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Commercializing fuel cells: managing risks

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Abstract

Commercialization of fuel cells, like any other product, entails both financial and technical risks. Most of the fuel cell literature has focussed upon technical risks, however, the most significant risks during commercialization may well be associated with the financial funding requirements of this process. Successful commercialization requires an integrated management of these risks. Like any developing technology, fuel cells face the typical 'Catch-22' of commercialization: "to enter the market, the production costs must come down, however, to lower these costs, the cumulative production must be greatly increased, i.e. significant market penetration must occur". Unless explicit steps are taken to address this dilemma, fuel cell commercialization will remain slow and require large subsidies for market entry. To successfully address this commercialization dilemma, it is necessary to follow a market-driven commercialization strategy that identifies high-value entry markets while minimizing the financial and technical risks of market entry. The financial and technical risks of fuel cell commercialization are minimized, both for vendors and end-users, with the initial market entry of small-scale systems into high-value stationary applications. Small-scale systems, in the order of 1-40 kW, benefit from economies of production — as opposed to economies to scale — to attain rapid cost reductions from production learning and continuous technological innovation. These capital costs reductions will accelerate their commercialization through market pull as the fuel cell systems become progressively more viable, starting with various high-value stationary and, eventually, for high-volume mobile applications. To facilitate market penetration via market pull, fuel cell systems must meet market-derived economic and technical specifications and be compatible with existing market and fuels infrastructures. Compatibility with the fuels infrastructure is facilitated by a separation of functions between stack convention and fuel processing, i.e. external reforming using low-cost, non-catalytic under-oxidized burners. Even for fuel cell technologies capable of internal reforming, the separation of functions offers the advantage of separate optimization of the fuel cell stack and fuel processor, leading to fuel flexibility and lower systems costs. The combination of small size fuel cells, high market values, low development and demonstration costs, low market entry costs, and availability of off-the-shelf balance-of-system components, provides a low financial and technical risk scenario for fuel cell commercialization.

Keywords: Fuel cells; Commercialization; Managing risks; USA

1. Introduction

This paper addresses the key issues associated with fuel cell commercialization and, specifically, the economic and technical risks associated with the commercialization.

However, before discussing these issues, attention is paid to two significant factors that provide major impetus to the early commercialization of small-scale distributed fuel cells. First, the utility industry in the USA and worldwide is undergoing a major restructuring because of pending deregulation and privatization brought about by increasing market pressures for lower energy services costs through competition. In addition, the electric power quality and reliability requirements are becoming more stringent due to the increased deployment of electronics in the home and workplace.

As a result, the utility industry is in the process of changing from highly centralized Government franchise monopolies to decentralized private organizational structures with a major shift in emphasis from large-scale central power plants to small-scale distributed, customer-oriented markets in terms of strategic planning.

Secondly, the costs associated with new generation and transmission and distribution (T&D) since the early 1970s are rapidly escalating, both in real and actual (nominal) currency units. Due to a variety of reasons, including costs of access and environmental considerations, the transmission and distribution costs for few developments are nearly equal to the generation costs. These changes in organizational structure and strategic planning, coupled with the rising generation and T&D costs, as well as potential EMF problems (real or imagined), provide an ideal opportunity for the emergence of small distributed systems. Small-scale fuel cells are ideally suited for such distributed applications.

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2. Fuel cells: critical technology for the 21st century

2.1. Stationary and mobile applications

Fuel cells offer well-recognized energy and emission reduction potential for both stationary and mobile applications. On the stationary side, fuel cells are highly-attractive since their low-emission, low-noise, and high-efficiency characteristics allow them to be installed near or at the end-user's location. Besides avoiding expensive transmission and distribution (T&D) costs, alleged EMF problems from transmission lines are avoided, thus potentially providing an additional environmental benefit. Consequently, fuel cells warrant the attention of electric and gas utilities as an enabling technology for distributed generation that will allow them to compete for and serve new customers and markets, using an economic low-emission technology with high potential for cost reduction due to cumulative production learning and innovation.

On the mobile side, vehicles using electric propulsion systems, including fuel cell vehicles, have been suggested as a means of reducing dependence on petroleum resources in the transportation sector and for drastically reducing mobile emissions. However, user acceptance will only be forthcoming if such low-emission vehicles offer the same economics, performance, and identical range (which is virtually unlimited through rapid refueling) as comparable internal-combustion engins (ICE) vehicles. Considering the present and projected battery technologies, powering vehicles with batteries alone cannot achieve the extended range necessary for significant market penetration. On the other hand, vehicles with fuel-cell and battery hybrid propulsion systems have been shown to eventually have the potential to achieve identical cost, performance, and range as comparable ICE vehicles. Consequently, fuel cells have the potential to penetrate the large decentralized stationary markets and, subsequently, the total vehicle market through market pull, with the associated benefits in terms of emissions reduction, oil displacement, balance of trade, and national security.

3. Fuel cell status

From its start in the US space program, the recognition of fuel cell benefits has led to several RD&D programs involving a variety of fuel cell technologies. These alternative technologies include the alkaline fuel cell (AFC), phosphoric acid fuel cell (PAFC), molten carbonate fuel cell (MCFC), proton-exchange membrane fuel cell (PEMFC), and solid oxide fuel cell (SOFC). These technologies are in various stages of development largely through Government-funded research since the late 1960s. Complete PAFC systems have been demonstrated at customer sites and commercial co-generation units are for sale but at much higher costs than comparable conventional state-of-the-art co-generation systems. MCFC's commercial demonstrations are underway but their costs also remain high and non-competitive. PEMFC and SOFC technologies are somewhat less developed but show great promise due to their high power densities and potentially low cost under mass production.

Overall, the move toward commercialization has been relatively slow. The current progress of RD&D efforts has been to develop small laboratory-size fuel cell units in the order of one to several kilowatts. Since many of these RD&D efforts are directed toward large-size (100 kW to MW scale) fuel cell applications, e.g. utility or bus applications, the prevailing notion among fuel cell developers, R&D organizations, and others is that they remain far from commercialization until they can scale-up to large (100 kW to MW) sizes, which will be shown to be an approach with high financial and technical risks.

3.1. Catch-22 commercialization problem and solution

Like any developing technology, fuel cells face the typical 'Catch-22' of commercialization: 'to enter the market, the production costs must come down, however, to lower these costs, the cumulative production must be greatly increased, i.e. significant market penetration must occur'. Unless explicit steps are taken to address this dilemma, fuel cell commercialization will remain slow and require large subsidies for market entry.

For example, in the mobile area to which a large part of the PEMFC development is directed, previous integrated assessments [1] by Polydyne, Inc. have shown that mobile applications inherently have low market values due to low-duty cycles and availability of low-cost competing ICEs. Polydyne's market-derived specification for automotive applications calls for fuel cell system specific and volumetric power densities that are much higher than the current values. The market-derived allowable equivalent fuel cell system cost is US $80–US $100/kW, since it must compete with an ICE whose average cost is only about US $50–US $60/kW. For luxury vehicles, the allowable fuel cell costs are somewhat higher. Currently, the specific costs of fuel cells today still are almost two orders of magnitude higher, although there is great potential for cost improvements through production learning and continued innovation. Therefore, because of these high fuel cell costs relative to the inherent low value for mobile applications, commercialization is not likely to start with the mobile market.

The same situation applies to large- or utility-scale (100 kW–10 MW) stationary fuel cell applications, since low-cost competing conventional technologies are similarly available. For example, the PAFC, which is perhaps the most developed and widely-demonstrated technology, cannot compete economically with conventional co-generation systems equipped with state-of-the-art emissions controls and noise abatement.

More important, because of their large size, the risks and associated costs for market entry are very high, thus requiring large subsidies for commercialization. The large size entails high technical risks, since it does not allow for rapid design changes and requires customized site- or application-specific engineering that has to be done conservatively in terms of design, process, and materials selection. The financial risks are high due to the magnitude of the necessary financial commitments.

3.2. *Market-driven commercialization is needed*

To address this commercialization dilemma, it is necessary to follow a market-driven commercialization strategy and identify high-value entry markets that can support the current high costs of fuel cell systems, minimize the technical and financial risks of market entry, and sustain market penetration with market pull. In this regard, using a market-oriented approach, Polydyne, Inc. assessed small-size stationary applications that have high operating duty cycles and high competitive costs (values), and entail very low risks (and costs) for market entry. By matching the currently available laboratory bench-scale fuel cells with potential high-value markets, significant cost reductions and learning can be realized by directing focus toward increased production and continued technological innovation.

4. Market-driven framework

A market-driven approach uses the requirements of the market to derive the product specifications and associated the research, development, and demonstration (RD&D) efforts and commercialization strategy. This ensures that subsequent market penetration is rapid and will be sustained via market pull rather than market push via subsidies or regulations. Fuel cell development programs that have this market orientation can inherently achieve commercialization at low technical and financial risks.

4.1. *Technology- versus market-driven commercialization*

As shown in Table 1, approaches to commercialization are either technology-driven or market-driven. To date, most commercialization efforts are technology-driven. The technology-driven approach is usually manifested when explicit market analyses are conducted after the technology has been developed to a significant degree. Thus, market requirements become secondary to technology development. In this approach, a technology is conceptualized and developed based primarily on technical status and merits. The premise is that once the widely-applicable technology is developed, it can be 'pushed' into a market that is yet to be clearly defined.

In contrast, the market-driven approach derives the technical and economic specifications for technology systems and components from market considerations. The specifications, in turn, define the RD&D goals and determine the associated time frames for development and market penetration (Table 1). This process insures that technologies can be implemented to attain business and policy goals by satisfying market criteria, without regulatory benefits or penalties on various market participants, thereby insuring smooth and sustained market penetration by means of market pull.

4.2. *Market-derived criteria*

4.2.1. *'Block' approach using differential comparison*

For example, the overall market criteria used for defining the residential fuel cell specifications are that the residual fuel cell system must be equal to or better than the comparable residential customer electric and thermal service in all aspects. The market-derived fuel cell specifications are derived from a differential comparison with residential customer grid-connected service. This is the 'block' approach, similar to the successful design approach used by the Sony Corporation for the portable compact disk (CD) players in which the engineers were required to develop the CD components within the volume limitations defined by a block of wood specific by the production manager [2]. This design constraint insured that the eventual cost of the manufactured units would be commensurate with the projected desired market price (value) for large-scale market penetration. The derivation of the 'block' specifications for high-value stationary (residential) application is described in Section 5.1.

4.3. *Infrastructure compatibility*

Based upon Polydyne's market-oriented framework, the residential fuel cell/storage system must be fully compatible with the residential and fuel infrastructures (natural gas, propane) to facilitate the rapid penetration of its potential market. Thus, the residential fuel cell/storage system, at least initially, should fit within the volume and footprint constraints of typical residential cabinet space, so it can readily be incorporated into current home designs. Similarly, the fuel should be compatible with the current fuel distribution system. This will avoid any radical and expensive changes in manufactur-

Table 1
Technology- vs. market-driven approach

Technology-driven approach	Market-driven approach
What is ...	What ought to be ...
Technology drives RD&D and business development	Market criteria drive RD&D and business development
Products are 'pushed' into the market, e.g. via subsidies, laws	Market-derived specifications will attain market penetration through market pull
Pragmatic, stepwise approach	Fully-integrated approach

ing, certification, distribution, and facilitate user acceptance and rapid introduction and penetration into the marketplace. Thus, the resulting residential fuel cell system will be transparent to the user and thus can be considered an evolutionary development from the consumer's point of view.

4.4. Separation of functions

In relation to the infrastructure compatibility, there are significant advantages to separation of functions, e.g. external instead of internal reforming, to separate stack conversion from fuel processing. This permits the optimization of the individual system components while providing fuel flexibility necessary to remain compatible with existing fuels infrastructures. For example, an SOFC in combination with low-cost, external non-catalytic under-oxidized burners, allows for the optimization of the fuel cell stack for the H_2 and CO mixed gases derived from the burner while any changes dictated by fuel availability can be achieved by the inexpensive under-oxidized burner instead of the expensive fuel cell stacks. Furthermore, external reforming will allow for fast start-up times such as those required for mobile applications. This consideration applies equally to fuel cell technologies that can reform fuel internally, since operation at elevated temperatures (>650 °C) required for internal reforming dictates the use of expensive high-temperature materials, thereby hindering market viability.

5. Low-risk, market-oriented commercialization strategy

Whereas the market-derived specifications for fuel cells indicate where the technology ought to be, a strategic plan must be developed on how to get there. With projected learned-out costs of less than US $100/kW of certain fuel cells at mass production, advanced low-cost fuel cells have large market potential for both stationary and mobile applications. An overall integrated commercialization strategy must consider all potential markets, including high-value entry markets, and potential synergy of these markets in accelerating commercialization. The integrated approach is predicated on three considerations: (i) market-orientation; (ii) low development costs and risks by starting with and progressing from small-scale configurations, and (iii) matching the development stages with the requirements of high-value entry markets to accelerate scale-up and commercialization via market pull (rather than market push via subsidies). The elements of this integrated approach are briefly described below.

5.1. High-value entry markets

High-value markets will accommodate the high initial costs of fuel cells during the early development stages, whereas the small scale minimizes the financial and technical risks of development and commercialization. In this regard, the commercialization strategy will target initially (i) high-value stationary (residential, micro-co-generation) market; (ii) high-value remote stationary applications, and, subsequently (iii) high-volume markets, such as large-scale automotive applications. This process will eventually provide fuel cells with projected learned-out costs less than US $100/kW, commensurate with the market-derived cost requirements for mobile applications. Lower-temperature SOFC designs and advanced PEMFC are the premier candidate fuel cells to achieve these stringent market-derived cost and performance specifications.

5.2. Matching high-value entry markets with R&D product status

The associated overall fuel cell commercialization program plan is summarized in Table 2, which shows the respective markets and applications for various fuel cell sizes and which capitalizes on high-value entry markets associated with high-duty cycle. The overall plan is to develop and demonstrate commercial prototypes of fuel cells for three broad size classifications and voltages corresponding to various applications.

By matching the currently available 'laboratory' fuel cell sizes and configurations with small-scale high-value entry

Table 2
SFCCG fuel cell system commercialization

Size (kW rated)	Applications	User
Small (2–5 kW)	Residential (high-value entry)	Utility/commercial/military
	Uninterruptible power (UPS)	Commercial/military
	Remote applications	Utility
Medium (5–100 kW)	Commercial/industrial	Utility
	Automotive (EV, HEV)	Commercial/military/Utility
	Aircraft	Commercial/military
	UPS	Commercial/military/utility
Large (100 kW–10 MW)	Transportation (trains/buses)	Commercial/military
	Aircraft/ships	Commercial/military
	Utility load substations	Commercial/utility

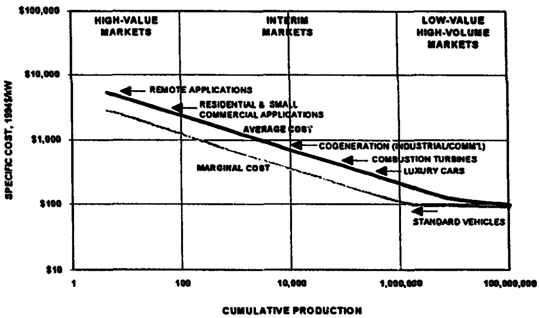

Fig. 1. Projected small-scale fuel cell production learning costs and market values.

markets, significant cost reductions and learning can be realized by focusing upon increased production and continued technological innovation. Typical production cost learning curves for fuel cell systems, including both the average and marginal (incremental) costs, are shown schematically in Fig. 1, which are linear when presented on a log–log scale. Learning curves reflect cost reductions due to increased production and technological innovation as a function of cumulative production, which has been manifested in all manufacturing products.

The potential fuel cell markets and applications are superimposed on the learning curves, indicating the approximate value (y-scale) of these applications *vis-a-vis* fuel cell costs. Since market penetration occurs when the fuel cell system costs equal the intrinsic value of the application, fuel cell market-pull commercialization can be sustained by following a strategy commensurate with the projected learning curve and associated market values.

5.3. Synergy between transportation and stationary fuel cell markets

Exploiting synergy with other applications paves the way into broader and larger applications by accelerating cumulative production. Thus, while the small-size high-cost fuel cell may have no immediate direct vehicle application, its development is integral to the development for vehicle applications, since the small size satisfies the requirements for both markets.

Consequently, success in the small size high-value fuel cell for stationary applications will inherently facilitate the development of fuel cells for mobile applications by lowering the cost through production learning and continued innovation, while simultaneously scaling up to the somewhat larger sizes required for this application. Once the fuel cell system costs have declined sufficiently to the levels necessary for market-viable automotive propulsion systems, the very large potential automotive market will greatly facilitate further reductions in fuel cell system costs due to large-scale mass production, which in turn will significantly broaden the stationary market applications.

6. Fuel cell commercialization: managing the risk

The small size of the residential fuel cells facilitates rapid commercialization due to the relatively low development and demonstration costs and risks (financial and technical). This is similar to the commercialization of wind machines, which started with small wind turbines and, subsequently, scale up to large sizes. Commercialization was sustained because although the projected learned-out costs of large machines at any given level of production were lower, the small wind machines were actually cheaper at any point in time due to rapid learning with increased production and market penetration of the smaller wind machines.

6.1. Small systems translate into low technical and financial risks

A comparative commercialization cost and risk assessment of small 2 kW residential fuel cells and the larger 2 MW fuel cell program is shown in Fig. 2. The total costs and associated

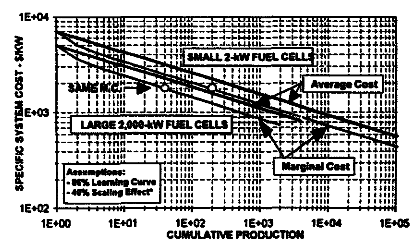

Fig. 2. Comparative production costs small-scale vs. large-scale fuel cell systems.

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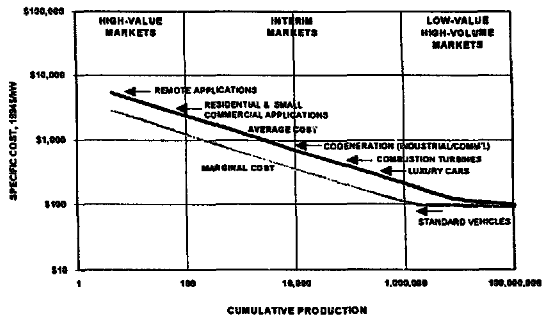

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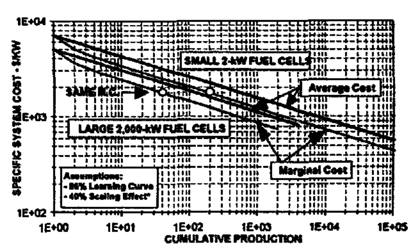

Fig. 2. Comparative production costs small-scale vs. large-scale fuel cell systems.

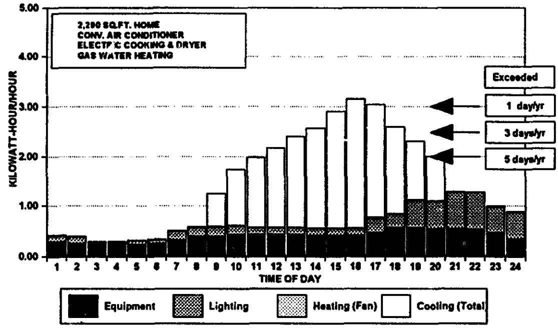

Fig. 5. Cooling peak day electric load profile Western utility example.

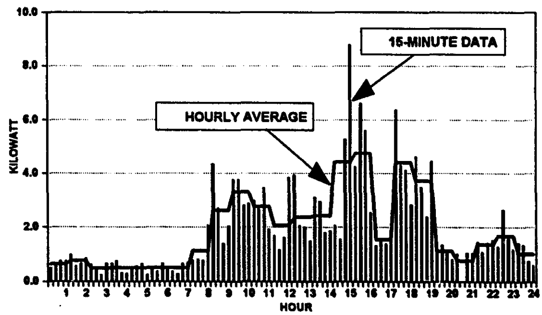

Fig. 6. Peak day load profile example: hourly average versus 15-min data.

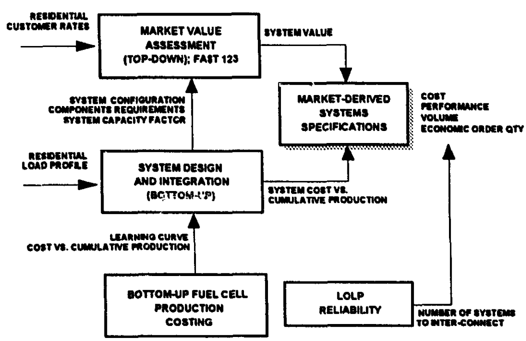

Fig. 7. Integrated market-driven fuel cell assessment.

the cumulative production level at which this cost-value match occurs, i.e. the break-even cumulative production or economic order quantity (EOQ). Supporting calculations are provided by an in-house Fuel Cell Design and Production Costing Model, which can be used to design and estimate the learning curve costs and learned-out costs of different fuel cell technologies in terms of average and marginal costs versus cumulative production (learning curve).

The optimum configuration and break-even cumulative production are shown in Fig. 8 for a high-value utility.

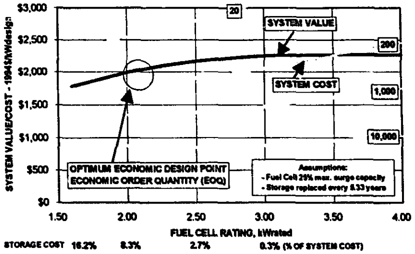

Fig. 8. Residential fuel cell system integrated value-cost comparison.

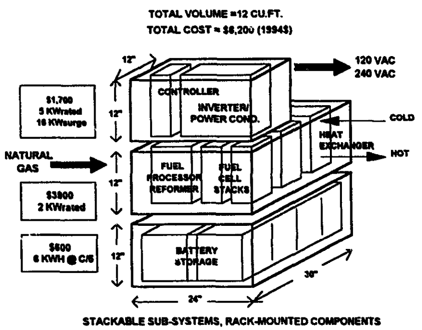

Fig. 9. Residential fuel cell/storage system cost and volumetric specifications.

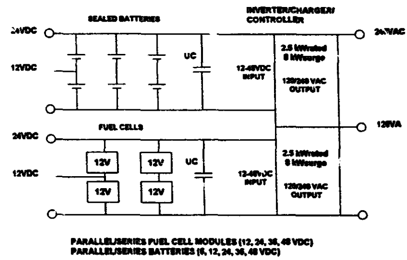

Fig. 10. Residential fuel cell/storage system 'strawman' configuration.

Beyond this break-even cumulative production, the system costs will become lower than the system value, thus facilitating market penetration by means of market pull. Thus, the break-even cumulative production defines the initial EOQ at which the fuel cell commercialization can be initiated by offering to purchase through a Market Opportunity Notice an EOQ of fuel cell/storage systems that satisfy the market-derived cost specifications. This assessment was conducted for the twelve utilities and the highest value utility cases were used to derive the economic and technical specifications for the entry market.

7.5. Economic and technical specifications

The resulting specifications include: (i) the initial system value (or allowable overnight cost) which, by definition, represents the system cost specification that must be met for commercialization to start; (ii) the optimum fuel cell rated capacity (kW) or fuel cell/storage configuration at which system costs equal or become lower than system values, and (iii) the cumulative production units at which system value is equal to the overnight cost, i.e. the EOQ, which is several hundred systems. The schematic product specifications are shown in Fig. 9.

The incorporation of storage permits fuel cells to be designed for baseload power only (which in residences is about 20% of peak power), resulting in fuel cell/storage systems costs that even in limited production can match the market-derived system values, thus facilitating commercialization of laboratory size fuel cells through market pull. For a typical 2000 ft^2 California or East Coast home, the residential fuel cell optimizes at about 2 kW baseload, while the 5–6 kWh/h (and power surges up to 16–20 kW) electrical peaking requirements can be served by battery storage. A schematic 'strawman' electrical configuration is shown in Fig. 10. Based upon preliminary analyses, the same grid-connected reliability of service can be achieved by interconnecting as few as four or five residences by means of a 240 V micro-distribution line.

The total market entry cost associated with the small fuel cells is very low, which permits large and small fuel cell companies to enter this high-value market. Furthermore, thanks to the computer industry, the uninterruptible power systems (UPS) is already a billion-dollar industry for the inverter and control systems. Consequently, the balance-of-system components (inverters, power conditioning and controls, and battery storage), represented by these off-the-shelf systems, are well along in their commercialization, with commensurate lower prices. The combination of high-market values, low market entry costs, and availability of off-the-shelf balance-of-system components, provides an ideal scenario for low-risk commercialization of fuel cells.

8. Small-scale fuel cell commercialization group

To implement the commercialization strategy, the participating utilities and Polydyne, Inc., have organized the next phase by incorporating the Small-Scale Fuel Cell Commercialization Group, Inc. (SFCCG, Inc.), as a business alliance to ensure and sustain the low-risk market-driven commercialization efforts. The SFCCG charter is to demonstrate and commercialize (not R&D) small-scale fuel cell systems (1–40 kW), starting with high-value stationary markets and, subsequently, high-volume lower value mobile applications. The group has been incorporated as non-profit corporation in the State of Delaware.

The SFCCG is managed by a five-member Governing Board nominated and elected by its members. The group has two committees set up to handle the group's key activities: commercialization (markets) and technical/system integration.

Membership in the SFCCG is currently limited to twenty (20) utilities and organizations and may include electric, electric and gas, gas utilities, and gas companies. To date, the US participants represent at least 20% of the US utility industry market. The SFCCG group intends to purchase market-derived systems at an economic order quantity at which initial systems production costs are projected to match system application values.

8.1. SFCCG program plan and status

The SFCCG program is a three-phased 'go–no-go' program.

Phase 1, which was recently completed, determined the market-derived specifications economic and technical for residential fuel cells based upon integrated fuel cell assessments conducted for each of the twelve geographically-diverse participating utilities. Since the objective of this program is to enter the highest value market and initiate commercialization, the highest value utility cases (generally those with high electrical rates) were used to derive the specifications, which were incorporated into a Market Opportunity Notice (MON) to purchase a large number of small fuel cells systems.

This MON was released early in Feb. 1995 [3] to prospective fuel cell vendors, developers, manufacturers and integrators in the USA and abroad. Responses were due by and several were received on 30 May 1995. The responses were reviewed and evaluated by all utility participants and, during its recent meeting (Sept. 1995, Chicago), one manufacturer was selected for initial technical demonstration at selected host utility sites during Phase 2.

Phase 2 will be a technical demonstration of a number of complete systems of the preferred system selected from the Phase 1 MON.

Phase 3 is a large scale commercial demonstration of the most viable system(s) at the economic order quantity determined in Phase 1. Preliminary estimates place this economic production order quantity at least 200 systems and up to 2000 systems depending upon utility requirements.

A key program objective is to get the small fuel cells out of the laboratory and into production, thereby decreasing their costs through learning and continued innovation. Since the market-derived specifications require that the costs of these residential fuel cell systems are competitive with the rates that customers are currently paying, the Phase 3 commercial demonstration will inherently be financed within the rate base of the utility, except for program monitoring costs, thus facilitating commercialization through market pull.

Phase 1, by providing market-derived fuel cell specifications for the first time, proved successful not only in terms of drawing responses from potential vendors but also in infusing market orientation and redirecting the fuel cell development and commercialization of several companies toward high-value small-scale applications, even among vendors who were unable to respond to the recent MON.

9. Summary and conclusions

The Catch-22 of fuel cell commercialization is addressed by using a market-driven commercialization strategy, starting with high-value entry markets that can accommodate the high initial costs of fuel cells during the early development stages. To facilitate market penetration via market pull, the economic and technical specifications of the fuel cell systems are derived from market considerations, to include compatibility with existing market and fuels infrastructures, such as natural gas, propane (for remote applications), gasoline and diesel.

Compatibility with the fuels infrastructure is facilitated by a separation of functions between stack conversion and fuel processing, i.e. external reforming using low-cost, non-catalytic under-oxidized burners. Even for fuel cell technologies capable of internal reforming, the separation of functions offers the advantages of separate optimization of the fuel cell stack and fuel processor, leading to fuel flexibility and lower systems costs since design optimization dictated by the available fuels can more readily be implemented at the lower-cost fuel processor rather than at the stack design.

The economic, operational, and technical risks of fuel cell commercialization are minimized, both for vendors and end-users, with the initial market entry of small-scale systems into high-value stationary applications. Small-cycle systems, in the order of 1–40 kW, benefit from economies of production — as opposed to economies to scale — to attain rapid cost reductions from production learning and continuous innovation. These capital costs reductions will accelerate their commercialization as the fuel cell systems become progressively more viable for various stationary and, eventually, at high-volume mobile applications.

Following this market-driven strategy, a consortium of electric and gas utilities in the USA and Canada have organized the SFCCG, to commercialize small-scale systems for stationary and, subsequently, mobile applications in a three-phase program. A MON was released in early 1995 to the fuel cell community soliciting bids to supply small-scale fuel cell/storage systems for high-value residential micro-co-generation market application, based upon market-derived economic, operating, and technical specifications.

Based upon the evaluation of MON responses, the SFCCG has selected a fuel cell manufacturer to proceed with the technical feasibility demonstration during Phase 2 and will start negotiations to install 15 to 20 systems in 1996. Contingent upon the results of Phase 2, a Phase 3 large-scale commercial demonstration of several hundred to a thousand systems is planned in the 1997–1998 time period.

During Phase 2, the SFCCG will also assess other high-value stationary markets, to include multi-family and small commercial, remote applications, and distributed telecommunication industry applications. Membership in the SFCCG is currently limited to twenty electric and/or gas utilities, not including other supporting organizations.

References

[1] (a) *Market-Derived Design Specifications for Fuel Cell Electric Vehicles, Final Rep.* prepared by Polydyne, Inc., for the US Department of Energy, Office of Transportation Technologies, and Argonne National Laboratory, Mar. 1991, San Mateo, CA; (b) *Market-Derived Design Specifications for Fuel Cell Electric Vehicles*, invited paper to the Society of Automotive Engineers, *TOPTEC Meet., 4–5 November 1991, Arlington, VA, USA.*

[2] E.S. Browning, Japanese triumph: Sony's perseverance helped it win market for mini-CD players, *Wall Str. J.*, (27 Feb.) (1986) A-1; A-17.

[3] *Market Opportunity Notice for Market-Derived Residential Fuel Cell Systems*, Prepared for Consortium of US Utilities, Electric Power Research Institute, Canadian Electrical Association, by Polydyne, Inc., San Mateo, CA, USA, 16 Jan. 1995.