted at "large residential, commercial and industrial greenfield projects where the firm provides fully-integrated infrastructure development and construction" (ENR, 1999, p. *1). And in August of 1999, H Power and ECO (a large association of US rural cooperatives) signed a 10-year, mutually exclusive marketing, distribution and servicing agreement (H Power, 2000).

Comical Complexity

Sometimes, the networks of relationships one finds in the industry can almost become comically complex. The joint venture linking DTE Energy Company and Mechnical Technology Inc, for instance, resulted in the creation of Plug Power in June 1997. MTI had the knowhow, DTE had the capital, as well as the marketing, sales and distribution network (Smith, 1999). Plug Power itself later formed a joint-venture with GE Power Systems's subsidiary, GE MicroGen (GEMG), in February 1999. Called GE Fuel Cell Systems, this company will "market, sell, install, and service Plug Power-designed and -manufactured fuel cells (...) for residential and small business power applications" (Norland, 2000, p. 20). And, just to make things a little more complicated, GE Fuel Cell Systems is planning to team up with energy companies that can give it access to residential and small commercial customers, and also provide it with a local sales presence and service infrastructure (Norland, 2000).

Vaillant GmbH (Germany), New Jersey Energy Resources, Kubota (Japan), KeySpan Energy, and Flint Energies (Georgia) have already signed up, and now two more companies have joined as well: Soroof Trading Development Company of Saudi Arabia, and RahimAfrooz of Bangladesh (GE, 2001). In turn, these firms are seeking out their own partners. Thus, “Soroof is in the process of establishing alliances with the local and national utility companies to make stationary power fuel cells available to anyone in the Kingdom, even in the most remote regions of Saudi Arabia," according to Prince Bander Bin Abdullah Al-Saud, President and CEO of Soroof Trading Development Company (*in* GE, 2001, p. 1). All in all, "GEMG's distribution network now extends to 8 countries on 3 continents and covers approximately 40 million residential customers. Deals currently in progress cover 7 additional countries and over 60 million additional residential customers," according to Barry Glickman, GE MicroGen’s president (*in* GE, 2001, p. 1).

E. Industry Associations and Councils

Multilateral Cooperation

Of course, cooperation needn’t be confined to bilateral (or trilateral) relationships. As a matter of fact, many associations and trade groups exist in order to promote multilateral collaborations within the industry. For instance, I earlier on briefly alluded to the existence of many associations that revolve around specific types of fuel-cells or particular applications. It is impossible to list them all within the confines of this dissertation (which is already way over the word limit...), but two of the more intriguing ones are worth a closer look. They are the methanol alliance and the California Fuel-Cell Partnership. The former brings together BASF (catalysts and methanol handling and processing), BP (fuel retailing), DaimlerChrysler, Methanex (the world’s biggest methanol producer), Statoil (fuel retailing), and Xcellsis (a methanol fuel-cell manufacturer jointly owned by DaimlerChrysler, Ballard and Ford). These companies wish to study the practicality of using methanol as a fuel-cell fuel, in the hope of eventually commercializing it (Scott, 2000). As for the California Fuel Cell Partnership, I described it in detail in the section on the role of the government (see above).

The US Fuel Cell Council

Other associations are more ecumenical. Peter Hoffmann referred me to two of the principal ones, namely the World Fuel Cell Council, based in Frankfurt (Germany) and run by Marcus Nurdin, and the US Fuel Cell Council, run by Bob Rose (Interview - Hoffmann). These are perhaps the best forums for the organization of conferences and trade shows, as well as the establishment of codes and standards. The US Fuel Cell Council (USFCC), for instance, is "dedicated to supporting the commercialization of fuel cell technology through education, technical exchange and market evaluation" (Anonymous, 1999a, p. 18). Its founding members, back in 1999, included 3M, the American Methanol Institute, Ballard Generation Systems, Daimler Benz, DuPont Fluoroproducts, Energy Partners, Energy Research Corp., EPYX Corp., Ford Motor Co., International Fuel Cells/ONSI Corp., M-C Power, Plug Power, WL. Gore and Siemens Westinghouse (Anonymous, 1999a, p. 18).

This list illustrates the Council's all-embracing nature: practically all the different fuel-cell technologies are represented, as well as some of the industry's key suppliers and customers. Naturally, their motives for joining the council, which was founded by Bob Rose, differed (Interview - Rose). "Some saw the council as representing the industry in policy circles in Washington and elsewhere. The majority believed that other issues should take priority including code and standard development, education and outreach and perhaps most important, the council should provide a forum for interaction among industry leaders" (Interview - Rose).

Actually, the very formation of a council was already an achievement in itself[34]. There had been several earlier attempts, but all had failed because the companies involved "could not even adopt a common agenda" (Interview - Rose). Even now that the USFCC is alive and well, the industry is still only just beginning to speak with a single voice, according to Bob Rose. But he seems confident that things will get better soon. In the meantime, the USFCC is performing many of its functions quite well. It is

[34] Of course, some fuel-cell trade coalitions pre-dated the USFCC, but were built around specific technologies or applications (Interview - Geyer).

helping to educate the public, through speeches and presentations to interested audiences, such as the propane industry (Interview - Geyer). In practice, the council doesn't even have to be particularly proactive, as people tend to come to it seeking information, rather than the reverse (Interview - Geyer). The USFCC also provides excellent networking opportunities, and has helped to spark a lot of collaboration between its members (Interview - Geyer). One activity it has steadfastly kept away from, however, is lobbying (Interview - Geyer). Mr Rose wants to promote public-private cooperation, but he is reluctant to ask law-makers for favors: he prefers to see fuel-cells succeed on their own merit (Interview - Rose).

. F. Conclusion: Cooperation is Definitely a Critical Need.

Innovating Firms Seeking out Incumbents, and Privileging Vertical Cooperation

According to Ballard's 2000 Prospectus, its multiple alliances and partnerships (see appendix 12) have proved valuable because it has "gained access to market knowledge, manufacturing expertise, relationships with key customers, distribution channels and funding for product development" (Ballard Power Systems, 2000, p. 6). This pretty much sums up why cooperation has become (and perhaps has always been) so crucial in the industry. All the industry's players, even gigantic ones like GM and Toyota, concede that fuel-cells are just too expensive and complex to develop on one's own. Much of the cooperation taking place, however, involves supporting technologies, infrastructures and standards, and not the fuel-cells per se. Indeed, there is much less horizontal collaboration between rival innovating firms than I had expected. Vertical and associative cooperation are privileged instead, as well as teaming up with incumbents (which, inversely, is occurring to a much greater extent that I'd expected). Conveniently enough, incumbents are also eager to team up with innovating firms, and prefer to do so through joint-ventures and alliances rather than outright mergers and acquisitions, as Lambe and Spekman (1997) predicted would be the case in the early commercialization phase. Finally, though there is a dense tissue of networks and alliances in the emerging fuel-cell industry, as I'd posited there would be, the time of tight-knit communities with a strong sense of solidarity is definitely past.

Cooperation is Taken Very Seriously

Considering the stakes involved, it is not surprising that selecting one's partners is as far as possible done with the utmost care. Indeed, all these alliances were not slapped together in reckless haste, on a whim or out of despair and/or fear. A whole lot of thought is put into them. For instance, GE began a very intensive investigation of distributed generation in 1998 before deciding to partner with Plug Power (Norland, 2000). It "launched a global search for the most promising fuel cell technology and developer" (Norland, 2000, p. 20): "we narrowed down the universe of fuel cell technologies to proton exchange membrane, and then we investigated literally dozens of potential developers of that technology and finally [chose] Plug Power in early 1999. So in terms of managing the risk, the decision to settle on Plug Power was the product of a year worth of technical evaluation" explains GE's Glickman (*in* Norland, 2000, p. 20).

But Competition is Never Far Away

One should hope that all this cooperation will not turn into collusion. Fortunately, it would seem that a strong competitive spirit still prevails in the industry. Even DaimlerChrysler and Ford, two of the industry's closest partners, have agreed that they will only share their knowhow, but continue to design and manufacture their fuel-cell vehicles separately (Ashley, 1998). Moreover, one should not exaggerate the extent of fuel-cell companies' willingness to cooperate with one another. Wayne Hartford suggests that most companies pay "lip service" to the need for cooperation, except in Asia, where there is indeed a lot of collaboration taking place (Interview - Hartford). Roger Saillant, Plug Power's president, who is quite keen on cultivating partnerships, and has approached many companies in order to do so, has not always heard back from them... (Interview - Rollins). All in all, it would seem that there is a strong tension between the need to cooperate, and the need to protect one's intellectual property (which, in such an industry, is basically one's lifeblood). Indeed, rather than talk of the *need for cooperation*, perhaps I should instead have spoken of the *need for coopetition.*

6. THE NEED FOR NICHES: A Bottom-Up Approach

I was surprised to discover that a significant number of companies, including some heavyweights such as Ballard, do not seem to be planning to target niches when they first bring their fuel-cells to market. Instead, these firms are proclaiming their intent to go straight for mass-market applications. However, further research unveiled that much of this is just bluster, aimed at inflaming the interest of investors. Indeed, all the companies I studied will begin, in one way or another, by commercializing their wares to specific market segments, where they will be more likely to be adopted quickly.

And fortunately for all these companies, there is no lack of niches to target! I have in fact identified at least 5 major advantages that fuel-cells have relative to their rivals, five advantages which offer strong prospects of profitable niches. Once again, my in-depth analysis of these 5 advantages has been relegated to the appendices (see appendix 13), because of space constraints. I will content myself with summarizing their potential, so as to determine which niches appear to be most promising. But before concluding on the *need for niches*, I will consider the case of PowerTek International, which I believe is an especially intriguing example of niche-targeting.

A. Thinking Big but Acting Small

Some Companies are Thinking Big

I had assumed that, if one strategy would truly be common to all the actors in an emerging industry, it would be niche-targeting. And yet, in its Annual Report, Ballard Power Systems insists that, rather than initially focusing on small niches, it wants to attack large markets from the outset. Indeed, it is targeting not just one, but three mass markets, namely portable power, distributed stationary power generation and transportation (Ballard Power Systems, 2001a, p. 31). This allows risk diversification, and the maximization of return on investment. The transportation market alone represents 180 billion dollars worth of potential sales (52 million cars are built a year, and an engine costs around $3,500), which is equal to all the other fuel-cell markets combined (Port, 2000).

Other companies are also thinking big. Hockaday, of Medis Technologies, is planning to first penetrate the cellular phone market, before taking on laptop computers (Chase, 1998). Plug Power estimates that its fuel-cells will appeal to at least half of the US homes that have access to natural gas, because of the savings it will allow (Chambers, 1998). Some companies, such as GE, are even planning to subsidize their fuel-cells at first (in other words, sell them below cost), so that they can immediately sell to a mass market (Scott, 2001). Indeed, Colin Jaffray of Johnson Matthey explains that "Cost is the big issue: The first 500,000 fuel cell powered homes will be subsidized by the major energy companies in a bid to generate critical mass" (Scott, 2001, p. ~42).

But in Reality, They are Targeting Niches as Well

Nevertheless, even these ambitious companies have selected certain niches within their bigger markets which they will initially target. Ballard, for example, first developed buses, and will probably begin by trying to sell fuel-cell cars to customers that run fleets of vehicles. The Belgian company Elenco (which has since been bought by Zevco, a British firm), has specifically developed an alkaline fuel-cell to power fleet vehicles, such as taxis (the first 2 are already plying the streets of New York) and delivery vans[35] (Leonard, 1999). Buses, and trucks in general, have more room to accommodate bulky hydrogen tanks or reformers. Their operators are also willing to spend more up-front it they can expect fuel savings later on. Finally, they can run on alternative fuels without provoking too much of a hassle, since they are usually refueled in central depots. This last feature is what makes commercial fleets ideal first customers, as they won't require an extensive alternative-fuel infrastructure (The Economist, 2001f).

When it comes to portable applications, the Ballard has recently launched its Nexa cell, which according to analysts[36] will be targeted at the premium market, ie those who can afford to pay over the odds because they really want small, light, clean and

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[35] Their customers include the British Post Office, Marks & Spencer, Sainsbury, and John Lewis (Leonard, 1999)

[36] Ballard has not released a price yet. Its VP of marketing, John Harris, contented himself with saying that "as you can imagine with any new technology, the initial pricing would probably be a little bit higher than the conventional technology" (Erwin, 2001, p. *1).

quiet power (Erwin, 2001). As for its stationary power systems, Ballard is also choosing its initial targets carefully. Indeed, the very fact that it plans to commercialize stationary fuel-cells before its better known fuel-cell car engines follows from its recognition that, as Paul Lancaster, the company's treasurer, puts it, "some companies will pay more for clean, dependable power" (*in* Verburg, 1998, p. ~35). In other words, they believe their generators will first appeal to the niche reliable-power market. Ballard is also focusing its initial efforts on certain geographic regions rather than others. Thus, though it is developing units that could power any normal household, it will first market them in Japan, "where electricity costs are significantly higher and cost competitiveness can be achieved much more easily" (Libin, 2000, p. ~98).

GE, though it plans to speed its access to mass markets by subsidizing its products, is not simply going to ignore niche markets that could quickly prove profitable. GE Fuel Cell Systems (a joint venture of Plug Power and GE MicroGen) is thus going to first address its wares (namely residential fuel-cell systems) to remote homes that do not have access to utility backup power or even to electricity grids in some cases (Valenti, 2001). After all, most households are not prepared to pay hefty premiums in order to avoid having to reset their clocks (Kopicki, 2001), so that even if GE accepts large losses and sells its fuel-cells at very attractive prices, most families won't really see the need to liberate themselves from the power grid. It is therefore much better to tackle certain customers and countries before others, namely those who will see the appeal of fuel-cells more rapidly. These niches include high-tech companies, telecommunications companies (Kopicki, 2001), hospitals, banks, computer operations centers (Dukart, 1999), vacation homes and cabins, remote villages and islands, industrial plants, military bases... (Anonymous, 1999b).

Because Targeting Niches at First is Quite Simply More Profitable

The potential of fuel-cells is such that many companies risk being distracted, and might end up going after too many markets when it is much more advisable to focus on a couple of applications (Interview - McNeill). Even if the company has bigger fish in mind, it is better to identify early adopters, who will be willing to pay a premium for the technology and thus help cover its (usually very significant) development costs. This is true for most technological innovations, as Mr. Hartford, of Energy Visions, pointed out (his own company is planning to start small, building units that can be used as chargers, or integrated into hybrids, or even used to power small vehicles such as golf carts -Interview - Hartford). Mr. McNeill, a hi-fi enthusiast himself, gave the example of Sony's new Super Audio CD technology, which offers substantially better, 24-bit sound. The first players cost about $6,000, expensive even for enthusiasts. And yet, even though everyone knew the price would eventually come down, some people, for whom cost is not a consideration, went ahead and bought the players ASAP (Interview - McNeill). Fuel-cells are not exactly in the same league as audio players, but the conclusion remains the same: it is always profitable to target niches at first.

B. Five Categories of Promising Niches

Environmental-friendliness

This advantage of fuel-cells relative to other power-generating technologies appears to have been one of the first sources of potential niches identified by companies in the industry. Indeed, in the case of car manufacturers, their initial R&D in fuel-cells was largely carried out in the hope of meeting California's stringent environmental regulations so as to be able to continue selling cars in the state. Though the entire Californian market can of course hardly be qualified as a niche, in view of the fact that the state contains the equivalent of three Belgiums in population terms, fuel-cell cars (and their ZEV rivals) will in reality only be aiming for a 10% market share at first. The niche in this case therefore actually consists of the environmentally conscious consumers in California, who will be willing to pay more for a fuel-cell car in order to assuage their conscience. Such consumers can be found throughout the US, and are especially common in Europe. However, it would be unwise to overestimate this niche's potential. Time and time again, studies have found that people are reluctant to pay significantly more for environmentally friendly products (see appendix 13).

Reliable power

A much more promising niche is the one consisting of consumers who need reliable power. Most people would think that grid-provided electricity is already pretty reliable, but in fact it is no longer adapted to the requirements of the information age, when mere second-long power outages can have extremely expensive consequences for firms that are totally reliant on their high-tech equipment (see appendix 13). Such firms include IT companies, of course, as well as financial institutes and many factories (including even diaper manufacturers! -Libin, 2000). But even very modest businesses may be eager to benefit from more reliable power. Indeed, according to Plug Power's CEO, Gary Mittleman, a Vermont farmer drove all the way to the company's headquarter's in Latham, New York and told the receptionist: "Honey, I'm here for my fuel cell. Where's the loading dock?" as he handed her $10,000 in cash[37]. Even residential households are in the market for dependable electricity: according to a survey by RKS, 10% of affluent American households already own some kind of emergency backup generator (Kirlin, 2000).

Art Mannion and his partner William Cratty, of Sure Power, were among the first to realize that reliability would make an ideal niche for fuel-cell technology. Indeed, and this just goes to show that management papers can sometimes be useful, Mr. Mannion was inspired by Clayton Christensen's Harvard Business Review article which later proved the basis for his book, The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail (Mack and Summers, 1999). In his book, Christensen basically explains that entrepreneurs should not try to do what a bigger company already does well. Instead, they should start in a neglected market (a niche, in effect), and use it as base from which to later attack their rivals (Mack and Summers, 1999). Mr. Mannion applied this thinking to his own case, and concluded that fuel-cells could not compete with local utilities on price. Instead, he considered all the positive attributes that fuel-cells did have, and decided that their reliability would make an excellent selling point[38] (Mack and Summers, 1999). Many other fuel-cell companies have reached the same conclusion, especially after what happened in California earlier this year.

All in all, the premium power market looks quite attractive, especially because of its considerable size (indeed some would argue that it doesn't even qualify as a

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[37] He unfortunately went home empty-handed, as Plug Power did not yet have a product available at the time.

[38] For a more detailed description of Sure Power's strategy, and the thinking underlying it, please refer to appendix13.

niche). But some analysts are skeptical. For instance, according to the research carried out by Frost & Sullivan, those who are in the market for reliable power still feel fuel-cells are too risky a proposition, not to mention too expensive, especially compared to more conventional technologies such as reciprocating engines or gas turbines that have recently made great progress (Gatlin, 2000).

Remote areas

Many, perhaps most, fuel-cell companies are focusing their attention on remote areas, where there is quite simply no grid to compete against. Fuel-cells, which are relatively rugged and can, provided they are equipped with the necessary reformers, run off many different kinds of fuels without frequent refueling, are particularly well suited for a variety of remote locations. Indeed, the list of remote locations suitable for fuel-cells goes on and on. They include penitentiaries, ships, Antarctica... (see appendix 13). Greenvolt has already sold a unit to someone who will be staying in the Sahara, and who needed a power source for his satellite phone and GPS locator[39] (Interview - Faul). But surely the most peculiar "remote" application I have come across in my research is the fuel-cell being used to power... the Central park police precinct station! As Sharke (2000, p. ~27) writes, "formerly a stable, the station is smack in the middle of the park, as far away from the street and the services below as one can get in New York. It is this kind of niche that International Fuel Cells and its sister company, Onsi Corp., of South Windsor, Connecticut, fill with their 200-kW phosphoric acid fuel cell power plants."

It seems the only major disadvantage of targeting the remote-power niche is the difficulty involved in delivering the product!

Developing countries

Taken as a whole, developing countries can hardly be called a niche market. In Brazil alone, about half of the population of more than 170 million is not connected to the grid (Saraiva Panik, 2001). Nevertheless, as far as fuel-cell companies are

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[39] A nearby oasis will provide the water, which is necessary to make this particular type of fuel-cell run (it needs salt water and magnesium). Four-millimeter thick magnesium anodes need to be replaced every 20 hours to provide 60W at 12V (Interview - Faul).

concerned, they form a niche, simply because most of the people in these countries cannot currently afford fuel-cell systems. In many ways, the developing country niche is assimilable to the previous, remote-power niche. Indeed, in both cases, fuel-cells are attractive because there is no grid power (or it is so unreliable as to be almost worthless -see appendix 13). The main difference lies in the fact that developing countries are riskier markets. However, they are also potentially much, much bigger ones (since it is to be hoped that their purchasing power will increase significantly with time). Thus, Rhett Ross, until recently director of development at the Breakthrough Technologies Institute, says that “there is not a manufacturer of any type of [fuel cell] technology, whether it be power generation or otherwise, that is not looking at China, India and Asia. Africa, you can throw in there, but Africa has a lot of problems that need to be resolved" (*in* Johnson, 2000, p. ~30).

Efficiency & heat generation

Finally, because fuel-cells are extremely efficient, they are suitable for applications in which efficiency is a key concern, such as industries that are very power hungry. Indeed, Rastler (2000) believes “combined heat and power” applications constitute one of fuel-cell’s best potential markets relative to rival technologies (see table below). Nurdin (1996) agrees that, In general, commercial and industrial co-generation constitute very good niches for fuel-cells.

C. PowerTek International, taking niching to new heights

An Early, and Very Rational, Niche Identification Process

Even more than Sure Power, PowerTek International has resolutely adopted a niche strategy. According to the company’s executive summary, its basic strategy “is to prove and establish our technology and gross margins in portable power applications and then move onto stationary systems” (PowerTek International Corp, 2000, p. 1). So far, this is pretty run-of-the-mill. But the strategy’s originality lies in the fact that the company has decided to initially focus its efforts on small fuel-cells for professional video cameras. Jacques de Groot, the firm’s Chairman, was kind enough to explain the logic behind this decision to me (Interview - de Groot).

The company was formed once Dr. Rocco Guarnaccia, the co-developer of the original biological fuel-cell, had come to the conclusion that his research had a good commercial potential. So, basically, they had the technology, they just needed a market. To identify one, the executive team proceeded in a very deliberative and rational manner. It wanted a market in which considerable investments would not be necessary (this ruled out automobiles), and in which commercialization could be attained rapidly, thus allowing the company to make money quickly (Interview - de Groot). A very complete analysis of suitable niches was competed, with the help of analysts specialized in the field of energy. In the end, two applications were chosen: professional cameras and stationary modules (500 watts to 30 kW).

Which Results in the Selection of the Professional Cameras Niche

Professional cameras are currently powered by heavy batteries (the average cameraman carries 10 kilos worth of them) that last about 160 minutes before needing a recharge. PowerTek's product, the Camera Power System, which will be commercialized later this year, is lighter, and lasts 300% longer (8 hours with both cartridges installed). The CPS's fuel-cell runs on hydrogen cartridges which can be refilled onsite in 30 minutes, which is 24 times faster than what it takes to recharge a conventional battery (PowerTek International Corp, 2000). The cartridges are hot-swappable, allowing for continuous operation of the camera. Most importantly, the CPS is backwards compatible (camera batteries have a standard shape and size), and is price competitive with current power systems (PowerTek International Corp, 2000). Jacques de Groot doesn't expect a rapid, brutal substitution (Interview - de Groot), but considering there are over 900,000 professional video cameras in existence (PowerTek International Corp, 2000), the future of the CPS looks bright.

And the Financial Institution and Developing Countries Niches

As for its stationary modules, PowerTek has again decided to focus its efforts, this time on two particular markets: banks and database-management companies, and developing countries (Interview - de Groot). The former will be offered racks of twenty to one hundred mobile fuel-cells that will provide continuous generation and advantageously replace the much more cumbersome and slow-to-activate backup generators these institutions currently depend on (Interview - de Groot). As for the company's interest in developing countries (specifically, to start out with, Nigeria and South Africa), this is what originally appealed to Mr. de Groot when he learned about fuel-cell technology (Interview - de Groot). Indeed, before becoming PowerTek's chairman, he'd fulfilled a 24-year career as the Executive Director of the World Bank and International Monetary Fund, two organizations dedicated to the development of the Third World (PowerTek International Corp, 2000). Mr. de Groot hopes to promote hygiene and education in these countries by providing power to remote areas (provided they can obtain government subsidies). The company may also run a few fuel-cell trials in Central Europe, where the population can already afford to pay market rates for electricity.

D. Conclusion: A niche strategy as a stepping stone to greater things

Confirmation of the Need for Niches

My research suggests that, though fuel-cells certainly have huge potential, and will likely become widespread (should they fulfill their promise), it would be foolish to attempt to initially introduce them to mass-markets, for the various reasons we have considered. Thus, fuel-cell companies are pretty much all planning to target niche applications at first, even if some of them do no readily admit it. This is what I expected to find. I was however somewhat surprised by the fact that car manufacturers, in particular, are emphasizing the importance of directly tackling mass-markets. One would think that since the existing technology they are up against[40] benefits from substantial "lock-in" effects, this ought to make niche-targeting the only viable strategy for them (as was suggested in the literature review). But it must be said that automobile makers find themselves in a very peculiar position, because of California's ZEV mandate.

[40] Namely internal combustion engines.

Remote Power as the Most Appealing Niche

So which niche can be said to be the most appealing? Well, it is perhaps a bit arrogant to second-guess companies, which after all have firsthand knowledge of market conditions and, most importantly, of their technology's actual capabilities. But all things being equal, it would seem that providing power for remote areas is the ideal niche for fuel-cells. Indeed, it has been since their emergence. After all, what are submarines and space shuttles, if not remote! More seriously, there is a large market for remote power, so that there is little risk of finding oneself stuck in a dead-end (which may be a concern regarding the efficiency and heat generation niche). Moreover, many of those interested in remote power can actually afford to pay for it, unlike the inhabitants of developing countries (where government subsidies would probably be needed to make the commercialization of fuel-cells attractive). Government support would also be required in respect to the "green power" niche, since without public regulations or aid to reduce costs, few consumers will be prepared to pay premium prices just to be more environmentally-sensitive. Finally, remote customers are much more likely to be willing to try fuel-cells (considering they have few other options) than businesses interested in reliable power (for whom fuel-cells are still too new and hard to trust with such an important function).

But the Prospect of Bigger Markets is Never Forgotten

Though all the fuel-cell companies I have studied have thus adopted some form of niche strategy, most are planning to widen their horizons as soon as they've established a secure position in their initial markets. For example, PowerTek is pursuing an extremely targeted niche strategy at the moment, but it estimates that its technology can potentially address 61% of the total market for fuel-cell based power systems (PowerTek International Corp, 2000). Clearly, sticking to a niche strategy in the long-run would be an inexcusable waste of fabulous opportunities. In fact, the transition from a niche to a mass market strategy may happen sooner rather than later.

Global Thermoelectric, for example, had initially planned to stick to niche markets, but because they have been so successful, they are now developing technology for mass markets (Interview - Kryzan). A similar story is told by Dr. Stannard, of Fuel Cell Technologies. His company had originally intended to focus on

Canada (where a rapid payback was thought possible), but the impact of California's energy crisis has sent shockwaves throughout the United States, and Fuel Cell Technologies is now receiving daily phone calls from Californian and Northeastern companies expressing interest in its products (Interview - Stannard). As Dr. Stannard explained, market pull is beginning to take over, which may soon make the *need for niches* irrelevant. Generally speaking, as the technology improves (which it is, and rapidly), more and more applications will benefit from fuel-cells. Already, Weinmann and Grubel (2001, p. ~32) argue that, as far as energy supply companies are concerned, fuel-cells are already viable for "use in district heating power stations, electricity generating and grid support/virtual power plants, uninterrupted electricity and house energy supply, load management and operator models/contracting."

7. Slow and Steady like a Turtle, or Fast and Nimble like a Rabbit?

Finally, let us consider whether there is indeed a *need for speed* in the fuel-cell industry, or whether it is late-movers who are likely to be advantaged. Unfortunately, because I only belatedly included speed to market in my framework, this section is comparatively under-researched. In particular, most of my interviews had already been conducted, making it difficult to acquire first-hand data. And, unfortunately, very few papers seem to deal with the question of speed to market, with regards to commercializing fuel-cells, in an in-depth manner. For instance, back in 1994, the Economist wrote that "the American [fuel-cell] companies are hoping for a gradual conquest. The Japanese want to achieve a dramatic break-out, rather as they did with their semiconductor industry in the 1970s" (The Economist, 1994, p. *1), but it failed to expand on the reasons behind these opposing goals. So though I have attempted to flesh out the cases made by those advocating the importance of being a first-mover and by those insisting that it is better to "wait and see," my analysis remains quite superficial.

A. The Rabbit's Case

Car Companies Falling Over one Another to be the First

One thing is for sure: practically all the car companies that are deeply involved in fuel-cell research are vowing to be the first to market with their fuel-cell equipped cars. On April the 14th, 1997, DaimlerChrysler opened the race by pledging to sell 100,000 fuel-cell powered cars in 2005, which was equivalent to about 15% of Daimler's 1999 production (McNicol, 1999). Professor Klaus Dieter Voehringer, the company's board member in charge of the fuel-cell program, is quoted as saying "we think we are ahead in the race and want to be first on the market" (Eisenstein, 1999a, p. 24). More recently, Jurgen Hubbert, boss of the Mercedes unit, made a similar declaration (The Economist, 2000a).

Not one to let himself frightened off, Toyota's President Hiroshi Okuda asserted in February 1998 (better late than never) that *his* company would be the first to commercialize a fuel-cell car (Naughton, 1998). Meanwhile, Ballard (DaimlerChrysler's partner) feels it is absolutely critical to be the first to market, which is why it claims to be targeting mass markets straight off, rather than niche applications (Panick, 1998). Only GM, which had originally declared its determination to be the first, has conceded defeat, and is now focusing its efforts on "merely" being the first manufacturer to sell one million fuel-cell cars. However, it has also quite recently decided to enter the stationary market for fuel-cells, since fuel-cells are already competitive for such applications, in order "to earn an early return on its hefty investment in the technology" (The Economist, 2001m, p. *1).

The Reasons Behind Such Haste

Why this seeming obsession with speed? Well, several reasons are advanced by Ballard's executives. First is their ambition to become the Intel of the fuel-cell world. In order to do so, they are convinced that is it essential to get to the market first (Verburg, 1998). Indeed, Mr. Rasul explains that "whoever gets to market first sets the rules" (*in* Verburg, 1998, p. ~33). Dr. Panik of DaimlerChrysler is in absolute agreement and affirms, in almost the exact same words, that whoever is the first to commercialize a viable fuel-cell vehicle will be able to determine the rules of the game (Panik, 1998).

Thus, basically, Ballard's strategy is to set the industry's standards and to develop awareness of its brand (Ballard Power Systems, 2000). This does seem to make being the first to market important, especially for its symbolic value. Having one's name forever associated to the emergence of a potentially very momentous technology is certainly worth an extra effort. But more prosaically, speed is essential because Ballard's patents (and presumably those of its rivals as well) will begin to expire by 2009, although most of its intellectual property is safe for much longer than that (Ballard Power Systems, 2000).

B. The Turtle's case

The Car-Makers are Unique in Being Confronted with a Specific Deadline

What none of the car-makers mentions is the fact that they have no choice but to be speedy if they want to continue to sell cars in California. Indeed, the implementation of the Golden state's zero-emission vehicle standards, in 2003, is looming. This would explain why all the other fuel-cell companies, while eager to commercialize their products and finally earn some sorely needed revenue, are not quite as obsessed with being the first. As Dr. Stannard explained to me, it is important to be among the initial 4 to 5 companies on the market, but being the absolute first is often a recipe for trouble. The chances are high of rushing the product's commercialization before it's ready for prime-time, which can have disastrous consequences for the firm in question -and maybe even for the industry as a whole (Interview - Stannard). His company, Fuel Cell Technologies, can't afford a "black eye," as he put it, and so it is quite content to concede the number 1 spot to one of its rivals.

Indeed, despite the looming Californian deadline, one of the car companies has reached the same conclusion. GM, which used to want to be the first to market, has since changed its mind and is now of the opinion that being the pioneer is, in itself, meaningless. The important thing is to be the "first to come up with a fuel-cell vehicle that will be as easy to operate as today's cars yet no more expensive" (Eisenstein, 2001, p. ~24). Thus, the co-director of GM's Global Alternative Propulsion Center, Byron McCormick, insists that "if fuel cells are going to fulfil their role, we've got to put millions of them out there. Our goal is to be the first company to sell a million fuel-cell vehicles" (*in* Eisenstein, 2001, p. ~24). In other words, they want to make sure their technology is capable of conquering the hearts and wallets of consumers before commercializing it.

The Benefits of Patience - The Need for Power isn't Going to Vanish

Other companies, usually the laggards it must be said, pooh-pooh those who say that speed is of the essence. Instead, they argue that taking one's time can pay-off. For instance, Honda's boss, Mr. Yoshino, believes that by the time fuel-cells become really widespread, all the key patents will have expired (as happened with televisions and the ICE itself), so that late-comers will be able to free-ride on the pioneers' research efforts (The Economist, 2000d) David Cole, director of the Center for Automotive Research, actually recommends that car-makers take it slow. He points to GM's unsuccessful commercialization of its EV1 electric car, which was introduced before there was enough "consumer demand or a network of stations for recharging the car's batteries" (*in* Popely, 2001a, p. *1). Most importantly, the technology is progressing so rapidly that "it's better to wait until the curve of improvements starts to flatten out. You can't go to high-volume production too early. It doesn't make economic sense" (Cole, *in* Popely, 2001a, p. *1).

Finally, others take an altogether more philosophical view. Jim Perry, President and CEO of Global Thermoelectric, refuses to let himself get carried away and says simply that "the fuel cell people are not going to make a dent in the overall power requirements [of the US] in a giant hurry. It will take time for the products to be properly developed and then rolled out. We don't see this as being something where first guy to the market wins. We see it as the guy with the best product wins. It's not something where it's a revolutionary technology. People buy power today and they'll buy power tomorrow. It's just a different way of producing it" (*in* Howes, 2001, p. *1).

C. Conclusion: More Research Needed

Personally, I feel the turtles make a better case, abstracting the fact that car companies are in a special situation in regards to speed to market. Though there are undoubtedly advantages to be had from being the first to market, these are likely to be short-lived, especially if the pioneer had to cut some corners in order to get there. At worst, botching the introduction of a new, disruptive technology could delay its successful commercialization for quite some time, which would be a terrible shame. But the question of whether speed to market is indeed important will only be resolved once fuel-cells are actually commercialized, which is still some time away. Therefore, the only firm conclusion that can be reached is that more research will be needed!

8. Conclusion: 5 Shifting Needs and One Question Mark

A Shifting Framework

The *six needs* are clearly not quite as clear-cut as I expected they would be. Indeed, the importance of each need varies greatly over time. For instance, it would seem that the *need for champions and visionaries*, though without a doubt crucial when the technology was in its preliminary stages (and its true potential thus still only dimly perceived), is fast becoming eroded. The *need for niches* is holding out better, but it also liable to be a very short-lasting requirement, if the cost of manufacturing fuel-cells comes down quickly enough, as it very well might. Even the *need for government support*, though it remains important, is on its way out: once fuel-cells reach the marketplace and prove themselves against their competition, firms will no longer be so reliant on the state's helping hand. Meanwhile, *the need for cooperation* is probably now at its highest point, as the widespread commercialization of fuel-cells looms into view. Collaboration is critical during this especially unsettled and fast-moving period, but it likely to decrease in importance later on.

As for *the need for merit,* it is tempting to also dismiss it as a very ephemeral need. One could even say it is a "one-timer:" a firm must assess its technology's potential merit only once, and can then draw the necessary conclusions and stick to them. This would be erroneous, however. The *need for merit* must be continually reassessed, as the firm's technology progresses and, in particular, as rival technologies progress. A breakthrough in solar panels, say, or wind turbines, or gas-powered generators, is not unimaginable, in which case fuel-cell technology may no longer be quite as appealing as before. There are actually many technologies out there that could yet vie with fuel-cells, including some very exotic ones, such as air-powered cars (MDI,

2001) or biodiesel fuel for ICEs (Adam Answers, 2001), but also some already relatively mature ones, such as hybrid ICE/Battery engines (The Economist, 2001f). So the need to assess merit does not simply disappear, even once the technology has matured and become firmly established. Companies must continually keep on their toes.

The Prospect of Generalization

The shifting nature of the needs I identified shouldn't come as too much of a surprise, however. After all, we did specify that the *Six Needs* framework is only relevant to emerging industries, which are, by definition, transitory in nature. Granted, the needs shift even while an industry is in the process of emerging, but they are always present, to some extent. It is only after an industry's emergence that many of these needs become irrelevant. But further research will be necessary to determine if the *Six Needs* are indeed important in all emerging industries, or if they are only present in certain ones, namely those involving disruptive technologies like fuel-cells.

The Links Between the Needs

The only undeniable point demonstrated by my research is that, when it comes to strategies in emerging industries, one size does not fit all. By this I mean that strategies must be adapted to the exact development stage of the technology being commercialized. Unfortunately, doing this in practice does not seem easy, as there appears to be quite a few complex interactions occurring between the *Six Needs*, making it tricky to find the right combinations. Indeed my research hinted at some of these links which exist between the *Six Needs.* For instance, I have suggested that there might be a connection between the assessment of merit that the *need for merit* calls for, and the emergence of a vision (discussed in *the need for champions and visionaries*). There is also quite clearly a relationship between government support and cooperation, since governments have done a lot to push for cooperation within the industry. Governments can also have an effect on the existence and appeal of niches, with their demand-pull policies. As for cooperation, it can do a lot to accelerate a technology's speed to market, whereas there would seem to be an inherent tension between the *need for niches* and the *need for speed*, since the focus on niches can delay one's arrival on the main markets. Finally, if I am correct in surmising that passion can be fueled by visionaries, and that passion can in turn lead employees to work better and faster (see part V), then it is possible that there is an indirect link between visionaries and speed to market.

Basically, all these needs are probably inter-linked in some way. Unfortunately, the structure of my research was not well suited to identify and explain these links, and I did not have the time to consider the question in sufficient detail. So this is one more thing that further research will be necessary to clarify!

Five Needs Rather than Six

Finally, we have determined that the *need for speed*'s importance is rather difficult to assess before fuel-cells have actually been widely commercialized. After all, only time will tell whether fuel-cell technology rewards first-movers or later-movers. At the moment, it seems the latter have more reason to hope, at least according to our predictions (but then predictions have a nasty habit of being wrong). In any case, until the *need for speed's* importance can truly be determined, it would be more appropriate for the time being to talk about the 5 Needs, and to leave the sixth one out of the framework. Although, in truth, there is a need that could take its place. This is of course the *need for luck*, which is necessary in all human endeavors. Unfortunately for strategists, it remains to be seen whether one can indeed make one's own luck...

V. PASSION:
A KEY STRATEGIC RESOURCE

"Without passion man is a mere latent force and possibility, like the flint which awaits the shock of the iron before it can give forth its spark."

-Henri-Frédéric Amiel (1821–81), Swiss philosopher, poet. Journal Intime (1882; tr. by Mrs. Humphrey Ward, 1892), entry for 17 Dec. 1856.

Bringing a disruptive innovation to market can be a long, tedious process, littered with disappointments and exasperation (Norling and Statz, 1998). As they say, "life in the fast lane really is 1% inspiration and 99% pure sweat" (The Economist, 2001j, p. *1). Few people have the patience, determination, or sheer tenacity to dedicate themselves to such a task, especially when the outcome is so uncertain. And yet, some do. I was particularly intrigued by what makes such individuals tick, what makes them accept difficult conditions, often for prolonged periods of time, for a mere promise of better things to come. It is while researching this particular aspect of the commercialization of fuel-cells that I came to the conclusion that passion is a key strategic resource.

This is what I will now attempt to argue, using various examples from the emerging fuel-cell industry as a basis for the elaboration of a very rough and sketchy framework that can, hopefully, help us reflect on the importance of passion in business. With luck, such a framework might also prove a foundation for further research on the subject, which will clearly be required... Indeed, because my insight was unfortunately rather belated, to say the least, I was unable to carry out much relevant research. Instead, my interviews and press reviews (most of which had already been conducted by the time I came up with the idea of studying the notion of passion) had delved into more tangible issues of strategy. So, since my research program had not been designed with the study of passion in mind, most of the examples I will provide are not only anecdotal in nature, but also rather trivial. In fact, to call it research is to use the term very generously indeed. It would be more accurate to consider my examples not as proof or demonstrations, but as mere illustrations that are meant to clarify my thoughts and arguments. Any empirical evidence that would substantiate my claims, if doing such a thing is even possible (which is questionable, as we shall see), will not be forthcoming in this paper. Rather, this section should be seen as mainly exploratory and conceptual.

Outline

I will begin by quickly defining what I mean by passion, and how I believe it is embodied in the business world. I will then, basing myself both on relevant management theories as well as on illustrations taken from the emerging fuel-cell industry, consider why passion can be considered a strategic resource and how firms can exploit the passion of their employees in order to achieve business excellence. But if passion is truly so important, why has it been so under-researched by the academic community? There are two reasons for this. First of all, business studies have been heavily influenced by economic science, which emphasizes the rational at the expense of the emotional. Second of all, passion does not lend itself well to quantitative research methods, which have become dominant in research. Indeed, it is doubtful whether we will ever be able to study passion with much rigor. However, this does not justify its complete exclusion from our analyses, as has largely been the case until now.

1. What Is Passion in Business?

A. Passion Defined

Before embarking on any analysis, it is important to define the principal terms employed. This is especially important for passion, since the word has, after all, multiple meanings, not all of which are particularly relevant to strategic management... For the purposes of this paper, therefore, passion will be defined as boundless enthusiasm, enthusiasm that is indeed so boundless that it can be unconstrained by rational considerations. However, passion, though clearly an emotion, is not necessarily opposed to reason. The two can coexist, and in fact I will later argue that the simultaneous presence of passion and reason is necessary to achieve business excellence. Passion alone is not enough, but nor does reason by itself suffice.

Passion is often focused on a process, rather than on an end product (this is a crucial point, as it implies that passion is not necessarily absent in seemingly "dull" businesses). Researchers (as I have found while studying the fuel-cell industry) are often passionate about their research per se, for instance. They are driven to understand, to control, to improve for the sake of understanding, controlling and improving. The fruit of their research, a marketable innovation, becomes almost secondary, a mere byproduct of the *really* interesting stuff. Although it could also be that the passion was initially elicited by the research's potential applications, and only later transferred itself to the process of researching. This point will be considered in more depth subsequently.

However passion, or boundless enthusiasm, does not necessarily revolve around the individual's specific responsibilities and role in the firm, but can concern the firm's overall goal, or, perhaps more concretely, its end product or service. In other words, an employee can, for instance, put up with a dull or hazardous job precisely because he or she is passionate about the product his or her company commercializes, and is eager to contribute to the firm's success even if it means experiencing personal hardship. Such behavior is probably not very frequent however, but other, more typical situations can be envisioned in which an employee's passion for his company's goals helps him or her surmount challenges and endure vexations and privations. It is this form of passion that is most clearly "unreasonable" in nature, at least according to rationalistic accounts of human behavior. It also this form of passion that can prove most beneficial to firms.

Finally, despite what the previous paragraph may suggest, passion, though it may lead to behavior that is in appearance altruistic, is deeply rooted in self-interest[41]. One is passionate because one expects some kind of payoff, whether it be the prospect of vast riches, or simply the satisfaction of a job well done. Thus, passion may be focused on a process or product, but its underlying goal is elsewhere. It is the prestige or self-satisfaction that comes from having participated in a grandiose or worthwhile project, it is the wealth amassed through one's efforts, it is the pleasure of solving a problem. Often, indeed probably in most cases, it is a little bit of all these things. But passion is never, I believe, without some kind of motive. And though, in many ways, the important thing, from a managerial point of view, is that some sort of passion exist, its underlying motive is not irrelevant. It is useful for a manager to understand why his or her employees are passionate, what they truly expect to obtain or achieve, in order to better nurture and direct their passion in ways that can benefit the company.

B. A Multiplicity of Motives

Let us therefore rapidly consider what some of these motives (ie the "determinants of goal directed behavior and in particular, the factors that initiate, direct, and sustain human action" -Kaufman, 1990, p. ~36) may be, basing ourselves for illustrative purpose on the fuel-cell industry.

The Thrill of the Chase

When I first began to study passion in the fuel-cell industry, I assumed that idealistic considerations would be the basis for much of the enthusiasm generated by fuel-cell research. I expected to find many comments like "we also know that as we succeed as a company, the world will be a better place" (Ballard, 2001, p. 8). But in truth, many of the industry's trailblazers, most of them scientists, appear to be passionate about the research process itself. Indeed, Roberts (1989), basing himself

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[41] Arguably, the pursuit of self-interest, and only self-interest, is hard-wired into all life. But because humans are social animals, the unabashed and unmitigated pursuit of self-interest is likely to be counterproductive, as it will eventually bring about a community's condemnation (a callous egoist is unlikely to benefit from anyone's help when he or she is in need of it...) . Thus what is commonly considered altruism may in fact be veiled self-interest (doing good for one's own long-term good).

on more than 20 years of research, concludes that the search for new and bolder challenges is one of the key motivations of technological entrepreneurs. Such people are, according to Livesay et al.'s typology (1996, p. 182), "pioneers," that is inventors "whose primary motivation lies in the innovation process activity itself." Other academics, especially entrepreneurship researchers, refer to this impulse as achievement motivation, or the need for achievement (McClelland 1961 and 1965 *in* Stewart et al, 1999), which is described as ". . . the desire or tendency to do things rapidly, and/or as well as possible. [It also includes the desire] to accomplish something difficult. To master, manipulate and organize physical objects, human beings or ideas. To do this as rapidly and independently as possible. To overcome obstacles (...). To excel one's self. To rival and surpass others. To increase self-regard by the successful exercise of talent" (Murray, 1938, p. 164 *in* Johnson, 1990, p. ~39).

Thomas Faul, for instance, told me that he'd been interested in technology and new product development all his life, and so founding a fuel-cell company seemed a natural progression for him (Interview - Faul). Men of science originally founded PowerTek as well, and their goal was, to begin with, to realize their scientific ambition: they wanted their research to succeed, to lead to concrete applications (Interview - de Groot). Jeffrey Bentley, a mechanical engineer by training, recognized that he too is mostly driven by his desire to work on advanced things, to see his projects gradually take shape. He refers to the thrill of seeing one's research reach fruition (Interview - Bentley). Johnson Matthey's engineers are also passionate about their research, and about the inner workings of fuel-cells. They enjoy the technical challenges they are being faced with, they thrive at the "very sharp end of scientific progress (...) and [are] thrilled to be involved in ground breaking research" (Interview - Jaffray).

Environmental Protection.

Contributing to the development of a technology that has the potential to conciliate environmental sustainability with our exponential need for energy struck me as perhaps the most powerful motivator in the fuel-cell business. Indeed, environmental preoccupations are prevalent in the industry (Interview - de Groot; Interview - Tangeman). "We in Shell Hydrogen want to make the fuel cell economy a reality, especially for social and ecological reasons," writes Thomas Bosch, for example

(Interview - Bosch). Even Joe Urso, Electrolux's CEO, explained that his company's development of a fuel-cell powered vacuum cleaner was the result of "personal and corporate convictions about the importance of sustainable energy and environmental concerns" (Harvey, 2001, p. *1). These individuals have been designated as crusaders, "socially conscious [inventors] seeking to use the innovation process as an instrument for social reform," by Livesay et al (1996, p. 181-182). Crusaders are not as uncommon as one may think, according to Anderson (1998), since, after all, "entrepreneurship is embedded in society," meaning that it is natural for entrepreneurs to share some of the concerns and moral attitudes held by their compatriots.

Third World Development.

Another high-minded motivation that can elicit passion in the fuel-cell industry is the desire to improve the lot of developing countries. Only one of the people I interviewed mentioned this particular point (although it cropped up frequently enough in the newspaper articles I consulted), namely Jacques de Groot of PowerTek. Having worked for many years as a the Executive Director of the World Bank and the International Monetary Fund, he was naturally strongly attracted by fuel-cell technology's promise of widespread distributed energy, which could have a significant beneficial impact on development programs (Interview - de Groot).

Being Part of History

Another motivation that was only brought up by one of my respondents, but which is likely widespread, is the desire to "go down in history" (Interview - McNeill). Indeed, Mr. Fagiano, President and CEO of the American Management Association, emphasizes that most of the entrepreneurs he works with have a need to "leave something behind." "These people want to leave a mark on society. They want their creations to outlive them and continue to be important contributors to the welfare of customers, suppliers and employees" (Fagiano, 1995, p. 5). Stringer (2000), agrees: innovators and entrepreneurs want to make a unique contribution to the world.

In practice, such motivations concern employees as well, not just founders. Thus, Mr. McNeill left a secure job in the auto industry because he realized that fuel-cells had a good chance of being a significant breakthrough, perhaps even ushering in a new era in economic history. He wanted to be a part of the coming revolution (by comparison, car manufacturing struck him as hopelessly dull), and the prospect of being involved in such a potentially momentous event infuses him with enthusiasm.

Profit.

Passion, although defined here as unbounded enthusiasm, does not necessarily have to be irrational (from an economic standpoint that is). The lure of money can generate quite a bit of enthusiasm. Indeed, it is: now that fuel-cells are seen as "respectable" by the business community, most of the new entrants into the industry are mostly motivated by the prospect of the hefty profits to be earned should fuel-cells really become the Next Big Thing. Thus, Mark Kryzan writes, in respect to his company Global Thermoelectric, "commercial considerations were foremost in our mind. There is no 'environmental guru' driving this company to success. We are firmly of the opinion that any fuel cell system must work economically. Finally, we do not particularly promote ourselves as an 'environmental' company (Interview - Kryzan).

Even old-timers like Ballard are shifting their sights. Soon after assuming the direction of the Canadian company in 1989, Firoz Rasul told his researchers: "if you guys are looking for a Nobel Prize, you are in the wrong place. If you are looking to make a lot of money, you are in the right place" (*in* Nauss, 1998, p. ~75). Colin Jaffray sums it up well when he writes that "the business types (like me!) are motivated by the prospect of developing a technology/market that could double [Johnson Matthey]'s profits within 10 years. All of us though have a good feeling that we're involved in something ecologically good; but this is an effect not an initiator" (Interview - Jaffray).

Indeed, many individuals are "motivated by the opportunity to 'do well by doing good,' or 'do good while doing well'" (Interview - Rose, although he himself believes that most are simply interested in doing well). Others, such as Mr. Bentley, argue that one simply can't do good without doing well. In other words, environmental and commercial considerations are inseparable: if one is an idealist at any cost, one will have no real-world impact and one's efforts will merely end in failure (Interview - Bentley). As John Lucas of Hydrovolt put it, "no one can survive for long without being profit motivated" (Interview - Lucas).

What much of this comes down to is that many firms in the industry are publically owned, and so must put the pursuit of profits first and foremost (Interview - Tangeman). This is a given in the business world. But what is usually not realized is the veritable enthusiasm that the quest for profits can engender. There is indeed an important emotional dimension to profit-seeking, as can be seen when Robert Lifton, Medis Technologies' CEO, says "what we're doing keeps me up at night, not from worry but from excitement. When we did these numbers, when we put them down on paper for the first time, we giggled. Maybe this is what Bill Gates saw. Maybe it will happen to us" (*in* Kopicki, 2001, p. 77). The prospect of substantial gain is enough to arouse passion in even the most level-headed businessman.

2. What Makes Passion a Strategic Resource?

A. What is a strategic resource?

Ever since the early 1990s, the growing influence of the resource-based view (RBV) of the firm has lead scholars to increasingly focus on a firm's internal characteristics in strategy analysis and formulation (Hoskisson et al, 1999). One consequence of this interest has been the clarification of what constitutes a strategic resource. Basically, "*firm resources* include all assets, capabilities, organizational processes, firm attributes, information, knowledge, etc. controlled by a firm that enable the firm to conceive of and implement strategies that improve its efficiency and effectiveness" (Barney, 1991, p. 101). Thus, the RBV in effect regards firms as resource bundles. But not all resources can truly be qualified as strategic. Indeed, a resource is only strategic when it can be used to produce a sustained competitive advantage. In practice, therefore, strategic resources must be:

Valuable (to obtain competitive advantage)

Plainly, if the resource in question does not help the company exploit opportunities or neutralize threats, it can hardly be considered strategic (Barney, 1991). Several features can help ensure a resource will be valuable, and include:

-relevance. Arguably, all resources are valuable in some way. But they are not always beneficial for the firm that actually controls them (Locket, 2001). When a resource is not applicable to a firm's current activities or to its probable future ones, it is not strategic.

-rareness. After all, if the resource is widely available to all the company's rivals, then it cannot form the basis of a competitive advantage (Barney, 1991). However, it may still remain valuable simply in order to achieve competitive parity (Barney, 1991). In other words, you can't succeed without it but its presence alone is not sufficient to win.

-appropriability. Having a valuable resource at one's disposal and actually securing its benefits are two very different things (Grant, 1991). For instance, a company's key resources will often be the knowledge and skills embodied in its employees, who are by no means permanent fixtures of the firm. Under certain conditions, employees will be able to appropriate for themselves most of the profits earned thanks to their abilities.

Sustainable (to maintain competitive advantage)

The resource must be relatively durable, its value relatively long-lasting, for it to qualify as veritably strategic (Collis and Montgomery, 1995). Ephemeral benefits, after all, cannot provide the foundation for a sustainable competitive advantage. To protect a resource's value (in particular its rareness), it helps if it is:

-hard, if not impossible, to imitate. If the resource can be replicated without too much difficulty, then any advantages accrued through its use will not be sustainable (Barney, 1991). Characteristics that can make a resource inimitable include physical uniqueness, unique historical conditions (which lead to unique resource outcomes because of path dependency), causal ambiguity and social complexity (Barney, 1991).

-hard, if not impossible, to replace. Even if the resource in question is impossible to replicate, it may still be possible for rivals to use other resources as substitutes in order to achieve a similar result (Barney, 1991). This would severely impair the resource's worth.

B. Passion Is Valuable

______a. The Benefits of Passion

Once again, the following statements are basically unfounded. More research will be necessary in order to empirically verify them. For the moment, I wish simply to suggest some lines of thought.

Passionate people are more productive & effective

I believe that individuals who are passionate about their work will, all other things being equal, be more productive, more resourceful than their dispassionate colleagues. Their enthusiasm will push them to succeed, to find better ways of working, to reach and surpass objectives. Indeed, everything seems to indicate that employees are not motivated by reason alone, and that infecting them with enthusiasm will stimulate them into working better and harder (Glassman and McAfee, 1990). A lot of research undertaken in classrooms (which, being closed environments, are easier to study) has shown that enthusiasm has a positive effect on student achievement, at least in the case of older adolescents and young adults (McKinney, 1983).

Mr. de Groot, PowerTek's chairman, unhesitatingly agreed that his employees are particularly creative and imaginative, particularly attentive to quality control and to customer satisfaction, because of their enthusiasm (Interview - de Groot). In short, their passion makes PowerTek a more effective company. Mr. Hoffmann, founder of the Hydrogen & Fuel Cell Letter, was less emphatic, but also agreed that passion probably makes many in the industry more innovative than they would otherwise be (Interview - Hoffmann).

Passionate people are more determined & daring

Many of the people in the fuel-cell industry have spent years, and even decades, striving to bring fuel-cell technology to the market, struggling to make it more affordable and more practical. Thomas Faul of Greenvolt, for example, envisioned the commercial applications of fuel-cells early on, but had to toil for more than a decade to perfect his own fuel-cell (Interview - Faul). And his is one example among many. Dr. Stannard, of Fuel Cell Technologies, also told me about how he and many of his colleagues in the industry are committed to the technology, and were hard at work back when nobody cared about fuel-cells or even knew what they were (Interview - Stannard). Mr. de Groot confirmed this, pointing out that many of PowerTek's researchers have been working on fuel-cells for the past 15 to 20 years (Interview - de Groot).

Clearly, such people are determined, more so than the average individual. I suggest that such determination is the result of their passion for fuel-cells and for the technology's potential. Indeed, Dr. Stannard affirmed that passion was often the only thing sustaining them in the face of the many obstacles they had to overcome. And Jacques de Groot was once again particularly convinced of the importance of passion. According to him, passion makes his employees more than determined: they are positively aggressive in their quest to commercialize fuel-cells (Interview - de Groot).

Passionate people are more capable of enduring hardship

Being determined in the face of uncertainty, widespread skepticism, and technical challenges is one thing. Being willing to endure actual, physical hardship and sacrifices in the name of one's goal is quite another, even if the two are somewhat related. Here too, passion has an important role to play: it reassures and sustains. One becomes convinced that any hardships experienced are momentary and worthwhile. Indeed, instead of being discouraged by difficult conditions, it would seem that the truly passionate see their resolve actually strengthened by adversity.

Many of those I interviewed told me about how they and their employees or colleagues had to work under dreadful circumstances, especially during the first few years of their corporate history. Thus, Paul McNeill told me how H Power used to be based in a garage in the middle on New York, in which its employees would toil during the stifling summer months without air conditioning (it can get very hot in New York, despite its Northeasterly location). Even worse, they often went unpaid, simply because no money was available (Interview - McNeill). And according to Mr. McNeill, such stories are a dime a dozen in the fuel-cell industry. The founders of PowerTek were also continually short of cash, and had to take on miscellaneous small jobs in order to finance their research (some of them sold 4x4s in North Africa and the Middle East, for example -Interview - de Groot). Still today, Greenvolt's executives are working free of charge (Interview - Faul), not because they are particularly well-off and generous, but because the company can't afford to remunerate them.

Not all the hardships faced were or are quite of the same caliber. Most of the time, they principally consisted, and still consist in, unpaid overtime, as well as generally small paychecks. Dr. Stannard described how his employees often work on weekends and late into the night, although they are not paid for overtime (Interview - Stannard). Mr. Faul also commended his staff for their willingness to accept meager salaries and yet work hard and put in overtime even though they are not asked to do so (Interview - Faul). However, David Rollins of Plug power writes that "Plug Power and others pay competitive wages - if they didn't there would be much fewer people in the industry" (Interview - Rollins). So perhaps things aren't as clear-cut as they may initially appear to be.

b. The Wide-ranging Relevance of Passion

Passion Seems More Important in Certain Industries than in Others

In an article entitled "Passion is also a necessary part of good business," Fletcher (1996), suggests that passion is essential in some businesses, but not in others. Generally it is not necessary for executives (the focus of his article) to feel passionate about their firm's products and services, which is "why so many big cheeses can and do switch jobs from industry to industry" (Fletcher, 1996, p. 7). As he puts it so memorably, "I doubt whether a rubber grommet panjandrum needs to be obsessed by rubber grommets, or whether a loo cleanser bigwig needs to love loo cleansers" (Fletcher, 1996, p. 7). On the other hand, to succeed in certain industries, he argues that it is vital to be truly passionate about the product being sold. Examples he provides include the fashion, publishing and movie businesses (perhaps entertainment in general?), automobile manufacturing, medicine, advertising or being a restaurateur. In these industries, and similar ones, being obsessed with the product is, according to Fletcher, not only an advantage but a job requirement.

But if passion does indeed foster productivity and effectiveness, determination and daring and the ability to endure hardship, then its importance is immeasurable when it comes to emerging industries, or indeed to any new enterprise, even in mature industries. After all, startups are often confronted with difficulties that call for commitment above and beyond the call of duty. I would therefore be tempted to assert that passion can in some cases be a prerequisite for survival, not just for excellence. Indeed, Glassman and McAfee (1990) explain that enthusiasm (ie passion in the context of this dissertation) is often equated to believability, and, as we have seen, believability is critical in the early stages of an industry's development. Inspiring belief, and by extension the trust and confidence of one's employees, but also of one's suppliers and customers, is absolutely essential when it comes to commercializing radical innovations.

But in Truth, Passion is Important in all Business Activities

But I would go further and contend that passion is a strategic resource in all fields of human activity. Passion is, I suspect, necessary in order to achieve any sort of superior performance. And, because so many different motivations can generate passion, including the seemingly universal wish to make more money, it need not be confined to certain specific situations or activities. Indeed, the enthusiasm engendered by the prospect of profit means that one can find passion even in what would otherwise seem to be very dull businesses. I discussed this with Mr. McNeill, whose own experience lead him to assert that enthusiasm plays a role in any successful team, regardless of what its actual tasks and goals are. As a marketing director, he insisted in particular on the need to be passionate about one's product so as to achieve ambitious commercial objectives (Interview - McNeill), but this is just one example among many other conceivable ones.

c. The Rarity of Passion?

Differences in Backgrounds, Personalities and Preferences

We have seen that a resource, in order to qualify as strategic, should be rare, otherwise it cannot prove the basis for a competitive advantage. Passion's rarity, or lack thereof, is something that will require further research, but it would not seem unreasonable to assume that passion is, as a general rule, relatively rare. For one, not all individuals are inclined towards being passionate. But it must be said that Butler and

Waldroop (1999) argue that most of us do have certain life-long passions. Indeed, in the course of their long-running research, they found that "most people in business are motivated by between one and three deeply embedded life interests-longheld, emotionally driven passions for certain kinds of activities" (Butler and Waldroop, 1999, p. ~148). Thus, everyone would seem to have the potential to be passionate about certain activities. However, the very fact that the two researchers identified eight major life interests[42] (through the administration of psychological tests), implies that even if most of us are potential enthusiasts, we can not be expected to become passionate about just any activity or product. Our personalities, our preferences and our backgrounds will determine whether or not a particular product or activity will elicit our enthusiasm.

Passionate Individuals Will be More Common in Certain Industries

This actually brings up an interesting question: are certain activities or industries inherently more passion-inducing than others? Intuitively, one would think this is the case. After all, working for a movie studio sounds more likely to send one's pulse racing than working for a tissue paper manufacturer. Thus, industries that have more cachet, more prestige, that are more popular and strike people as interesting or fun to work for, will probably attract an above average amount of individuals who will be passionate about their firm's activities and products (although whether they remain passionate, once they get to know the industry better, is another matter...).

I believe that emerging industries, because of the excitement they tend to generate, are also particularly attractive to those who are passionate by nature. This is very true for industries that are seeking to commercialize new technologies, as western culture is, in general (though not always) quite keen on technological innovation and quick to embrace new inventions. In other words, such industries benefit

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[42] The application of technology (the desire to understand and improve technology), quantitative analysis (the desire to work with and manipulate numbers), theory development and conceptual thinking (the desire to theorize and analyze, to deal with abstract concepts and focus on the why rather than the how), creative production (the desire to create, imagine and innovate -a desire shared, according to Butler and Waldroop, by many researchers and entrepreneurs), counseling and mentoring (the desire to teach and perform a socially valuable function), managing people and relationships (the desire to deal with people), enterprise control (the desire to be in charge, to make the decisions) and influence through language and ideas (the desire to express oneself so as to influence and persuade) - Butler and Waldroop, 1999.

from positive a priori attitudes, that favor the appearance of passion. Mostly, though, emerging industries are propitious for engendering passion because of the intimate relationship that exists between passion and vision (which is, as we have seen, a key element in the commercialization of new technologies).

The Relationship between Passion and Vision

To a much greater extent than run-of-the-mill managers, champions and visionaries are expected to be passionate about their projects and ideas. In fact, it would appear that passion on the one hand and visioning and championing on the other are inextricably linked: an unenthusiastic champion would be a contradiction in terms! Markham and Aiman-Smith (2001) confirm that the limited literature on champions consistently describes champions as passionate about what they do. "Champions use the language of vision, excitement, passion, and commitment to describe their activities," (Markham and Aiman-Smith, 2001, p. ~47). Convinced that they have an important mission to fulfill, driven by the desire to make a difference and/or enrich society (Markham and Aiman-Smith, 2001), they are almost akin to missionaries spreading the gospel.

Vision and passion are so intricately coupled because, basically, vision creates passion (I owe this insight to Mr. McNeill of H Power). The vision is in effect a catalyst that can trigger fervent enthusiasm (Interview - McNeill). The more compelling the vision, the greater the passion it will bring forth. The broader the vision, the greater the amount of people who will espouse it and thus become potential enthusiasts. In general, the higher the stakes, the higher the potential for passion. So industries that propose particularly sweeping and appealing visions will be most likely to have a passionate workforce to call upon. The fuel-cell industry is an excellent example of this. There is no doubt that its vision is all-encompassing (quite simply because energy is such a basic need). As Paul McNeill explains, fuel-cells have the potential to play a major role concerning environmental protection, accelerating the development of the Third World, ending the isolation suffered by remote locations (Interview - McNeill), not to mention decentralizing and democratizing power generation... There is something for everyone to be happy about. Such a vision is bound to generate powerful passions.

The Prevalence of Passion Within the Fuel-Cell Industry

And, there indeed appears to be no shortage of passion within the fuel-cell industry. The very fact that so many people were willing, and even eager, to answer my questions -despite being very busy- tends to suggest that enthusiasm is endemic in the field. As Mr. Kryzan puts it, “many people who have joined [Global Thermoelectric] are excited about the prospect of developing a product which can have [an] environmental benefit and I would say there is a distinct sense of a mission that we are trying to do something very positive for the world” (Interview - Kryzan).

Granted, now that widespread commercialization is imminent, and that fuel-cells are no longer a pie in the sky, the industry is beginning to attract people who are perhaps not quite as intensely enthusiastic as their predecessors were, but rather more down-to-earth, sensible and risk-averse. Nevertheless, according to Dr. Stannard, there is still a high percentage of passionate people in fuel-cell development (Interview - Stannard).

So is passion too widespread to be considered strategic in the case of the fuel-cell industry? Well, there are two points that need to be made. First of all, the presence of passion is by itself no guarantee of superior performance. Passion is a resource that must imperatively be exploited in a particular fashion in order to generate benefits. We will expand upon this point subsequently, but for the moment, let us simply consider its implication, namely that the ubiquity of passion does not rule it out as a strategic resource. Second of all, and perhaps more importantly, fuel-cell companies are not competing exclusively against other fuel-cell companies. On the contrary, their main rivals are, and will likely continue to be for the foreseeable future, companies that develop and sell other power-generating technologies. Therefore, passion may be a strategic resource for the fuel-cell industry as a whole, in comparison to the makers of, for instance, internal combustion engines.

d. Are Passion’s benefits truly appropriable?

Employees Can Leave & They Expect to be Rewarded for their Efforts

If passion truly makes employees more productive, effective, determined and willing to endure hardship, then a company can indeed expect to appropriate many of the resulting benefits in terms of better performance. However, there is a rub: employees are free agents, and as such they are quite capable of leaving the firm to seek employment elsewhere. Indeed, many strategists warn against relying too much on one's human resources to achieve competitive advantage, as they are liable to disappear at a moment's notice.

Moreover, it bears repeating that passion does not entail altruism. The employees in question will definitely want to see their efforts succeed, will want their company to come out with a marketable product, because they are passionate about their work. But they are expecting to get something out of it as well. Sometimes, the mere knowledge that they contributed to making the world a better place will be enough, but most often, they are seeking something a bit more substantial. When this is the case, the firm will be expected to reward their commitment (through stock-options, for instance), so that it will in effect be redistributing some of the gains it obtained thanks to their passionate efforts. Arguably, this is only fair (besides, the tendency to think that there is a constant, inevitable conflict between employees and their managers is probably outdated and certainly counterproductive).

Some Companies Are Better Placed to Appropriate the Benefits of Passion

Yet companies may have more room for maneuver than the previous paragraphs suggest. Indeed, we have proposed that passion is in part inspired by a firm's vision, or by the very nature of the industry in which it operates. In this case, the company may be able to appropriate a larger share of the benefits which are engendered by its employees' passion, since it will be more or less assured of a constant supply of enthusiastic recruits. In other words, the firm's bargaining position will be much stronger, as it can pick and choose from among a multitude of equally passionate individuals.

C. Passion Seems Sustainable

There is thus a strong conceptual case for considering passion to be a potential source of competitive advantage. However, would such a competitive advantage be sustainable?

The Fluctuation of Passion

Now that fuel-cells are on the brink of widespread commercialization, it is reasonable to wonder whether the passion that seems to permeate the industry will endure. Presumably, now that their goal is at hand, the enthusiasm experienced by certain insiders will no longer be fueled by their overwhelming desire to bring fuel-cells to market. Moreover, many of the people I interviewed observed that the industry has already changed quite a bit, and is now more driven by money than by passion per se (Interview - Stannard), although of course profit and passion are not necessarily at odds with one another. Mr Hoffmann estimates that, in absolute terms, the number of passionate people in the industry has not varied, but the percentage they represent has significantly decreased (Interview - Hoffmann).

So then, is passion just a strategic resource during the R&D and pre-commercialization phases of an emerging industry, and not afterwards? Certainly the importance of enthusiasm is likely to diminish somewhat, as aspirations catch up with reality, and reality rules out some of the more ambitious goals. All in all, as an industry matures, it probably becomes less capable of eliciting enthusiasm. But I do not believe passion will disappear completely. After all, passion is, I think, a strategic resource in many, if not all, industries -not just emerging ones. But its nature and extent will most certainly undergo changes, perhaps drastic ones.

Passion Appears Inimitable and Unreplaceable

At first glance, it is difficult to see how passion could be either imitated or replaced. After all, one is either passionate or one is not. It may be that a strategy based on pure rationality, with no trace of emotion and consisting exclusively of hard-headed reasoning, might advantageously stand in for one based on passion. But this would invalidate much of my claims regarding the strategic importance of passion. In the end, only further research will be able to throw some light on this particular point.

3. Passion as Panacea?

Passion is Not Enough to Guarantee Success

Contrary to what I may have seemed to suggest so far, passion is by no means the solution to all of a company's problems. It does not guarantee business excellence. If that were the case, many, indeed practically all of the start-ups in the fuel-cell industry would be well on their way to triumphal success, which is clearly not the case. As Mr. Hoffmann noted in his reply to me, "there are some scientists, also some experienced entrepreneurs that I know who try or tried to start companies but who in the end needed to hire outside professional management help, fell by the wayside, or gave up" (Interview - Hoffmann). The intense will to succeed that passion creates is certainly beneficial, but it must be bolstered by concrete resources and competencies as well. Passion won't make the impossible any less impossible.

Passion can be Detrimental

In fact, this brings us to how passion can actually be detrimental in some cases. Being unconstrained by reason can all too easily bring one to ignore the telltale signs that an undertaking is futile, and thus cause one to persist in its pursuit when to do so is clear folly. Passion may therefore actually expedite failure rather than success if it makes one lose sight of economic fundamentals. Basically, the real danger of passion, its "dark side," is the blind, unyielding determination it can elicit, which can impede flexibility and even understanding. Mr McNeill thus described how some of the really driven individuals in the fuel-cell industry could truly be described as prima donnas, who will stand by their convictions no matter what (Interview - McNeill). This makes collaboration rather laborious, if not impossible, although it is usually sorely needed.

Perhaps the most pertinent, although hardly very academic, example of how excessive enthusiasm, if it is not properly directed, can have adverse consequences is the way in which I conducted my own research. I was certainly quite eager to learn more about the fuel-cell industry, so much so that I spent an inordinate amount of time gathering and reading material, in particular magazine and newspaper articles, but also scholarly papers (often very technical ones) on the subject. I undoubtedly went into too much depth, and in the end, I found myself short of time when it came to writing up my findings. Despite a (much needed) extension, I was unable to fulfill everything I'd meant to do, probably in part because I once again got carried away as I described fuel-cell technology, its potential, and the fascinating individuals and companies that are striving to commercialize it. Clearly, passion is not all it's cracked up to be!

4. Making Passion Work for the Firm

Directing it

Passion is thus an ambivalent force. It would seem that, as one my friends[43] put it, “it's a Charybdis and Scylla problem: too much and too little are bad.” The trick, therefore, is to harness one’s employees’ passion in a way that will steer clear of the pitfalls while seizing the benefits. In practice, this means that one must guide and direct their passion (Interview - McNeill), and one’s own, with a healthy dose of business savvy (ie, reason). Success will be, I believe, assured if passion and reason can be combined. This brings us back to the conventional precepts of strategic management research, namely that managers must understand their business, their environment, their rivals, their strengths and their weaknesses... in order to implement effective strategies.

Spreading it

Passion, when it can be directed properly, is certainly worth having in quantity. After all, the odd enthusiastic employee won’t make much of a difference, unless he or she is particularly skilled or high ranking. Passion truly becomes a strategic resource when it is widespread throughout a company, when it makes itself felt at most levels of the organization, when all the firm’s employees are committed and feel a sense of purpose (Livesay et al, 1996). One way of achieving this is to attempt to hire only those who show the potential to become, or who already are, passionate about the firm’s products and goals. This is not always very practical, but it would seem that firms belonging to certain industries, or companies that have excellent reputations and are prestigious, can indeed see to it that they only take on passionate individuals. This is certainly the case for fuel-cell firms, which seem to have no trouble attracting top-class people, who are very much motivated by the technical challenge and environmental aspects of fuel-cell technology (Interview - Bosch).

Fortunately for companies in industries which are less inherently “exciting,” there would appear to be another way to spread passion. Indeed, it seems that passion is,

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[43] Samuel Lisi

to a certain extent, contagious, according to empirical evidence cited by Glassman and McAfee (1990). We tend to imitate our associates, so that their enthusiasm (or lack of it) will directly influence us, making us enthusiastic (or halfhearted) as well. This opens up the possibility for managers to use their own passion in order to infuse their subordinates with similar levels of enthusiasm. Thus, Glassman and McAfee (1990) suggest that enthusiasm, which they define as an "ardent zeal toward a project or goal that involves risk" (Glassman and McAfee, 1990, p. 4) is the "missing link" in leadership. It is of course risky for a manager to enthusiastically embrace a project, since, by taking ownership of it, its success or failure will be reflected directly on him or her. But the reward can be worthwhile, as it can enable them to "contaminate" their subordinates with their passion, with all the benefits this entails.

Therefore, an effective leader will be passionate, not just rational, and able to communicate this passion to his or her subordinates. Such assertions are not merely unfounded claims. Some psychologists have found evidence linking, for instance, positive student attitudes to the enthusiasm of their teachers (Streeter, 1986, *in* Glassman and McAfee, 1990). But Glassman and McAfee (1990) are also quick to point out that managers should not overdo their enthusiasm, as excessive passion is not an appropriate managerial image in our culture, which places a premium on being calm, cool and collected in the face of adversity.

Creating it

Many firms are somewhat disadvantaged when it comes to passion, as they are in industries commonly considered dull or even distasteful. Rather than attempt to make an inherently uninteresting activity interesting so as to elicit enthusiasm, which is unlikely to succeed, such companies would be better advised to capitalize on the fact that strong enthusiasm can be generated by the prospect of material gain (as we have seen). Indeed, perhaps the most widespread passion-generating mechanism in existence is quite simply the stock-option, and other related instruments. By giving employees a direct stake in the firm's success, one is in effect hoping they will become intellectually but also emotionally involved in the effort to achieve superior performance. Unfortunately, it is not clear whether most employees will actually perceive that there is a link between their own performance and that of their company's stocks. After all, it is quite likely that any such link is tenuous at best. In which case, other means will have to be found to generate passion.

One of these is the auto-generation of passion in a quasi-artificial manner, an intriguing possibility advanced by Glassman and McAfee (1990). According to the authors, it has been empirically demonstrated that by pretending to feel an emotion, one will eventually end up by actually experiencing the emotion being played out. Presumably, this applies to passion, so that by acting enthusiastic, one will actually become enthusiastic. Whether such a feat is indeed possible in the context of a firm remains to be seen, however, and some skepticism would not seem misplaced.

5. Passion: Under-researched in Management Studies.

If passion is indeed such an important strategic resource, why is there such a dearth of research on the subject? Although I did my best to track down empirical studies, I came up mostly empty-handed. Many management books certainly wax almost lyrical on the importance of passion and enthusiasm, but the evidence presented is just as anecdotal as what I myself proffered. There are two reasons for this: the heavy influence of economics on management research, and the academic obsession with quantitative studies.

___________A. Economic Science: Reason at the Expense of Emotion

The Maximization of Profit

The field of strategic management can largely trace its origins back to economics, and economic theory continues to suffuse much of the literature on corporate strategy today. Consequently, there is a strong emphasis on the rational, the planned, the reasoned. Indeed, one of the key assumptions of conventional economic theory is that individuals are rational, or at the very least boundedly rational (Simon). Seeking to maximize their utility, they carefully weigh the pros and cons of each possible course of action as they make their economic decisions. This reasoning applies to firms as well, with the difference that utility maximization is advantageously boiled down to profit maximization (Zafirovski, 1999). In other words, it is assumed that business executives have one overriding concern, and that it is the maximization of their firm's profit. Indeed, when a firm is operating in a truly competitive marketplace, it has no choice but to adopt profit maximization as its goal, or it will soon be competed out of existence (although Feinberg, 1975, suggests that deviations can occur, even if they remain small in most cases).

Attempts by Economists at Considering Other Motivations

Economists, or most of them at any rate, realize of course the abstract and incomplete nature of their assumptions. Some have attempted to flesh them out a bit, to give them more substance. Simon (1955, *in* Kaufman, 1990), for example, has suggested that one should speak of "satisficing" behavior rather than of maximizing behavior, as this would more accurately reflect the fact that, since it is exceedingly difficult to cope with imperfect information and complexity, most managers are content with finding satisfactory courses of action, instead of the optimal ones that maximization calls for. Other researchers, in particular Baumol (1959 *in* Kaufman, 1990), have been slightly more radical and have emphasized managerial motives such as the quest for power and prestige, for high salaries and perks, rather than the search for profits. But such managerial motives seem to be confined to situations in which there is an owner/manager split, and even then, it can be argued that managers enjoy less discretion in choosing what goals to pursue now that shareholder scrutiny is so high.

The Contribution of Entrepreneurship Researchers: Animal Spirits

Perhaps it is entrepreneurship researchers who have, among management scholars, distanced themselves the most from the focus on reason rather than on emotion. Schumpeter, in many ways the doyen of entrepreneurship research, was one of the most forceful critics of "homo economicus": "what a miserable figure he is. … he has no ambition, no entrepreneurial spirit, in brief he is without force and life" (Schumpeter, 1928, *in* Anderson, 1998, p. 138). Since then, the study of entrepreneur motives has lead academics to emphasize the non rational aspects of entrepreneurship. According to Zafirovski (1999, p. ~362), for example, "a large if not dominant portion of entrepreneurial activities is probably a dependent variable not of rational (mathematical) calculations and expectations, but of spontaneous optimism and pessimism, and other non-rational factors" so that "forces such as emotions and values, not logic and rational calculations, play a central role in entrepreneurship" (Zafirovski, 1999, p. ~362). Such non rational, or "soft," motivations include the quest for status, power, morality, trust, justice, religious faith... (Zafirovski, 1999).

Clearly, and we have already touched upon this previously, entrepreneurs are driven by a variety of needs and desires, or "animal spirits," as Keynes memorably put it (*in* Zafirovski, 1999). Birley and Westhead (1994) provide a relatively exhaustive list, with the need for approval, the need for independence, the need for personal development, welfare considerations (both moral and ideological) and the perceived instrumentality of wealth being the most recurring ones. Once again, Schumpeter (1949, p. 93 *in* Zafirovski, 1999, p. 363) was one of the first to suggest that entrepreneurs are inspired not by the lure of profit, but by "a dream and will to build a private kingdom," a "will to conquer: the impulse to fight, to prove oneself superior to others" and the "joy of creating, of getting things done, or simply exercising one's energy and ingenuity." Technologically-minded entrepreneurs, in particular, seem to be driven more by the desire to innovate, to overcome challenges and to fulfill their visions than by the wish to make more money (Amit et al., 2001).

The Displacement of Passion by Reason

This dissertation does not have the temerity to undertake a detailed analysis of the profit-maximization assumption. I am not sufficiently well-versed in economics to attempt such a thing. All in all, it would seem that profit-maximizing or satisficing would appear to be a valid simplification in economic theory. Too much realism would only produce unwieldy models that wouldn't necessarily provide additional understanding (or not enough of it to warrant the excessive complexity). But the prevalence of economic thought in the field of strategic management has, I believe, lead to the unfortunate negligence of very powerful motives and driving forces that can play a critical role in business. In effect, the study of Reason has displaced the study of Emotion.

___________B. The Scientifically Intractable Nature of Passion

Academia in the Thralls of Scientism

The influence of economic theory isn't the only thing that must be blamed for the neglect of passion in strategic management. Indeed, the lack of references to human passions is endemic to all the social sciences, whether it be in the fields of economics, political science or psychology... (Sears, 1992). Rationalism, or variations thereof, now dominates most of the social sciences. For example, psychology, under the influence of behaviorism, used to emphasize animal drives and "tissue needs," but with the advent of cognitive psychology, the jungle animal was replaced by the computer as the main metaphor for human behavior (Sears, 1992). But apart from these shifts in academic fashion, the real culprit explaining the dearth of passion in business studies is quite certainly the fact that the academic community is enamored with scientific methodologies, or rather with attempts at replicating scientific methodologies for the purpose of studying humans and their interactions. Quantitative methods are, it seems, deemed the only valid ones with which to undertake research: the adoption of qualitative methods is almost viewed with suspicion (Sears, 1992). And this is, to a certain extent, understandable, if not entirely justifiable. As Sears (1992, p. ~188) explains:

> "Our academic reward system depends heavily on peer evaluation, whether it is for publication or hiring or promotion. Scientific work can readily be evaluated by our academic evaluation system. We have a great deal of consensus about what a good experiment is or a properly specified model is. We do not have good consensus about evaluating case study or qualitative research. Of course we equate "objective" evaluation with "consensual" evaluation, but I just assume that the key issue is consensus, because that is what produces reliability, and that is what gives evaluators a sense of confidence in their judgments. As a result, the more scientific and more quantitative work (...), seems to me to, over time, drive out less scientific work."

Thus, academia's reward system discourages the study of issues that are not scientifically-tractable, such as passion. And it would indeed seem that passion cannot be carefully measured and dissected, that it is “hopelessly subjective” (Sears, 1992).

Measuring Passion May in Fact be Possible

Perhaps Sears is a bit too hasty, however. Indeed, McKinney (1983) refers to, and indeed employs in his research, a framework devised by Collins (1976, *in* McKinney, 1983) to measure enthusiasm. To do so, researchers consider a whole array of different behavioral and physiological cues in order to rate an individual’s enthusiasm on a scale from 1 to 5. These cues include vocal delivery, eye movements, gestures, body movements, facial expressions, word selection, acceptance of ideas and feeling and overall energy level (McKinney, 1983). For instance, one can analyze the individual’s voice for changes in pitch, volume and speed.

One could conceivably also ask firm insiders to rate their colleagues’, and their own, levels of enthusiasm, which is what I myself did for my research. Such ratings are usually based on the (admittedly superficial) analysis of behavioral patterns. Thus, for example, employees who often work overtime (without being paid for it) were deemed to be passionate about their work. But such inferences are far from rigorous. Indeed, it is quite possible that these employees are working overtime because of peer pressure, or from fear of losing their jobs if they do not push themselves to the limit, which are two very frequent reasons for such behavior. More problematically, this methodology cannot truly distinguish between different degrees of passion. Therefore, Sears’s (1992) conclusion that passion is difficult to study in any way other than qualitatively, with the intense use of case studies, is probably correct.

6. Conclusion: The Need to Study Emotions in Business

Summary of Principal Propositions

I propose that passion is an important strategic resource. It is especially beneficial for managers, visionaries and champions, who can use their enthusiasm to inspire their subordinates and colleagues. It is not confined to these categories of people, however, nor is it confined to certain industries or activities. This is because passion can be driven by a variety of motives, including the ever popular pursuit of profit. I suggest, however, that passion is strongest when derived from a combination of both profit and welfare motives. Finally, passion is contagious, and can even be generated, but must be directed with care if it is not to become detrimental.

Passion can Compensate for the Lack of Other Resources

More intriguingly, I believe that passion can in effect offset the absence of other strategic resources. To understand how this is possible, let us consider what Hamel and Prahalad (1990, 1993) call *strategic intent*. Hamel and Prahalad have coined this term to describe the way in which companies can set ambitious targets that, by inspiring their employees, can lead to extra effort and commitment on their part. This *strategic intent*, by giving rise to an obsession with winning, can allow firms that are apparently less well endowed than their rivals to nevertheless surpass them. This is because the highly ambitious goals embodied in the company's *strategic intent* can lead to *strategic stretch,* ie the leveraging of what resources the firm does have so that it can make the most of them (Hamel and Prahalad, 1990 and1993). Prahalad and Hamel point out that much of *strategic intent*'s value lies in its ability to unleash the creativity and aspirations of the firm's employees. Indeed, according to them, emotion is a critical constituent of *strategic intent.*

Much of my analysis is strikingly similar to theirs. But rather than call upon a new concept, such as their *strategic intent*, to underpin my framework, I content myself with suggesting that one resource can replace another. Namely, passion is in some cases capable of compensating for a limited resource-endowment. Indeed, this is perhaps passion's greatest potential contribution to firms.

The Need for More Research

In the end though, all these are merely hypotheses. More conclusive evidence[44] will need to be gathered, by the carrying out of further research on passion, and perhaps on other emotions as well. Indeed, there is a distinct, and deplorable, lack of research on the question of emotions in the business world. Such a situation, unjustifiable considering the importance emotions seem to have in all human activities, must be addressed as soon as possible.

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[44] If such a thing can exist in the social sciences!

VI. CLOSING REMARKS: WILL FUEL-CELLS BE BIG?

A. Methodological Limitations and Regrets

I have already discussed in detail most of the limits of my methodology (please refer to the relevant sections). But perhaps the greatest limitation in my research was its failure to compare multiple cases[45] of emerging industries, in order to better determine how widespread the *Six Needs* really are. The study of multiple cases would also have proved useful for my research on passion. Indeed, the fuel-cell industry is overflowing with enthusiastic entrepreneurs, researchers and executives, and so my focus on it perhaps led me to exaggerate the importance of passion. Passion may in reality simply be a useful resource, but not a particularly strategic one.

Another major limitation was, strangely enough, my excessive ambition (or perhaps foolishness would be a better term), which caused me to tackle a research project that was much too large for a mere dissertation. This made my research rather unwieldy, and hard to structure in a concise yet clear way. My analyses certainly suffered from this, and it no doubt would have been much better, as far as the quality of my research is concerned, for it to have been more focused. Fortunately, my interest was sustained throughout (and then some!), which is essential for such long-term projects (Watson, 1994).

B. Fuel-Cells: the Next Big Thing

All of the people I discussed my dissertation with were much more interested in learning when fuel-cells are going to be commercialized than in hearing me describe

[45] See Eisenhardt (1991) for an explanation of the importance of multiple case logic in research.

my research on passion[46]. And, frankly, I can't say I blame them... Once informed about the technology's promise, they all wanted to know whether fuel-cells will indeed succeed in becoming widespread. I thus decided to conclude my dissertation with a brief discussion of fuel-cells' prospects. Because, if there is one thing that my research has convinced me of, it is that fuel-cells are going to come and they are going to be big. In fact, I have been so well brain-washed that, as soon as I hand in this dissertation (well, after I've had a few days of much needed rest at any rate), I will begin sending off my resume to fuel-cell companies!

Skeptics Denounce the Unbelievable Hype

First, it is necessary to point out that there is an unusual amount of hype surrounding the fuel-cell industry. Mr. Mannion (Interview - Mannion) was particularly eager to warn me not to succumb to it myself (it seems that perhaps I've failed on that count). He noted that there are still some "real issues in performance." Indeed, International Fuel Cells has solved many problems that most of the other people working in the industry don't yet even know exist (Interview - Mannion). So it is definitely worth taking what some of the more fervent fuel-cell advocates are saying with a grain of two of salt. As McNicol (1999) explains, fuel-cells have been "just around the corner" for more than 25 years. Back in the 1970s, fuel-cell firms were already promising their technology would be on the market in five years' time... In fact, some analysts have been warning that car companies will not be able to launch their fuel-cell powered cars by 2004 (Anonymous, 1999c).

Pullin (1999, p. 3) bases his skepticism on the principle that "the one certainty about technological prediction is that, in 99% of cases, it will be wrong, sometimes deliciously and ludicrously so." Thus "fuel cells may prove to be a dead end, a transitory technology, or just a Californian dream" (Pullin, 1999, p. 3). Most skeptics, however, do not dismiss fuel-cells out of hand, but instead seek to refute the more optimistic announcements of fuel-cell companies by insisting that the commercialization of fuel-cells will be a lot more protracted than supposed. Thus, Mike Monaghan of Ricardo Consulting Engineers is confident that diesel engines still have a good thirty

[46] Except of course my supervisor Professor Lampel!

odd years in front of them before they are replaced by fuel-cells as the engine of choice for light-duty vehicle fleets (Anonymous, 1999c). Murphy (2001), in an article entitled “long live the internal combustion engine!" agrees. Peter Lehman, director of the L.W. Schatz Energy Research Laboratory, doesn’t even think fuel-cells will be mass-produced at all until 2020-2025, even though he is himself an avid supporter of the technology (Gardner, 1998). Ironically enough, however, the most discouraging item I read about the future of fuel-cells was the mandatory section in Ballard’s share prospectus detailing all the risks it faces (Ballard, 2000)...

But Fuel-Cells are Definitely Coming

“I've heard it said that the only guys who have made money in fuel cells so far are conference organizers,” wrote Mr. Hoffmann (Interview - Hoffmann). But he adds right afterwards that “given the pace of developments, the churning and frothing, the amounts of money that are apparently being spent (DaimlerChrysler talks about a billion dollars, GM and Toyota are probably spending comparable amounts) it's difficult to shrug it off as PR ploys to bump up company stock. Seems to me there are too many seriously enthusiastic technologists, engineers, academics, environmentalists and the occasional knowledgeable politician (such as U.S. Senator Tom Harkin who contributed the Foreword to my book) to shrug off these developments as so much hot air” (Interview - Hoffmann). Mr Rose, Director of the US Fuel-Cell Council, goes further and states that “I would say that fuel cells have a certain inevitability, since they utilize a carbon-free fuel (indeed are the enabling technology for a hydrogen economy). As such, they support a trend as old as the age of fire, away from high-carbon fuels and combustion and toward low- or no-carbon gases and electrochemistry” (Interview - Rose). Tangeman agrees: “fuel cells have so much going for them in the long run in terms of energy efficiency and so on that they will be a winner, I think."

Clearly, those involved in commercializing fuel-cells are probably not the most objective people to ask (although they are certainly the best informed). But as The Economist writes (2001f, p. *1):

> “Not long ago, dozens of people from around the world descended upon an idyllic country retreat in Canada for a most energetic pow-wow. The motley crew sat in a giant circle with native drums of every imaginable size and shape, and

banged away till green inspiration struck. They then strategised about how to move the energy world beyond the filthy but durable workhorses of today's fossil fuels and internal combustion engines. They agreed that the future belongs to fuel cells, which produce clean energy by combining hydrogen with oxygen without combustion. Now, here is the weird part: those peculiar percussionists were not wild-eyed greens, but sober technical experts from the world's biggest car companies, energy firms and research laboratories. Indeed, the whole shindig was organised by the new hydrogen division of BP, an oil giant. The reason for their enthusiasm was that, more than 150 years after its invention, the fuel cell is finally about to become a commercial reality."

And Sooner Rather than Later: a Possible Time-Table

Fuel-cell manufacturers are not shy when it comes to making predictions. Indeed, Ballard's Harris says, referring to fuel-cell technology, that "you'll see it under Christmas trees or powering your Christmas trees by the end of the year" (*in* Erwin, 2001, p. *1). Of course, in this case, he might be right, since Ballard has just announced the commercial launch of the first mass-produced PEM fuel-cell for portable applications, the Nexa (Ballard Power Systems, 2001b). Indeed, most of us will probably first be introduced to fuel-cell technology through portable devices, although fuel-cell powered laptops and mobile phones will probably only become available in 2004-2006 (The Economist, 2001i).

Stationary fuel-cells won't be far behind the Nexa. According to Rob Privette, the fuel-cell business director at dmc[2] (a major supplier of fuel cell catalysts and components), we can expect to see the first generation of stationary fuel-cells between 2002 and 2003, the second one around 2004-2006, and a third one between 2004 and 2007 (Boswell, 2001). Finally, fuel-cells for cars should be shipping by 2003, if Ballard can keep on schedule (Boswell, 2001). The actual cars ought to become available between 2003 and 2006, in the case of DaimlerChrysler and Honda, whereas GM is aiming to have fleet-ready vehicles in 2008, and fuel-cell cars on the mass market in 2010 (Boswell, 2001). If all goes according to plan, 7-20% of all new cars (and possibly all urban buses) will be powered by fuel-cells by 2020, according to DaimlerChrysler (Anonymous, 2001f). In fact, Ford predicts that, rather than only just emerging in 25 years' time (as predicted by some skeptics[47]), fuel-cells will then be the "predominant automotive power source" (Anonymous, 2001f).

Implications: Winners & Losers

Apart from the fuel-cell industry itself, many industries will benefit from the commercialization of fuel-cells. These include chemical companies, such as Nafion, DuPont, Celanese and Engelhard (Tullo, 2001), natural gas companies (Johnson, 2000), perhaps methanol vendors (Scott, 2001), and, eventually, all the companies involved in the production and storage of hydrogen. Inversely, quite a few industries are likely to wish fuel-cells would just go away. These include the power utilities, since distributed generation may severely disrupt their businesses, especially if fuel-cell cars end up powering the homes of their owners. Indeed, as Popely (2001b, p. *1) points outs, "1 million fuel-cell vehicles would have more electrical generating power than all of California's utilities." And, of course, the oil industry may suffer quite a bit as well (McNicol, 1999).

Implications: A Brave New World?

If fuel-cells can truly fulfill their promise, the implications will be quite mind-boggling. As Mr Rollins of Plug Power puts it (Interview - Rollins), there will be "greater conservation and utilization of resources, higher overall productivity/efficiency, increased standards of living worldwide and increased communication and connectivity." It will change the way we think about energy, according to Ms. Geyer (Interview - Geyer), since our fuel-cell cars, with their 50 kW or so engines, would be capable of powering not only our own houses, but nine others as well (see appendix 8).

But perhaps the advent of fuel-cells will have the greatest beneficial impact on Third World countries. Indeed, according to Mr. de Groot, fuel-cells could power the *favelas* that currently have no access to electricity (with all the dire consequences that has). Cottage industries will be able to run off them, which will be good for employment and production. He even envisions fuel-cells helping to spread schooling and access to information (Interview - de Groot).

Should all of this occur, then we will all be winners. Let us hope, therefore, that fuel-cells will indeed make it big!

Note: *for more information on fuel-cells, please consult the websites listed in* ***appendix 15***

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[47] It must be said however that those particular references are a bit dated. Fuel-cell technology has progressed quickly over the past couple of years, so that some of the skeptics quoted may no longer be quite as skeptical!

APPENDIX 1

APPENDIX 1: COMPANIES CONTACTED

Note: Email addresses were included whenever possible, but some companies had to be contacted by mail or through their websites.

ASSOCIATIONS, COUNCILS, INSTITUTES & PUBLICATIONS

Electric Power Research Institute	askepri@epri.com
Fuel Cells 2000	marleen@fuelcells.org
Hydrogen & Fuel Cell Letter	hfclettr@idsi.net
National Fuel Cell Research Center	kb@nfcrc.uci.edu
	Kim Bergland, Outreach Director
Rocky Mountain Institute.	outreach@rmi.org
US Fuel Cell Council	brose@fuelcells.org
	Robert Rose, Executive Director
World Fuel Cell Council	info@fuelcellworld.org

COMPANIES

3M	innovation.uk@mmm.com
Astris Energy	info@astrisfuelcell.com
Avista Labs	mranniger@avistalabs.com
	Maria Ranniger
Ballard	investors@ballard.com
CellexPower	info@cellexpower.com
Coval H2 Partners	wharris@covalh2000.com
	Warner O, Harris, PE, President / CEO
DaimlerChrysler	
Dais-Analytic Corporation	info@daisanalytic.com
DCH Technology	jbradt@dcht.com
Delphi Automotive Systems	laura.m.katona@delphiauto.com
	Laura Katona, Intern
Dupont	info@dupont.com
Energy Partners	info@energypartners.net
Energy Related Devices	energyrd@aol.com
Energy Visions	president@energyvi.com
	Wayne Hartford, President and CEO
ExxonMobil	
Ford	
FuelCell Energy	dferenz@fce.com

FuelCell Resources	info@fuelcell-resources.com
Fuel Cell Technologies	fct@fuelcelltechnologies.ca
GE Distributed Power	GEDistributedPower@ps.ge.com
Global ThermoElectric	fuelcell@globalte.com
GreenVolt Power	tlfaul@greenvolt.com
	Thomas Faul MaSc, P Eng, President
H Power	Investorrelations@hpower.com
Hydrogenics	sales@hydrogenics.com
Hydrovolt	John@hydrovolt.com
	John Lucas, President / CEO
Idatech	info@idatech.com
Innogy	john.newton@innogy.com
	John Newton, Marketing Officer
International Fuel Cells	ifcinte@ifc.utc.com
Johnson Matthey	JAFFRC@Matthey.com
	Colin Jaffray
LynnTech, Inc	info@lynntech.com
Manhattan Scientifics, Inc	maslow@ix.netcom.com
	Marvin Maslow, President, CEO & Chairman
Medis Technologies	info@medisel.com
McDermott Technology	Larry.basar@mcdermott.com
Mosaic Energy	gerry.runte@mosaicenergy.com
	Gerry Runte, President
Motorola	
Nuvera Fuel Cells	mhand@nuvera.com
Plug Power	David_Rollins@plugpower.com
	David Rollins, Market Engagement Manager
Proton Energy Systems	pes@protonenergy.com
Shell	
Sure Power	amannion@hi-availability.com
	Art Mannion, Exec VP & Cofounder
Xcellsis	info.service@xcellsis.com
ZeTek Power	info@zetekpower.com

APPENDIX 2: INTERVIEW QUESTIONS

Notes: my questions varied over time, as I gradually focused on certain issues. Initially, they were very open-ended so as not to unnecessarily circumscribe my research. Though I did not originally refer to the concept of passion, my last three interviews did take up the subject in quite some depth. The questions below were those most frequently asked (during the midpoint of my research).

Naturally, I personalized these questions depending on the nature of my interlocutor's organization and his or her role in that organization. Questions 8 and 9 were tacked on mainly to satisfy my own curiosity, but were not directly relevant to my research.

QUESTION 1

1- Who founded [INSERT COMPANY NAME] and decided to develop fuel cell technology? What were his/her/their motives? (a few possible answers I thought of: out of a desire to enter an emerging industry with huge potential returns, to take advantage of synergies with other business units or particular competencies, to make fuel cells a reality for social and ecological reasons, from fear of being left behind in case fuel cells become the Next Big Thing...)?

Variation for firms whose activities do not exclusively focus on fuel-cells:

1- Who at [INSERT COMPANY NAME] suggested the company engage in fuel cell related research and campaigned for the initiation of a fuel cell program? What were his/her/their motives?

Variation for associations, councils, or institutes:

1-Who (or which companies) founded [INSERT ASSOCIATION NAME]? What were his/her/their motives (to lobby the government more effectively, to share research findings, to promote best practice...)?

QUESTION 2

2-Would you call him/her/them a visionary (ie an idealist, motivated principally by reasons other than profit, and driven to make his or her vision a reality)? Why or why not? Would you say that visionaries play a key role in the fuel cell industry? Or does the widespread hype concerning fuel cells tend to conceal the fact that the industry is driven, like most other industries, by practically-minded leaders who mainly have the interests of their shareholders at heart?

QUESTION 3

3-Would you agree that many or indeed most of [INSERT COMPANY NAME]'s employees who are involved in the fuel cell program are motivated in part by idealistic considerations (particularly of an ecological nature)? If so, do you believe this makes them more productive, innovative and/or determined? Has the commercialization of fuel cells become a sort of crusade that must be achieved at all costs? Or do these employees' concerns remain more sensible and pragmatic (mainly economic profitability / earning a living)?

In other words, would you describe them as passionate about their work?

Variation for associations, councils, or institutes:

3-Would you agree that many or indeed most of [INSERT ASSOCIATION NAME]'s members are motivated in part by idealistic considerations (particularly of an ecological nature)? If so, do you believe this makes them more productive, innovative and/or determined? Has the commercialization of fuel cells become a sort of crusade that must be achieved at all costs? Or do these members' concerns remain more sensible and pragmatic (mainly economic profitability)?

QUESTION 4

4-Can one speak of a "fuel cell" community of like-minded individuals who seek to cooperate in order to promote fuel cells? Or do the companies involved (***when addressing a company:*** such as your own) prefer to remain secretive and "aloof" in order to protect sensitive information? For example, do you and colleagues from rival companies share common motivations and beliefs? Do you sometimes share information and advice? Is there a common sense of purpose?

QUESTION 5

5-It would seem that many fuel cell trade & industry associations exist. Which would you say are the most important/influential ones? What kinds of things have they been able to achieve? What kind of things would you like them to achieve? Do you think more cooperation would be useful, and in what ways?

Variation for associations, councils, or institutes:

5-What kinds of things has your association been able to achieve in order to promote the development and commercialization of fuel cells (ex: educate the public, coordinate research, lobby, organize conferences...)? What kind of things would you like to achieve? Do you think more cooperation would be useful, and in what ways?

QUESTION 6

6-What is your strategy for commercializing your fuel cell technology? (a few possible strategies: forming alliances with powerful incumbents in related industries, teaming up with other fuel cell developers, obtaining government assistance -at least initially-, focusing at first on certain niche markets...)?

Variation for associations, councils, or institutes:

6-What must be done to commercialize fuel cell technology successfully?

QUESTION 7

7-Why are fuel cells just beginning to become a commercial reality? Are they being "pushed" (by new developments in research, by enthusiastic supporters, by generous government assistance and subsidies...) or "pulled" (as one of many potential solutions to excessive dependency on oil, because of growing environmental concerns -illustrated by California's clean air laws, for example-...)?

QUESTION 8

8-Do you believe that fuel cells have the potential to become one of our main energy sources in the mid to long term (20-30 years)? Or must the hype surrounding them be taken with a grain or two of salt?

QUESTION 9

9-If so, what principal consequences will this have (economic, social, geopolitical...), considering it might lead to the widespread adoption of distributed power and to "energy independence?"

APPENDIX 3: INTERVIEW REQUEST LETTERS

Note: Whenever possible, these letters were personalized and addressed to specific individuals.

Dear Sir/Madam,

As part of my Master in Strategic Management (at the University of Nottingham Business School, UK), I am working on a dissertation about the fuel cell industry (my supervisor is Professor Joseph Lampel). I am interested in the business strategies that are involved in the commercialization of a new, breakthrough technology (is government support necessary? How does one deal with powerful, incumbent rivals?…). In particular, I would like to determine whether "visionaries" (ie driven, enthusiastic individuals who push a new technology primarily for ideological reasons -such as ecological considerations- and not solely to make a profit) play an important role in the fuel cell industry.

TO AN ASSOCIATION, COUNCIL, INSTITUTE OR PUBLICATION:

As part of my research, I'm seeking to learn about the networks and associations that exist to promote fuel cells. I would therefore greatly appreciate being able to interview someone from [INSERT ASSOCIATION NAME HERE] concerning your work with fuel cells. I realize that you are all probably quite busy, and can't easily spare much time to help a student with his research. I assure you however that I have but a very limited number of questions I would like to ask (please find them below -the first seven are particularly important for my research). Moreover, as I can unfortunately not afford to travel to [INSERT COUNTRY HERE], the interview would have to be by phone or email, which hopefully should be more convenient for you as well.

TO A COMPANY:

I would therefore like to interview someone from [INSERT COMPANY HERE] who would be in a position to tell me what motives lie behind the company's decision to pursue fuel cell technology, and what strategies have been implemented in order to do so. I realize that the top management of a company such as yours must be extremely busy, and cannot afford to spare much time to help a student for his research. But I assure you that I have but a very limited number of questions I would like to ask (please find them below -the first seven are particularly important for my research). Moreover, as I can unfortunately not afford to travel to [INSERT COUNTRY HERE], the interview would have to be by phone or email, which hopefully should be more convenient for you as well.

Thank you very much for your time and consideration,

Amaury Laporte

P.S.

I need to submit my dissertation in September, so I would be extremely grateful if an interview could be arranged as soon as possible, if that is convenient.

APPENDIX 4: LIST OF RESPONDENTS

NAME	COMPANY	JOB TITLE	VIA	EMAIL ADDRESS:	DATE
Mark Kryzan	Global Thermoelectric	Director, Corporate Affairs	Email	MarkK@ globalte.com	25/07/2001
Wayne Hartford	Energy Visions (previously Energy Ventures)	President & CEO	Email	energyvi@istar.ca	26/07/2001
David Rollins	Plug Power	Market Engagement Manager	Email	David_Rollins@ plugpower.com	27/07/2001
Art Mannion	Sure Power	Executive VP & Co-founder	Phone	amannion@hi-availability.com	01/08/2001
Paul C Tangeman	Dupont	Global Market Manager	Phone	Paul.C.Tangeman @USA.dupont.com	02/08/2001
Peter Hoffmann	Hydrogen & Fuel Cell Letter	Founder & Editor	Email	hfclettr@idsi.net	07/08/2001
Bob Rose	US Fuel-Cell Council	Founder & Executive Director	Email	brose@ fuelcells.org	08/08/2001
Jeffrey Bentley	Nuvera	Founder & COO	Phone	mhand@ nuvera.com	13/08/2001
Bernadette Geyer	US Fuel-Cell Council	Director of outreach programs	Phone	Bernie@ fuelcells.org	14/08/2001
Thomas Bosch	Shell	Market Analyst - Distributed Energy	Email	Thomas.T.Bosch@ opc.shell.com	14/08/2001
Thomas Faul	Greenvolt	Founder & President	Phone	tlfaul@encode.com	15/08/2001
Colin Jaffray	Johnson Matthey	Commercial Director - FC	Email Phone	JAFFRC@ Matthey.com	15/08/2001 16/08/2001
John Lucas	Hydrovolt	CEO	Email	john@ hydrovolt.com	16/08/2001
Paul McNeill	H Power	VP of Business Development	Phone	smurray@ hpower.com	22/08/2001
Jacques de Groot	PowerTek International	Chairman of the Board	Phone	jacques.degroote@ verizon.net	03/09/2001
Dr. John Stannard	Fuel Cell Technologies	President & CEO	Phone	Barbara@fuelcell technologies.ca	21/09/2001

APPENDIX 5: LIST OF FILES CREATED

COMPANY - Amoco.txt
COMPANY - Astris Energy.txt
COMPANY - Avista Labs.txt
COMPANY - Ballard.txt
COMPANY - BMW.txt
COMPANY - Daimler-Chrysler.txt
COMPANY - DCH.txt
COMPANY - Delphi-GM.txt
COMPANY - Dupont.txt
COMPANY - EDF.txt
COMPANY - Energy Conversion Devices.txt
COMPANY - Energy Related Devices.txt
COMPANY - Exxon.txt
COMPANY - Ford.txt
COMPANY - FuelCell Energy.txt
COMPANY - GE.txt
COMPANY - Global Thermoelectric.txt
COMPANY - GM.txt
COMPANY - H Power.txt
COMPANY - Honda.txt
COMPANY - Hypercar.txt
COMPANY - ImpCo.txt
COMPANY - Johnson Matthey.txt
COMPANY - Medis Technologies.txt
COMPANY - Metallic Power.txt
COMPANY - Millennium Cell.txt
COMPANY - Mosaic.txt
COMPANY - Motorola.txt
COMPANY - Nuvera.txt
COMPANY - Peugeot.txt
COMPANY - Plug Power.txt
COMPANY - PowerTek -de Groot.txt
COMPANY - Shell.txt
COMPANY - Siemens Westinghouse.txt
COMPANY - Sure Power.txt
COMPANY - Toyota.txt
COMPANY - UTC.txt
COMPANY - Xcellsis.txt
COMPANY - ZeTek.txt
COMPANY - Zevco.txt
COUNTRY - Iceland.txt
FUEL CELLS - Advantages.txt
FUEL CELLS - Advantages 2.txt
FUEL CELLS - Explanation.txt
FUEL CELLS - Fuels.txt
FUEL CELLS - Types.txt
FUEL CELLS - Uses & Niches.txt
FUEL CELLS - Weaknesses.txt
INDUSTRY - Alliances.txt
INDUSTRY - Commercialization.txt
INDUSTRY - Commercialization 2.txt
INDUSTRY - Commercialization 3.txt
INDUSTRY - Commercialization 4.txt
INDUSTRY - Economics - Structure.txt
INDUSTRY - Investment.txt
INDUSTRY - Potential Market.txt
KEY INDIVIDUALS - Motivations & Passions.txt
KEY INDIVIDUALS - Skeptics & Critics 2.txt
KEY INDIVIDUALS - Visionaries.txt
PART I - Champions & Visionaries.txt
PART I - Champions & Visionaries 2.txt
PART I - Cooperation.txt
PART I - Cooperation 2.txt
PART I - Government.txt
PART I - Government 2.txt
PART I - Government 3.txt
PART I - Merit.txt
PART I - Niches.txt
PART I - Niches 2.txt
PART I - Speed.txt
PART II - Passion Bad or Not Enough.txt
PART II - Passion Good.txt
PART II - Theory - Amaury.txt
THEORY - Alliances and Disruptive Innovation.txt
THEORY - Discontinuous Innovation.txt
THEORY - First-mover & Pioneering.txt
THEORY - First-mover & Pioneering 2.txt
THEORY - Government Role.txt
THEORY - Incumbents & Radical Innovation.txt
THEORY - Industry Creation.txt
THEORY - Managing Innovation.txt
THEORY - Merit.txt
THEORY - Niche.txt
THEORY - Technological Paradigm.txt
THEORY 2 - Entrepreneur Motives.txt
THEORY 2 - Entrepreneur Motives2.txt
THEORY 2 - Entrepreneurship & Theory.txt
THEORY 2 - Environmentalism & Entrepreneurship.txt
THEORY 2 - Passion.txt
THEORY 2 - Visionaries & Champions.txt

APPENDIX 6: KEY WORDS

This list is not exhaustive but does cover most of the key words I used on the academic databases.

-breakthrough technology
-competence destroying/enhancing.
-discontinuous innovation
-disruptive innovation
-early mover and advantage
-emerging industry
-entrepreneur and motivation/motive/reason/objective/goal
-first mover and advantage
-fuel cell and:
    commercial
    commercialization
    community
    development
    framework
    government
    history
    industry
    investment
    market
    review
    strategy
    visionary
-innovation community
-passion/enthusiasm and economy
-passion/enthusiasm and management
-radical innovation
-systemic technologies
-technology community
-technological evolution
-technological guidepost
-technological paradigm
-technological pioneering
-technological systems
-vision and technology
-visionary and technology

APPENDIX 7: INCUMBENTS VS. INNOVATING FIRMS

Much of this dissertation assumes that incumbent firms (that is, the firms which are currently active in the target market) are not the ones developing the innovation. Inversely, it is largely assumed that the innovating firms are relatively small, and are not yet present in the target market (or any market, for that matter). Thus, we have the stereotypical Goliath (big, powerful incumbents) vs. the perennial David (nimble entrepreneurial innovators). To what extent are such assumptions warranted?

Incumbents are Disadvantaged

Large incumbents are often dismissed as hopelessly slow and clumsy, unwilling and even unable to confront change. Innovation and incumbency are seen as a contradiction in terms. To some extent, this is justified. America's Small Business Administration estimates that small firms out innovate large firms by a factor of 2.4 to 1, on a per employee basis (Stringer, 2000). This is probably due to the fact that large companies have too much invested in the status quo, and so are extremely reluctant to challenge it (Stringer, 2000). More specifically, Chandy and Tellis (1998) suggest that incumbents are often unwilling to cannibalize their existing sales, which naturally makes them reluctant to pursue radical innovations that often require such cannibalization.

In addition, big companies tend to be bureaucratic, which is never conducive to radical innovation. They are too likely to evaluate a project's merit based on short term financial criteria (presumably because of shareholder pressure), rather than on longer term strategic ones (Stringer, 2000). Moreover, their organizational filters, which screen out information considered unessential for their main activities, may lead them to focus on maximizing their current technology for their current customers, rather than spot and develop radical innovations (Henderson 1993, in Chandy and Tellis, 2000). Finally, they rely too much on internal R&D, and are unable to attract or retain the truly radical innovators, whose need for achievement cannot be satisfied in such a stifling, anti-individualistic environment (Stringer, 2000).

On the other hand, smaller companies, being less bureaucratic, offer more opportunities for individual contributions. They naturally have less invested in the status quo, and their small size makes them more responsive, a key advantage when commercializing an innovation, what with all the uncertainty involved (Stringer, 2000).

But They Have a few Aces up Their Sleeves

Of course, such an analysis is simplifying in the extreme, and one can easily think of many counter-examples. Many big companies have made quite a reputation around their ability to innovate! As a matter of fact, Chandy and Tellis (2000) point out that the perception that "large, incumbent firms rarely introduce radical product innovations (...) is based on anecdotes and scattered case studies of highly specialized innovations" (Chandy and Tellis, 2000, p. ~1). Their own, more rigorous research, indicates that in the recent past (ie since World War 2), "large firms and incumbents [have actually been] significantly more likely to introduce radical innovations than small firms and nonincumbents" (Chandy and Tellis, 2000, p. ~8).

This is because they benefit from large scale and scope economies in their R&D, because they are less vulnerable to the risks involved in commercializing radical technologies, and because they have greater resources, in terms of manpower, money and existing intellectual property (Chandy and Tellis, 1998). Moreover, many have taken to heart Levitt's 1960 harangue that they stop resting on their laurels ("they may be natural monopolies now, but tomorrow they may be natural deaths" -Levitt, 1975, p. 27) and that they take a less narrow-minded view of what industry they're in so as to not be afraid to "plot the obsolescence of what now produces their livelihood" (Levitt, 1975, p. 28).

The Case of Fuel-Cells

When it comes to the fuel-cell industry, the conventional wisdom initially seems more or less accurate. Many of the players in this emerging industry, including some of the more advanced ones, are (or at least started out as) small entrepreneurial firms. Ballard, generally regarded as the leader in PEM (polymer electrolyte membrane) fuel-cells, is a case in point, even if it can hardly be called small at present, considering its market capitalization hovers around the 2 billion dollars[48] mark. Yet one should keep in mind that International Fuel-cells, the granddaddy of them all, is part of the United Technologies Corp. conglomerate, the 155th largest company in the world (according to Fortune). And most of the companies working on fuel-cells for stationary applications also tend to be rather large incumbents.

Basically, it would seem that being a "new kid on the block" is advantageous in the early stages of the pre-commercialization process, when the technology is not yet proven and creativity is at a premium. When its potential becomes clearer however, incumbents can mobilize their resources in order to secure themselves a strong position in the new industry (by acquiring their start-up rivals for instance), and to grab market share. For certain applications though (the military and aerospace, stationary power...), size is an advantage from the start, as the R&D costs are simply too great for smaller firms to bear.

[48] According to the Financial Times dated 10.10.2001.

APPENDIX 8: FACTS & FIGURES

When I first began my research on the fuel-cell industry, I found that much of the data provided was meaningless to me. For instance, I had no idea how much power 1 kW represents, nor did I know how expensive batteries are compared to fuel-cells and internal combustion engines (per kilowatt-equivalent). The following figures should hopefully clarify things a bit for you!

WHAT'S IN A KILOWATT?

Basically, 1,000 watts (or 1kW) is equivalent to approximately 1.34 horsepower (Ballard Power Systems, 2000, p. 72).

So, to power a car, one needs about 50-75 kW (Ballard Power Systems, 2000).

And a bus can run off 205 kW (Ballard Power Systems, 2000), which also happens to be the amount of electricity produced by a stationary power plant (Wilks, 2000).

A 2,500 square-foot house, on the other hand, could see all its electrical needs met by a mere 4.5 kW (Popely, 2001b). Therefore, 400 kW is enough for about 100 residential homes (Port, 2000). Kopicki (2001) however, reckons a house needs about 7 kW for its base load.

Colin Jaffray notes that 10 kW would be enough to power an entire cottage industry in the developing world, or a restaurant in the West (interview - Jaffray).

A modern commercial building which houses IT companies needs a lot more though: about 20-30 megawatts (O'Leary and Louria-Hahn, 2000).

According to Libin (2000), 1 gigawatt can meet the needs of 400,000 homes.

Finally, Kopicki (2001) informs us that in 2000, 3.8 trillion kilowatt hours of electricity were used in the US, which is 35% more than a decade ago.

RELATIVE COSTS OF COMPETING TECHNOLOGIES

A rechargeable battery costs about $10,000 or more per kilowatt (The Economist, 2001i).

A internal combustion engine costs about $50 per kilowatt (The Economist, 2001i).

Fuel-cells cost about $75-$100 per kilowatt when used to produce electricity for the grid, which is still quite expensive compared to the $25-$30 per kW paid by most residential consumers (Scott, 2001).

Energy prices actually vary a lot from place to place, from as low as 4 cents per kW hour (please refer to the glossary) in the Pacific Northwest to 10 cents per kWh in New York (Wilder, 2000). Prices in California soared past 15 cents per kW back during its energy crisis in March[49]. In Canada, prices can actually exceed 20 cents per kWh in some isolated communities (Gatlin, 2000). On average, and in 1998, residential customers paid about 9.1 cents/kWh, commercial customers 8.71 cents/kWh and industry got away with 4.95 cents/kWh (Gatlin, 2000).

Fuel-cell companies are hoping to reach the 4-6 cents per kWh mark by 2003-2004 (ENR, 1999).

THE ENERGY MARKET

"Energy is the biggest business in the world; there just isn't any other industry that begins to compare. By the reckoning of Booz, Allen & Hamilton, a consultancy, the turnover of the global energy business amounts to at least $1.7 trillion-$2 trillion a year. The World Energy Council, an umbrella body for various energy interests, estimates that global investment in energy between 1990 and 2020 will total some $30 trillion at 1992 prices. And it is not just size that distinguishes the industry, says Mr Raymond: Energy is the very fuel of society, and societies without access to competitive energy suffer" (The Economist, 2001c, p. *1).

"Power is every bit as big a business as telecoms. America's $220 billion electricity market is larger than those for cellular and long-distance telephony combined" (The Economist (2000f, p. *1).

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[49] Source: The Economist (2001). "How to keep the fans turning," The Economist, July 19th.

APPENDIX 9: AN EVALUATION OF FUEL-CELL TECHNOLOGY

Strengths

Fuel-cell technology could appear to be, and is often presented, as manna from heaven. It does indeed have many attractive features.

Environmental friendliness

This is perhaps the attribute most often heralded by fuel-cell promoters, eager to present their technology as the green solution to the world's energy needs. Simply put, because fuel-cells do not actually burn fuel, they produce no emissions. However, this is only true when pure hydrogen is used to fuel the cells. When another type of fuel is used, such as methanol or gasoline, it must first be reformed, a process which emits pollution, particularly in the form of carbon dioxide. Moreover, even if hydrogen is used, pollution is not altogether taken out of the picture. Indeed, hydrogen must be produced, as it does not exist naturally in a pure form on Earth, and in order to produce hydrogen, for instance by electrolysis (which is quite simply the reversal of the process which takes place within a fuel-cell), energy is required. Currently, this energy would be obtained mostly from power plants running on coal, natural gas, or nuclear power, none of which are particularly pollution-free. Although fuel-cells could in theory be totally emission free, if the hydrogen they ran on was produced thanks to renewable energy sources (solar, hydro or wind power), this is unlikely to be feasible in the near to mid term. Thus, Mr. Kryzan was especially eager to debunk the usual claim that fuel-cells are "zero-emission," for they almost always are not (Interview - Kryzan).

However, even when reformers are used, fuel-cells still emit considerably less pollution than internal combustion engines or even gas turbines. Smith (1999) estimates that should fuel-cell technology become widespread, it could reduce noxious emissions by anywhere between forty and ninety-nine percent in any given country. Panik (1998), the director of DaimlerChrysler's fuel-cell research efforts is more emphatic, and asserts that, overall, taking into account the entire "energy conversion chain," fuel-cells produce 90% less emissions than internal combustion engines, even if methanol is used as a fuel instead of pure hydrogen. Finally, fuel-cells also produce less noise pollution than conventional energy systems (as low as 55 dB at 90 feet -Energy Center of Wisconsin, 2000). Clearly, although no panacea, fuel-cells have the edge when it comes to environmental friendliness (at least relative to their immediate rivals, internal combustion engines).

High efficiency

They also have the edge when it comes to sheer efficiency. Estimates vary, but generally fuel-cells are considered to be twice as efficient as internal combustion engines (ICE). In other words, "a fuel-cell vehicle running on petrol would get nearly twice the mileage of a vehicle with an internal combustion engine" (Eisenstein, 2001, p. ~24). They are also likely, with efficiencies of 50-70%, to be more efficient than gas or coal burning power plants (30-40% efficiencies), according to the US Fuel-cell Commercialization Group (Dukart, 1999). Indeed, even when both are fueled with gasoline, Chrysler estimates that a fuel-cell is 50% more efficient than an ICE -and also produces 90% less emissions (Renzi and Crawford, 2000). Toyota's own measurements are remarkably similar, and it is convinced that even its first fuel-cell cars will be at least 50% more economical than its current models (The Economist, 1997).

To take just one concrete example, whereas current ICEs are about 15% efficient (Renzi and Crawford, 2000), DaimlerChrysler's fuel-cell powered NeCar II was already running at 28.8% efficiency in 1998, and efficiencies of 40-45% are considered possible by 2003, compared to the mere 26% predicted for diesel engines by that time (Panik, 1998). In fact, in theory, a fuel-cell can be up to 90% fuel efficient, quite simply because it has no moving parts, thus, unlike other power-generating systems, no energy is needed to create energy (Darbonne, 2001). Or as an engineer would put it, "since fuel-cells are not heat engines, efficiencies are not constrained by Carnot principles" (Harmon, 1992, p. ~68). Efficiencies of 70-90% are of course only possible if the waste heat generated by fuel-cells is exploited to heat or even cool homes, or as part of combined-cycle power generation (Wilder, 2000). Because fuel cells are so efficient, they must only be infrequently refueled. Indeed, in theory, a fuel-cell the size of an existing cellular phone battery would run eight times longer on one "charge."

To summarize a fuel-cell's efficiency in simpler terms, "for every 100 units of energy that enter [a fuel-cell] power system, the appliance produces 50 units of electrical power. The remaining 50 units of energy are liberated as heat. Some of this heat is required to keep the [fuel-cell] at operating temperature and the remaining heat can be used to heat water and /or air." (Fuel Cell Technologies, 2001, *1).

Reliability / Simplicity

Because fuel-cells have no moving parts[50], they are in theory significantly more reliable than ICEs (which have pistons) or gas-powered turbines. In theory, and in practice as well. The US Space program and the Department of Defense Fuel-cell Program have convincingly demonstrated the reliability of fuel-cell technology, as well as the relatively low maintenance they require (Energy Center of Wisconsin, 2000). In 1996, International Fuel-cell's PC25 (the only commercially available fuel-cell at that point) could last on average 2200 hours before a forced outage, which is 2-3 times better than a gas turbine and 3-4 times better than an ICE (Nurdin, 1996).

Higher reliability, combined with the fact that a fuel-cell drive-train has fewer parts[51], and in particular fewer high tolerance parts[52], than the equivalent drive-train in a conventional car, means that a fuel-cell powered automobile could, potentially, be cheaper to manufacture than a conventional one (Renzi and Crawford, 2000). Finally, to top it all off, many fuel-cell components are flat and thus amenable to automated handling (Brown, 2001). Indeed, Eisenstein (1999, p.~14) writes that "today, the membranes that serve as the heart of the catalytic process must be machined to aerospace specifications. But Brad Bates, Ford's in-house fuel cell guru, believes it will be possible to stamp out next-generation components, or perhaps even weave the membranes like so much paper."

Power / High energy density

So far, most of the points we have considered give fuel-cells the advantage over internal combustion engines and turbines, but not necessarily over batteries, their other principal rivals (in portable as opposed to mobile or stationary applications). But fuel-cells still have a few aces up their sleeve. For instance, they benefit from far higher energy densities than batteries (The Economist, 2001i). Specifically, Mr. Maslow of Medis Technologies claims that "weight for weight and size for size, methanol has 30 times more energy than a lithium ion. That means if right now you keep your lithium ion phone lit on standby for one week, in theory you could keep a methanol-fueled phone for about six months" (Libin, 2000, p. ~99). Bob Hockaday, chief fuel-cell scientist for Manhattan Scientifics Inc., similarly explains that his Hockaday Micro Fuel Cell will eventually be 50-100 times more powerful than an equivalent-sized nickel-cadmium battery (Chase, 1998), although it can "only" power a cell phone for 40 days on standby (with a talk time of 100 hours) at the moment... More generally, batteries are physically incapable of satisfying the Pentagon's future portable energy requirements of 1,000 Wh/kg by 2003 and up to 3,100Wh/kg by 2006 (The Economist, 2001i). Fuel-cells however, are. And such high energy densities aren't only of interest to the military: laptop, cellular phone and PDA makers will all be needing better power sources for their next-generation devices.

The fact that fuel-cells are highly energetic for their size is not only an advantage for their smaller materializations. A fuel-cell equipped car will be able to power all sorts of electrical accessories, not to mention an entire household (Interview - Jaffray)! Indeed, in 1997, researchers in Australia "successfully demonstrated a solid-state fuel-cell the size of a two-liter soft drink bottle that could meet the electricity needs of an average household" (Hoffman and Paulson, 1997, p. ~30). Imagining powering your home with a self-contained unit the size of a TV! At the moment though, a fuel-cell capable of powering a home would probably be the size of a small fridge, and fifty homes or an apartment building could be powered by a fuel-cell the size of a small trailer (Francis, 2001).

Basically, a single, reasonably-sized fuel-cell could quite conceivably meet all of a building's energy needs. As Johnson (2000, p.~28) writes, "fuel-cells, depending on the size of the building and the type of technology, can produce more than enough heat energy to be used [1] in the winter to heat the building, [2]

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[50] Although their subsidiary systems, such as the pumps and transformers required in any power generating system, do contain moving parts (Energy Center of Wisconsin, 2000).

[51] Indeed, the manager of fuel-cell research at the Argonne National Laboratory, Michael Krumpelt reckons that "the fuel-cell, air pumps, fuel system and other hardware add up to less than 500 parts versus more than 3,000 for a conventional engine" (Popely, 2001a, p *1)

[52] An ICE's parts are "made chiefly of heat-treated metal alloys and subject to the stresses of motion and explosion" -Lovins and Williams, 1999, p. ~3-, unlike a fuel-cell's

throughout the year to heat the hot water used inside... and [3] maybe, if it's an industrial building, in the industrial process." Specifically, a fuel-cell capable of producing 3 megawatts worth of power can fit in an area the size of a tennis court (Dukart, 1999).

Scalability & Modularity

Perhaps fuel-cell technology's scalability, more than any other of its strengths, will ensure its success. Indeed, whereas cumbersome batteries strain to power electric cars, and the idea of a laptop powered by a miniature internal combustion engine is laughable, fuel-cell technology is quite capable of both feats. Fuel-cells "are scalable from room-temperature micro to high-temperature massive applications" (Wilder, 2000, p. 59). This opens a wide range of potential applications for the technology, virtually guaranteeing it will be commercialized, somewhere, somehow.

Thus, just as fuel-cells will probably power our cellular phones and some of our powerplants, as well as our "lawnmowers, leaf-blowers and DIY power tools" (Harvey, 2001, p. *1), they may end in our vacuum cleaners as well! Electrolux, in association with Manhattan Scientifics and Lunar Design, is now developing a vacuum which will be able to run several hours off a 500g fuel-cell delivering 1,000 watts worth of power (Harvey, 2001; Anonymous, 2001b). The entire vacuum will weigh 4.5 kg and should become available in 2002 as a backpack model (Anonymous, 2001b). Meanwhile, fuel-cell powered scooters are being designed in Taiwan, by H-Power in New Jersey, and by Yamaha Motor of Japan, using Ballard fuel-cells (Colella, 2000). Clearly, fuel-cells may become ubiquitous. More impressive yet is the perspective of fuel-cells small enough to be used in hearing aids (Arnst and Port, 1998).

Because a fuel-cell's efficiency and power density is not significantly affected by its size (in other words, a large fuel-cell is not more efficient than a small one), the technology is inherently modular. So, instead of building a large-scale power plant from the outset, which is what happens with conventional technologies, one can simply add more fuel-cells as they are needed, and so avoid building generating capacity that would simply remain idle until needed in a few years time (Libin, 2000). These characteristics, combined with many of the others mentioned above, make fuel-cells ideally suited for distributed power. Perhaps Edison's vision of decentralized energy industry, in which electricity is generated near its end-user, will come to pass after all.

Of course, not all fuel-cell types can be miniaturized or enlarged. PEM fuel-cells, for instance, cannot really be scaled down, because of the inherent bulkiness of their support systems, such as the fans and fuel pumps (The Economist, 2001i). Direct methane fuel-cells, however, can be made quite small. Alternatively, some types of fuel-cells are better suited to major industrial applications than others (see appendix 14).

Fuel flexibility

The other major selling point fuel-cells have is the variety of fuels they can run on. Indeed, any hydrocarbon will do the trick, as well as a whole array of other hydrogen rich substances. Examples include natural gas, propane, butane, gasoline, JP-8 jet fuel, diesel, naptha, methanol, and of course pure hydrogen (Energy Center of Wisconsin, 2000). In Brazil, ethanol (produced from sugar canes) is likely to be a prime candidate to power fuel-cells, as there is already an existing ethanol infrastructure in the country (Saraiva Panik, 2001). Russia may also benefit from fuel-cells' undiscriminating nature, considering that Robert Lifton, Medis Technologies' CEO, has stated that his firm's fuel-cells can run off vodka, as demonstrated by the company's Russian researchers! (The Economist, 2001i).

Other potential sources of hydrogen are even more exotic. Electrolux's vacuum cleaner, already mentioned above, will probably run off sodium boro-hydride, an "innocuous and non-flammable substance used today in the manufacture of paper" (Harvey, 2001, p. *1). "Ruthenium within the cell acts as a catalyst to render hydrogen from the compound and the by-product is borax, a chemical commonly used in the production of soap. This may either be thrown away or recycled, as may the ruthenium" (Harvey, 2001, p. *1). Thomas Faul, founder of Greenvolt, told me his company's fuel-cells run off salt water and magnesium, two entirely non-toxic substances. One microbial fuel-cell, developed by South Florida Professor Stuart Wilkinson, even runs off the anaerobic digester gas produced by sugar-eating bacteria (The Economist, 2001k)! The professor demonstrated this technology by building a robot, christened Chew-Chew, that can function (admittedly only for very short periods of time) by breaking down sugar cubes. Perhaps one day we shall see robots consuming vegetation in order to power themselves...

More intriguingly, and in keeping with the fuel-cell's green credentials, land fill gas (LFG) has been successfully used to power fuel-cells. In Sacramento, a 2 megawatt fuel-cell runs off the gas produced by the daily breakdown of 100 tons of organic municipal waste (Wichert et al, 1994). According to Siuru (1999), similar fuel-cells, but which are, just like Chew-Chew, fueled by anaerobic digester gas (emitted during the treatment of wastewater) are also operating in Boston, Yonkers (NY) and Yokohama (Japan). More are planned in California, Oregon and Japan, and perhaps Europe as well. The EPA[53] estimates that as many as 1,700 US landfills could be fitted with LFG fuel-cells, which would provide enough power for almost 500,000 homes (Siuru, 1999).

Though only hydrogen and methanol (in the case of Direct Methanol fuel-cells) do not require reformers and are thus truly emission free, the multiplicity of potential fuels is a welcome change from our current dependance on petroleum, because such dependance is both dangerous and expensive. Indeed, in the 1990s, petroleum imports accounted for about half of the American merchandise trade deficit (Harding, 2000), and the real costs of gasoline are even higher if one includes the military expenses necessary to ensure uninterrupted supplies. Thus, the US spent about $365 billion between 1980 and 1990 to "police" the Middle East, and the Gulf War alone cost $61 billion (Harding, 2000).

Gasoline's price at the pump does not take into account all these hidden costs (Harding, 2000, tells us the true cost of oil in 1998 was approximately $5 a gallon), but consumers certainly suffer the vagaries and uncertainties that are an intrinsic part of the extremely politicized oil industry. The Arab Oil Embargo of 1973 and the Iranian Oil Embargo of 1979 cost Americans 1.5 *trillion* dollars (Harding, 2000). More recently, when gasoline prices passed the $30 a barrel mark in 1999, many European countries (in particular France and the UK) experienced mass protests by truck drivers and farmers that brought their economies to a standstill (The Economist, 2001d). And after the shocking and absolutely revolting terrorist attacks of September 11th (two days ago as I write this), oil prices once more skyrocketed as the world feared the worst[54] (The Economist, 2001n).

Developing countries also suffer, of course (though their economies are not quite as oil-dependent as those in the industrialized world), as do oil exporters when prices are too low (as they were early in 1999). All in all, excessive dependence on any one energy source is detrimental for everyone. On the other hand, do we really want a profusion of alternative fuels, with the incompatible standards and complexity that would entail? Well it is likely that different fuels will be reserved for different applications (safer though perhaps less energetic substances being used in portable devices, for example), and that, hopefully, manufacturers will agree amongst themselves to use certain fuels rather than others. Otherwise, multi-use reformers are being developed so that the same fuel-cell could be supplied with different types of hydrocarbons, which would greatly simplify things. Another possibility suggested by Bos (1996) would be to market reformers and fuel-cell stacks as separate units, so that users could purchase several reformers in order to use diverse fuels.

In any case, choice is better than no choice. And even if pure hydrogen eventually becomes the dominant fuel, because of its cleanness, energy-dependance will still be kept to a minimum. Indeed, there are least four major ways of producing hydrogen, many of them available to all nations, which ensures that no group of countries will monopolize a crucial energy source (Lovins and Williams, 1999). It would be hard to hoard hydrogen, considering that although it is the lightest element, it still represents 90% of the universe's weight, which gives us a good inkling of just how widespread it is (Kopicki, 2001).

Miscellaneous Strengths

Fuel-cells also have excellent part-load performance (Energy Center of Wisconsin, 2000) and can provide a constant torque, regardless of speed (The Economist, 2001f). And then there is the well-known fact that fuel-cells produce pure water, which may prove extremely valuable in certain circumstances (such as on space shuttles). Speaking of space shuttles, a decisive advantage fuel-cells have, as far as NASA is concerned, is the fact that they work in conditions of weightlessness (Quinn, 2001). But this is not likely to prove especially important to most of us...

[53] Environmental Protection Agency (US Federal Government)

[54] They have since dropped considerably as investors fear the onset of a global recession.

WEAKNESSES

Nothing is perfect, and fuel cell technology is no exception.

Expensive

As we have just seen, fuel cell technology is extremely promising. But why, if it really is so appealing, is it only being commercialized now, when the basic principle was discovered in 1839, more than 160 years ago, by Sir William Robert? "Lovely technology, shame about the cost" (The Economist, 1997b, p. *1). In 6 words, the gist of the fuel cell conundrum is summed up: what has prevented fuel cells from reaching the mainstream is their prohibitive cost, although a few major technical issues had to be ironed out as well.

Unfortunately, fuel cells continue to be expensive. Although they will be cost-competitive with rechargeable batteries (indeed, they will likely be significantly cheaper), they still have some way to go before rivaling an internal combustion engine's price. Currently, GM estimates that a fuel-cell would cost about 2 to 3 times what a conventional gasoline engine and transmission cost, which is about $5,000 (Popely, 2001a). And this may be a tad over-optimistic, as Renzi and Crawford (2000) calculate that a fuel cell costs 100 times more than an equivalent ICE ($40 per kilowatt of engine power to manufacture an internal combustion engine, vs. $4,000 for a fuel-cell).

Much of a fuel cell's expense can be imputed to the need for platinum, an expensive metal, as a catalyst (not all types of fuel-cells require platinum though). In addition, the electric motor needs magnets made of molybdenum and titanium, two more pricey metals, and special thyristors switches which do not come cheap either (The Economist, 1999a). Finally, another major source of cost is the fact that fuel cells are not yet being mass-produced (or only just beginning to be). Instead, they are still painstakingly assembled by hand, often by PhD-holding engineers and researchers, who are paid a bit more than your run-of-the-mill employee (Kopicki, 2001). But once fuel-cells start to be produced in quantity, both Ford and GM believe they will become price-competitive with ICEs (Verburg, 1998).

Indeed, there is cause for hope as humans are resourceful, and particularly adept at finding ways to reduce costs. The engineers at Ballard in particular, but their rivals in other companies as well, have devised processes by which to slash the amount of platinum needed in the making of a fuel cell (Naughton, 1998 and Nauss, 1998). They are also searching for cheaper substitutes, for the platinum catalysts and for other expensive components, and rationalizing their designs so that they will be better adapted to speedy assembly lines (The Economist, 1999a). And they are weeding out "overkill." GM's initial prototype, for example, was over-designed, so the firm's engineers were able to pare things down a bit, matching capabilities to requirements to make the fuel-cell smaller and cheaper (The Economist, 2000c).

These savings, and scale economies, ought to significantly lower the cost of fuel cells, bringing the price of a kilowatt pretty rapidly down to $20 (The Economist, 1999a), or about half the price per kilowatt of an ICE. As Lovins and Williams (1999, p. ~3) write, "it is a truism of modern manufacturing, verified across a wide range of products, that every doubling of cumulative production volume typically makes manufactured goods about 10–30 percent cheaper. There is every reason to believe fuel cells will behave in the same way." All this helps explain why Ballard is so confident about its ability to meet the carmaker's price goal of "$20 per kilowatt for the fuel-cell stack at the 300,000-unit production rate, or $50 per kilowatt for the car's entire electric propulsion system" (Brown, 2001, p. ~168T). After all, from 1997 to 2001, fuel-cell prices have already fallen by 100 orders of magnitude, even without mass-production (Butters, 2001).

Until these savings are achieved, manufacturers can implement pricing schemes that will help make fuel-cells more affordable or, rather, spread their cost over a prolonged period of time. Many commentators have thus suggested that utility companies, in particular, should initially lease their stationary fuel-cell units to their customers. That way, their clients would not have to take on the heavy installation and capital costs, nor would they have to assume the risk involved in owning such a new technology. Sure Power is in fact already commercializing its products in this fashion. Its clients pay a flat, monthly fee (under a long term contract) while Sure Power covers the unit's installation, operation, maintenance and repair costs, and of course its capital cost (Sure Power, 2001).

Building a Hydrogen / Methanol infrastructure.

A more daunting challenge is the need to build an infrastructure for the distribution, but also the production, of hydrogen and/or methane, the two main alternative fuels for fuel-cell powered cars. Though GM and Chrysler are both investing considerable sums to develop fuel cells that can run off gasoline (The

Economist, 1997), this is likely to only be an interim solution, as it would not end our dependance on petrol, and the resulting engines would not be zero-emission. Eventually, gasoline will have to be replaced, probably by hydrogen or methane, and this will not come cheap. It has been estimated that setting up a hydrogen infrastructure would cost 100+ billion dollars in the US alone (The Economist, 2001f), and Chrysler has pegged the cost of creating methanol stations at $200 billion. These figures may be misleading however, as Thomas et al. (2000, p. 551) calculate that "the total fuel infrastructure cost to society including onboard fuel processors may be less for hydrogen than for either gasoline or methanol." Nevertheless, since hydrogen does not occur naturally in a pure form on Earth (Kopicki, 2001), it will have to be produced using relatively energy-hungry methods, which will mean constructing many new power generating plants, with all the expenses this implies (Kruger, 2000).

Adapting the current gasoline infrastructure to carry methanol would be a simpler proposition, but some companies (such as BP and GM) are reluctant to overhaul the current infrastructure if it'll only be to see methanol replaced by hydrogen -the cleanest alternative- in a few years time (The Economist, 1999b). Indeed, as Mr. McCormick of GM puts it, explaining his company's decision to drop methanol from consideration, "if we intend to have hydrogen as soon as possible, why would we encourage people to invest billions into something you're going to replace? It doesn't make sense to develop something you're trying to obsolete" (Popely, 2001a, p. *1). However, hydrogen is unlikely to become a practical option in the near future, so it will probably be necessary to resort to an interim fuel while "the glitches in hydrogen storage and distribution are sorted out" (The Economist, 1999b).

Basically, fuel-cell companies are confronted by a chicken and egg problem (Renzi and Crawford, 2000). They can't sell the cars without an infrastructure to fuel them, but no one's willing to build the infrastructure when there are no cars to fuel yet! Actually, this is somewhat of an exaggeration, as "duplicating today's petrol infrastructure, from day one, is simply not necessary. Experience with the introduction of diesel in America and unleaded petrol in Germany shows that even if only 15% of forecourts offer it, a new fuel can become widely accepted" (The Economist, 2001f, p. *1). Lovins and Williams (1999) even explain why the gradual introduction of a hydrogen infrastructure would not only be feasible, but profitable at every stage. Fuel-cell equipped buildings could quite economically power the equipment required for the electrolysis of water (doing so is cost-effective even at relatively small scales), and thus produce enough hydrogen for several dozen cars. The authors estimate that such a nationwide de-centralized hydrogen sources would cost $4.1 billion (Lovins and Williams, 1999). More problematic is the fact that there is over $200 billion invested in the current gasoline infrastructure, according to Francois Castaing, Chrysler's vice president of vehicle engineering (*in* Chambers, 1997). In all likelihood, energy companies will not be keen to write off such considerable sums any time soon, but will want to see them amortized first.

All in all though, it is easy to make too much of the infrastructure problem. After all, there was no infrastructure for internal combustion engines when they were first introduced.

<u>Dependence on platinum (for PEM fuel-cells).</u>

We have seen that the need for platinum is one of the main reasons fuel cells remain very expensive. This need is also a major disadvantage in that it creates a new dependence on platinum, a relatively uncommon metal. What is the point of no longer being dependent on petroleum if one becomes dependent on platinum? Granted, researchers have made much progress in reducing the amount of platinum required to build PEM fuel cells (The Economist, 2000g), and it is likely that lower-cost alternatives will be found (palladium and ruthenium, in particular, look promising -The Economist, 2000g). Indeed, some types of fuel-cells, such as the alkaline ones being developed by ZeTek Power, already do not require platinum, but use cobalt instead (The Economist, 1998b).

But it is estimated that, despite these developments, automakers will need roughly 550,000 ounces of the metal by 2010, which is about 10% of the current output (Anonymous (2001a). And, if one includes all the other fuel-cell applications, the total demand is likely to be closer to 1 million ounces (The Economist, 2000g), about a fifth of existing production. Considering there probably already won't be enough platinum mined this year to satisfy the demand for platinum in car catalysts (Anonymous, 2001a), it is reasonable to wonder whether there will be enough of this new-age gold to go around! Borgwardt (2001) is particularly skeptical, and his in-depth analysis of the question suggests that, under a best-case scenario, the transition from ICE-powered to FC-powered vehicles would take about 66 years in the US, because of the limited availability of platinum.

<u>Public ignorance and fear.</u>

Perhaps the greatest obstacle to the successful commercialization of fuel cells is the fear hydrogen inspires. Indeed, the word hydrogen usually brings to mind the Hindenburg disaster and nuclear bombs, hardly the most reassuring images. In general, hydrogen has a pretty bad reputation as a highly inflammable and even explosive gas. But, although hydrogen does burn, it is much safer than generally believed. Indeed, it is actually less flammable than gasoline, and since it disperses so quickly, a "hydrogen leak is about as dangerous and destructive to the environment as aftershave."[55] Lovins and Williams (1999) are particularly adamant that using hydrogen as a fuel would in fact be safer than gasoline. They explain that a "hydrogen fire can't burn you unless you're practically inside it" (Lovins and Williams, 1999, p. ~7), so that all the victims of the Hindenburg disaster of 1937 died in the diesel-oil fire or because they jumped to their deaths, not because of the hydrogen-fire itself. "All 62 passengers who rode the flaming dirigible back to earth, as the clear hydrogen flames swirled upwards above them, escaped unharmed" (Lovins and Williams, 1999).

Hydrogen may not even become the main fuel used to power fuel-cells, as we have seen. But then, no fuel is truly safe. "Methanol is corrosive and extremely toxic, and petrol is both a carcinogen and easily ignited (The Economist, 2001f). Whatever fuel is eventually chosen, it is likely that, just as we learned to handle gasoline more or less safely, we will soon adapt to, and learn to handle safely, any alternative.

Thus, the difficulty really lies in making people accept what will be the most energetic power source ever widely commercialized (apart perhaps from the internal combustion engine -The Economist, 2001i). This point was underscored by Sir Moody-Stuart (2000) in his speech at the International Hydrogen Energy Forum. He insists that public acceptance can never be taken for granted. The proponents of nuclear power, for example, focused on the technology's potential while failing to address the public's safety concerns, so that it never really fulfilled its promise. Sir Moody-Stuart concludes that all parties (governments, NGOs, customers, manufacturers) will need to get together to deal with the critical issue of public acceptance. Above all, fuel-cell companies must take care not to suddenly introduce their technology to an unprepared and uninformed public, but rather pave the way for rapid consumer acceptance. One way of doing this, which has been repeatedly demonstrated in other emerging industries, is to use fuel-cells in order to augment, support or improve another, better known technology (Souder, 1989). By embodying the unfamiliar technology in a familiar one, consumers will be more likely to embrace the innovation.

Basically, fuel-cells are not inherently more dangerous than rival technologies, but it will be necessary to change peoples' perceptions, and to elaborate new standards that will minimize the inevitable risks while still making the widespread commercialization of fuel cells possible. For instance, many countries now ban taking methanol and hydrogen onboard airliners (The Economist, 2001i), but such regulations will probably need to be changed if fuel cells are to become common in portable devices.

Miscellaneous Weaknesses

Let us briefly consider the other weaknesses of fuel-cell technology. First, they need a minimum temperature in which to operate efficiently (in part because they produce water, which can cause damage when it expands as it freezes). In addition, the reformers themselves (if and when they are needed to convert a fuel into useable hydrogen) need to warm up before they can start the reforming process. In other words, start-up is not instantaneous. A fuel-cell car, for example, usually needs a few minutes to warm up before it can start running (Renzi and Crawford, 2000), although this shortcoming is now being successfully addressed. GM's HydroGen1, for example, takes only 30 seconds to deliver maximum performance at -20° C, or one minute at -30° C (Krantz, 2000).

Second, certain types of fuel-cells still have relatively short operating lives, although this too is being resolved (Energy Center of Wisconsin, 2000), just as their bulkiness relative to ICEs was, by constant tinkering and improvements. Plug Power boasts that its Plug Power 7000 units are designed to last for 20 years with minimal maintenance (Chambers, 1998), and Greenvolt's fuel-cell can last 2000 hours before it needs replacing (Interview - Faul).

More problematic is the fact that some types of fuel-cells, and in particular PEMs, need very pure fuels to run on, otherwise they suffer from electro-catalyst poisoning (Energy Center of Wisconsin, 2000). They also need access to oxygen (the plain O_2 found in our air is usually sufficient), which may limit their usefulness. And, finally, though the fact that fuel-cells produce water is generally seen as a good thing, it is not necessarily very practical: "As one Sony executive says: I don't want my mobile phone to wet my pants if I put it in my pocket" (The Economist, 2001i).

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[55] I unfortunately lost the reference for this particular quote.

APPENDIX 10: CHRONOLOGY OF FUEL-CELL DEVELOPMENT

Note: this chronology is by no means exhaustive but is merely meant to provide the reader with an idea of the industry's history.

1839	The first fuel cell is built by Sir William Robert (a Welsh judge, inventor and scientist), as he seeks to reverse the process of electrolysis (Bellis, 2001).
1889	The term "fuel cell" is coined by Ludwig Mond and Charles Langer when they attempt to build the first practical cell (using air and coal gas). Alternatively, William White Jaques, the first to use phosphoric acid in a fuel cell, may have come up with the expression (Bellis, 2001).
1920s	Extensive research is carried out in Germany (particularly concerning carbonate cycle and solid oxide fuel-cells). But the internal combustion engine is better understood, and benefits from the widespread exploitation of petroleum, so it supplants rival energy production concepts (Bellis, 2001).
1932	Dr. Francis T. Bacon begins researching fuel cells (Bellis, 2001).
1959	The work finally pays off, and the Bacon Cell is unveiled. A five-kilowatt version powers a welding machine. In October, Harry Karl Ihrig (of the Allis-Chalmers Manufacturing Co) demonstrates a 20-horsepower tractor powered by a fuel cell (it is the first vehicle to be so powered) (Bellis, 2001). 1959 is also the year of "The American Chemical Society Symposium on Fuel Cells," the first major international fuel-cell conference (Schaeffer, 1998).
1950s	The PEM fuel cell is invented at General Electric Co.
1960s	The US army installs fuel-cells in its submarines. The Bacon Cell design (built by GE) is selected by NASA to power space missions, including the Apollo and Gemini programs (nuclear reactors were deemed to risky, batteries too heavy and short- lived, and solar panels too unwieldy). NASA funds more than 200 research contracts to develop fuel cell technology. Fuel cells are still used today in the space shuttle to produce electricity and water for the crew. This sparks interest in the concept, and fuel cells are heralded as the solution to the world's energy problems. But technical hurdles remain (Bellis, 2001).
1960s - 1990s	More than $1 billion is spent to tackle these difficulties. Many industrial companies initiate their own research programs, and governments in Europe and Japan take an active interest (Bellis, 2001).
1989	Ballard Power Systems begins to focus its research efforts on PEM fuel-cells.
1990	California introduces its Zero-Emission Vehicles mandate (10% of the new vehicles sold in the state must be ZEV by 2003)
1991	Ballard (a Canadian company) and Daimler-Benz team up to develop fuel cells for automobiles (Bellis, 2001). UTC starts to sell the first commercially available fuel-cell, the 200-kW PC25 (United Technologies, 2000)

1992	More than 200 million dollars are spent annually on the development of fuel-cell technology. At least 7 major industrialists have installed production facilities (Hirschenhofer, 1992).
1993	The first fuel-cell powered bus is built by Ballard (Bellis, 2001).
1995	Ballard's researchers achieve the energy density required to power a car (namely 1000 watts per liter, as mandated by the US Department of Energy) (Ballard Power Systems, 2000). There are about 200 fuel-cell units operating in 15 different countries (Hirschenhofer and McClelland, 1995).
1996	The Congressional Hydrogen Future Act promotes research into fuel cells (Bellis, 2001).
1997	Ballard, DaimlerBenz and Ford announce a partnership to develop fuel cell technologies. DaimlerBenz and Toyota launch prototype fuel cell cars (Toyota is estimated to have 200 researchers working on the technoogy) (Bellis, 2001). In the summer of this year, the first residential fuel-cell to power a house is installed by Plug Power in Latham, N.Y. (Chambers, 1998). Alstom of France signs a deal with Ballard Power Systems to commercialize its fuel-cells in Europe once they are ready.
1998	California's target is re-evaluated. Only 4% of new cars sold in 2004 will need to be ZEVs, and 6% must be Low-Emission Vehicles (LEVs). Meanwhile, California Governor Gray Davis announces the Fuel Cell Partnership which joins the efforts of Ballard, DaimlerChrysler, Ford, ARCO, Shell, Texaco, California's Air Resources Board and the California Energy Commission. Objective for 2003: 50 fuel cell powered cars, 20-25 busses (6 fuel-cell busses already operate in Chicago and Vancouver). Iceland announces plans to become a hydrogen economy, with the assistance of DaimlerChrysler and Ballard. By 2008, all of Iceland's transportation vehicles (including the fishing fleet) should be fuel-cell powered. Shell Oil and Norsk Hydro join the initiative in March 1999 (Bellis, 2001).
1999	Europe's first public commercial hydrogen stations opens in Hamburg (February). The liquid hydrogen NECAR 4 is unveiled by DaimlerChrysler (April). Top speed: 90 mph, 280-mile range. Limited production is planned for 2004. Singapore physicists announce a new technique making hydrogen storage safer (August). San Yang (Taiwanese company) is developing the first fuel cell powered motorbike (Bellis, 2001).
2000	On January 9th, the Mark 900 is unveiled by Ballard. It will be its first commercialized fuel-cell. In winter, the California Air Resources Board unanimously upholds its zero-emissions mandate, which requires 10% of all new cars sold in California to be pollution-free by 2004 (Vaitheeswaran, 2001).
2001	The California Energy Crisis spurs new legislation to promote micropower, which could prove beneficial for the commercialization of fuel-cells. But environmental rules have also been slightly relaxed, to encourage the construction of new power plants (The Economist, 2001g).

APPENDIX 11: EXAMPLES OF ENVIRONMENTAL LEGISLATION

Energy Security Act (1978)

Energy Tax Act (1978)

Gasohol Competition Act (1980).

Crude Oil Windfall Profit Tax Act (1980)

Energy Security Act (1980)

Surface Transportation Assistance Act (1982)

Tax Reform Act (1984)

Alternative Motor Fuels Act (1988)

Omnibus Budget Reconciliation Act (1990)

Clean Air Act Amendments (1990)

Energy Policy Act (1992)

Building Efficient Surface Transportation and Equity Act (1998)

Energy Conservation Reauthorization Act (1998).

Source: Harding, 2000.

APPENDIX 12: BALLARD'S NETWORK OF ALLIANCES

Undoubtedly, the company that has woven the most elaborate web of partnerships is Ballard Power Systems. Its first major alliance dates all the way back to 1992/93, when it teamed up with Johnson Matthey (an expert in catalysts) to figure out a way to reduce the amount of platinum needed to build a fuel-cell (The Economist, 1997). This lead to several breakthroughs, which helps to explain why Ballard is presently leading the PEM fuel-cell pack. But in order to maintain its position, it has strived to develop an ever growing network of alliances, especially with large incumbents that have a stake in rival technologies (The Economist, 1998d). Such behavior is certainly counterintuitive, but it also quite clearly very wise, as it gives these companies a stake in the success of fuel-cell technology, thus blunting their incentives to obstruct its commercialization. Indeed, Ballard's "industrial partners have a direct, financial interest in seeing products emerge from the collaboration" (The Economist, 1997). In addition, it "also [helps] Ballard to get fuel cells into more than just its own prototypes" (The Economist, 1998d).

That such a marginalization should occur is perhaps Ballard's greatest fear. It brings back memories of the rotary combustion engine, which automakers spent millions developing in the 60s and 70s, and which was supposed to replace the internal combustion engine (Verburg, 1998). DaimlerChrysler and Mazda (one third owned by Ford) were the technology's main proponents, while other car makers remained rather dubious and so did not get too involved (Verburg, 1998). Their lack of involvement is what eventually prevented the rotary engine from taking off. Firoz Rasul, Ballard's CEO, confirms that "the failure of the rotary engine is a lesson we look at very carefully. The problem was no other auto companies bought into the technology. That's a concern we have. We don't want to be a one-company attraction. We want to make sure we educate the world about this technology" (*in* Verburg, 1998, p. ~32). Most importantly, he goes on to assert that Ballard "will not become captive suppliers. Our partners agree that if we don't sell to everybody, this technology will not become viable (Rasul, *in* Verburg, 1998).

Nevertheless, Ballard does have a special relationship with two car-makers in particular: DaimlerChrysler and Ford (hopefully they too have learned from the rotary engine's failure!), who together produce 25% of the world's cars (The Economist, 1999a). There is a "historical irony" to this as Mr. Rasul takes pleasure in pointing out to Mr. Verburg. "Gottlieb Daimler and Karl Benz invented the internal combustion engine (...) [and] Henry Ford brought it to mass production. Now, a century later, their companies are helping Ballard turn that same technology into a museum piece" (Verburg, 1998, p. ~31). In practice, the terms of their agreement stipulate that both car companies must buy fuel-cells from Ballard (with certain caveats) before they are commercialized. Afterwards, they must continue to rely on Ballard as their fuel-cell supplier, provided it can fulfill their reasonable requirements. They will, however, have the right to license from Ballard the intellectual property needed to manufacture their own fuel-cells, in which case they will no longer need to purchase them from the Canadian firm (Ballard Power Systems, 2000). Finally, their alliance has been formalized by cross holdings (DaimlerChrysler owns 23.6% of Ballard Power Systems, and Ford holds another 19.5% -Tait, 2001) and by the granting of seats on Ballard's board of directors to both DaimlerChrysler and Ford (Ballard Power Systems, 2001a).

Ballard has actually just recently decided to restructure its relations with both car-makers by taking full control of the two joint-ventures in which all three used to be partners. But the company insists that this buy-out was simply carried out in order to streamline and rationalize its operations, and does not in any way imply that their three-way alliance is falling apart (Tait, 2001). Nevertheless, despite the continuing intimate partnership with two of the world's leading car-makers, "Ballard does business with virtually all of them through joint ventures, partnerships and by selling them prototypes to try in their vehicles" (Francis, 2001, p. *1). Indeed, it has supplied fuel-cells to Daewoo, GM, the GIE Renault/Peugeot, Honda, Hyundai, Mazda, Nissan, Volkswagen, and Volvo (Ballard Power Systems, 2000).

Ballard isn't just a developer of fuel-cells for cars, and its alliances reflect its broader interests. In December 1996, it formed a joint-venture, Ballard Generation Systems (BGS), with General Public Utilities (GPU) to commercialize stationary fuel-cells of between 1kW and 1gW (Weiner, 1998). Later, Alstom SA of France and Ebara Corp of Japan joined them. Although GPU no longer owns part of BGS, and Ballard has just recently bought back Ebara's shares in the company, the alliances remain strong (Ballard Power Systems, 2001c). Both Alstom and Ebara have also separately set up joint-ventures with Ballard (Alstom Ballard and Ebara Ballard respectively) in order to exploit their exclusive rights to market and distribute the Canadian's fuel-cells in their respective regions (namely Europe and Japan). However, in exchange, they are required to buy all their fuel-cells from Ballard, which in turn must supply them with the desired units (Ballard Power Systems, 2000).

In regards to portable applications (between 1kW and 25kW of power), Coleman Powermate, a leader in portable internal combustion engines, has become Ballard's principal partner (Ballard Power Systems, 2000). Its commercialization of a fuel-cell unit is imminent (indeed, Ballard recently announced the launch of its portable Nexa module (Ballard Power Systems, 2001b). But Ballard was reluctant to proffer exclusivity to Coleman Powermate, as it plans to sell its portable fuel-cells to various OEMs, such as Matsushita, Honda, and Yamaha, who have all shown interest in the technology (Ballard Power Systems, 2000).

In addition to its alliances with its key customers and distributors, Ballard also has many agreements with its core suppliers. Indeed, it has 23 supply agreements, so as to minimize its risks (Ballard Power Systems, 2001a). It has recently struck deals with Quest Air, which is developing hydrogen purification and oxygen enrichment technologies that could ultimately allow smaller and more powerful fuel-cells; and with Millennium Cell, which can generate pure hydrogen from environmentally friendly raw materials (Ballard Power Systems, 2001a). In order to ensure that the infrastructure necessary for fueling its cells will indeed be erected, Ballard is working with all the major oil companies (BP, ExxonMobil, Petro-Canada, Shell, Texaco) as well as Air Products and Chemicals, Methanex, and Praxair (Ballard Power Systems, 2001a). Finally, Ballard, already an important and active member of the California Fuel Cell Partnership, is pressing for the elaboration of global standards and a global certification program for fuel-cells (Ballard Power Systems, 2000).

APPENDIX 13: A MULTIPLICITY OF NICHES

Fuel-cell companies are rather blessed in that they have a wide variety of niches they can target. This is due to the fact that fuel-cell technology has plenty of advantages over its rivals.

a. Environmental-friendliness

The first advantage that comes to mind is of course its lower emission levels, as well as its relative silence. As we have seen in the preceding section on government, California and certain other states, such as New York, are likely to become important niche markets for fuel-cells, because of their stringent environmental regulations. Although the word niche may not really be applicable to a state that has three times the population of Belgium... Perhaps a better example would be the market for motorcycles in Taiwan, where the government has implemented very strict emission standards and fuel economy regulations. Some manufacturers are thus already developing fuel-cell motorcycles with this market in mind (Wang et al, 2000). Coleman, working with Ballard, is developing portable fuel-cell devices that, because they do not emit carbon monoxide like Coleman's more conventional products, will be usable indoors (Brown, 2001). Indeed, relatively enclosed areas, such as shipping companies in port areas and urban shopping districts, will likely be very interested in fuel-cells (Clark, Jr. and Paolucci, 2001). Finally, some environmentally focused companies may purchase fuel-cells so as to emphasize their green credentials, and thus bolster their public image (Gatlin, 2000).

There are also environmentally conscious customers to take into consideration. These individuals are often willing to pay a premium in order to assuage their conscience and do their part to protect the environment. H Power, for instance, will target "alternative lifestylers", who live in rural (and often remote) areas and who have strong ecological beliefs (Interview - McNeill). Metallic Power is developing fuel-cell units that are designed to be used in conjunction with solar or wind power so that homeowners will be able to meet all their energy needs with renewable sources exclusively (Dukart, 1999). It is also working with an Arizona utility to install several fuel-cell generators in rural/remote Arizona homes because, as Jeff Colborn, the company's president explains, "these residents don't want a noisy, dirty diesel generator. They moved there in the first place to get away from all the noise and stuff" (Dukart, 1999, p. ~42)

Such eco-consumers do exist. When GM presented its electric concept-car, the Impact, some people promptly sent the company checks as initial payments for one (Cowan and Hultén, 1996. Unfortunately, it was not yet commercially available at the time. Less anecdotally, the Colorado firm Public Service Company has successfully offered wind power to residential customers at a $2.50 premium for every 100 kW-hours[56] (The Economist, 1998a). Indeed, green-pricing schemes, as they are called, now exist in Austria, Britain, the Nordic countries... and in the Netherlands, they are even oversubscribed (The Economist, 1998a).

However, it would be unwise to overestimate this niche's potential. As Energy Visions' Wayne Hartford explained, "the [fuel-cell] industry is not going to be driven by environmental concerns, it will be driven by economics and the environmental benefit is 'value added'. The average consumer will not take a loss of performance or an increase in price to support the environment but they will chose to use environmental products if everything else is at least equal" (Interview - Hartford).

[56] A typical home needs about 500 kilowatt-hours per month.

b. Reliable power

A much more promising niche is those who need reliable power. Most people would think that grid-provided electricity is already pretty reliable, but it is fact no longer adapted to the requirements of the information age. As Art Mannion, of Sure Power, explained to me, traditional utilities usually attain a 99.9%, maximum 99.99%, reliability rate. This sounds impressive, but when most high-end computers, such a servers and mainframes, are now designed to run 99.9999% of the time, 99.9% just doesn't cut it anymore (Interview - Mannion). Indeed, in practice, power that is only 99.9% reliable is, on average, unavailable for about 9 hours per year! This can get rather expensive, if, like a Wall Street investment firm Mr. Mannion knows, each minute without electricity means an 8 million dollar loss (Mack and Summers, 1999). Even if the losses only amount to a "few" million dollars an hour, which is the case for the National Bank of Omaha, it is easy to see why many companies are dissatisfied with their current power supplies (Popely, 2001b). Indeed, it is estimated that American industries lose $25.6 billion every year in loss product alone because of power outages (Kirlin, 2000).

Even when the electricity is on, it is not always of a high grade. This is partially because the power lines themselves were designed in the 1960s, and so are no longer suitable for modern electric devices (Bylinsky, 1999). Moreover, spikes and sags are a growing problem, as the constant conversion between 120 V alternating current to lower-voltage direct current (which is necessary to run most of our electric devices) provokes harmonics that distort the grid's power (Bylinsky, 1999). Indeed, "since AC flows in two directions, constantly reversing itself, the cumulative effect of all the conversions is to dirty up the power in the utility grid. If severe enough, harmonics can wreak havoc on somebody else's factory miles away, causing motors to overheat, and even catch fire, and knocking out electronic circuits in control devices" (Bylinsky, 1999, p. ~168A). So, ironically enough, as we grow increasingly dependent on our digital and electronic equipment, it is undermining the very power supply necessary to run itself. According to the Electric Power Research Institute, dirty power costs US business 4-6 billion dollars a year (Bylinsky, 1999). This is because "even the briefest sags cause computers to lock up or reboot, and corrupt data. Programmable logic controllers (PLCs), computerlike devices that direct many factory machines, also freeze" (Bylinsky, 1999, p. ~168G).

Hi-tech factories and financial powerhouses aren't the only ones at risk. High-speed manufacturing is now so widespread that even clothing mills, cigarette facilities and diaper manufacturers rely on clean power for their production process (Libin, 2000). Microchip fabrication plants require extremely reliable power in order to conduct their ultra-precise operations (Lovins and Williams, 1999), but even farmers' livelihoods depend on a constant supply of quality electricity. In fact, according to Plug Power's CEO, Gary Mittleman, a Vermont farmer drove all the way to the company's headquarter's in Latham, New York and told the receptionist: "Honey, I'm here for my fuel cell. Where's the loading dock?" as he handed her $10,000 in cash (he unfortunately went home empty-handed, as Plug Power did not yet have a product available at the time).

Even residential households are in the market for dependable electricity: according to a survey by RKS, 10% of affluent American households already own some kind of emergency backup generator (Kirlin, 2000). Indeed, RKS's report reads: "the strong signals we receive from affluent consumers indicate a large potential market for power generation devices that deliver a higher degree of protection, control, and independence to sophisticated, technology-rich households. (...) These customers consider a premium of 17 percent more than their present electric bill a fair price for back-up support" (Kirlin, 2000, p. ~32). And one shouldn't forget home business owners and people who live in places that regularly experience severe weather (such as Florida, North and South Carolina, the Midwest): these households will probably be among the first to adopt fuel-cell technology Gatlin (2000).

Art Mannion and his partner William Cratty, of Sure Power, realized that reliability would make an ideal niche for fuel-cell technology. Indeed, and this just goes to show that management papers can sometimes be useful, Mr. Mannion was inspired by Clayton Christensen's Harvard Business Review article which later proved the basis for his book, The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail (Mack and Summers, 1999). In his book, Christensen basically explains that entrepreneurs should not try to do what a bigger company already does well. Instead, they should start in a neglected market (a niche, in effect), and use it as base from which to later attack their rivals (Mack and Summers, 1999). Mr. Mannion applied this thinking to his own case, and concluded that fuel-cells could not compete with local utilities on price. Instead, he considered all the positive attributes that fuel-cells did have, and decided that their reliability would make an excellent selling point (Mack and Summers, 1999). Many other fuel-cell companies have reached the same conclusion, especially after what happened in California earlier this year.

Art Mannion realized that access to reliable power was becoming ever more critical, for two reasons (Interview - Mannion). First, computers, now indispensable, are very sensitive to spikes and outages, as we have seen. Second, more and more operations run all day, every day. These require electricity that's always there, no matter what the weather. Onsite generation is the obvious solution, but existing technologies were quite unsatisfactory. Diesel backup generators (the most widespread kind), for instance, must be turned on (which isn't instantaneous) and are too dirty for California, with its tightening environmental regulations (Interview - Mannion). This was a market where silent fuel-cells could compete effectively, considering the technology is capable of very high reliability rates. In fact, Sure Power's units have been independently tested to be 99.9999% reliable, thus matching the capabilities of the high-grade computer equipment they are designed to power (Sure Power, 2001).

Sure Power signed its first deal with National Bank of Omaha (one of the largest privately owned banks in the US) in July 1999 (Mack and Summers, 1999), and the new power system soon proved its worth in mid-1999, when the bank was unaffected by a series of brownouts in its area. Indeed, since the fuel-cells were installed in 1999, they have been down only 2 or 3 seconds per year (Popely, 2001b).

All in all, the premium power market looks quite attractive. According to research by Frost & Sullivan ("North American Stationary Fuel Cell Markets," January 2000, *in* Gatlin, 2000), industry consumes more than 70% of all the electricity generated in the US, and in 1998, 28% of businesses indicated they were interested in onsite power generation (Gatlin, 2000). Perhaps it isn't much of a niche after all! But some analysts are skeptical. Indeed, according to the research carried out by Frost & Sullivan, those who are in the market for reliable power still feel fuel-cells are too risky a proposition, not to mention too expensive, especially compared to more conventional technologies such as reciprocating engines or gas turbines that have recently made great progress (Gatlin, 2000). Even Sure Power is considering a move into gas turbines, which are almost as clean as fuel-cells and seem better suited for large applications (Interview - Mannion). As for high profile customers, they usually don't have too many complaints about their grid-provided power, because, being so important, they tend to receive special treatment from the utilities (Gatlin, 2000).

c. Remote areas

Many, perhaps most, fuel-cell companies are focusing their attention on remote areas, where there is quite simply no grid to compete against. Fuel-cells, which are relatively rugged and can, provided they are equipped with the necessary reformers, run off many different kinds of fuels without frequent refueling, are particularly well suited for a variety of remote locations. Dr. John Stannard's aluminum/oxygen semi-fuel-cells, for instance, are used to power underwater exploration devices, and microwave repeater stations in the Arctic, where they are replacing zinc-air batteries that had to be completely replaced every year (Interview - Stannard).

Greenvolt has already sold a unit to someone who will be staying in the Sahara, and who needed a power source for his satellite phone and GPS locator[57] (Interview - Faul). Greenvolt's fuel-cell is entirely non toxic and is self-regulating (there is no need for electronics), making it ideal for such uses (Interview - Faul). So much so that Mr. Faul is hoping to sell two million units (at $120 each) by 2002, which would correspond to a pretty big niche market! Indeed, remote areas could perhaps be considered a market in their own right. However, H Power, which has chosen to go after the rural market, is not alone in affirming its desire to eventually target less isolated customers once its fuel-cells become more price competitive (H Power, 2000). So because fuel-cell firms' ultimate market basically encompasses all power-needing activities, considering remote locations a niche seems justified.

The list of remote locations suitable for fuel-cells goes on and on. Gatlin (2000) mentions state and federal correctional facilities, which are often situated in isolated areas and which definitely need backup power generators. Sattlet (2000) points out that they have great potential onboard ships, for "(1) emergency power supply; (2) electric energy generation, especially in waters and harbours prescribing particular environmental regulations; (3) small power output for propulsion at special operating modes (e.g., very quiet run); and (4) electric power generation for the ship's network and, if required, the propulsion network on vessels equipped with electric power plants" (Sattlet, 2000, p. ~61). Marschoff (1998) argues that fuel-cells should be used to power Argentinian bases in Antarctica, perhaps the most remote area on earth. Not only would this reduce pollution (a key concern in this continent, where the signatories to the International Antarctic Treaty have pledged to minimize the environmental impact of their activities), it would also lead to savings in storage space (important when one considers how expensive it is to ship materials to Antarctica) since the quantity of methanol needed to run the fuel-cells would be less than the quantity of gasoline and diesel presently required by the diesel generators (Marschoff, 1998). But surely the most peculiar "remote" application I have come across in my research is the fuel-cell being used to power... the Central park police precinct station! As Sharke (2000, p. ~27) writes, "formerly a stable, the station is smack in the middle of the park, as far away from the street and the services below as one can get in New York. It is this kind of niche that International Fuel Cells and its sister company, Onsi Corp., of South Windsor, Connecticut, fill with their 200-kW phosphoric acid fuel cell power plants."

d. Developing countries

Taken as a whole, developing countries can hardly be called a niche market. In Brazil alone, about half of the population of more than 170 million is not connected to the grid (Saraiva Panik, 2001). Nevertheless, as far as fuel-cell companies are concerned, they are a niche, simply because most of the people in these countries cannot currently afford fuel-cell systems. In addition, though the political and economic risk in these nations does favor small-scale, distributed power rather than big projects (The Economist, 1998a), it also discourages western firms from becoming too involved in these markets. But the appeal of this market is just too strong to ignore. Indeed, "developing countries, may represent the biggest piece of the pie for fuel cell companies" (Johnson, 2000, p. ~30).

Rhett Ross, until recently director of development at the Breakthrough Technologies Institute, which directs Fuel Cells 2000, says that "there is not a manufacturer of any type of [fuel cell] technology, whether it be power generation or otherwise, that is not looking at China, India and Asia. Africa, you can throw in there, but Africa has a lot of problems that need to be resolved" (*in* Johnson, 2000, p. ~30). After all, the inhabitants of these countries fervently

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[57] A nearby oasis will provide the water, which is necessary to make this particular type of fuel-cell run (it needs salt water and magnesium). Four-millimeter thick magnesium anodes need to be replaced every 20 hours to provide 60W at 12V (Interview - Faul).

aspire to all the comforts we enjoy, and these comforts all depend on reliable, universal energy. Perhaps even more crucially, their development and the acceleration of their economic growth will only occur once they have widespread access to electricity. Here, what Marschoff (1998) has to say about Latin American countries applies to many other developing nations: many of their important centers of economic activity (in particular when it comes to the exploitation of natural resources) are isolated and so are not linked to the power grid. Even the companies that do have access to the grid have to put up with frequent power failures, which is hardly conducive for business-making. Finally, there isn't too much sunk investment in a power infrastructure, which would otherwise have deterred the spread of distributed power (Marschoff, 1998).

Fuel-cell busses are already running, or will soon run, in Brazil, China, Egypt, India and Mexico (Saraiva Panik, 2001). And if the fuel-cell companies don't go to the developing countries, the developing countries will come to the fuel-cell companies. China, in particular, has shown a great interest in this new technology (GM Motor Co, 2000), as it would relieve its dependence on petroleum imports.

e. Efficiency & heat generation

Finally, because fuel-cells are extremely efficient, they are suitable for applications in which efficiency is a key concern, such as industries that are very power hungry. And as we have seen, part of a fuel-cell's efficiency comes from the fact that it produces high quality waste heat, which can be used in a variety of ways. For instance, "the clean hot water created by the fuel cells is an ideal feedstock for the [microchip] fab's ultrapure water system; and the manufacturing process requires pure hydrogen as a reagent, offering the opportunity to share the hydrogen source" (Lovins and Williams, 1999, p. ~5). Indeed, Rastler (2000) believes "combined heat and power" applications constitute one of fuel-cell's best potential markets relative to rival technologies (see table below). In general, commercial and industrial co-generation constitute very good niches for fuel-cells (Nurdin, 1996).

Application	Relative strength
Combined heat and Power	**++**
Grid support and load management	**++**
Peak shaving	**+**
Premium power	**+**
Low-cost energy	**-**

(Source: Rastler, 2000, Table 1 p. 8)

APPENDIX 14: FUEL-CELL TYPES

There are many different types of fuel-cells, some of them better suited to certain applications than others. The following list, though wide-ranging, is not exhaustive (note: through lack of time, I chose to directly quote from some of my sources).

ALKALINE FUEL-CELLS

"Alkaline fuel cells, long used by the National Aeronautics and Space Administration on space missions, can achieve power generating efficiencies of up to 70 percent. They use alkaline potassium hydroxide as the electrolyte. Until recently, they were too costly for commercial applications, but several companies are examining ways to reduce costs and improve operating flexibility" (Kirlin, 2000, p. ~25).

DIRECT METHANOL FUEL CELLS

"Direct methanol fuel cells (DMFCs) are a relatively new member of the fuel cell family. These cells are similar to the PEMFCS in that they both use a polymer membrane as the electrolyte. However, in the DMFC, the anode catalyst itself draws the hydrogen from the liquid methanol, eliminating the need for a fuel reformer. Efficiencies of about 40 percent are expected with DMFCS, with would operate between 120 deg F and 190 deg F" (Kirlin, 2000, p. ~26).

HYDROGEN PEROXIDE FUEL CELLS

"Hydrogen peroxide fuel cells are under development at Purdue University Based on reactions between hydrogen and aluminum, they have the capacity to generate more than 20 times the power of traditional car batteries per pound" (Kirlin, 2000, p. ~26).

MOLTEN CARBONATE FUEL CELLS

Operating temperature: 200C / 400F

"Molten carbonate fuel cell (MCFC) systems are in the demonstration phase, with systems ranging from 250 kilowatts to 2.5 megawatts. Operating at about 1,200 deg F, this technology, too, is best suited for large-scale centralized power applications. Developers project that MCFCS will provide electricity in the 50-60 percent efficiency range, with cogeneration efficiency approaching 85 percent. The high operating temperature of an MCFC necessitates the use of expensive materials and presents electrolyte vaporization, leakage, and corrosion challenges" (Kirlin, 2000, p. ~24).

"MCFCs are high temperature fuel cells that offer several advantages for onsite or utility-scale power generation. They produce high quality waste heat that can be used for fuel processing and cogeneration, internal methane reforming, and conventional production of electricity. The waste heat is of sufficient temperatures to produce high pressure steam for industrial processes. Developers are targeting commercial markets such as hotels, schools, small to medium sized hospitals, and shopping malls, as well as industrial applications (chemical, paper, metal, food, and plastics) for onsite power generation" (Energy Center of Wisconsin, 2000, p. 10).

"At 650C (1200F), the operating temperature of MCFCs is substantially higher than that of PEMFCs or PAFCs. The higher operating temperature enables internal reforming of hydrocarbon fuels, improving system design and efficiency. Additionally, the elevated operating temperature, combined with fast electrode kinetics, eliminates the need for expensive noble metal electrocatalysts and results in the highest electric efficiency of all fuel cell types. MCFCs have a verified efficiency of up to about 44 percent and developers expect efficiencies to reach 50 to 60 percent" (Energy Center of Wisconsin, 2000, p. 10).

PHOSPHORIC ACID FUEL CELLS

Operating temperature: 650C / 1250F

“Phosphoric acid fuel cell (PAFC) systems are commercially available and currently installed at utility power plants, hospitals, hotels, schools, office buildings, and an airport terminal. Operating at about 400%, PAFCs offer 40-45 percent electrical efficiency, with the potential for greater than 80 percent efficiency when used in a cogeneration arrangement. The system's high operating temperature requires a high-priced support system and costly maintenance, which makes PAFC more suitable for large-scale stationary and mobile applications” (Kirlin, 2000, p. ~24).

“PAFCs are the only commercially available fuel cell today (made by ONSI, a subsidiary of International Fuel Cell Corporation). Worldwide, PAFC technology has been demonstrated at levels ranging from 50 kW to 11 MW, with most demonstration units between 50 and 200 kW. PAFCs can be used for onsite power generation in hospitals, hotels, schools, and commercial buildings requiring heat, high power quality, or premium power services” (Energy Center of Wisconsin, 2000, p. 8).

“PAFCs are the only fuel cell to consistently achieve demonstrated lifetimes of 40,000 hours or better under production conditions. Field units have been operated at ambient temperatures of –32C to 49C and altitudes of one mile. Additionally, the PC25 units operating in California have been exempted from the air pollution permitting process because their emissions have been so low” (Energy Center of Wisconsin, 2000, p. 9).

“In comparison with other fuel cell types, the electrical efficiency of PAFCs is low. This disadvantage is offset by their tolerance to fuel contaminants, cogeneration potential, and technology readiness” (Energy Center of Wisconsin, 2000, p. 9).

“PAFC development historically included transportation applications, such as transit buses. However, due to the rapid advancements of PEMFCs, PAFCs are not likely to compete in light and medium duty vehicular transportation. Future applications for PAFCs may be found in marine, locomotive, or space applications” (Energy Center of Wisconsin, 2000, p. 9).

PROTON EXCHANGE MEMBRANE FUEL CELLS

Operating temperature: 80C / 175F

“Proton exchange membrane fuel cell (PEMFC) systems are in the precommercial beta testing stage. Operating at around 200F, PEMFCS provide electrical efficiency at less than 40 percent, with no potential for cogeneration applications. However, the system's high power density and fast output shifting make it suitable for automobiles, small stationary power plants, and applications as small as battery replacements for portable devices” (Kirlin, 2000, p. ~25).

“PEMFCs are currently being developed primarily for sizes less than 500 kW. Applications for PEMFCs include:

• Light duty (50–100 kW) and medium duty (200 kW) vehicles
• Residential (2–10 kW) and commercial (250–500 kW) power generation
• Small and/or portable generators and battery replacements” (Energy Center of Wisconsin, 2000, p. 6).

“Low operating temperature, rapid start-up, light weight, high power density, and simplicity make PEMFCs attractive for transportation applications. However, many technological barriers remain and it is expected that PEMFCs will be marketed first in stationary applications. The same characteristics that make the PEMFCs attractive for transportation also make them attractive in remote, standby, and premium power onsite markets” (Energy Center of Wisconsin, 2000, p. 7).

REGENERATIVE FUEL CELLS

"Regenerative fuel cells, a very young member of the fuel cell family, would be attractive as a closed-loop form of power generation. Water is separated into hydrogen and oxygen by a solarpowered electrolyser. Both molecules are fed into the cell, which then generates electricity, heat, and water-the water is then recirculated to the electrolyser" (Kirlin, 2000, p. ~26).

SOLID OXIDE FUEL CELLS

Operating temperature: 1000C / 1800F

"Solid oxide fuel cell (SOFC) systems are currently being demonstrated. With an operating temperature of about 1,800 deg F, SOFCs demonstrate 50-60 percent electrical efficiency, with cogeneration efficiency in a range of 70-85 percent. According to Frost & Sullivan's 1999 report on the North American stationary fuel cell market, SOFCS 'are considered the only fuel cell technology with a wide span of possible market applications ranging from 2-kilowatt residential systems to wholesale distributed generation systems of 10-25 megawatts'" (Kirlin, 2000, p. ~25).

"SOFC technology can potentially span all of the traditional power generating markets (residential, commercial, industrial/onsite generation, and utility) but is likely to penetrate niche markets first, such as small portable generators and remote or premium power applications" (Energy Center of Wisconsin, 2000, p. 12).

"SOFCs also have the potential for high system efficiencies. When integrated with a gas turbine (SOFC-GTs), SOFC systems are expected to achieve 70–75 percent (LHV) electric efficiencies, representing a significant leap over all other energy technologies. Additionally, developers expect commercial SOFCs to have lifetimes of 10 to 20 years, two to four times longer than other fuel cells" (Energy Center of Wisconsin, 2000, p. 12)

"The disadvantage of the SOFCs high operating temperature is the stringent materials requirement for the critical cell components. Exotic ceramics, metal-ceramic composites, and high temperature alloys drive up the cost of SOFCs, as do the manufacturing techniques demanded by these materials" (Energy Center of Wisconsin, 2000, p. 12).

"So if fuel cells are the energy of the future, what's the future of fuel cells? The answer may be ceramics. This solid-state technology, also known as solid oxide, is potentially the smallest, lightest, least expensive kind of fuel cell of all" (Hoffman and Paulson, 1997, p. ~31).

ZINC-AIR FUEL CELLS

"The chief advantage zinc-air technology has over other battery technologies is its high specific energy, which is a key factor that determines the running duration of a battery relative to its weight. When ZAFCs are used to power [electric vehicles], they have [been] proven to deliver longer driving distances between refuels than any other EV batteries of similar weight. Moreover, due to the abundance of zinc on earth, the material costs for ZAFCs and zinc-air batteries are low. Hence, zinc-air technology has a potentially wide range of applications, ranging from EVs, consumer electronics to [the] military (Powerzinc, 2001, p. *1).

Zinc-air fuel-cells use zinc pellets as fuel, which, once used, can be recycled by the user to almost 100% of their original composition (Clark, Jr. and Paolucci, 2001).

E PLURIBUS UNUM

"One of the problems with fuel cells is that the different types are all trying to get into the market," says Dicks. But fears of a Betamax/ VHS scenario developing are likely to be unfounded. "I think that there will be particular market niches for all of them. And there are good reasons for developing hybrid systems, combining PEM and a solid oxide cell, for example. This would give substantial efficiency gains" (Andrew Dicks, principal fuel-cell scientist of BG Technology *in* Wilks, 2000, p. ~29).

APPENDIX 15: GLOSSARY

Anode:
"The negative electrode in a fuel-cell. In a PEM fuel-cell, the anode is a catalyzed structure which converts hydrogen fuel into electrons that are released to the external circuit and positively charged hydrogen ions (protons), which are drawn into the electrolyte."[58]

Catalyst:
"A material, such as platinum, which promotes or increases the rate of a chemical reaction without itself undergoing any permanent chemical change."[58]

Cathode:
"The positive electrode in a fuel-cell. In a PEM fuel-cell, the cathode is a catalyzed structure which converts oxygen, usually from the air, electrons received from the external circuit and protons from the electrolyte into water."[58]

Cogeneration:
" The simultaneous production of both heat and electricity using a single process."[59]

Computer grade power:
"Electricity meeting the Institute of Electrical and Electronic Engineers Standard 446-1987. This standard sets time and voltage intervals which electronic equipment must tolerate without malfunction."[59]

Critical load:
"The computers, disk arrays, tape drives, and other associated hardware that must operate without interruption and require electricity to do so."[59]

Efficiency:
"The proportion of energy contained in a fuel which is converted by an energy conversion device into useful work, such as electricity."[58]

Electrode:
"An electrically conductive structure in an electrochemical device which transfers electrons to or from reactant atoms or molecules."[58]

Electrolyte:
"The medium in a fuel-cell which provides the ion transport mechanism between the anode and cathode necessary to sustain the electrochemical process. In a PEM fuel-cell, the electrolyte allows the transport of positively charged hydrogen ions (protons) from the anode, where they are produced, to the cathode where they react with oxygen molecules and electrons to produce water."[58]

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[58] Source: Ballard Power Systems, 2000, p. 72.

[59] Source: Sure Power Corporation Glossary, p. 1 (available on their website, http://www.hi-availability.com).

Electron:

"The negatively charged component of an atom and the unit of negative electrical charge."[58]

Fuel-cell:

"An electrochemical device which, without combustion, converts the chemical energy of a fuel, usually hydrogen or a hydrogen-containing mixture, and oxygen, usually from the air, directly into electricity."[58]

Fuel-cell stack:

"A stack comprised of multiple single fuel-cells."[58]

***Ion*:**

"An atom or a molecule that has acquired an electrical charge by the loss or gain of electrons."[58]

Kilowatt (kW):

"1,000 watts, which is equivalent to approximately 1.34 horsepower."[58]

Kilowatt hour (kWh):

"A kWh is a standard unit of measuring electricity consumption, and all local power companies bill in kilowatt-hours. A kilowatt-hour is equal to 1000 watt-hours. In other words, it's the amount of electricity which would be used by a 1000-watt device running for 1 hour. A kilowatt hour would be used operating:

A typical hairdyer (1000 watts) for 1 hour
A typical light bulb (100 watts) for 10 hours
A typical refrigerator every 10 hours."[60]

Megawatt (MW):

"1,000,000 watts." [58]

Power density:

"The ratio of power output to weight or volume."[61]

Proton:

"The positively charged component of the nucleus of an atom. The positively charged hydrogen ion which remains when an electron is removed from a hydrogen atom is a proton. The proton's positive charge is equal in magnitude to that of the electron's negative charge."[61]

Zero Emission Vehicle (ZEV):

"A vehicle that does not produce any air pollutants such as carbon monoxide, oxides of nitrogen, unburned hydrocarbons and particulates."[61]

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[60] Source: Environmental Protection Agency (2001). Internet WWW page at: <http://www.energystar.gov/products/utilityrates.shtml>. Date accessed: 12.10.2001

[61] Source: Ballard Power Systems, 2000, p. 73.

APPENDIX 16: INTERNET RESOURCES

For those who are interested in learning more about fuel-cells and the fuel-cell industry, there are many, many resources regarding available on the Internet. The following list is by no means exhaustive (it is also rather poorly organized), but is a good starting point. Search engines (such as www.google.com and www.yahoo.com) are also a good place to start.

ASSOCIATIONS

American Hydrogen Association Fuel Cells
http://www.clean-air.org/fuelcellfaq.htm
California Fuel Cell Partnership Driving the Future
http://www.fuelcellpartnership.org/
California Hydrogen Business Council - Harnessing the Power of Hydrogen For the Future of Mankind
http://www.ch2bc.org/
EPRI Science & Technology solutions for the global energy industry.
http://www.epri.com/
Fuel Cells 2000's Homepage
http://www.fuelcells.org/
Fuel Cell Group - Loughborough University
http://www.lboro.ac.uk/departments/tt/Research/fuelcell/aaets-24.html
National Hydrogen Association
http://www.ttcorp.com/nha/
Rocky Mountain Institute
http://www.rmi.org/
US Fuel-Cell Council Home Page
http://www.usfcc.com/
World Fuel Cell Council
http://www.fuelcellworld.org/

COMPANIES

Note: not all of these companies manufacture fuel-cells, but all are involved, in one way or another, in the fuel-cell industry.

3M's Fuel Cell Vision
http://www.3m.com/us/mfg_industrial/fuelcells/
Analytic Power
http://www.analyticpower.com/
Astris Fuel Cells
http://www.astrisfuelcell.com/
Avista Labs Home
http://www.avistalabs.com/
Ballard Power Systems
http://www.ballard.com/
Cellex Power
http://www.cellexpower.com/
Dais-Analytic Corporation (subsidiary: American Fuel Cell Corporation)
http://www.dais.net/
DCH Technology
http://www.dcht.com/
Delphi Automotive Systems
http://www.delphiauto.com/
DTE Energy Technologies
http://www.dtetech.com/home

DuPont.com
http://www.dupont.com/
ElectroChem
http://www.fuelcell.com/
Energy Conversion Devices, Inc.
http://www.ovonic.com/
Energy Partners
http://www.energypartners.org/
Energy Related Devices
http://www.energyrelatedevices.com/
Energy Ventures inc (aka Energy Visions).
http://www.energyvi.com/
ExxonMobil
http://www.exxonmobil.com/
Ford
http://www.ford.com
Fuel-Cell Energy (was Energy Research Corporation).
http://fuelcellenergy.com/
http://www.ercc.com/
Fuel-Cell Resources, inc.
http://www.fuelcell-resources.com/
Fuel Cell Technologies, Limited
http://www.fuelcelltechnologies.ca/
Fuji Electric Co
http://www.fujielectric.co.jp/eng/
GE Power Systems
http://www.gepower.com/en_us/index.html
GE Distributed Power.
http://www.gepower.com/distributed_power/index.html
Global Thermoelectric Inc. Generators
http://www.globalte.com/
Greenvolt
http://www.greenvolt.com/
H Power
http://www.hpower.com/
H-Power Pacific Pty Ltd
http://www.hpowerpacific.com/
Hitachi, Ltd
http://global.hitachi.com/
Honeywell
http://www.honeywell.com/
Hydrogenics Corporation
http://www.hydrogenics.com/
Hydrovolt Energy Systems Inc.
http://www.hydrovolt.com/
IdaTech (was Northwest Power Systems)
http://www.idatech.com/
IMPCO
http://www.impco.ws/
Innogy
http://www.innogytech.com/
InnovaTek
http://www.tekkie.com/
International Fuel Cells
http://www.internationalfuelcells.com/
Ishikawajima-Harima Heavy Industries
http://www.ihi.co.jp/index-e.html
Johnson Matthey
http://www.matthey.com/

Lynntech, Inc
http://www.lynntech.com/
Manhattan Scientifics, Inc.
http://www.mhtx.com/
MC Power
http://www.mcpower.com/ (Site not yet complete)
McDermott Technology
http://www.mtiresearch.com/
Mechanical Technology, Inc.
http://www.mechtech.com/
Medis Technologies
http://www.medisel.com/
Millennium Cell
http://www.millenniumcell.com/
Mitsubishi Electric
http://www.mitsubishielectric.com/
Mosaic Energy LLC
http://www.mosaicenergy.com/
Motorola Energy Systems Group
http://www.motorola.com/ies/ESG/
Nuvera Fuel Cells
http://www.nuvera.com/
Plug Power
http://www.plugpower.com/
PowerTek International
http://www.powertek-international.com/
PowerZinc
http://www.powerzinc.com/
Proton Energy Systems
http://www.protonenergy.com/
Shell Hydrogen
http://www.shell.com/hydrogen-en/0,6011,,00.html
Siemens Westinghouse
http://www.siemenswestinghouse.com/en/
Stuart Energy
http://www.stuartenergy.com/
Sure Power
http://www.hi-availability.com/
Toshiba Corporation
http://www.toshiba.co.jp/worldwide/
Toyota
http://www.toyota.com/
XCELLSIS
http://www.xcellsis.com/
ZeTek Power Homepage
http://www.zetekpower.com/

GOVERNMENT

California Air Resources Board
http://www.arb.ca.gov/
Energy.gov
http://www.energy.gov/

LABORATORIES

National Renewable Energy Laboratory (NREL) Home Page
http://www.nrel.gov/
NATIONAL FUEL CELL RESEARCH CENTER (NFCRC)
http://www.nfcrc.uci.edu/

NEWS

Fuel Cell Technology News January 2001
http://buscom.com/letters/fctnpromo/fctn/fctn.html
Hydrogen & Fuel Cell Letter
http://www.hfcletter.com/

REFERENCE

Hydrogen Fuel Cells
http://inventors.about.com/science/inventors/library/inventors/blfuelcells.htm
Fuel Cells - Green Power LOS ALAMOS
http://education.lanl.gov/resources/fuelcells/
Fuel Cell World
http://members.aol.com/fuelcells/
What is a Fuel Cell Fact Sheet, Fuel Cells
http://www.ttcorp.com/fccg/fc_what1.htm

RESOURCES

Fuel Cell - online
http://www.fuelcellonline.com/
Hydrogen and Fuel Cells resources at Business.com
http://www.business.com/directory/energy_and_environment/hydrogen_and_fuel_cells/
HyWeb -- the Hydrogen and Fuel Cell Information System in the Internet
http://www.hyweb.de/
The Hydrogen & Fuel-Cell Investor
http://www.h2fc.com/
Yahoo! Science Energy Fuel Cells
http://dir.yahoo.com/Science/Energy/Fuel_Cells/

LIST OF REFERENCES

Note about page numbers:

The vast majority of these articles were obtained on the Internet, often in "html" or "txt" format. Because these two formats do not indicate page numbers, it was necessary for me to make estimations regarding these whenever I directly quoted a paper (the ~ symbol preceding a page number in my dissertation denotes such an estimation, which is based on the pagination in my word processor).

Moreover, many of the newspaper or magazine articles I found on the Internet did not include their original location in the relevant publication. When I directly quote such articles, which are often less than a page long, I chose to use the *1 symbol, to indicate that the quote probably comes from the article's first page, but that I am unsure as to the exact number of this first page.

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