Development and Diffusion of Fuel Cell Powered Automotive Vehicles And Its Impact

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1. Purpose of Study

The State of California, U.S.A., is expected to enforce stringent restrictions on automotive emissions so that at least 10% of the passenger cars and light-duty trucks produced and delivered for sale in California must be " zero-emission" vehicles in and after 2003. In an effort to cope with such a global movement to strengthen the environmental regulations, automotive manufacturers have been intensifying competition in developing fuel cell powered vehicles. Since the development of a reformer corresponding to the type of fuel used is indispensable, the most crucial problem lies in selecting what type of fuel used as the source of hydrogen. While methanol is the most promising fuel from the technical point of view, it will be necessary to make studies of methanol-related matters, including the improvement of an infrastructure and securing of the safety. Meanwhile, the oil companies are insisting on the predominance of a gasoline-based fuel over other fuels. This study reviews the current status of the diffusion of fuel cell powered vehicles in Japan and its impact.

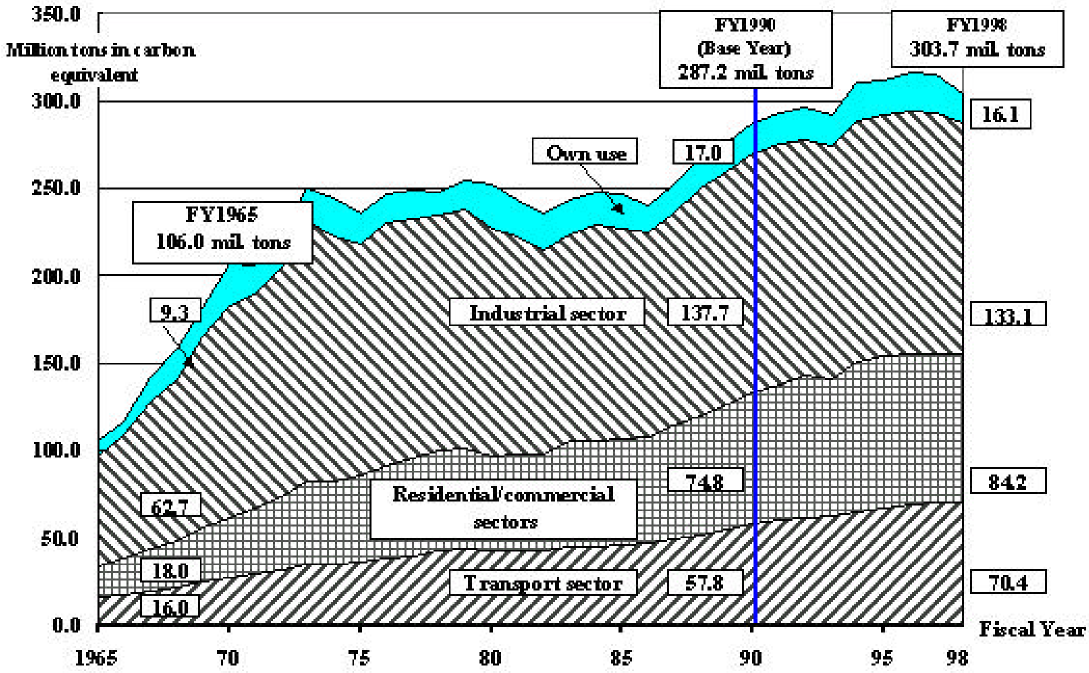
The results and other data referred to in this report are based on the " The Development of Fuel Cell Vehicles and Energy Demand and Supply (March 2000)," a study that IEEJ conducted on behalf of the CEPP (The Committee for Energy Policy Promotion). Acknowledgements are due to CEPP for its kind permission of our releasing the results here.

2 Ever-increasing Carbon Dioxide (CO_2) Emissions in the Transport Sector

Measures to counter global warming is one of the most crucial energy-related issues. At the Third Conference of the Parties to the United Nations Framework Convention on Climate Change (referred to as COP3), held in Kyoto in December 1997, the participating countries centering on major industrialized nations adopted the " Kyoto Protocol," under which greenhouse gas emissions are to be reduced to targeted levels by around 2010. Japan pledged to reduce greenhouse gas emissions by 6 percent from the 1990 levels and vigorous nationwide efforts are being made to achieve this objective.

Japan' s energy-derived CO_2 emissions in fiscal 1998 totaled around 300 million tons (in carbon equivalent, an increase of around 6 percent from the 1990 level). In order to achieve the objective referred to above, these CO_2 emissions should be restricted to the fiscal 1990 level (or 287 million tons). In the transport sector, emissions in fiscal 1995 - 68 million tons - are the targeted level, whereas emissions in fiscal 1998 were 70 million tons, which accounted for around 23 percent of the total and showed a high 10 percent increase from the previous year' s level (Fig. 1).

Fig. 1 Trends in CO_2 Emission by Sector

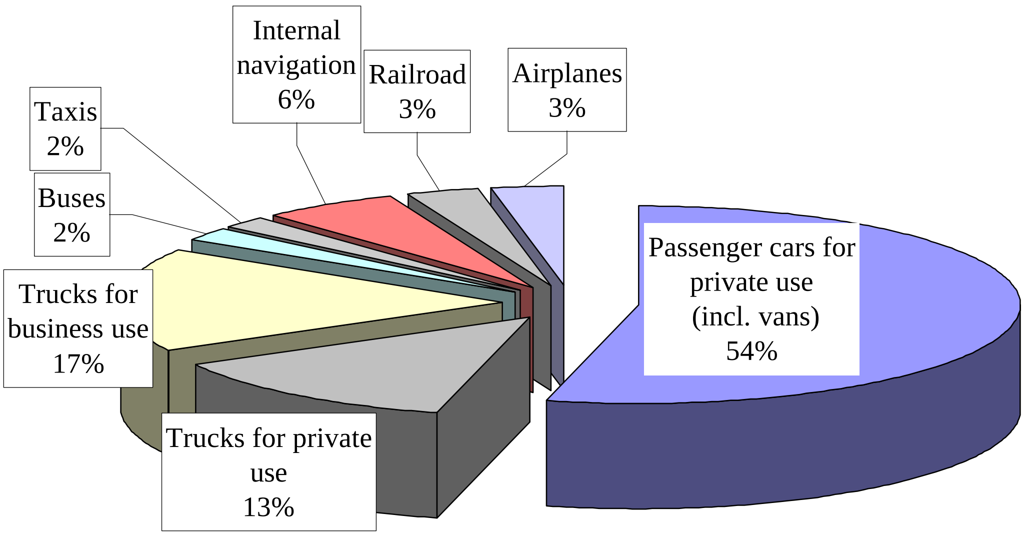


(Source: Energy Economics/Statistical Handbook - 2000 Edition; compiled by the Energy Data and Modelling Center of the Institute of Energy Economics, Japan)

3 Restrictions over Automotive Emissions Being Strengthened

Given the fact that automotive emissions account for around 90 percent of total CO_2 emissions in the transport sector, to improve the automotive fuel economy - the rate of fuel consumption per km-run - is believed to be a particularly effective means as it directly reduces automotive emissions (Fig. 2). Under such circumstances, various policy measures aimed at streamlining traffic conditions such as the construction of roads and the like either have been implemented or are being studied, including the revision of the Energy Conservation Law, which took effect in April 1999, establishing new standard rates for automotive fuel consumption for introduction in fiscal 2010 (Table 1).

Fig. 2 Distribution of CO_2 Emissions in Transport Sector (1996)



(Source: Transport Policy Council's report on "Measures for Promotion of Further Diffusion of Fuel-Efficient Automotive Vehicles," dated May 20, 1999)

Table 1 Fuel Efficiency Standards (Unit: km/liter)

		Actual fuel rates (FY1995)	Targeted standard rates for FY2010	Rate of improvement (%)
Passenger cars	Gasoline-powered	12.3	15.1	22.8
	Diesel-powered	10.1	11.6	14.9
Trucks (2.5 tons or less)	Gasoline-powered	14.4	16.3	13.2
	Diesel-powered	13.8	14.7	6.5
Total	Gasoline-powered	12.6	15.3	21.4
	Diesel-powered	12.1	13.1	13.1

(Note) In actuality, the targeted standard rates are subdivided for each vehicle's gross weight, and for gasoline-powered trucks (2.5 tons or less) the standard rates are shown separately for AT(automatic transmission) and MT (manual transmission) vehicles.

From the standpoint of reducing the environmental load, it is requested to produce high-efficiency engines, aimed at reducing emissions of CO_2 as well as other noxious gases such as NOx and HC. In the U.S., the State of California enforced " zero emission" regulations as a means to prevent air pollution, under which automotive manufacturers selling more than a given number of automobiles in California are obligated to produce and deliver " zero emission" vehicles 10 percent or more of the total number of automobiles sold by them (Table 2).

Table 2 Classification of Low-Emission Vehicles in California State

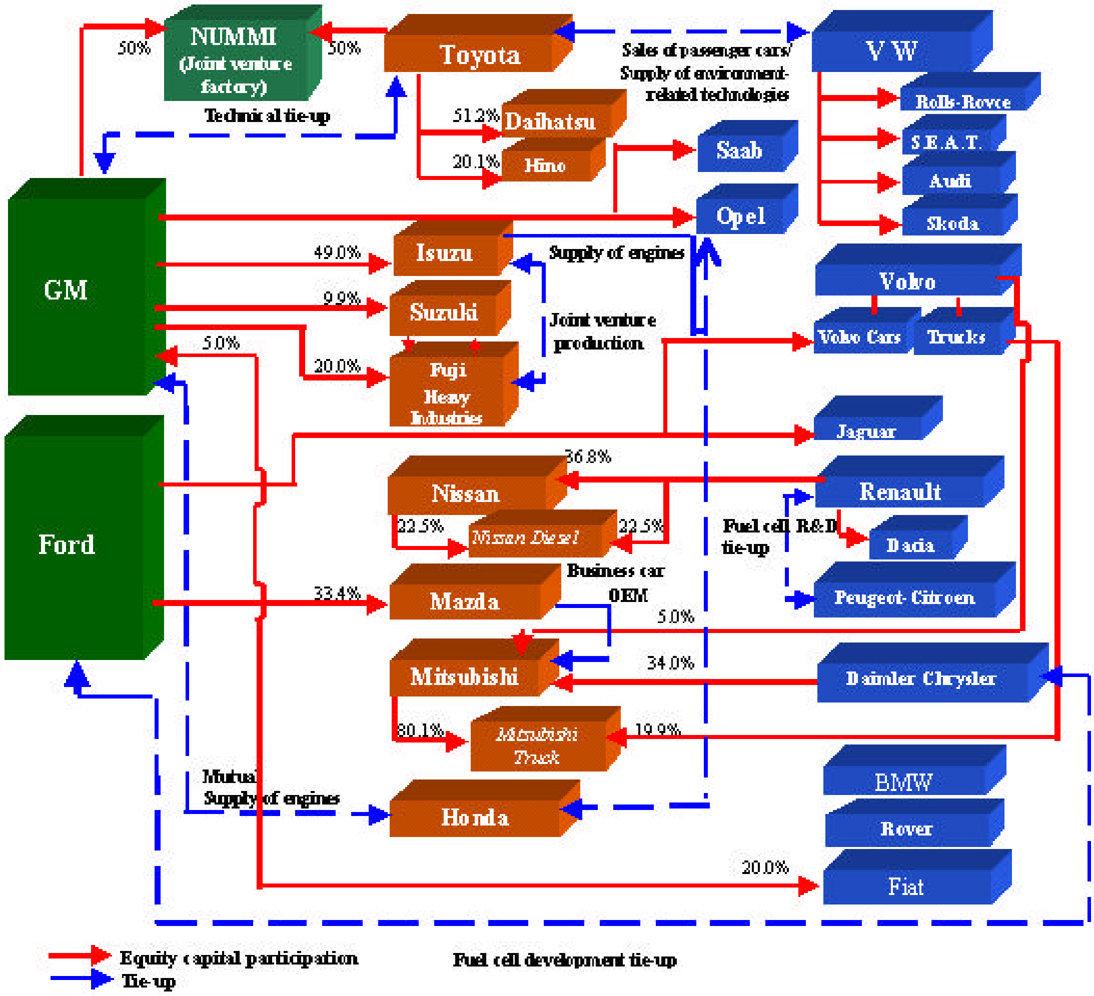
Passenger car emission reductions	HC	CO	NOx
Transitional Low-Emission Vehicle (TLEV)	50%	*	*
Low-Emission Vehicle (LEV)	70%	*	50%
Ultra- Low-Emission Vehicle (ULEV)	85%	50%	50%
Super- Ultra-Low-Emission Vehicle (SULEV)	96%	70%	95%
Zero -Emission Vehicle (ZEV)	100%	100%	100%

*;equivalent emissions to vehicles meeting the basic standard

(Source: CARB' s Home Page; http://www.arb.ca.gov/homepage.htm/)

Automotive manufacturers are being forced, for their survival, to develop the environment-related technology so as to meet the needs of the society, which is strengthening its environmental regulations. The automotive manufacturing industry is thus prompted to reorganize itself, intensifying cutthroat intercompany competition in technological development (Fig. 3). In this connection, the hybrid cars, " Prius," which Toyota Motor placed on the market in 1997, have played a leading role in developing environmentally friendly automobiles. Automobiles equipped with fuel cells are being eyed as those that should be developed next to the hybrid cars.

Fig. 3 Intercompany Relations in Automotive Industry in Terms of Equity Capital Participation and Business Tie-up and Development of Fuel Cell Powered Vehicles

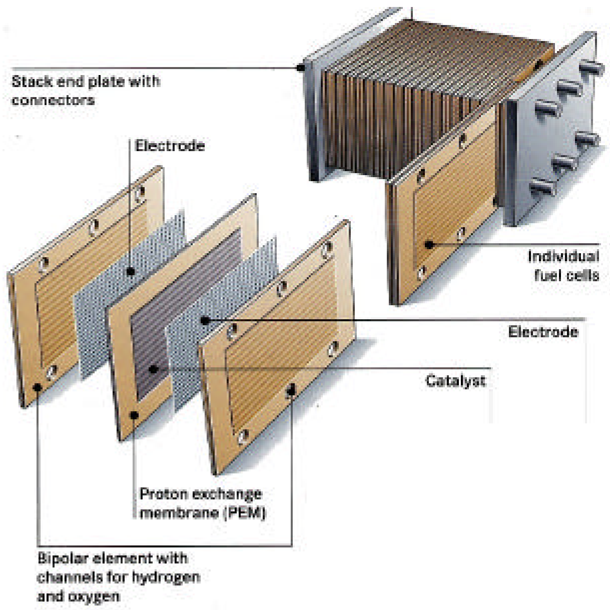


(Source: Prepared by IEE based on various materials)

4 Stepped-up Competition for Developing Fuel Cell Powered Vehicles

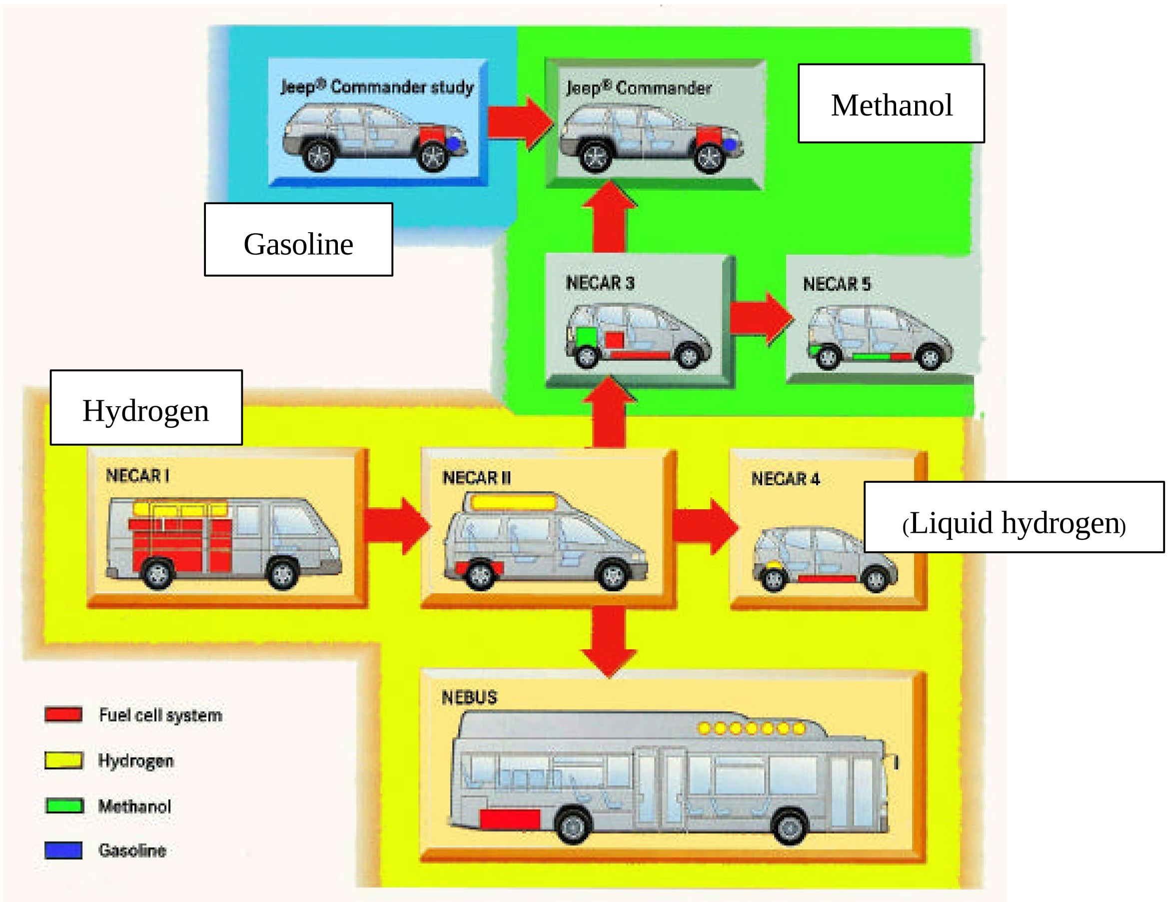
Ballard, a Canadian venture business firm, pioneered in the development of "Polymer Electrolyte Fuel Cells (PEFC)," with its discovery of the possibility of reducing costs suddenly attracting public attention (Fig. 4). In March 1999, Daimler Chrysler which had been promoting joint studies with Ballard, announced that it had succeeded in developing "NECAR4," a model car nearing its commercialization stage, equipped with a 70 kW fuel cell. The production cost of this fuel cell system is reported to be around $35,000 (or $500 per kW), while Daimler Chrysler's current plans call for placing the fuel cell system on line production by 2004 to reduce its cost to around $3,500 (or $50 per kW) before putting it on the market (Fig. 5).

Fig. 4 Structure of Polymer Electrolyte Fuel Cells



(Source: Revision to p.14 of Daimler Chrysler' s Hightech Report 1999)

Fig. 5 Daimler Chrysler' s Plans for Development and Commercialization of NECAR



(Source: Revision to p.15 of Daimler Chrysler' s Hightech Report 1999)

Triggered by the announcement by Daimler Chrysler, major automotive manufacturers in Japan and abroad, centering on GM, Ford and Toyota followed suit by baring their plans to accelerate development of fuel cell systems and to place them on the market almost simultaneously. Meanwhile, fuel cells as small-scale co-generation systems for residential and commercial uses are likely to be commercialized earlier than those for automotive use because of the former' s high efficiency, with heat generated by the systems utilized effectively, and because of less stringent requirements for the former in cost and capacity terms. Under such circumstances, business firms and research organizations in various fields such as heavy electric machinery and household electrical appliances as well as basic materials manufacturers are entering into competition for developing fuel cells, making vigorous moves to aim at de facto standards of related technologies.

5 Problems to be Solved for Diffusion of Fuel Cell Powered Vehicles

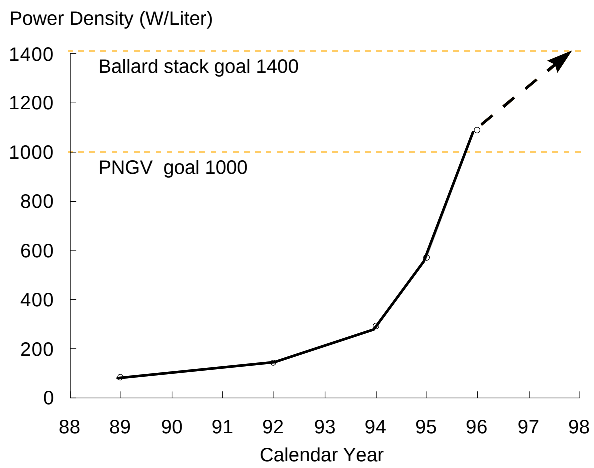
Required conditions for diffusion of fuel cell powered vehicles include improvements in performance and production costs. As for the performance of fuel cell systems, compactness and light weight of the whole systems are required. The performance of the fuel cell itself has made a remarkable improvement in recent years, with some exceeding the development goal (Table 3) of PNGV (Partnership for a New Generation of Vehicles), set up by the U. S. Department of Energy (DOE) and others, appearing on the market (Fig. 6). As for the performance of the reformer in terms of the startability and transient response, it is yet to be improved, while it is related to the type of fuel selected. The change of the vehicle to the hybrid system is considered to be one way of improving it (Fig. 7).

Table 3 PNGV Goals for Automotive Fuel Cell Technology

Target Year	Power Plant			Stack		Fuel Processor	
	Cold Start minutes	Efficiency %	Specific Cost US$/kW	Power Density kW/liter	Specific Power kW/kg	Power Density kW/liter	Specific Power kW/kg
2000	1.0	-	150	0.35	0.35	0.60	0.60
2004	0.5	min.48%	50	0.50	0.50	0.75	0.75

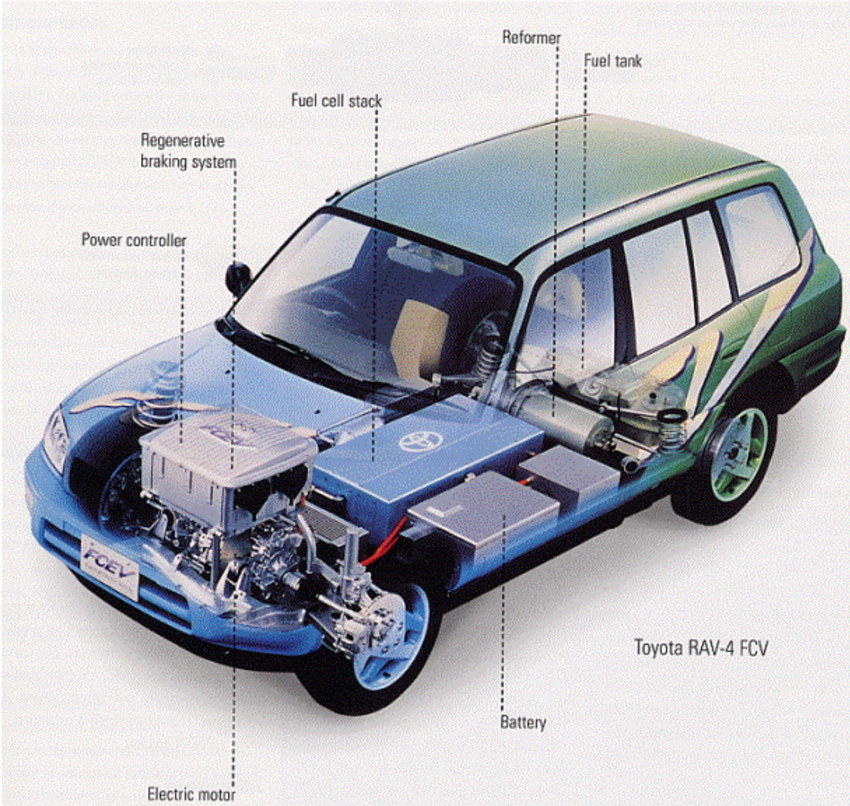
(Source: Status and Prospects of Fuel Cells as Automobile Engines, ARB Board Meeting, July 30, 1998)

Fig. 6 Evolution of Ballard PEM Fuel Cell Stack Power Density



(Source: Status and Prospects of Fuel Cells as Automobile Engines, ARB Board Meeting, July 30, 1998)

Fig. 7　　RAV4FCV Fuel Cell System Developed by Toyota



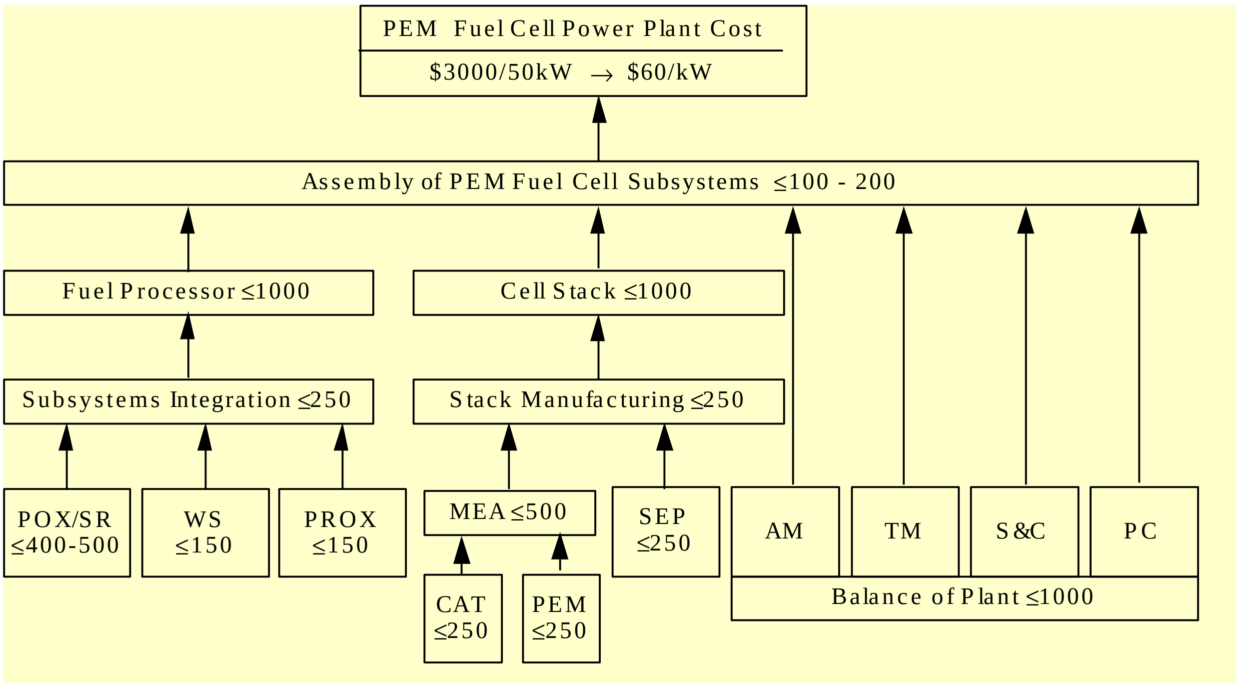
(Source: Revision to " Fuel Choices for Fuel Cell Powered Vehicles," American Petroleum Institute)

As for the cost, it will be necessary to reduce it to the level of \$50-60/kW from the current level which is reported to be \$10,000 so that it can be competitive with the current gasoline engine (Note 1) (Fig. 8). To achieve this objective, it is necessary to reduce the quantity of platinum catalyst used in cells and to reduce the cost of the proton exchange membrane. The technological development alone is not enough, and the reduction of costs due to the economy of scale expected from mass production is also necessary, but this is by no means a low hurdle to be cleared(Note 2).

(Note 1) For output capacity of 50 kW (68 PS), the targeted total cost, including the fuel cell itself, the reformer and supplementary equipment, is \$2,500-3,000 (approximately ¥300,000).

(Note 2) Assuming typical values such as 1A/cm^2 for electric current density, 0.7 V for the cell voltage, and 500 cm^2 for the cell area, one cell has an output capacity of 1 x 0.7 x 500 = 350W. For a 50 kW fuel cell itself, the number of cells is 50 kW/350 W = 140. The proton exchange membrane area is 500 cm^2 x 140 = 7 m^2. Since the current cost of the proton exchange membrane is around ¥100,000/m^2, the total cost of proton exchange membrane is around ¥700,000. The quantity of catalyst used is around 0.3 mg/cm^2 and the quantity of catalyst for the whole fuel cell system is 0.3 mg/cm^2 x 7 m^2 x 2 (both sides) = 42 g. Based on the current platinum cost of around ¥1,800/g, the total cost amounts to around ¥76,000.

Fig. 8 Approximate Cost Goals Breakdown for Fuel Cell Systems(Source : Status and



(Prospects of Fuel Cells as Automobile Engines,ARB Board Meeting, July 30, 1998)

Since the development of a reformer corresponding to the type of fuel used is indispensable for commercialization of fuel cell powered vehicles, what is selected as the source of hydrogen (fuel) is the most important problem. The fuel for NECAR4 is liquid hydrogen, and when we take into account the construction of infrastructure for supply of liquid hydrogen, the commercialization of NECAR4 within the next few years appears to be difficult. Meanwhile, automotive manufacturers are eyeing methanol as a fuel, which means a possibility of getting rid of the current oil-oriented automotive fuel structure, making it necessary to study the construction of infrastructure and the safety of handling methanol. In Japan, the government is leading and coordinating discussions among all parties concerned with regard to fuels, while oil companies are insisting on the predominance of a gasoline-based fuel over others (Table 4).

Table 4 Comparison between Gasoline and Methanol as Source of Hydrogen

System	Technology of Fuel Processors				Construction of Infrastructure for Fuel
	Reforming Temperature ºC	Production of Hydrogen H_2kg/liter of fuel	CO_2 emissions CO_2kg/liter of fuel	Technology	
Hydrogen (onboard)	-	-	-	No problems (unnecessary)	Fairly difficult
Methanol	about 260ºC	0.150	1.08	Relatively easy	Slightly difficult
Gasoline	700 - 800ºC	0.301	2.16	Relatively difficult	No problems (already available)

(Source: Addition to a report, written by Mr. Tsunehiko Nishina, which appeared on "Automotive Technology," Vol. 53, No. 5, 1999)

When the current status outlined above is taken into account, a number of obstacles to overcome still lie ahead before commercialization of fuel cell powered vehicles. Automotive manufacturers are promoting technological development for improvement of efficiency of internal-combustion engines, while putting hybrid cars on the market as low-emission vehicles for the moment. Moreover, not a few uncertainty factors exist as competition with electric cars and compressed natural gas-powered cars (CNG) - so-called "eco-cars" - continues.

6 Projection of Diffusion of Fuel Cell Powered Vehicles

Given below is our projection of an impact that fuel cell powered vehicles will have on Japan's energy supply and demand for fiscal years 2010 and 2020. The Long-term Energy Supply and Demand Forecasting Model, which was used in the 31st Symposium on Long-term Energy Economics (held in December 1998), was used again in our macro-economic and energy supply and demand projection through fiscal 2020. The Cost Model and Introduction Number Determining Model have been used in our projection of introduction of fuel cell powered vehicles (Fig. 9). The cost model is a model which defines a gradual reduction in costs with the passage of time due to an effect of technological development, and the comparison of the cost thus obtained with the conventional vehicle prices will determine the timing of introducing fuel cell powered vehicles to the market. The extent to which the vehicles will penetrate into the market will be determined by the introduction number determining model (Fig. 10).

Fig. 9 Framework for Projection

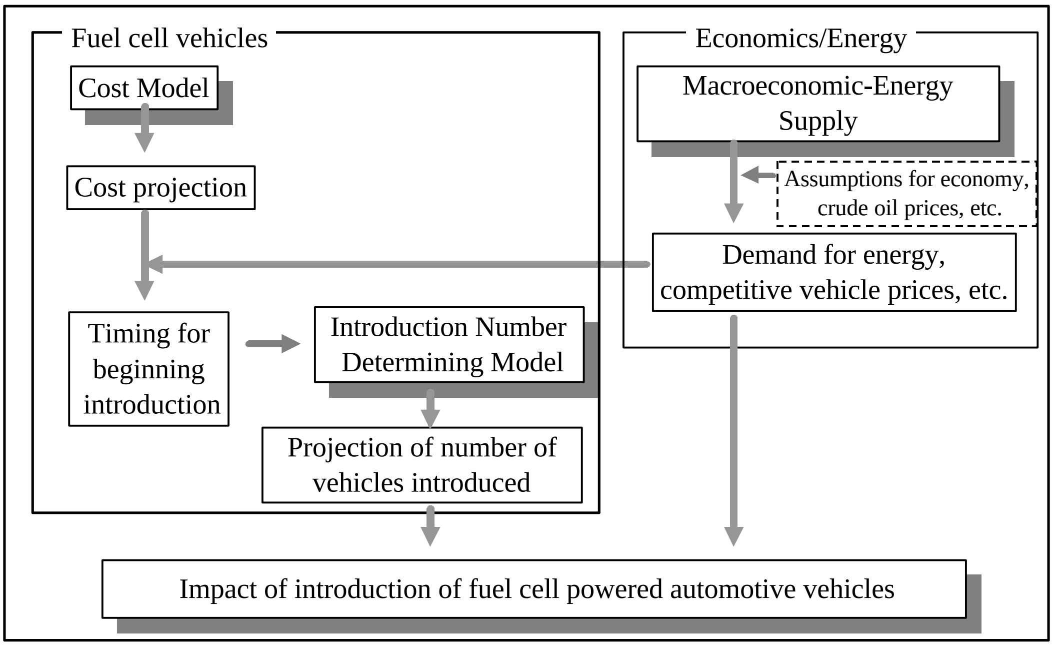
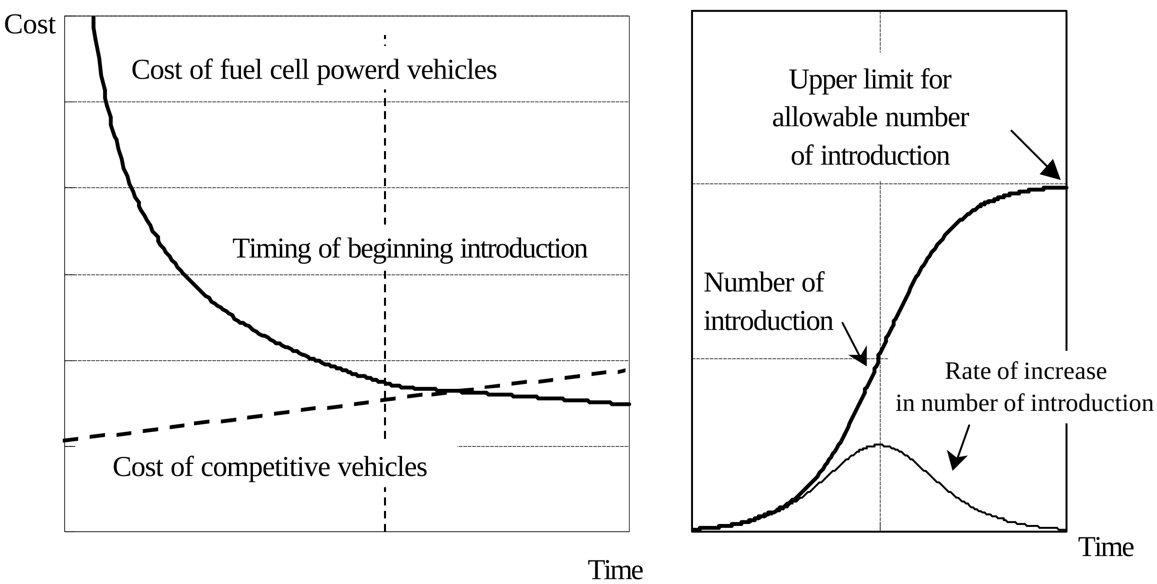


Fig. 10 Sketches for Cost Model and Introduction Number Determining Model



The price of the vehicle is projected to be around ¥5 million (approximately $47,600) in an early stage of its introduction in 2003, but is expected to come down to around ¥2 million - the level competitive with small-sized passenger cars -- due to the economic effect of mass production in subsequent years, as projected in three cases outlined below:

I. Rapid Cost Reduction and Rapid Introduction Case; II. Slow Cost Reduction and Slow Introduction Case, without government financial assistance measures; and III. Slow Cost Reduction and Slow Introduction Case, with government financial assistance measures (Table 5).

Table 5 Projection of Number of Fuel Cell Powered Vehicles Placed on Market

Unit : Number of vehicles	Year of introduction	Number of new cars sold		Number of registered cars	
		FY2010	FY2020	FY2010	FY2020
I. Low Price & High Introduction Case	FY2006	7,400	1,790,000	16,600	4,340,000
% share in small passenger cars		0.3	62.1	0.1	15.3
% share in all passenger cars		0.1	33.5	0.03	7.4
II. High Price & Low Introduction Case	FY2013	-	3,200	-	9,500
% share in small passenger cars		-	0.11	-	0.03
% share in all passenger cars		-	0.06	-	0.02
III. High Price & Low Introduction Case with government financial assistance measures	FY2012	-	4,700	-	14,000
% share in small passenger cars		-	0.16	-	0.05
% share in all passenger cars		-	0.09	-	0.02

Results of projection in the three cases above were as follows. Even when Case I. in which a sharp cost reduction and a high rate of introduction are assumed, the number of registered fuel cell powered vehicles is projected to be less than 1 percent of the total in 2010, while under the same assumptions the cost of fuel cell powered vehicles will drop further by fiscal 2020, thereby raising the number of fuel cell powered vehicles to the 4.3 million level, or around 7 percent of the total number of registered automotive vehicles projected to reach 59 million.

In Cases II. and III., in which the reduction of costs of fuel cell powered vehicles do not proceed as rapidly as anticipated, the vehicles' share of the total number of automotive vehicles will be limited to less than a mere 1 percent in 2020, even when the government financial assistance measures aimed at promoting the introduction of these vehicles is taken into account.

As a result of projecting demand for gasoline and gas oil (or automotive diesel oil) in the transport sector for fiscal years 2010 and 2020, using the Long-term Energy Supply and Demand Forecasting Model, demand for gasoline is projected to be around 62 million kl in fiscal 2010 and around 60 million kl in fiscal 2020 (Table 6).

Table 6 Projection of Fuel Demand for Transportation

(Unit: 1,000 kl)		FY1998 (Actual)	FY2010 (Projected)	FY2020 (Projected)	Rate of increase, %		
					2010/1998	2020/2010	2020/1998
Gasoline	Passengers	50,945	57,883	56,250	1.1	-0.3	0.5
	Freight	4,621	4,149	3,752	-0.9	-1.0	-0.9
	Total	55,566	62,032	60,002	0.9	-0.3	0.3
Gas oil	Passengers	8,771	6,975	6,662	-1.9	-0.5	-1.2
	Freight	25,415	28,661	29,478	1.0	0.3	0.7
	Total	34,186	35,636	36,140	0.3	0.1	0.3
Grand total		89,752	97,668	96,142	0.7	-0.2	0.3

(Source: MITI' s Energy Balances in Japan for actual data; The Institute of Energy Economics, Japan for projection)

If we assume that methanol is selected as a fuel, fuel cell powered vehicles will have little impact on energy supply and demand and on the reduction of CO_2 emissions in 2010 - the targeted year adopted at COP3 - as the number of these vehicles will be limited to less than 1 percent of the total number of automotive vehicles in 2010 even in Case I. -- the case of rapid cost reduction. In 2020, however, around 3.6 million kl of gasoline, or 6 percent of total gasoline demand, will be replaced by methanol, resulting in a reduction of around 1.2 million tons in CO_2 emissions, which is equivalent to the reduction by around 1.7 percent in the transport sector, or the reduction by around 0.3 percent in Japan' s total CO_2 emissions. In a high price case, the number of vehicles introduced will be less than 1 percent of the total number of automotive vehicles, even with the government financial assistance measures referred to in Case III. above, and its impact will be almost nil (Table 7).

Table 7 Projection of Methanol Demand

	Demand for methanol, kl		Number of required filling stations	
	FY2010	FY2020	FY2010	FY2020
I. Low Price & High Introduction Case	16,000	3,550,000	33	8,700
II. High Price & Low Introduction Case	-	7,800	-	19
III. High Price & Low Introduction Case with government financial assistance measures	-	11,000	-	28

In Case I., if one methanol filling station is assumed to supply 500 vehicles, about 9,000 filling stations must be installed. Assuming that one station costs ¥20 million ($190,000) to build, total funds of around ¥170 billion ($1,620 million) will be required. When additional costs for construction of distribution infrastructure, securing of the safety in methanol distribution systems, the worldwide methanol supply capacity (Note 3), and the instability of methanol prices (Note 4) are taken into account, there appear to be a number of obstacles to overcome before methanol is used as a fuel.

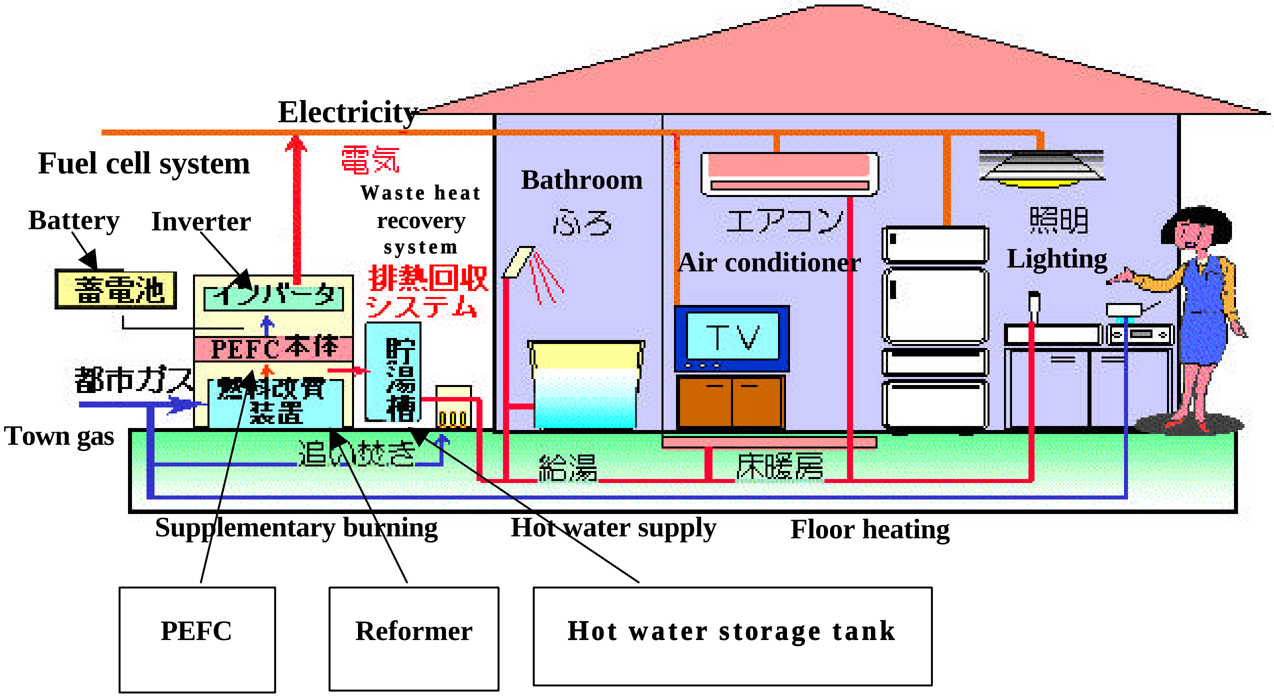
(Note 3) The world's methanol production capacity totaled 33.49 million tons in 1999 vis-à-vis total demand of around 27 million tons.

(Note 4) International methanol prices are said to move almost in relation to the natural gas market price in North America. The market price soared to close to $500/ton in 1994-1995, but plunged to the $200/ton level in 1997, followed by a further drop in the first quarter of 1999 to break the $100/ton line - the bottom price since 1986. It now stands at the $130/ton level.

Although fuel cells with the gasoline-based reformer have many technical problems, the fuel supply side seems to have few problems as the existing infrastructure can be used for its distribution. This advantage is expected to favor the introduction of fuel cell powered vehicles. It is necessary, however, to provide a place for discussions between oil companies and automotive manufacturing companies with regard to establishment of gasoline quality requirements (such as the boiling range, sulfur content, etc.). It remains to be seen how automotive manufacturers can be approached for discussions, given their attitude to keep many business secrets - understandably unavoidable from the standpoint of competition for technological development.

Meanwhile, introduction of small-sized fuel cells of around 1 kW in the residential and commercial sectors, particularly for residential use, can be expected at a relatively early date, as they can be used not only for electricity but also for hot water supply as well as space heating, taking advantage of waste heat generated, provided that their production costs are reduced to some extent and their performance and durability are improved (Fig. 11). Moreover, when the diffusion of fuel cells for residential and commercial uses proceeds, fuel cell costs will also decline, eventually leading to the reduction of production costs of fuel cell powered vehicles.

Fig. 11 Image of House Introducing Fuel Cell for Home Use



(Source: Osaka Gas' s Home Page; http://www.osakagas.co.jp/rd/sheet/026i2.gif)

7 Conclusions

(1) The polymer electrolyte fuel cell is the mainstream of the development of fuel cells used for automotive vehicles. In order that fuel cells become competitive with conventional internal-combustion engines, it is essential that fuel cells exhibit good performance and economic viability. Even when it is assumed that the cost of fuel cells is greatly reduced and fuel cells are widely introduced, the number of fuel cell powered vehicles in Japan is projected to be around 20,000 in fiscal 2010, or less than 1 percent of the total number of registered passenger cars, which is estimated to reach the 57 million level. Consequently, its impact on energy supply and demand in fiscal 2010 and on the reduction of CO_2 emissions to the targeted level adopted at COP3 in Kyoto will be quite limited.

(2) Meanwhile, the number of fuel cell powered vehicles is projected to increase to the 4.3 million level by fiscal 2020, accounting for about 7 percent of the total number of registered passenger cars which are projected to reach the 59 million level by that year. The type of fuel to be selected will be either methanol or gasoline. If methanol is to be used as a fuel, about 3.6 million kl of gasoline - accounting for 6 percent of total gasoline demand projected to total around 60 million kl - will be replaced by methanol, and CO_2 emissions in the transport sector will be reduced by around 1.2 million tons, or approximately 1.7 percent of total CO_2 emissions in this sector. (Japan' s total CO_2 emissions will be reduced by approximately 0.3 percent.)

(3) While the performance of the fuel cell itself has made a remarkable improvement in recent years, the performance of the reformer, which takes hydrogen out of the fuel and supplies it to the fuel cell itself, is yet to be improved. What matters greatly here is the type of fuel to be selected. Methanol occupies a predominant position over other fuels in terms of the reforming technology, but it will be necessary to increase the number of methanol filling stations from the current level of about 50 to approximately 8,700 by fiscal 2020 according to our current projection. (Assuming that one methanol filling station costs about ¥20 million, or US$190,000, to construct, capital investments totaling around ¥170 billion, US$1,620 million, will be required.) Moreover, there are a number of obstacles to overcome, if methanol is to be used as a fuel, including the safety of distribution to be ensured and the stabilization of methanol prices, etc.

(4) Although the gasoline-based reformer has many problems to be addressed in its technological development, when gasoline is used as a fuel, the existing infrastructure can be used, thus causing less problems in its distribution - a decided advantage in favor of introduction of fuel cell powered vehicles. In working out required gasoline quality requirements, however, it will be necessary to coordinate interests between automotive manufacturing companies and oil companies. Since this matter is related to their business development strategies which must be kept strictly confidential, it will be indispensable to establish cooperative relations among all related parties involved.

(5) To make 50-70 kW (68-95 PS) fuel cell powered vehicles competitive with internal-combustion engines, it is necessary to reduce their production cost presently estimated to total $10,000 per kW to the $50-60/kW level. To achieve the cost reduction, it is necessary to reduce the quantity of platinum catalyst used for electrodes and to reduce the cost of proton exchange membranes, which are components of fuel cells. Reduction of costs due to the economy of scale expected from mass production is also necessary, but this is by no means a low hurdle to be cleared.

(6) In case efforts to reduce production costs of fuel cell powered vehicles fail to produce satisfactory results as they constitute preconditions for projections 1 and 2 above, there is a possibility that the number of fuel cell powered vehicles in commercial use in fiscal 2020 will be around 10,000, accounting for less than 1 percent of the total number of automotive vehicles, even with government financial assistance measures aimed at promoting their introduction.