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Assessment of strategic approaches to the commercialization of fuel cells

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Abstract

This paper assesses the state of commercialization of fuel cells and compares it with forecasts made at the 1991 Grove Fuel Cell Symposium. Applications appropriate to different technologies are evaluted and arguements are mentioned that each technology should be commercialized for those applications, stationary and mobile, for which it is suitable when it becomes sufficiently technically mature. As with other power generation technologies, it is agreed that governmental support is needed, not merely to demonstrate the technology, but to take the technology through to the point where it can compete with conventional alternatives. Comparisons are drawn between the governmental approach of commercialization of fuel cells in Japan, USA and Europe. It has been pointed out that phosphoric acid fuel cells have reached sufficient technical maturity and should be brought to the point of competitive commercialization. This could happen in the near term and the government funding requirements are modest. Failure to support commercialization of this technology could put the future for other fuel cell technologies at risk. Finally, suggestions are made as to how commercialization of fuel cells could proceed.

Keywords: Fuel cells; Commercialization

1. Review of developments since the Second Grove Symposium in 1991

When the World Fuel Cell Council was launched at the Second Grove Symposium in 1991, the Symposium theme was 'Progress in fuel cell commercialization'. It was felt that the fuel cell, which had promised so much since its use in the Apollo Programme in the 1960s, was about to emerge from earthbound laboratories and to enter the market as an efficient and clean alternative to conventional technologies.

We would like to highlight some of the important points that were mentioned at the 1991 Symposium and look at what steps have been taken to achieve commercialization since then. Finally, steps in the near-future will be suggested.

1.1. Keynote address and forecast — Arthur D. Little

Peter Teagan of Arthur D. Little gave the keynote address entitled 'The role of fuel cells in our energy future' [1]. He forecasted that energy use would increase dramatically during the next twenty years, and in consequence, a doubling of CO_2 emission and other air-borne pollutants would happen. In his view, Society cannot afford to accept this trend. Fuel cells could be one of the critical technologies that allow these energy needs to be met in a way consistent with the environmental integrity of the plant. He said that fuel cells could be a growing commercial success and achieve a market size of 4100 MW by the year 2000. However, he identified a number of barriers which would have to be overcome:

- the cost of fuel cell systems should be reduced to around US $1500/kW
- government had to become an active partner with constructive policy support and direct financial support through the commercialization process, a role the governement had played with every sophisticated energy technology in the past
- technically, highly reliable operation for periods in excess of 25 000 h needed to be demonstrated, as well as confidence in stack replacement schedules approaching 40 000 h to be established

Today we do not believe that the rather optimistic projection of 4100 MW will be achieved by the end of the decade. Sometime after, but not by 2000. Japan has delayed its programme in order to improve some systems. The USA has only started recently to provide commercialization support. Europe is still in developmental research. Nevertheless, in some areas, considerable progress has been made.

1.2. Major US molten carbonate fuel cells: commercialization initiatives

In 1991 we were informed of a major commercialization effort in the USA, initiated by a coalition of utilities and the Energy Research Corporation (ERC) for a 2 MW molten

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carbonate fuel cell (MCFC) system. Serfass and Glenn [2] provided details of this imaginative and aggressive programme which shares technical and financial risks and benefits between ERC and the utilities. The high cost and risk of early production units would be offset by royalties paid to the original utility participants on subsequent low-cost production. It was expected that this plant would be available at a cost of US $1000/kW (at 1990 prices: about US $1200 at today's prices, about US $1400 at the end of this decade).

A demonstration unit was planned to begin operating in spring 1994, finishing its trial in 1996. The city of Santa Clara would host the first demonstration plant, the US $46 million cost, equivalent to US $23 000/kW, being partly paid by the US Department of Energy.

1.3. Current status: MCFC commercialization

We understand that stacks are currently being delivered to the site, and plant start-up is now expected early 1996. Since no complete, full-scale system has been built yet, the commercial plant will, probably, not be available before the end of this decade.

This high-profile ambitious project should succeed. Should it stall, or even worse fail for either technical or commercial reasons, the impact on the credibility of the fuel cell industry would be serious.

1.4. International Fuel Cells and ONSI Corporation

International Fuel Cells (IFC), an important US manufacturer, did not present a paper at the 1991 Symposium. At that time, they were preparing, for the 1992 launch of the world's first pre-competitive system, the 200 kW phosphoric acid fuel cell (PAFC) co-generation plant known as the PC25.

IFC, its subsidiary ONSI and their partners Toshiba, CLC/Ansaldo and Hyundai now have 60 of these power plants generating heat and electricity for a variety of applications across the world. These modular units have accumulated more than 730 000 operating hours. Twenty-one units have achieved more than 16 000 h cumulative running time and several units are now over 20 000 h. The unit with the longest continuous run over 8500 h is still operating.

These pre-competitive units are already demonstrating reliability far in excess of their conventional competitors. The mean time between forced outages for the PC25 is 2200 h. This is two to three times better than gas turbines and three to four times better than competitive internal-combustion engines. The new PC25, launched this year, is expected to be nearly twice as good as its older brother.

The first PC25s cost US $1.2 million to produce, but their sale was heavily subsidized by IFC. The new PC25 will cost US $600 000 (or US $3000/kW) to produce. It is being sold at break-even point.

US $3000/kW is still too high to generate an economic sales volume and IFC is working on a cost reduction programme to halve the cost to US $1500/kW. It is necessary to generate sales of a minimum of 200 units or 40 MW per year (a relatively small volume) between 1995 and 1997, but this quantity cannot be purchased at the current price. Who will fund this difference in costs?

1.5. Funding the gap between cost and market price

Initially, the US Administration seemed not prepared to fund commercialization programmes. However, in 1993 and 1994, Congressmen frustrated by the lack of commercial success initiated a Department of Defense purchase programme for near-term plants. Last year the Congress approved a US $18 million subsidy for 1995. This year a subsidy of US $12 million has been approved for 1996 and a similar programme for 1997 is anticipated.

These programmes reduce the cost of the plant; they are limited to one third of the total cost or US $1000/kW (which ever is smaller). Consequently, as production growths and unit costs fall the subsidy will also reduce, setting up a virtuous cycle of increased sales and reduced cost for a limited three-year term until the system is fully cost competitive.

Sophisticated technology does not normally move from a high-cost prototype to a competitively priced commercial plant in one leap. This is particularly true of a radically different technology such as the fuel cell. Fuel cells will have to compete with mature combustion technology which has benefitted from a century of continuous development. IFC have already halved the cost of their PAFC. This fact may give credibility to the statement that costs could be halved again in the near-term when PAFCs will be competitive with conventional equipment for on-site co-generation in very many applications.

It is often implied that PAFCs will not be competitive with other fuel cell technologies. The current cost of high-temperature fuel cells is still in the tens of thousands of dollars per kW. High-temperature fuel cells may be produced at lower cost, but it is very unlikely that they will be able to compete with PAFCs in small-scale commercial co-generation applications. Proton-exchange membrane or PEM fuel cells may be produced at very low cost given the high volume production for automobiles. However, PEM fuel cells will only compete with PAFCs in the market segment for on-site co-generation.

1.6. PEM fuel cell development

Prater [3] presented a paper at the 1991 Symposium on PEM fuel cell developments at Ballard Power Systems. The company had significantly advanced the state-of-the-art of PEM fuel cell technology and had begun to focus attention on fuel cells in practical applications. Prater described a programme to develop and demonstrate a proof-of-concept transit bus by March 1993.

On schedule, Ballard launched the world's first fuel cell powered zero-emission bus. This 20-passenger vehicle is powered entirely by a PEM fuel cell system fuelled by compressed hydrogen; it has a range of 160 km.

A second bus, a commercial prototype, is scheduled for launch in 1995. Ballard have been able to more than double the power density, one year earlier than expected. The 205 kW power plant is retrofitted into a standard transit bus and takes up the same space as the diesel engine it replaces. The new 60-passenger bus will also have a range of 400 km and a top speed of 95 km/h.

Between 1995 and 1997 Ballard plans to produce a number of demonstration fleets and expects to have commercial buses available in 1998. It is understood that the cost will then be roughly twice that of a conventional diesel bus; however, a fleet of fuel cell buses will be considerably less expensive than an electric trolley-bus system. High value applications, notably in areas with air quality problems, will create an early market.

1.7. Commercialization programmes in Japan

In 1991, in his paper entitled 'Japanese fuel cell market projections', Fukutome of the Japanese New Energy and Industrial Development Organisation (NEDO) [4], referred to a technical and economic study that identified distributed power and on-site co-generation as having relatively high break-even cost, and considered the PAFC as a promising technology for these applications. Consequently, they planned multiple demonstration and field tests at a small-scale, i.e. 50 to 500 kW co-generation systems with the objective of having commercial plants available in 1995.

Today, Japan has installed more than one hundred small-scale PAFC systems and, consequently, has substantial experience covering a variety of sizes, applications and fuels.

Tokyo Gas believes that the primary verification of the PAFC technology is now complete. However, cell durability of some systems needs further to be improved, and NEDO has instituted a crash programme to address this problem which will be operated in conjunction with the extended field trials of current plants [5]. The situation will be reviewed in 1996. The introduction of fully commercial plants for on-site co-generation is expected in 1998 or 1999.

Fukutome also noted in 1991 that the Tokyo Electric Power Company had started the operation of an 11 MW PAFC, the world's largest fuel cell power plant. This demonstration will continue until 1997; at that time it is expected that the utilities will be in a position to decide on commercializing PAFCs. Tokyo Electric Power, earlier in 1995, indicated their continued interest in a 10 MW PAFC for distributed power and expressed the view that, although MCFCs may have potential above the level of 10 to 20 MW, the technical problems experienced by this complex technology would delay introduction for some time yet.

In 1991, Fukutome also announced the development of a 5 MW and a 1 MW PAFC plant. It was intended that these systems would have completed a two-year demonstration period at the end of 1996.

These plants were put into operation in February 1995. Initial results met or beat specification. The demonstration will end operation early 1997, a few months later than foreseen in 1991 [5].

1.8. MCFC commercialization in Japan

In 1991 NEDO announced the second phase of the development of a 1 MW class MCFC pilot plant which would be tested by 1997. This was intended to verify the prospects for a 10–50 MW demonstration plant leading to commercial plant becoming available by 2005. Work on the development of the stack was authorized in 1993. The demonstration plant is expected to be completed on schedule in 1997 [5].

1.9. Commercialization in Japan: Government commitment

The Japanese Government has committed considerable resources to the development and commercialization of all types of fuel cell.

Typically, research and development receives a 100% subsidy, demonstration plants 50% and field tests 33.3% of the total cost. In addition, field tests have been qualified for special loans and tax allowances.

Government agencies, fuel cell manufacturers, electric and gas utilities are working closely together to establish a commercialization pathway. Japan enjoys a substantial lead in installed capacity with nearly 30 MW out of the global installed base of around 38 MW. They also lead in terms of operating experience as well as in terms of number of applications, sizes and fuels. This will place the Japanese industry in a privileged position once their commercial units become available. This should happen by 1999.

2. Requirements for successful commercialization

After four years, the fuel cell community can be truly proud of its achievements but today we have to acknowledge that commercialization remains elusive.

We are learning that potential commercial buyers are reluctant to purchase fuel cell plants in economic quantities until the following conditions can be met:

- the price should be competitive for the applications under consideration, unfortunately too much attention is paid to capital cost rather than life-cycle cost, cost of power and return on investment
- fuel cell stack life of 40 000 h and reliability should be proven
- O&M cost should be predicted with confidence
- a cost-effective service structure should be available
- plant performance should be guaranteed in terms of competitivity

To satisfy these conditions we estimate that about 100–150 MW of the early commercial demonstration and field-test capacity must be installed over a three-to-four year period for each system or group of related systems. The cost and risks in achieving this are substantial. Even large corporations have difficulties in convincing their shareholders of the value of high investment in a project on which little or no return would be seen for at least five years.

Smaller corporations lack the necessary financial resources. Therefore, who pays the commercialization cost and how should programmes be organized? The answer will be dealt with later, but in the first place the issue of fuel cell technologies and applications will be taken into consideration.

3. Fuel cell technologies and applications

Some confusion has been caused by the perception that the fuel cell community is engaged in internal debate on which technology is the best. While this perception exists it is unlikely many governments, or customers, will commit themselves to fuel cell commercialization.

We hope to demonstrate that each fuel cell technology has unique operating characteristics which makes them suitable for different applications. There is no 'winner', each will serve its own market segment.

3.1. Proton-exchange membrane

The PEM fuel cell is the most promising technology for automobiles because of its high power density, fast start-up and CO_2 tolerance. It has been shown that cost has the potential, in volume production, to fall to low levels necessary for this application.

At these costs this technology could appear to be very attractive for small-scale commercial co-generation, as well as residential applications. However, the life-time requirement for stationary power is 40 000 h whereas automotive applications only require 4000 h. Different material specifications and systems, as well as different fuel requirements, will probably be needed to address this. These can be expected to increase significantly the cost of PEM fuel cells for stationary applications.

3.2. Phosphoric acid fuel cell

The near-term PAFC technology is ideally suited to commercial co-generation: available heat is suitable for hot water, space heating and cooling via absorption chilling for commercial buildings such as hospitals.

Potential users and utilities have stated that only PAFCs provide heat at the required temperature for most commercial applications.

PAFCs are not subject to the same electrolyte phase-change difficulties, when the system is shut-down and restarted, as is the case of high-temperature fuel cells. These may react badly to any necessary thermal cycling necessary in commercial applications.

PAFCs operate also efficiently over a wide power range and at part load; the cell stack heat loss does not significantly reduce their efficiency. This could be a particular problem for high-temperature fuel cells in this application.

During a recent visit to Japan, utilities and manufacturers stated that in their view PAFCs would be the most applicable technology for commercial co-generation up to about 5 MW and possibly up to 10 MW distributed power.

3.3. Molten carbonate and solid oxide fuel cells

The high-temperature MCFCs and solid oxide fuel cells (SOFCs) have the potential for high electrical efficiency, particularly in integrated systems that combine steam or gas turbine technologies. They both could be suited to the following: (i) large-scale utility generation, distributed power and repowering, and (ii) industrial and large-scale high-temperature co-generation.

Fuel cells integrated with coal gasifiers could represent the most efficient and cleanest use of coal known. This could, in time, be the largest market for all fuel cell systems.

It is a general view that these high-temperature fuel cells offer a lower cost potential than do other technologies. However, studies undertaken by Arthur D. Little [6] have indicated that at a 5 MW level MCFCs and SOFCs will not have significant cost advantages over PAFC systems and they are expected to be more expensive in smaller capacities.

4. Commercialization strategies

Following numerous discussions with potential customers, suppliers and others in the fuel cell community, the following commercialization strategies are suggested.

4.1. Target high value applications

First, manufacturers must target high-value applications which will allow the highest capital cost. In a recently published paper, Arthur D. Little [6] defined the various segments of the power generation market and estimated the allowable capital cost for each.

Market segments and allowable cost (US $/kW)

Commercial co-generation	200 kW–2 MW	1500–2500
Distributed power	5–20 MW	1000–1500
Repower	50–500 MW	900–1500
Central station	100–500 MW	700–1100
Industrial co-generation	5–200 MW	600–1400

The highest prices will be obtained in the commercial co-generation, distributed power and repower segments where modular construction, low emission, and low O&M characteristics of fuel cells have particularly high value. Commercial co-generation will allow the highest prices, ranging from US $1500 to US $2500/kW and will be certainly almost the first large market for fuel cells. A number of co-generation applications are emerging which will provide an early market for fuel cells. For example:

- Hospitals require the high quality, reliable power which can be provided by fuel cells that can also save the cost of expensive emergency generators. A PC25 located at the St Vincents Medical Center Staten has been named '1995 Co-generation Project of the Year' by the US Co-generation and Competitive Power Institute.
- Kaiser Permanente, a US health maintenance organization has installed four PC25s in their clinics. This dual plant won the '1994 Efficiency Building Award for Energy and the Environment' from the prestigious US trade publication 'Energy User's News'. Kaiser Permanente expects savings of over US $1 million per fuel cell over the design life of 20 years.
- There is a need for uninterrupted, high quality clean power in computer and telecom centres. AT&T has recently installed a PC25 at its Bell laboratory's facility for this purpose.
- Cities in the USA are considering installing large numbers of PC25s in city centres over three-to-five year periods to avoid replacing the existing distribution grid in order to accommodate growth in demand. This would also reduce financing cost and the cost of temporary idle capacity associated with building large-scale central generating facilities.
- A number of organizations are developing fuel cell systems to use landfill and water treatment (or sewage) off-gas.
- The residential market offers a high premium $/kW opportunity for very small fuel cells.
- Heavy-duty vehicles and in particular urban transit buses, represent the earliest and most appropriate entry into the transportation market. They are significant and politically, highly visible sources of pollutant emission in urban areas. They use central fuelling depots which will facilitate the use of hydrogen. They can support a higher purchase price for a fuel cell power system due to expected life-cycle cost advantages.

Even in the case of high value applications, early production units will still cost more than the market will pay. Arthur D. Little [6] has indicated that the 'integrated gap' or cumulative difference between the acceptable market price and production cost could total somewhat in excess of US $100 million over the period when production is building up.

5. Who pays for the commercialization costs and how?

In the absence of a proven market, manufacturers and customers are unwilling and unable to carry this investment risk alone. As has been demonstrated in Japan the investment and risk should be spread across all participants including the public who will be the ultimate beneficiaries of clean, sustainable power and increased energy security.

Here are a number of ways to address this:

- Direct government purchase of early units can help kick-start demand and build operating experience on which durability and reliability can be assessed
- Purchase support programmes such as the subsidies provided by Japan and the USA to reduce the purchase price by one third. Subsidies have a greater leverage effect on volume for the same investment compared with direct Government purchase
- Forward buy programmes as in the ERC MCFC example
- An extension to fuel cells of taxation benefits to renewable energy provided by a number of countries
- A wider adoption of the California scheme where clean power is rewarded by credits for reduction in pollutant emissions. These credits can be traded and have cash value
- Progressive tightening of environmental standards until only the cleanest technologies, including fuel cells, are allowed to operate. The California zero-emission vehicle (ZEV) mandate is an example of this
- Fuel cell vehicle prospects would be substantially improved if substantial ZEV credits were allowed in California for fuel cell buses. Buses and heavy duty vehicles are not included in the ZEV legislation

The agreement between the US Corporation Enron and IFC to market an energy service based on the PC25 is an example of how the issue of technical and financial risk can be addressed. Customers of this service will purchase the electrical and thermal energy, not the generating plant. They will not bear the up-front capital cost, technology risk, or any maintenance cost or risk.

Government, users and manufacturers must collectively decide on and work together to establish a clear commercialization pathway. To avoid waste of resources and time, the plan should target the development of specific technologies and systems for the application for which they are best suited.

The plan should follow a logical sequence. The leading PAFC technology should be supported to the point of competitive commercialization for high value commercial co-generation applications. In fact failure to achieve this, coupled with, possibly, a significant failure with another technology, could seriously damage the future for all fuel cells. Interest which has waxed and waned a number of times since the 1960s will die as well as the funding.

On the other hand, the successful creation of an early market for fuel cells will build confidence in the technology which will generate private funding for the accelerated development of additional systems.

Fuel cell researchers, manufacturers, customers desperately need success but this success is needed in the next three to four years to quash the cynical and dangerous view that fuel cells are always ten years away.

Government must recognize their responsibility to provide public support during the critical first few years of commercialization, in addition to providing R&D support for the development. Compared with nuclear power the public contribution will be tiny. If this support is not provided the public will still pay and pay dearly their children's health and future in terms of employment, global warming and energy security.

6. Conclusions

Japan is demonstrating the necessary social responsibility and foresight and is organized and committed to a clear commercialization pathway. The USA is now moving in the same direction.

European Union efforts are limited and focused on futuristic technology which will not commercialize in time to allow Europe to compete effectively with the USA and Japan. The Commission has yet to publish its long promised fuel cell strategy. There seems little pressure to adopt the technology, consequently Europe will lag behind the USA and Japan. Europe could well end-up spending money on R&D while importing fuel cell equipment and exporting jobs.

The World Fuel Cell Council has regarded 1995 as a very critical year for fuel cells, as is 1996 and 1997. There have been some magnificent achievements but any further delay in commercialization could be very dangerous for the evolution of all fuel cells [3].

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