American fuel cell market development

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Abstract

Over the past three decades several attempts have been made to introduce fuel cells into commercial markets. The prospective users recognized the attractive features of fuel cells, however they were unwilling to pay a premium for the features other than the easily-calculated fuel cost savings. There was no accepted method for a user to calculate and then accrue the economic value of the other features. The situation is changing. The Clean Air Act signed into law by President Bush on November 15, 1990, mandates a nation wide reduction in SO_2, NO_x and ozone emissions. This law affects specific utilities for SO_2 reduction, and specific regions of the country for NO_x and ozone reductions – the latter affecting the utility-, industrial- and transportation-sectors in these regions. The Act does not direct how the reductions are to be achieved; but it specifically establishes a trading market for emission allowances whereby an organization that reduces emissions below its target can sell its unused allowance to another organization. In addition to the Clean Air Act, there are other environmental issues emerging such as controls on CO_2 emissions, possible expansion of the list of controlled emissions, mandated use of alternative fuels in specific transportation districts and restrictions on electrical transmission systems. All of these so-called 'environmental externalities' are now recognized as having a real cost that can be quantified, and factored in to calculations to determine the relative economic standing of various technologies. This in turn justifies a premium price for fuel cells hence the renewed interest in the technology by the utility and transportation market segments.

Introduction

Fuels cells have been under development by industrial firms in the United States since the late 1950s. The most notable uses of fuel cells to date have been in the space program; General Electric (GE) provided the fuel cells for the Gemini manned spacecraft orbital missions, and Pratt & Whitney (now International Fuel Cells Corporation) for the Apollo and Space Shuttle flights.

Over the past three decades these and other firms have attempted to introduce fuel cells into commercial service. One of the first attempts was by Allis-Chalmers (A-C) with an alkaline electrolyte fuel cell system, using cracked ammonia as fuel and air as oxidant, to power their line of electric fork-lift trucks. A prototype is shown in Fig. 1. This was solely a fuel cell power system, no battery was included, so the power system was sized for the peak load requirement of approximately 15 kW when the average load was only 3 to 4 kW. This may have contributed to A-C management's decision to cancel the effort due to unacceptably high cost projections. This system had immobilized electrolyte, with a concentrated KOH stream flowing through the anode chamber of each cell for moisture control and heat removal. All metal components in the cell were of flat sheet stock that were punched or slit by the same machines

Fig. 1. Prototype fuel cell powered lift truck by Allis-Chalmers.

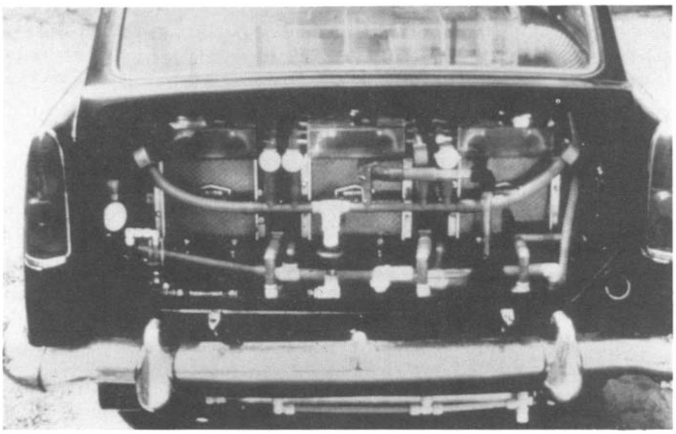

Fig. 2. Experimental fuel cell powered automobile by Union Carbide.

that stamped out electric motor-, rotor-, stator- and transformer core-laminations — a manufacturing process well known to A-C.

In the mid 1960s Union Carbide Corporation constructed a pilot assembly line for fuel cell stacks. These were designed for use with a circulating alkaline electrolyte and oxygen or air as oxidant. The stacks were a neat, leak-free fully encapsulated design. The automobile shown in Fig. 2 was constructed by Dr Karl Kordesch and used for some time in his daily commute. But buyers did not materialize for the stacks. Perhaps Union Carbide though that fuel cells could be sold like batteries, i.e. that the buyer would put the necessary system around them to perform the desired function. But buyers of fuel cell stacks did not materialize — a situation that was repeated 20 years later when Occidental Petroleum tried to commercialize Alsthom-developed fuel cell stacks.

General Electric was also active throughout the 1960s, developing phosphoric acid as well as ion exchange membrane fuel cell technology. The system shown in Fig. 3 was delivered to the US Army in the late 1960s. It produced 1.5 kW using jet fuel

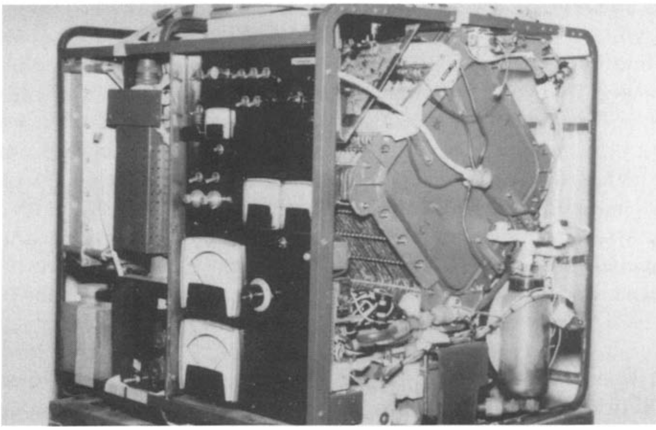

Fig. 3. Experimental 1.5 kW fuel cell by General Electric.

Fig. 4. 12.5 kW field test fuel cell by International Fuel Cells.

(JP-4, the military equivalent of Jet-A fuel commonly used in commercial aircraft) and was evaluated for use as a silent auxiliary power unit for combat vehicles. If this system had been produced in quantity for the military, GE believed a commercial market would develop for a similar product in recreational vehicles and pleasure boats. In the plant shown, sulfuric acid was circulated between ion exchange membranes fixed to each of the electrodes. The fuel desulfurizer and reformer was a particularly neat, light weight and excellent performing unit. The Army people monitoring the development program would have preferred that GE incorporate their phosphoric acid cell technology in the system.

Pratt & Whitney's (now the International Fuel Cells Corporation) activity in fuel cell development is well known. Their first system, field tested by numerous utility companies in the early 1970s, is shown in Fig. 4. It was a phosphoric acid fuel system, used natural gas as fuel and produced 12.5 kW. A mock-up a subsequent more compact version is shown in the foreground. The decision was made later to scale the system to 40 kW and again numerous units were field tested by utilities in North America and Japan in the mid-1980s. These were, of course, precursors of the 200 kW phosphoric acid fuel cell systems that will be entering service shortly.

So up to the present time the only application where fuel cells are routinely used is in the US space program and then only for manned missions. Why, since fuel cells have been in use in the space program for more than two decades, have they not been accepted for other applications? Why are fuel cells acceptable in space but not in terrestrial applications? What needs to be changed in order for fuel cells to be accepted on earth? For the manned spacecraft, the fuel cells' high efficiency relative to other power generation systems minimizes the weight of reactant chemicals and tankage that must be launched into space. This weight savings exerts a powerful leverage on the size, weight and cost of the rockets needed to boost the space vehicle into orbit. Hence the fuel cell, event at a cost of hundreds of thousands of dollars per kilowatt, is economic in space applications.

Fuels cells have often been promoted on the basis of other beneficial features such as low noise and pollution, etc. It is doubtful these features have much value to the space program; any level of noise or pollution from the on-board electrical power source is miniscule compared to that developed during the launch. The absence of vibration and recovery of potable water are plusses for fuel cells, but are not compelling justification for the expenses incurred by NASA in developing fuel cells for space. It was, in all likelihood, a decision based on economics.

It may well be that potential commercial users have discounted the value of the beneficial features of fuel cells and that this had slowed commercialization of the technology. Estimates have been made of the value of these features, i.e. EPRI published a report in 1983 where a group of twenty five electric utility companies estimated that fuel cells were worth on the average $166 per kilowatt (in 1981 dollars) more than competing systems [1]. These values were in addition to the cost savings that are easy to calculate, i.e. reduced fuel costs over the full range of power output and avoidance of purchasing additional pollution control control equipment. But the utility purchasers were unwilling to actually pay any premium price for fuel cells that would have had to be explained to their owners or to governmental bodies that audit their expenditures. Their overriding questions as reported in a market study EPRI published in 1990 were about the fuel cell ownership costs compared directly to gas turbine-combined cycle plants or power purchased from neighboring utilities [2]. This study identified the market for fuel cells of 1 to 50 MW size in urban areas. The text of this report stated that many of the fuel cells beneficial features were important to potential buyers, yet the market penetration statistics (hence the purchase decisions) came down to simple cost of electricity comparisons with the presently available alternatives. This head-to-head cost competition is a difficult hurdle to overcome for any new technology without some compelling price-is-no-object market niche.

So, are fuel cells forever relegated to the aerospace market niche in the United States? There are some recent events that suggest that fuel cells might be allowed a price premium due to the low level of environmental intrusion. The most important of these events, in my view, is the recently passed Clean Air Act. Since this is important to the fuel cell market development, some description of the Act is warranted.

Clean Air Act

The US Congress passed a new Clean Air Act which President Bush signed into law on November 15, 1990. This law mandates a national reduction in sulfur dioxide emissions of 10 millions tons per year by the year 2000 relative to 1980 levels, a 2 million ton per year reduction in nitrogen oxide emissions from expected 2000 levels, and caps emissions at those levels. The Act does not direct how the emission reductions are to be achieved, but to an extent it directs who must reduce emissions.

The electric utility industry is expected to account for 85% of the sulfur dioxide emission reductions, which amounts to a reduction of nearly 50% from 1980 levels. Specific power stations have been identified to meet most of these reduction goals [3] in order to reduce acid rain, and these power stations are largely in the eastern one-third of the country. The Act breaks new ground by specifically establishing a trading market for sulfur dioxide emission allowances. This allows an organization that reduces its emissions below its target level to sell its unused allowance (the difference between the target level minus the emission level achieved) to another organization that has not achieved its emission target level. Thus a utility has many options for compliance, such as installing additional emission control equipment, switching to cleaner fuels, purchasing power from others, replacing old stations, implementing conservation measures or trading in the emissions allowance market. Concerning this last option, a study prepared by the US Department of Energy [4] estimates the cost of compliance with the sulfur dioxide emission reductions to be approximately $240 per ton in 1995, increasing to $400 per ton by 2000. A modern pulverized coal plant with flue gas desulfurization meeting national standards controls emissions to 2.5 pounds SO_2 per million Btu. With a typical fuel consumption of 10 000 Btu/kW h, 25 pounds of SO_2 ($\sim$11.5 kg) are released per MW h by such a plant so simple arithmetic gives the added cost of compliance with the Act as 3 mills/kW h in 1995 increasing to 5 mills/kW h ($0.005/kW h) by 2000 (1 mill = $/1000). Since fuel cells typically release only a few grams of SO_x per MW h, their use can provide added revenues of 3 to 5 mills/kW h through the emissions sales which in turn can justify a premium on purchase price.

The Clean Air Act mandates specific NO_x reductions in certain areas of the US that the Environmental Protection Agency designates as ozone non-attainment areas, and EPA considers NO_x a precursor to ozone. While the best-known of these areas is Los Angeles, CA, there are approximately 100 in total which include most of the nation's largest cities. The impacts of NO_x reduction requirements are still being studied. From some viewpoints, the impact is less a matter of cost than the ability to live and conduct business in the area. An example is the requirement to use alternative fuels in vehicles in several of the non-attainment areas. Los Angeles and perhaps other cities have gone beyond the federal regulations and mandated the introduction of specified quantities of zero emission vehicles, i.e. electric vehicles. Who will be required to own such vehicles? Will an auto manufacturer without alternative fuel or electric vehicles be prohibited from doing business in the area? The impact on utilities is not clear either; some people project increased electricity usage at the expense of petroleum and natural gas, especially if the electricity is generated outside the non-attainment area. If that is the case, wouldn't a fuel cell become the ultimate natural gas appliance? What would its value be to gas utilities?

In any case, the Clean Air Act legitimizes the concept of placing a real cost on reducing selected emissions. This concept is now being extended to other real or perceived problem areas, all of which have been given the name of 'environmental externalities'. In terms of electric power generation, consideration is being given to controlling CO_2 emissions by enacting a carbon tax; some regions have tightened regulations on construction of electrical transmission and distribution lines for environmental reasons; and some regulators as well as utilities have embraced the concept of evaluating conservation measures by the same methods as supply measures. All of these fall under the umbrella of environmental externalities, which are becoming requirements for technology evaluations, and fuel cells are obviously one of the technologies that benefit from evaluations of this kind.

Dispersed generation benefits

Quantifying the environmental externalities in order to determine competitive prices for energy supply options is not an exact science by any means, but attempts are being made. As a step towards the end, EPRI and several utilities are attempting to determine the benefits of siting generation (or conservation measures) close to the customer by comparing them to the present cost of supplying electricity (and perhaps thermal energy) at the customer's meter. To simplify the analysis, costs are determined at the customer's side of the transformer for each of the utility's distribution substations at different times of the day and during different seasons of the year. The cost factors calculated are:

- energy value
- capacity value
- spinning reserve support
- load-following capability of the system
- enhanced distribution system reliability
- transmission capacity value
- transmission loss savings
- VAR support
- transmission and distribution system upgrades
- environmental savings
- byproduct heat value

The first step in the analysis is to calculate the present cost of service at the substation level in order to identify the sites with the highest costs. The next step is to compare the cost of correcting any deficiencies by conventional means with the cost of providing small-scale generation at the substation or nearby at a customer's site. The small-scale generation technologies being evaluated initially are fuel cells, combustion turbines and photovoltaics. The plans are to develop the capability to also evaluate battery energy storage and demand side management technologies.

Some of the cost factors are quite simple calculations; energy and capacity values for the small-scale generators can be derived from the installed cost, fuel price (if used) and efficiency. Others are not easily calculated; in some instances the cost of one or more alternative methods that can provide the feature are calculated and the lowest calculated cost is used as a proxy. All of the cost factors are highly site specific and often time-of-day specific. This is particularly true of those relating to the transmission and distribution system where accurate power flow data is essential.

The results of a distributed generation assessment conducted in conjunction with the Los Angeles Department of Water and Power are shown in Table 1. The ranges of costs savings for four specific sites are summarized. The fuel cell characteristics used in the assessment are those anticipated for the 2 MW molten carbonate fuel cell being developed by Energy Research Corporation. These benefits indicate that the 2 MW fuel cell, at an installed cost of \$1500/kW, at each of the four sites would be competitive with remotely-sited combined cycle power plants at \$800/kW. Both types of plants are assumed to operate at a 65% capacity factor.

TABLE 1

Distributed generation benefits (mills/kWh)[a] levelized 1995$

Spinning reserve	3–4
Peaking operation	4–5
T&D	2–14
Loss savings	7–14
Reliability	0–13
Environmental	4–6
Thermal	TBD

[a]Some are mutually exclusive thus non-additive.

Five other utilities from other regions of the country are conducting similar assessments. Preliminary results appear to confirm that the fuel cell's features warrant a premium price at certain specific locations on the distribution grid. Equally important, the utility decision makers believe these results and appear willing to defend the purchase decisions they would make to their shareholders and regulators — a situation that has changed dramatically in only a short time.

Conclusions

There are five other papers in this symposium describing fuel cell commercialization programs underway in the US for electric utility, natural gas utility and transportation applications. All for these programs are driven to a large extent by the acceptance that environmental externalities will be important factors in selecting power systems in the near feature. Each of these are truly serious commercialization efforts involving several different manufacturers, different fuel cell technologies and numerous users. The impact of this on the fuel cell market development is obviously very positive. The acceptance of a premium price, the development of novel cost- and risk-shared commercialization programs and the identification of sufficiently large high-value niche markets to justify manufacturing facilities are all factors that were not present in earlier commercialization attempts. Clearly this is the best opportunity yet to overcome the market acceptance hurdle, and clearly one that should not be allowed to pass.

References

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