Innovation And Market Entry In The Energy Industry: Lessons For Fuel Cells And New Technologies

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ABSTRACT

Regulatory, environmental, and market changes are spurring new technological development in the energy industry. Fuel cells are the largest new entrant to the energy industry, and this technology faces enormous challenges in entering the transportation and power generation markets. Potential barriers include slow market acceptance, the resistance of incumbent energy firms, the lack of hydrogen infrastructure systems, and significant design and engineering obstacles. This paper compares challenges faced by the fuel cell industry to those faced by several previous breakthrough energy technologies – including incandescent light bulbs, fluorescent light bulbs, and combustion turbines – all of which faced comparable market entry challenges before ultimately succeeding. Results of this study and historical comparison show how other energy companies and industries overcame similar and daunting barriers. Lessons from these earlier success stories include the need for critical enablers such as using niche markets to sustain R&D, building new infrastructure systems or conforming to existing ones, and benefiting from favorable public policies.

Keywords: Innovation management, Market entry, Energy industry, Fuel cells, Research and development

INTRODUCTION

As the energy industry transitions to more environmentally-friendly technologies, new market entrants can learn a great deal from earlier generations of energy technologies. This paper examines the market entry challenges of a series of different energy technologies, then uses those findings to suggest lessons for one of the latest market entrants: companies in the fuel cell industry.

Although fuel cells hold some advantages over rival clean energy technologies, the fuel cell industry faces major economic, technological, and market challenges (Edwards, et. al., 2008). Fuel cell advantages include environmentally benign emissions, high reliability because no moving parts are necessary, and steadily increasing economic competitiveness. Despite these advantages, fuel cells face many technical obstacles and the fuel cell industry faces significant market entry barriers. Some of these major obstacles include the high cost of fuel cell components, insufficient power densities, the lack of hydrogen infrastructure or distribution systems, slow market acceptance, and resistance from incumbent companies with established technologies (Schoots, et al., 2010). These are daunting technology management challenges.

Inspiration can be found in other energy technologies that are now common, yet were once in similarly precarious positions: incandescent light bulbs, fluorescent light bulbs, and combustion turbines. The successful market entries of these technologies are now known, but their successes were not foregone conclusions during their infancies. These other technologies initially faced similar hurdles, including expensive components, inferior performance, high costs, and resistance from market leaders. They finally gained market entry because of critical enablers for which the fuel industry must find parallels. In the past, those enablers included establishments of networks, improved technologies, and the establishment of standards or favorable policies. The fuel cell industry may achieve success through similar means.

BACKGROUND AND LITERATURE REVIEW

The fuel cell industry has grown over the past decade to become an almost \$1.1 billion industry, including about \$416 million in revenue and \$800 million on research and development (R&D) annually (National Research Council, 2008; PriceWaterhouseCoopers, 2007; Wilhelm, 2001). Forecasts suggest growth to a \$60 billion market by 2018, although some estimates are higher if they include auxiliary equipment and sectors (Chung, 2008). These auxiliary sectors are important because many fuel cells still require the use of expensive materials, such as platinum or patented chemicals for anodes and proton-exchange membranes. These specialized materials are necessary for fuel cells to cleanly convert hydrogen into electricity for power generation or motive power for automobiles.

Fuel cells were experimentally developed in 1839 and named in 1889, but remained both expensive and obscure until GE developed the first proton exchange membrane in 1955 and NASA began using fuel cells to power electronics for the Gemini and Apollo space programs in the 1960 and 1970s (Sorensen, 2005). Fuel cells now have niche commercial applications in the power generation industry and experimental applications in the transportation industry, where they are considered environmentally friendly because of their low emissions (Hendry et al., 2010; Peters and Coles, 2010). Fuel cells are no longer obscure, but they are still expensive. For example, fuel cell cogeneration plants cost about \$3000/kW, about 2 to 9 times more expensive than equivalent nuclear or coal-fired generators; they therefore tend to be cost-effective only in special circumstances (De Almeida, et al., 2008, Werner, 2007; Unger, 2001). Costs are expected to drop with larger scale production, but more significant cost reductions are necessary to achieve competitiveness.

Previous research on the fuel cell industry points to both its strengths and weaknesses. Advocates claim that the society will inevitably shift from fossil fuel consumption to a hydrogen-based economy with fuel-cell cars and power plants. For example, Cook (2002) argues that, just as steam engines dominated the 19th century and internal combustion dominated the 20th century, so fuel cells will dominate the 21st century. Some prior research examines expanding hydrogen and fuel cell infrastructures in other countries (Zhang and Cooke, 2010; Vasudeva, 2009). Other sources focus on technological improvements that make fuel cell success more likely, including cost reductions in proton exchange membranes and increased energy densities (Sorensen, 2005; Fernandes and Ticianelli, 2009). Several sources consider fuel cells to be a disruptive technology likely to succeed in ways unexpected by incumbent firms (Christensen and Raynor, 2003, Harborne et al., 2009). In contrast, others suggest that fuel cell obstacles are still too high and that other technologies are likely to maintain their dominance (Romm, 2006; Ross, 2006). These authors point to the high costs of fuel cells and hydrogen distribution as reasons why other energy options are more favorable.

Another market entry barrier for the fuel cell industry is the chicken-and-egg problem of fuel production and distribution. For example, auto manufacturers will not invest heavily in fuel cell cars if there are no hydrogen refueling stations for customers (Senor and Singer, 2009). Meanwhile, energy companies have little incentive to provide hydrogen refueling stations unless there is a critical mass of fuel cell vehicles on the road. The lack of a hydrogen infrastructure and consumer unfamiliarity with hydrogen fuel remain significant obstacles (Ricci et al., 2007). Further, while most countries have methods of transporting or distributing oil, gasoline, or natural gas, creating a hydrogen system would require enormous investment. Establishing a hydrogen fuel infrastructure would cost hundreds of billions of dollars, or \$100-\$600 per car fueled, which is beyond the means of many energy companies, although perhaps achievable with devoted government funds (McCarthy et al. 2007; Ogden et al., 1999; Macleod, 2008).

Fuel cells have great potential but technology challenges, lack of infrastructure, and other market entry barriers make their future uncertain. The remainder of this paper draws lessons from other technologies that faced similarly uncertain futures during their introductions.

METHODOLOGY AND CASE ANALYSIS OF THREE TECHNOLOGIES

In order to view fuel cell market entry challenges in the context of history, it is useful to make comparisons to dissimilar technologies in the same energy industry. This research examines the emergence of three different energy technologies: combustion turbines, incandescent light bulbs, and fluorescent light bulbs. For each case, this

section discusses the technology's invention and commercialization, its historical progress, its market entry barriers, and how they were overcome.

To incorporate both supply and demand, the industries used in this comparison included both the power generation and power consumption sides of the energy industry. Combustion turbines proved to be a good basis for comparison because they perform a power generation function similar to fuel cells (although in a technologically different way) and underwent years of development and doubt before finally penetrating the power generation market. The lighting industry provided the other two bases of comparison because it consumes 20-25% of all U.S. generated power and represents the other end of the energy spectrum. Each industry case study was conducted using a combination of data from historians, company sales records, and public or government data on energy use and market entry.

Incandescent Light Bulbs

Although ubiquitous today, the incandescent light bulbs that Thomas Edison patented in 1880 were initially inferior to the gas lamps that he hoped to supplant. Despite over 50 years of experimentation and iteration by Edison and previous inventors, the light quality and reliability of incandescent bulbs were poor. Because early filament materials were incapable of illuminating brightly without burning, material experimentation was critical. Developmental bulbs were also vacuum-sealed to prevent filament combustion. Modern incandescent bulbs, with tungsten filaments, low-pressure inert gasses, and long lives were still decades away.

Incandescent bulbs faced further competitive disadvantage because they required an electric infrastructure that did not yet exist. In contrast, the gas lamp industry relied on a strong gas distribution system that delivered natural gas to streetlights and structures. Gas lamps, which started appearing on city streets 50 years before Edison's patent, helped to establish and entrench gas companies with strong interests in preserving their markets. Gas companies were deeply entrenched in both the political and physical infrastructure of major cities (Hargadon, 2004).

For incandescent bulbs to displace the incumbent gas industry, they had to overcome both the technical and market challenges presented above. Several counterintuitive methods were used in market entry, including mimicry of existing conditions, creation of a network, and seeking investment from entrenched competitors. Mimicry of market conditions was necessary because Edison felt that early adopters would more readily accept electric light bulbs if they were similar to gas lamps. He therefore offered relatively dim, 12-watt bulbs that emitted approximately the same number of lumens as gas lamps, even though he could easily manufacture 40-watt bulbs. To create a network, Edison created the Pearl Street Station power plant and an electric network of several square blocks to serve as an initial market. This creation of an entire network was expensive and required investors, and Edison went so far as to seek investment from traditional gas company investors such as J.P. Morgan (Hargadon, 2004; Alexis, 2002).

Incandescent light bulbs were not instantly successful. They had existed for almost 40 years before Edison made his technical improvements and market introduction in the 1880s. With Edison's improvements and the creation of small electric grid islands with power generation facilities, the incandescent bulbs came to occupy niches in the lighting market. The 1911 introduction of an inexpensive method of manufacturing tungsten filaments, which both reduced bulb prices and increased bulb lifetimes, helped secure further market adoption. By 1930, almost 70% of U.S. households had electric service for lighting, marking the growing triumph of the electricity infrastructure and incandescent bulbs (Hall & Kahn, 2002; Nye, 1990).

Fluorescent Light Bulbs

Fluorescent light bulbs use the same network as their incandescent predecessors, yet they are more efficient, have no filaments and create light using an entirely different technology. Although versions of these gaseous bulbs appeared in the mid 1800s, they created distinct light colors (often red or blue) depending on the gas used. They did not become practical until 1926, when Edmond Germer invented modern phosphor-coated bulbs, and finally entered wide commercial use in 1938, after G.E. bought the patent. Compact fluorescent bulbs have

entered the residential lighting market in the past decade by mimicking the shape and outlet connections of traditional incandescent bulbs.

Market barriers to entry for fluorescent bulbs include high purchase costs, slow consumer acceptance of white lighting, and the special challenges of light ballasts. Costs are the most deceiving of these barriers because the operating costs of fluorescent bulbs are lower than their incandescent equivalents, while their manufacturing or purchase costs are about 4-8 times higher per lifetime hour (Johnson, 2007; USDOE, 2007). In order to have an economic incentive to use high-efficiency bulbs, purchasers must have the capital available for the initial purchases and be the same agents who pay for the operating electricity. Then, the payback periods for the high-priced bulbs are 1.1-2.5 years of average use, depending on the bulb wattage and cost of electricity (USDOE, 1996).

Consumer and social acceptance of fluorescent bulbs depends on the ease of bulb use and the quality of light. For their first 50 years, fluorescent bulbs were large tubes that required ballasts on each end. Although they used standard electricity, they were incompatible with conventional sockets because of ballast requirements. This incompatibility with home light socket standards dissuaded individuals and residential buyers from purchasing fluorescent bulbs. Furthermore, most consumers prefer yellow or broad-spectrum lights rather than pale white fluorescent lights (Kolanowski, 1989; McShane, 1997).

Four main factors are enabling fluorescent bulbs to overcome the market barriers described above. First, compact fluorescent bulbs are 75-50% more efficient than their incandescent counterparts. Second, technology improvements have allowed manufacturers to change light hues by either making broad-spectrum bulbs or by including color-correcting filters. Third, the introduction of compact fluorescent bulbs coincided with ballasts that were compatible with standard light bulb sockets. Fourth, consumers are encouraged to become new technology adopters by both commercial and policy campaigns. Commercial campaigns include manufacturer Siemens' rebates and retailer Wal-Mart's marketing campaign of in-store demonstrations used to influence customer selection (Abdou, 2006; Barbaro, 2007). Policy campaigns include Australian and European Union efficiency regulations that effectively ban most incandescent bulbs and US regulations that will phase out most incandescent bulbs by 2012 (Kanter, 2009; Waide, 2010).

As a result of these economic, technological, and social enablers, compact fluorescent bulbs are now enjoying significant market penetration. Their sales increased from negligible levels in 1995 to a peak of almost 397 million bulbs in the U.S. in 2007 (Lifsher and Uribarri, 2007; USDOE, 2009). Although sales slumped during the recent recession, demand remains strong and some major manufacturers such as Philips have announced plans to stop manufacturing incandescent bulbs by 2016 in anticipation of more energy-efficient fluorescent bulbs (Daley, 2008; Karney, 2009).

Combustion Turbines

Combustion turbines represent another energy technology that emerged to capture a significant new share in an existing market. Traditional steam turbines, which still generate the majority of the world's electricity, operate by using fuel in boilers to create steam that circulates around the turbine blades. The rotating blades then turn a generator to create electric power. Combustion turbines operate using an entirely different thermodynamic cycle – and often a different fuel as well. Combustion turbines generally burn either natural gas or oil inside the turbines themselves to create rotational energy. In this sense, they are like jet engines, except that they produce electrical power instead of thrust.

The first combustion turbine patent was issued to John Barber in 1791, but early versions were not commercialized because the energy needed to compress burning gas into the engines far outweighed the power generated by the turbines themselves. Practical machines would also require much higher operating temperatures and needed materials that were not yet available. Combustion turbines made their real debut during World War II, when the military need for jet engines combined with massive government R&D subsidies. The Lend-Lease agreement transferred early British designs to American companies and turned the design recipients (GE and Pratt & Whitney) into market leaders in the military aircraft industry (Unger, 2001).

Combustion turbines were unable to enter the power generation market after the war because their efficiencies were still far lower than their steam turbine counterparts. Their major barriers to entry were technical: efficiency improvements required operating temperatures too high for most metals to withstand. A second barrier to entry was the dominance of coal. The U.S. had a strong coal infrastructure in which coal was plentiful, inexpensive, and easily transportable by the existing rail infrastructure. In contrast, the oil or natural gas necessary to fuel combustion turbines were both more expensive and lacked a pipeline system for easy transport.

Manufacturers were able to overcome these market barriers by sustaining R&D through niche markets for several decades until a convergence of three forces enabled significant market entry. First, niche markets such as military aircraft engines in the 1950s and then commercial aircraft engines in the 1960s allowed manufacturers to improve their designs and raise the operating temperatures (and therefore efficiencies) of combustion turbines. Major improvements included the introduction of cobalt metal alloys and cooling systems that allowed turbine efficiencies to increase by almost 50% between 1945 and 1967 (Bannister et al. 1996).

A second niche market opened in 1965, when a major U.S. blackout prompted utility companies to seek small, surplus electricity generators for emergencies or peak power periods. Manufacturers redesigned combustion turbines for ground-based power. Steam turbines still shouldered the base generation load, but demand for combustion turbines skyrocketed. Within one decade, over 40 million kW of capacity were installed in the U.S., and manufacturers like GE, Westinghouse, and Brown-Boveri (later ABB) continued to make technological improvements.

Combustion turbines were still unable to penetrate the main power generation market until the 1990s, when three forces finally converged to enable their success in the U.S. First, the operating costs of combustion turbines decreased because the government rescinded natural gas policies (including the Power Plant and Industrial Fuel Use Act of 1978) that had previously limited industrial gas consumption and kept natural gas prices high (Zinc 1996). Second, environmental regulations increased the operating costs of coal-fired steam turbine plants, to the advantage of natural gas-fired combustion turbines, which emit considerably fewer pollutants. Finally, electric market restructuring created a market incentive for smaller power plants with lower capital costs, faster construction times, and shorter payback periods (Unger, 2001). Thus, after nearly 40 years of technological improvements enabled by niche sales in the aircraft engine and peak power industry, these three forces converged to allow the turbine market to grow. As a result, deliveries rose dramatically near the turn of the century and combustion turbines came to dominate U.S. plant capacity additions (USDOE, 1995).

RESULTS

The incandescent, fluorescent, and combustion turbine case studies share important similarities. All three products successfully entered their markets after decades of invention and refinement. Incandescent bulbs and combustion turbines are unqualified success stories; they are now established products affecting the lives of billions of people. Fluorescent bulbs constitute a qualified success story; ordinary fluorescent bulbs were successful in industrial markets, but were not strong in residential lighting markets until recently.

Fuel cells are still nascent compared to light bulbs and turbines, yet they face challenges similar to those overcome by older energy technologies. A comparison and contrast of some key market entry barriers and conditions are listed below in Table 1.

The market entry barriers in the left column of Table 1 correspond with those discussed in the earlier case analysis. Some rows reveal important differences. For example, the first row indicates that incumbent firms played different roles, depending on the technology. Incumbent firms developed fluorescent bulbs and combustion turbines, but new entrants played a larger role in developing fuel cells. The second row indicates that although all new entrants needed infrastructure, fluorescent lights had the benefit of a preexisting electric distribution system, whereas combustion turbines required expansion of a gas pipeline system. The last row indicates that standardization was more important for incandescent and fluorescent bulbs – whose designs were limited by the need to have them fit in common sockets or ballasts – than it was for turbines or fuel cells, which need only produce AC electricity but can do so through multiple potential designs.

Table 1: Comparison of Market Entry Barriers across Different Energy Technology Products

Market entry barrier \ Case study	Incandescent bulbs	Fluorescent bulbs	Combustion turbines	Fuel Cells
Role of incumbent firms	Developed independently, opposed by rival, entrenched gas companies	Manufactured by incumbent incandescent bulb firms (incl. GE, Philips, Sylvania)	Developed mainly by incumbent firms (GE, ABB, Westinghouse)	Developed independently, opposed by direct rivals
Need for new infrastructure	Yes, electric infrastructure nonexistent	Electric infrastructure pre-established, but ballasts were required	Gas pipeline infrastructure established as turbines developed	Yes, hydrogen infrastructure nonexistent
Need for cost reduction	Yes	Yes	Yes	Yes
Need for technological improvement	Yes	Yes	Yes	Yes
Need for favorable policy changes	Yes	No	Yes	Likely yes
Adoption time	Decades	Decades	Decades	Likely decades
Need for niche market to sustain development	Yes, public events/festivals and areas with early electric infrastructures served as test markets	Yes, niche markets included industrial lighting until compact fluorescents were introduced for residential use	Yes, niche markets included aircraft engine and emergency power markets	Yes, niche markets include space programs and distributed generation
Standardization	Yes – sockets	Yes – ballasts and sockets	No – only standard output	No – only standard output

Some rows in Figure 1 reveal important similarities. For example, the 3rd row illustrates that all new technologies in this field required lower production costs in order to achieve market entry. Although high production costs served as a universal barrier to market entry in this field, they do not necessarily play the same role in other industries. In many common consumer goods, for example, a new product may be produced as inexpensively as an existing product.

Another similarity among the four technologies in Figure 1 is the need for a niche market to sustain the nascent innovation until improvements allow for greater market acceptance. Other similarities include the need for technological improvement and the significant length of time for market adoption.

DISCUSSION AND LESSONS LEARNED

This study demonstrates some compelling similarities among the market entry challenges faced by several energy technologies. It suggests that the market entry of incandescent light bulbs, fluorescent light bulbs, and combustion turbines can serve as potential guides for the fuel cell industry.

Table 1 demonstrated how both fuel cells and incandescent light bulbs required infrastructure development to succeed. Indeed, if fuel cells succeed, the creation of a hydrogen manufacturing and distribution system may closely resemble the creation of electric power plants and transmission wires in the 20th century. However, unlike the case for light bulbs, where Edison himself was able to finance and build early electrical grids, fuel cell manufacturers are not positioned to provide the hydrogen network that fuel cells need for successful market entry. The problem cannot be ignored; both the fluorescent lights and combustion turbine models also display the need for infrastructure to precede market expansion. In the case of fuel cells, significant investments will be necessary from governments, energy companies, or consortia.

The fuel cell industry can also learn lessons from the role that incumbent companies play in the introduction of new energy technologies. In the case of light bulbs, rival gas companies had no interest in the new and rival technology, despite Edison's efforts to woo their investment. Because Edison was able to finance an electricity network without the gas industry, entrenched incumbents were swept away. In contrast, when fluorescent bulbs were invented, GE (originally founded by Edison) considered the new technology to be a potential threat and purchased the patent rights so that the company could manufacture fluorescent bulbs itself. It profited from selling fluorescent bulbs, but was not eager to see long-lasting fluorescent bulbs cannibalize its more profitable incandescent bulb business. In this sense, an incumbent firm simultaneously benefited from a new technology while preventing it from entering the residential lighting market for decades. In the case of combustion turbines, incumbent firms were among the earliest developers of the new technology because only the incumbent firms had the expertise and capital to conduct large-scale R&D in turbine blade development. Finally, in the fuel cell industry, development has taken place among chemical and independent companies often new to the power generation or automotive markets. Most direct and incumbent rivals view fuel cells as threats, dismiss fuel cells as unviable alternatives, or make minor R&D investments to hedge their bets and diversify.

Table 1 also suggests a common need among emerging energy technologies for continued technological improvement and cost reduction through R&D, as well as public policies that are either favorable to the new technologies or detrimental to the old ones. Until such a convergence of favorable conditions – many of which are not in the control of fuel cell companies – emerging technology industries must often sustain themselves through niche markets. Because the adoption time for many new energy technologies spans decades, the need for successful niche markets becomes even more pressing.

In historical context, fuel cells parallel incandescent light bulbs because they are a promising emerging technology based on an entirely different fuel, different technology, and different infrastructure than their entrenched competition. Fuel cells also resemble fluorescent lights and combustion turbines because their early versions are technologically inadequate to serve major markets, but useful enough for small applications.

Just as fuel cells face market entry barriers similar to their predecessors, they may have analogous paths or critical enablers that can help them enter markets successfully. Incandescent light bulbs overcame their market entry barriers in part because proponents created small infrastructure networks – in the form of local power plants and electrical grids – to service the new technology. They were also designed to woo customers by mimicking the gas lamps they were replacing. The fuel cell industry can potentially imitate this by promoting hydrogen fueling stations and cars in small areas or with delivery fleet vehicles to demonstrate their viability.

Fluorescent bulbs and combustion turbines overcame their market entry barriers by using niche markets to sustain R&D until economic conditions, technological improvements, and public policies converged to usher them into larger markets. The fuel cell industry could imitate this pattern if their current consumers of small products are considered to be niches or stepping-stones towards larger markets. Apart from the barriers, both fluorescent bulbs and fuel cells are affected by enablers. Just as policy changes were a factor that helped fluorescent bulbs overcome entry barriers, growing environmental concerns may act as an enabler for fuel cells to expand in the energy market.

CONCLUSION

The success of the fuel cell industry may lie in its ability to learn lessons from its predecessors. This study demonstrates that fuel cell and hydrogen-based or fuel cell economies may be viable if several key challenges can be overcome as they were for previous energy industry success stories. Strategies include either conforming to or establishing necessary infrastructure networks, finding niche markets until technologies are proven, and achieving competitiveness through both cost reduction and favorable public policies.

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