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The role of fuel cells in our energy future

Brian M. Barnett and W. Peter Teagan
Arthur D. Little, Inc., Acorn Park, Cambridge, MA 02140-2390 (USA)

Abstract

This paper reviews the potential role of fuel cell technology in meeting the diverse needs of both stationary and mobile power generation and how the special technical performance characteristics of fuel cells are becoming increasingly valued by policy/regulatory trends in response to growing environmental pressures. The growing value attached to the high efficiency and very low emissions of fuel cells combined with the technical advances in fuel cell technology will help ensure their commercial success in the coming decades.

1. Introduction

The demand for energy services worldwide will increase by at least a factor of two over the next two decades with much of the increase taking place in the developing countries (LDC). Even with this large increase in energy use, the per capita use of energy in the LDCs will typically be less than 20% of that in the industrialized countries. These projected increases in energy use should then be viewed as a minimum requirement consistent with a world community which is advancing in its standard of living.

Growing concerns over global environmental issues, such as global warming, casts in doubt whether the growing need for energy services can be met with conventional energy technologies even if the basic energy resources to do so are available. To meet the needs of societies worldwide to improve their standards of living consistent with environmental constraints will require revolutionary changes in both energy conversion and end use technologies. Fuel cells could be one of the key technologies allowing for the expanded scope of human activities whilst being consistent with the environmental integrity of the planet.

2. Worldwide growth in energy use and associated environmental problems

There is a wide diversity in the projections for the future growth in energy use on a worldwide basis. One recent projection for energy use by region is indicated in Fig. 1, while Fig. 2 compares a number of projections by fuel form. Most projections show a substantial increase in overall energy use even if energy use in the industrialized countries grows very slowly if at all. This reflects several salient facts which complicate any discussions on energy/environmental linkages. These include:

(1) Currently about 25% of the world population is in the industrialized and former Eastern block countries — a proportion which is expected to diminish to under 20% over the coming two decades as the population of the developing countries increases from about 4 billion to 7 billion (Fig. 3). By contrast, the industrialized

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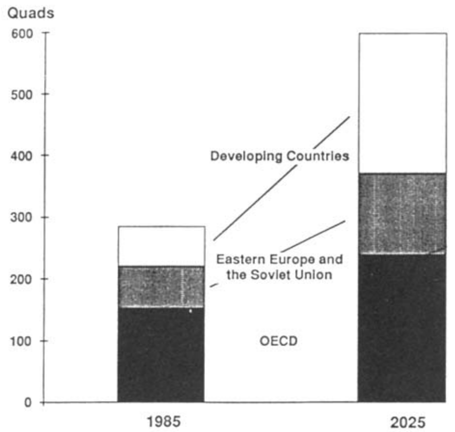

Fig. 1. Worldwide growth in energy consumption by geographical region. Source: US Working Group in Global Energy Efficiency.

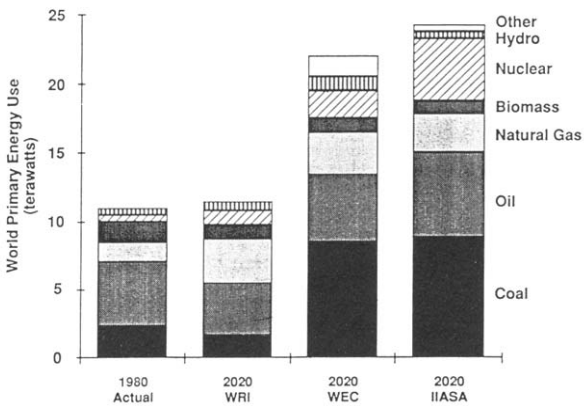

Fig. 2. Worldwide growth in energy consumption by fuel form: WRI (World Resource Institute), WEC (World Energy Conference), IIASA (International Institute for Applied System Analyses). Source: EPRI.

countries (including Eastern block) currently consume over 60% of fossil fuels and emit a corresponding proportion of CO_2 and other combustion-related pollutants.

(2) The per capita energy consumption of the LDCs is about one-tenth to one fourth that of the industrialized countries — even a doubling of absolute energy use in the LDCs over the next 20 years would still result in per capita consumption at approximately the same level due to simultaneous population increases (Fig. 4). It should be noted that modest increase in per capita energy consumption in the LDCs would still leave most of the world population with living standards well below those in the industrialized countries — even assuming that economic growth can be achieved with levels of energy use intensity well below those which have prevailed heretofore.

Worldwide energy growth currently is projected to be met primarily by the increased use of fossil energy sources with the largest increases associated with the consumption

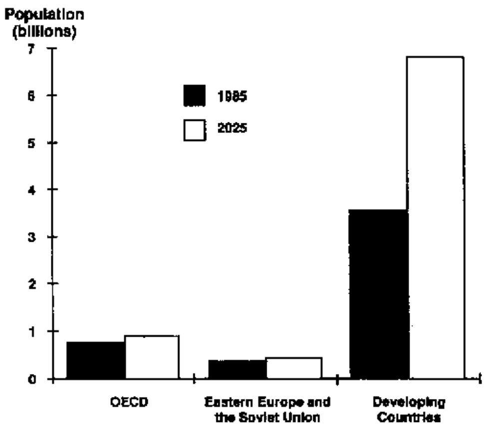

Fig. 3. Growth in world population by geographical region. Source: US Working Group on Global Energy Efficiency (1991).

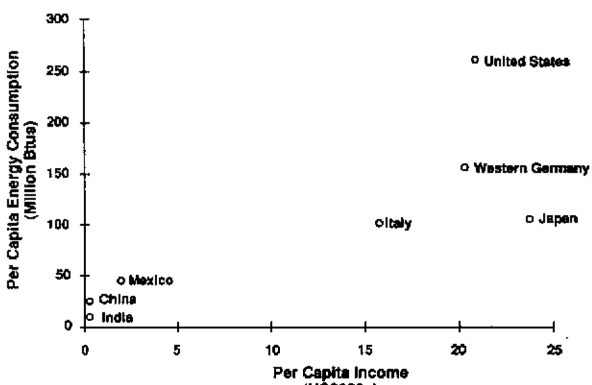

Fig. 4. Relationship between income levels and energy use. Source: World Bank, US OTA.

of indigenous coal resources in both the industrialized and LDC countries. Such an increase in fossil fuel energy use would greatly exacerbate growing environmental problems on several grounds:

- the emissions of NO_x, SO_x and other ground level pollutants leading to air pollution would be seriously increased — particularly in heavily populated urban areas of the LDCs where air pollution is already a serious problem
- the emission of CO_2 would be dramatically increased

Of the above, the issue of the impact of increased CO_2 emissions leading to an acceleration of global warming is potentially of greatest concern. Careful attention to technology selection can reduce emissions of NO_x, SO_x, and other pollutants in both stationary and mobile sources. CO_2 emissions are, by contrast, directly related to the quantity of fossil fuel being consumed, i.e. there is not a technological fix.

Figure 5 indicates the levels of CO_2 emissions resulting from the baseline energy use projections. Overall, CO_2 emissions would more than double over the next 20 years according to these projections with most of the increase taking place in the LDCs. If current projections on global warming prove correct, society cannot afford

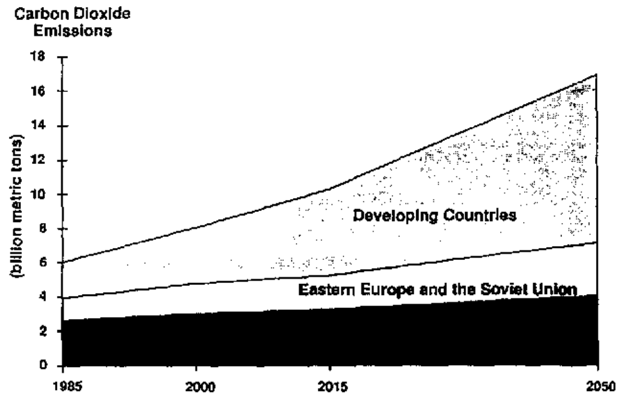

Fig. 5. Global CO_2 emissions projections by region. Source: USEPA (1989).

to let this happen. In short, the energy use projections are totally incompatible with the needs to limit further the emissions of greenhouse gases and other air borne pollutants. On the other hand, the energy use projections are absolutely essential to provide hope for even a modest increase in the standards of living for most of the world's population. This issue, therefore, constitutes one of the great issues of the day — how society worldwide can modify both energy supply, use, and transformation processes to allow continued improvement of the living standards of the world community consistent with the environmental integrity of the planet.

3. Technology strategies

The energy use projections implicitly assume a range of conversion efficiencies for both end use equipment and power generation. In general these projections tend to assume relatively modest improvements in the energy efficiency of major functions as compared to current practice.

There is increasing awareness, however, that increased utilization of a relatively small number of advanced technology options could dramatically reduce the energy intensity of the economic development process and allow for increasing standards of living worldwide more consistent with environmental constraints. Specifically:

(1) The efficiency of end use equipment used to perform such energy intensive functions as heating, lighting, air conditioning and refrigeration can be increased by 25% to over 75% as compared to current practice.

(2) The efficiency of power generation is typically about 33% in the industrialized countries and even lower in the LDCs. This can be increased to 40–45% near term and to over 50%–60% after the year 2000 by the increased application of advanced power generation technologies, including fuel cells.

(3) The efficiency of the engines used for vehicle propulsion is typically in the range of 18% to 25% over normal driving cycles. The use of fuel cells and electric vehicles charged via high efficiency power systems could increase this efficiency by a factor of two to three.

TABLE 1

Potential impact of fuel cell technology energy use by sectors

Sectors	Functions served	Reduction in primary energy use[a] (%)
A. End-use in buildings		
Fuel cell/vapor compression Heat pump	space heating, air conditioning, hot water	50–70
Fuel cell co-generation	all electric and thermal services	40–50
B. Power generation		
Gas-fired fuel cell	electric power	20–40
Coal-fired (with gasified coal)	electric power	30–40
C. Transportation		
Fuel cell vehicles (on board reformation)	buses, trucks, cars, railroads	30–50
D. Industrial		
Fuel cell/co-generation	electric power + heat	40–50

[a]As compared to current conventional practice.

It is highly encouraging that society has technology options which in both the near and long term can dramatically reduce the primary energy requirements associated with delivering essential energy services.

The more rapid development and implementation of these technologies via appropriate policy initiatives worldwide will be critical in resolving the potential conflict between rising living standards and growing environmental problems.

Fuel cell technology should be considered of particular importance as one of the strategic options available to society to address energy/environmental issues due to its very high efficiency potential, adaptability to both stationary and mobile power generation, extremely low emissions of NO_x, and suitability to a wide range of co-generation and distributed power applications. This opportunity is illustrated in Table 1, which indicates the potentials for fuel cells to reduce energy consumption in the most important of power generation and end use functions, which, in turn, define overall energy use and associated environmental impacts. The use of fuel cell technology can, in principle, reduce the energy required to provide essential services by 40%–50% as compared to current good practice. No other single technology has the widespread potential for major impacts across almost all energy generation/consumption sectors!

4. Competitive analysis of alternative power generation technologies

Fuel cell technology has the technical capability to make a large impact on both energy use and associated environmental impacts. However, the ultimate role of fuel cells will depend on how they compare in cost and performance with other alternatives. These options include improved versions of conventional technologies and, in the future, renewable energy technologies. The following discussion focuses on the comparative positioning of fuel cells *vis-à-vis* other fuel fired technologies which are the most likely competition over the next decade, during which fuel cell markets will be established.

4.1. Stationary power

In power generation applications, fuel cells must compete for markets with a number of established and emerging power generation technologies. In general, these technology options will include reciprocating engines (ICs), gas turbines, and steam-driven turbines. In many cases, the alternative power technologies are benefitting from substantial commitments of both industry and government technology development funding (for example, integrated gasification combined cycle power plants using advanced gas turbines).

In considering the potential opportunity for fuel cells, it is necessary to recognize realistically the large variations in application requirements, the varying impacts of external factors by application sector, and the impact of application requirements on fuel cell technology options. It is expected that system capacity will strongly influence technology selections.

Large scale applications (>100 MW) — stationary

In larger scale applications (greater than 100 MW), fuel cells will be competing primarily with gas turbine combined cycles (GTCC) plants and high efficiency coal-based technologies. Table 2 tabulates various power generation options with which fuel cells will be obliged to compete.

In the near-to-medium term, GTCCs will be the technology of choice in the 100 MW and higher size range power plant when using natural gas as a fuel. GTCC units can be expected to exhibit efficiency levels approaching 55% or more (HHV basis) by the mid-to-late 1990s. By late in the decade advanced coal technologies will become increasingly competitive for large base load power stations (absent considerations of possible CO_2 taxes). These technologies may include pressurized fluidized beds, integrated gasification combined cycle, and ultra-supercritical pulverized coal.

Smaller scale applications — stationary

Power generation needs increasingly will be met by co-generation and distributed power systems having typical capacities of as low as 50 kW to 50 MW. The principal technologies with which fuel cells will have to compete in these smaller size applications over the coming decade will be reciprocating (IC) engines (primarily in the 25 kW–5 MW size range) and gas turbines (primarily in the 10–50 MW size range).

In the following paragraphs, the performance/cost characteristics of fuel cells are compared to those of the most likely competition based on efficiency, emissions and capital costs.

Efficiency

As indicated in Table 3, the efficiency of conventional power system technologies tends to decrease as the size of the power generation unit decreases. This effect is expected to enhance the competitive advantage for fuel cells in the smaller applications. However, in determining the degree of competitive advantage which might be achieved by fuel cells, it is important to account for the continuing improvement in efficiency of these competing technologies as they are refined and improved. This factor will be especially crucial with respect to gas turbine combined cycles, as advanced aero-derivative technology is incorporated into progressively smaller GTCC units.

Emissions

Fuel cells should also achieve a competitive advantage relative to reciprocating engines and gas turbines due to lower emissions (Table 4). Although a specific NO_x

TABLE 2

Power generation technology cost/performance projections (utility scale)

Technology	Full load efficiency (HHV)		Projected timeframe		NO_x (1b/MM Btu)
	Best available (%) ±0.5%	Target (%)	Commercial availability	Projected cost \$/kW; (1990 \$) @ 10 plants/yr.	
GTCC 100–300 MV	44	48	1990–92	standard: 550 ± 70	0.14 (42 ppm)
			2000	low NO_x: 630 ± 100	0.03 (9 ppm)
		50–52 55			
Ultrasupercritical PC 200–500 MW	36	39	1994–96	1700 ± 200 inc. FGD	0.5 standard 0.3 low NO_x burners 0.1 w/SCR
CFBC 80–200 MW	35	37	1993–1998	1750 ± 200	0.1–0.2
PFBC Combined Cycle 200–350 MW	34.5	39	1997–2002	1500 ± 300	0.3
		41 43			
IGCC 200–800 MW		35	1995–200	1400 ± 300	0.28
	N/A	38 41 45	1998–2004 2000–2008 2003–2010	1300 ± 400 1400 ± 400 1200 ± 400	0.2–0.3 0.2–0.3 0.1–0.2

TABLE 3

Comparison of fuel cell efficiency levels with conventional alternatives (< 50 MW capacity range)

Technology	Typical power generation efficiencies[a]				
	Timeframe	Efficiency (%)			
		1 MW	5 MW	10 MW	50 MW
Gas turbine	current	23	28	31	30
	1995	28	32	34	36
Gas turbine	current	N/A	38	40	44
combined cycle	1995	N/A	42	44	46
Reciprocating engine					
gas/spark	current	31	35	37	N/A
diesel	current	36	39	42	48
Fuel cells[b]	current	41	41	41	41
	1995	45	45	45	45

All efficiencies are based on fuel higher heating value (HHV), at full load, ISO conditions, at generator terminals. N/A = not applicable.
[a]Efficiencies vary widely depending upon prime mover type and design and level of pollution control, only typical values are shown.
[b]Based on PAFC.

TABLE 4

Comparison of fuel cell NO_x emissions with conventional alternatives

Technology	Emission characteristics of competing technologies		
	Emissions (ppm @ 15% O_2)		Control technologies
	Uncontrolled	Controlled	
IC engine	750–2500	75–400	lean burn
		75–150	SCR system
Gas turbines	100–200	30–60	steam injection
		20–40	lean premix
		10–20	SCR system
Fuel cells	5	5	None

emissions standard is a major market factor at the moment in only a few areas (such as California), environmental emissions issues will become increasingly important in other areas over the next decade. Furthermore, regulatory pressure to reduce NO_x emissions will increase system costs for competing power generation technologies, creating a quantitative benefit assisting the relative competitive advantage of fuel cells.

Although simple gas turbines are relatively inexpensive, the types of units that would be competing with fuel cells (gas turbine co-generation, or gas turbine combined cycle GTCC) are likely to exhibit capital costs in the range of $900 to $1300 per kW (Fig. 6). Provision of selective catalytic reduction (SCR) to meet stringent environmental

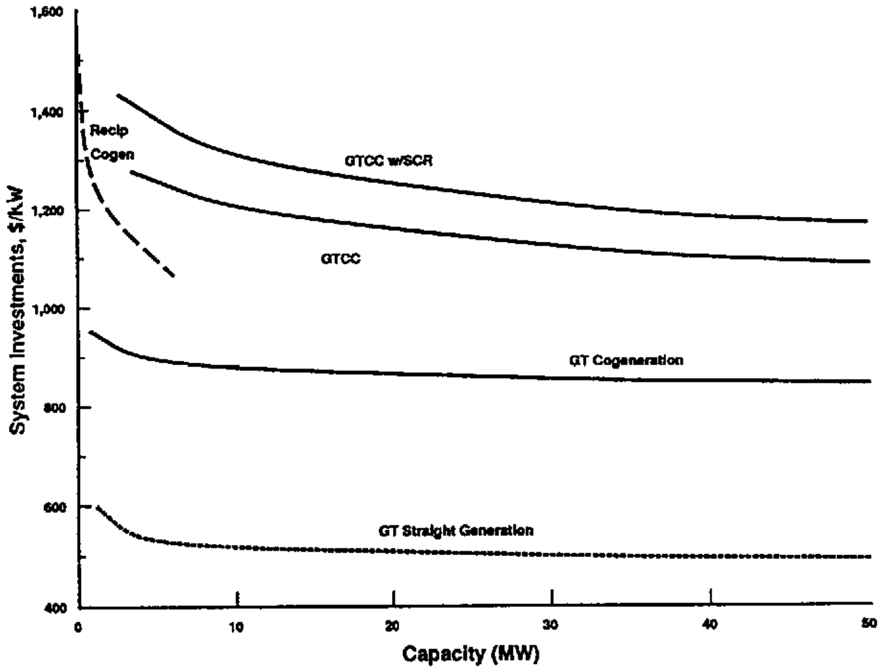

Fig. 6. Impact of capacity on costs of power system alternative (<50 MW).

requirements (as now in place in California) adds an additional $50 to $120 per kW to the gas turbine cost, depending on the size of the power generating equipment. The cost of competing technologies, when retrofitted with environmental controls, is typically over $1000 per kW in target application (for fuel cells) segments.

Capital costs

The capital costs for various technologies which would compete with fuel cells are strongly dependent upon the configuration and the size of the power generation system. As the size of the equipment decreases, its cost per unit of capacity increases. This economy of scale provides part of the economic advantage of fuel cells, in that the latter technology exhibits costs that are somewhat less dependent on size. Fuel cells will be relatively more economic, relative to competing power generating technologies, in smaller applications. This is exemplified by the cost of energy estimates of Fig. 7 for power systems under 50 MW.

4.2. *Traction applications*

There is increasing interest in the use of fuel cells for traction applications — initially to power trucks, buses, delivery vans and other larger vehicles with high daily use cycles. The primary motivations include the high efficiency of fuel cells (40%+ as compared to 18% to 25% at best for IC engines), low emissions, a flat load curve and fuel flexibility. Recent studies (e.g. by Los Alamos National Laboratories in the US) concluded that with reasonable improvements in power density, a fuel cell powered vehicle could deliver comparable performance to an IC engine powered vehicle at approximately twice the energy efficiency and with negligible pollution. The fuel cell system could provide driving ranges and refuel times comparable to those now found for IC engine powered vehicles.

In the last few years, dramatic improvements in the power density performance of solid polymer fuel cell (SPFC, also known as proton exchange membrane fuel cell, or PEM) technology have greatly enhanced the opportunities for fuel cells in traction applications. Nevertheless, the capital cost targets for large scale use of fuel cells in traction applications are especially demanding.

Traction applications could become one of the most exciting markets for fuel cells, particularly if on-board hydrogen storage and compact reformer technologies are improved over the next decade. During this decade the technical/economic potential of this critical application area will be verified via government/industry programs both to develop the technology base and to conduct field demonstrations. Large scale commercialization is unlikely in this decade.

4.3. Competitive economics

Power generation economics

The potential impact of fuel cells will depend on their economics as compared to alternative power system technologies. These economics, in turn, depend on:

- efficiency levels
- capital costs (for comparable levels of emission control)
- fuel and electricity costs
- financial parameters

Figure 6 indicates the cost of power from fuel cells and the most likely gas-fired technologies assuming fuel costs typical of those in the industrialized countries and assuming fuel cell system costs approach $1200/kW as projected by several firms in the field. The potentially attractive economics of fuel cells, particularly in lower

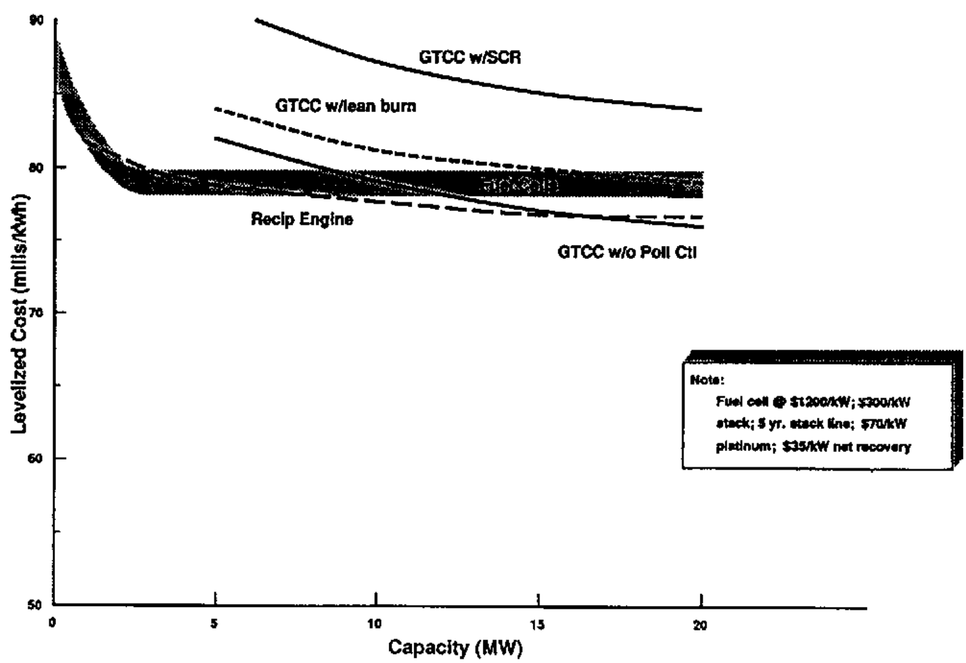

Fig. 7. Impact of capacity on economic performance of power system alternatives (<50 MW).

capacities, is demonstrated by these figures, which should help ensure a strong market position in the lower capacity power range once cost/performance goals are demonstrated.

4.4. Impact of environmental externalities and T&D issues

The analyses leading to Fig. 6 do not incorporated the potential impacts on economics of growing trends, particularly in the US, to attach cost to emission levels (referred to as monetizing the externalities) and to the financial benefits of reducing the costs of transmission and distribution capacity when distributed power systems are utilized.

Formal recognition of these benefits in the selection of power generation technology will likely grow worldwide both in response to environmental pressures and, in the case of T&D credits, to reduce the capital costs associated with expanding electric system network. Figure 8 indicates the potential impact of monetizing externalities on power generation options. It indicates that fuel cell technologies would look attractive compared to all coal based systems on a ‘total cost’ basis and highly competitive with GTCC in capacities below 50 MW, for the monetized value of externalities assumed.

Figure 9 indicates the electricity costs from both central power systems and distributed power systems assuming T&D costs of \$500/kW – approximately the average in most industrialized countries. T&D costs are even higher in LDCs where loads are more diffuse. This figure displays the potential benefits in total delivered electricity costs of distributed power based on a highly efficient, inherently modular, power technology such as fuel cell.

4.5. Observations/conclusions

Fuel cell technology shows excellent potential for being economically competitive near term with alternative power system technologies – particularly in capacities below

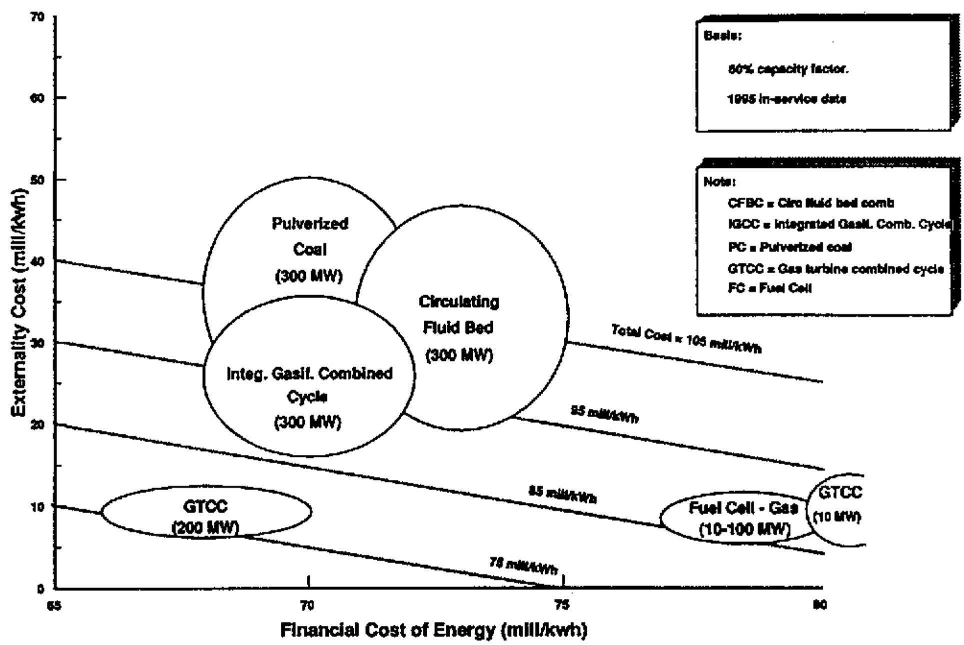

Fig. 8. Impact of monetized externalities on fuel cell economics.

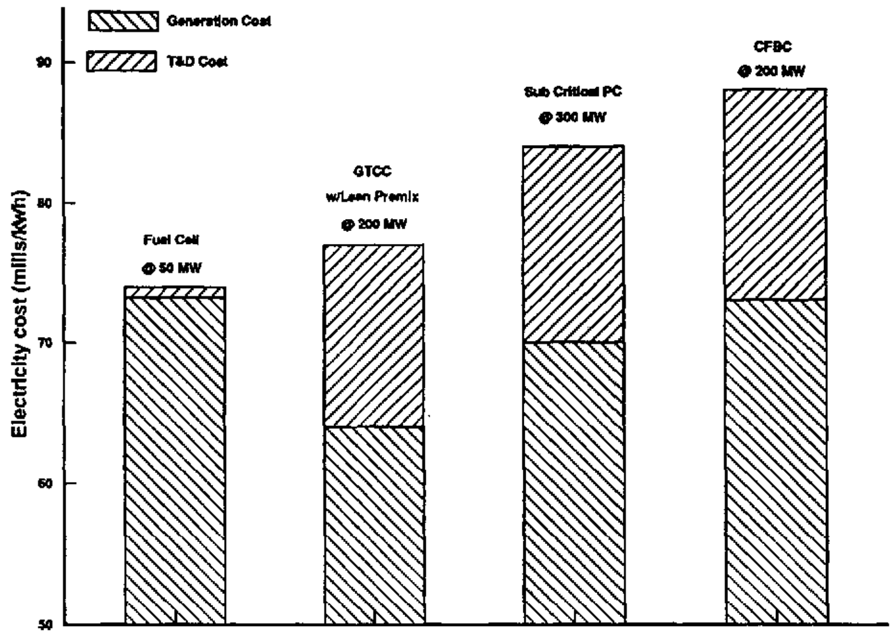

Fig. 9. Comparison of central power and distributed fuel cell power economics taking into account T&D costs.

100 MW. Due to the growing worldwide interest in co-generation and distributed power this lower capacity range will be among the fastest growing on a worldwide basis. The growing concern over global warming, ground level emissions, and T&D cost will only serve to enhance further the economic prospects for fuel cells as policies are implemented over the coming years in response to the global environmental/ institutional issues.

5. Potential markets for fuel cell power

5.1. Market segments

The power generation market has been divided into four distinct segments in order to evaluate the market potential for fuel cells. These segments, summarized in Table 5, are:

- central power stations
- distributed power generation
- repower/replacement
- commercial and industrial co-generation

Within each segment, all users will focus on similar technology attributes and exhibit similar decision criteria for selection of power generation technology. To some extent, this segmentation is customized for the consideration of markets for fuel cells. It includes some segments that are not usually employed in consideration of the power generation markets.

Centralized electric generating stations are the traditional source of electricity. Central stations tend to be large power generators (typically in excess of 100 MW), and also

TABLE 5

Major potential market segments for fuel cells

Application	Fuel cell consideration	Important parameters	Competitive technologies (examples)
Utility power (100–500 MW)	– High efficiency (55% +) important – Low emissions	Life-cycle cost	– Gas turbine/combined cycle – Integrated gasification/combined cycle
Distributed power (1–100 MW)	– Low noise and emissions – Modular capacity increments – Good part load efficiency – Low emissions	Reliability, cost	– Little real competition for use in urban environments – IC engines and gas turbines in remote applications
Co-generation (25 kW–50 MW)	– Ready access to waste heat – Low noise and emission – Modular construction – High reliability/low maintenance	Overall efficiency Quality of waste heat	– Gas/diesel IC engines – Small gas turbines
Traction	– High power density needed – Low emissions – High efficiency	Weight Initial cost	– IC engine with alternative fuels – Electric vehicles
Repowering (50–150 MW)	– Small footprint – Low emissions – Modular 2 capacity increments	Retrofit difficulty Footprint (size) Life-cycle cost	– Gas turbine/combined cycle – Integrated gasification/ combined cycle

tend to be located remotely from end-users (often by distances of several hundred miles). Typical power generation technologies employed in this market segment include coal-based steam cycles and, increasingly, gas turbine combined cycles.

Distributed power generation entails the location of smaller generating units in close proximity to end-users. Distributed generation has tended in the past to be limited to remote applications, or locations with unusually high T&D costs. It is expected that distributed power will increase significantly in the future, due to the increasing costs of T&D and increasing concerns of the health effects of electromagnetic radiation.

Repowering of older power generation units involves decommissioning older units close to retirement, reusing the site or rehabilitating the salvageable components (e.g., the steam turbine and generator) and adding new components in some type of mixed cycle. Most of these repower applications would be in the size range of these older units, typically 50–150 MW. Repowering applications will become increasingly common in most of the industrialized countries due to the large number of existing plants that are nearing retirement. In addition, since a large number of older power plants are located in urban areas, today's environmental regulations tend to inhibit the installation of new capacity in the form of traditional power generation technologies. The environmentally benign characteristics of fuel cells are very attractive in such sites.

Commercial co-generation involves provision of both electricity and heat to commercial buildings, residential building complexes and industry. In the near term, fuel cells will probably not become a major force in the industrial co-generation market, in which thermal and electrical demand characteristics and relatively large capacity requirements tend to favour steam turbine-based systems and gas turbine co-generation systems. However, in the commercial co-generation market, fuel cells may become an enabling technology, helping to facilitate a major increase in market size. This market has traditionally tended to favour reciprocating engines, however the drawbacks of the latter technology (noise, odor, size, emissions) have tended to limit the extent of introduction of co-generation systems. In contrast, fuel cells do not have these limitations, and would facilitate co-generation in commercial office buildings (for example), a potentially large co-generation market which has not been significantly penetrated to date.

5.2. Market size projections

The demand for electricity generating capacity is projected to continue to grow over the next two decades, absent dramatic policy shifts to limit growth in energy use in the industrialized countries. Most estimates now call for continued growth in electricity demand of the order of 1–3% per year in the OECD countries and 5–7% per year in the LDC.

Rough estimates for the type of capacity to be added as a function of market segments are summarized in Table 6. Even given the uncertainties inherent in such estimates, there are large markets available in market segments in which fuel cells should be competitive.

These projections indicate about 800 000 MW of total worldwide capacity additions will be required over the next decade, of which about 580 000 MW is new capacity and the balance is replacement of aging and inefficient existing capacity. The bulk of the additions will be in central power plants, accounting for 55% of expected capacity additions. However, there will be large capacity additions in the co-generation, repower, and distributed power market segments in which the advantages of fuel cells are compelling.

TABLE 6

Worldwide markets for generating capacity, years 1996–2000

	1991–2000 Projected capacity additions					
	Co-generation		Utility			Total
	New	Retro	Distributed[a]	Central	Repower[b]	
North America	12000	25000	25000	107000	50000	219000
South America	3000	3000	9000	45000	7000	67000
Western Europe	9000	18000	13000	48000	25000	113000
Eastern Europe	2000	2000	5000	25000	5000	39000
Japan	3000	6000	5000	20000	12000	46000
Asia	13000	4000	36000	185000	15000	253000
Other identified		2000	4000	13000	3000	22000
Unidentified						53000
Total	42000	60000	97000	443000	117000	812000

[a]Arthur D. Little estimates based on evaluation of technology/regulatory trends.
[b]Arthur D. Little estimates, assume non-US trends are similar to US.

TABLE 7

Estimates for fuel cell markets, year 2000

Market segment	Approximate generation additions - 2000	
	All technologies (MW/y)	Fuel cell (MW/y)
Central station	44300	400
Distributed	9700	1400
Repowering	11700	900
New co-generation	4200	600
Retrofit co-generation	6000	800
Total	75900	4100

Estimating market potential for new technologies in such a fluid market environment is a risky undertaking at best. Nevertheless, Table 7 indicates potential markets for fuel cells for the year 2000, assuming fuel cell technologies gain market shares of 5–15% in market segments served by capacities of under 50 MW during this time period and only start to penetrate the utility market. These assumptions would lead to markets in the order of 4000 MW/yr. in this time-frame in stationary power applications alone.

5.3. Implications of market estimates

The development of fuel cell markets to the level of 4000 MW over the next decade represents a formidable challenge to the industry. Furthermore, this projection assumes that a positive policy/regulatory environment in major market areas of the industrialized countries in response to environmental concerns will accelerate the introduction of fuel cells and other environmentally beneficial technologies over the next decade.

The projections also assume that key technical and cost goals are demonstrated by 1995 by virtue of ongoing and planned field verification programmes. These goals include:

- highly reliable operation for periods in excess of 25 000 h and stack replacement schedules approaching 40 000 h
- system level efficiency levels using natural gas of, at least, 40% with improvements to 45% to 55% anticipated
- system capital costs for early markets of \$1500/kW–\$1700/kW with potential for approaching \$1200/kW or lower once production levels increase (implying stack costs of \$300 to \$500 with conventional systems)

The industry is confident that these goals will be met or exceeded!

6. Concluding remarks

On occasion there have been questions raised regarding the potential for fuel cell technology to make a major impact due to its use of high value materials such as platinum used in catalysts of PAFC and PEM, nickel in MCFC and rare earth materials in the ceramics of SOFC. The fuel cell community has worked to reduce the need for such materials so that they will not, in themselves, be a significant cost barrier nor a barrier to large scale implementation. This effort is proving to be highly successful as exemplified by the large reductions in the use of platinum in PAFC so that its impact on stack costs is now on the order of \$60–\$70 per kW. Given the relatively advanced state of PAFC technology in the commercialization process, much of the fuel cell market over this decade is likely to be with this technology. If this is the case, the estimated market of 4000 MW annually by the year 2000 would result in additional platinum use of about 500 000 ounces or roughly 14% of recent consumption, well within the flexibility of the industry to address without additional production capacity. There are no inherent barriers based on resource limitations for fuel cell technology to make a major contribution to addressing the energy/environmental needs of society over the coming decades.

There are, however, significant institutional and financial barriers which have heretofore hindered the commercialization of fuel cell technology and which must be addressed forthwith if the potential of this technology is to be realised. Other power generation technologies have often benefitted from large financial resources provided by government in order to initiate the utilization of technology and/or cover many of the large R&D costs associated with its development. This largesse is exemplified by the huge resources devoted to nuclear technology and the large military spending on gas turbine technology, which is the foundation of the aeroderivative gas turbine now used by the utility industry.

The fuel cell industry, by contrast, has and continues to be constrained in its ability to commercialize the technology by a circular logic whereby it cannot generate significant commercial sales due to relatively high costs of units produced in low quantities. Without the demand, the costs cannot be reduced. It is imperative that this cycle be broken by concerted actions of the fuel cell industry, the user community and government.

The fuel cell community is making both major technical advances and significant commitments to manufacturing facilities as exemplified by Toshiba and Fuji in Japan and International Fuel Cells and ERC in the United States. These commitments to both technology improvements and lowering costs via investments in production facilities are indicative that industry is doing its part to 'make it happen'.

The major end-users are likely to include both the electric and gas utility industries. The active participation of these industries is critical to accelerating the commercialization process. Here again good progress is starting to be made as exemplified by the recent purchase agreements of the American Public Power Association (APPA) in the US and ongoing technology verification and commercialization activities by several major utilities in Japan and Europe. The role of the utility industry will have to be expanded, however, to ensure market sizes consistent with the needed reductions in cost structures.

The role of government relative to fuel cell technology development and commercialization has been highly variable. In part, this is due to a surprising lack of awareness on the part of the government policy makers in many countries of the potentially pivotal role fuel cell technology could play in addressing the societal energy/environmental problems. It is imperative that this lack of awareness be corrected and that government become an active partner via both constructive policy support and direct financial support in the early commercialization process.

In summary, as the result of the dedicated efforts over many years of those attending this conference, fuel cell technologies are now poised to play a role in addressing the myriad energy and environmental issues facing the world community. The challenge now is to devote private sector and government resources towards the commercialization of fuel cell technology at levels which reflect the urgency of these global energy and environmental issues.