Mass Production Cost of PEM Fuel Cell by Learning Curve

International Journal of Hydrogen Energy, **29**, Issue 10, 985-990, 2004

Haruki Tsuchiya[a]*, Osamu Kobayashi[b]

[a]Research Institute for Systems Technology, Tokyo, Japan

[b]WE-NET Center, Institute of Applied Energy, Tokyo, Japan

[Excerpt]

A learning curve model has been developed to analyze the mass production cost structure of PEM fuel cells for automobiles. The fuel cell stack cost is aggregated by cost of membranes, platinum, electrodes, bipolar plates, peripherals and assembly process. The mass production effects on these components are estimated. Nine scenarios with different progress ratios and future power densities are calculated by learning curve for cumulative production of 50 thousands and 5 million vehicles. The results showed that the fuel cell stack cost could be reduced to the same level as that of internal combustion engine today, and that the key factors are power density improvement and mass production process of bipolar plates and electrodes for reducing total cost of fuel cell stack.

Learning curve or experimental curve is a kind of macro-scope model describing human activity of accumulating knowledge or experience by cumulative production, and is usually adapted to an industrial production process. The typical learning curve is described as follows,

$$Yi=A*Xi^{-r} \quad (1)$$

Where the variables are defined as follows,

Xi: cumulative number of products at i th production

Yi: product cost at i th production

A: constant

The number "r" in the exponent is not easy to understand, so simpler expression is introduced as a progress ratio, $F=2^{-r}$. F shows how production cost could be reduced each time when cumulative production is doubled. When F is 90%, it means that the cost is reduced to 90% each time the cumulative production volume is doubled. If we have historical cost data, we can estimate progress ratio F by regression analysis. Experience data in variety of industrial products show that F is 80-95% for mechanical assembly products and 70-85% for semiconductors and electronic devices. But 70% looks as a minimum number known as progress ratio.

The progress ratio of photovoltaic cost was 82% from 1979 to 1999 in Japan. Model T of Ford had 85% progress ratio from 1909 to 1918. Laser Diode of Sony had progress ratio of 75% at initial stage and 80% thereafter. Usually the learning curve is an analytical tool to discuss the history of mass production. However there are some attempts to forecast the future overall fuel cell cost in mass production by learning curve. In this paper a learning curve has been applied to estimate the cost of each component of fuel cell stack and to discuss the cost structure in mass production.

Cost of Fuel Cell Stack

A typical PEM fuel cell stack consists of numbers of cells, which have proton exchange membranes, electrodes, bipolar plates and peripherals. Also catalyst metal of platinum is included in electrodes or membranes but the cost of platinum is treated separately in this paper.

The cost of fuel cell stack ($/kW) is described by assuming power density per cell area, the material cost per cell area, and the assembly cost as follows.

$$C=(Cm+Ce+Cb+Cpt+Co)/P+Ca \quad (2)$$

$$Cpt=Cwpt * Ypt \quad (3)$$

$$P=10*Vc*Ac \quad (4)$$

Where,

C: Fuel cell stack cost per kW ($/kW)

Cm: Membrane cost ($/m^2)

Ce: Electrode cost ($/m^2)

Cb: Bipolar plates cost ($/m^2)

Cpt: Cost of platinum catalyst loading ($/m^2)

Cwpt: Weight of platinum catalyst loading (g/m^2)

Ypt: Unit cost of platinum ($/g)

Co: Cost of peripheral materials ($/m^2)

P: Power density per cell area (kW/m^2)

Ca: Assembly cost ($/ kW)

Vc: Cell voltage (V)

Ac: Cell current density (A/cm^2)

This description is based on summing up all cell area and has no explicit expression of number of cells. Cost of materials such as electrodes, bipolar plates and peripherals are assumed to be independent of power density. But the performance of membrane and weight of platinum have sometimes a strong relationship with power density. So, if such performance change occurred together with cost change then the overall progress ratio should be examined whether it is within experienced range. A certain model of automatic production system is used to estimates the assembly cost. We assumed 50kW fuel cell production systems for average sized automobile.

Typical performance of single fuel cell has 0.6-0.7 Volts and 0.3-0.6 A/cm^2 cell current density, which is 2 kW/m^2 or more of power density. But the stack performance is somewhat less than that of single cell. If an automobile has 50 kW rated output, then the cell area for 2 kW/m^2 power density is 25 m^2, that is 278 layers of cell with 30cmx30cm cell area. The power density is expected to increase to the level of 5 kW/m^2 or more. Tab.1 shows present, future and bottom line cost of each element.

Learning Effects

The automobile industry hopes to have fuel cell stack at $40/kW, which is nearly the same as the internal combustion engine. This possibility is examined by learning curve approach. The Advisory Panel on Fuel Cell for the Agency of Natural Resources and Energy in Japan predicted officially that the number of fuel cell vehicles is 50 thousands in 2010 and 5 millions in 2020. Using these numbers we constructed 9 scenarios with combinations of power density improvement (3 scenarios) and cost reduction speed (3 scenarios) as shown in Tab.2.

Power density improvement is assumed as from 2 kW/m^2 at initial stage to 5 kW/m^2 for H (High power density) scenario, 4 kW/m^2 for M(Medium power density) scenario and 3 kW/m^2 for L(Low power density) scenario at 5 million cumulative vehicles. The power density improvement process is calculated by equivalent learning curve with progress ratio F=94.5% for scenario H, F=96% for scenario M, and F=97.5% for scenario L. Cost reduction speeds of membrane, electrodes and bipolar plates are assumed as F=78% for Rapid Scenario(A), F=82% for Moderate Scenario(B), and F=88% for Slow Scenario(C). The highest learning effect case is HA scenario, and the integrated progress ratio is 94.5% x 78%=73.7%, which is in the range of experientially known progress ratios.

Platinum loading begins with 0.4 mg/cm^2 and decreases to 0.05mg/cm^2 for scenario A(equivalent F=89%), to 0.1mg/cm^2 for scenario B (equivalent F=92%) and to 0.2 mg/cm^2 for scenario C (equivalent F=96%). Platinum cost is assumed constant throughout the simulation.

Progress ratio of peripheral cost is assumed 95%, and that of assembly cost 92% for all scenarios. The cost reduction limit is given by bottom line cost per weight as shown above. 9 scenarios are generated by combining power density improvement and cost reduction speed such as HA,HB,HC,MA,MB,MC,LA,LB and LC.

Tab.2 shows the scenario framework and calculation results in 2010 and 2020. Fig.1 shows the learning process of 9 scenarios. The learning curve calculations show that the fuel cell stack cost in 2020 would be $15/kW to $145//kW depending on scenarios. The cost reduction went to the bottom line cost only in case of bipolar plates of HA,MA and LA scenarios in the year 2020. The platinum cost share is 1.7% at the beginning but it increases gradually to the level of 7-11 % for variety of scenarios.

The results show that fuel cell stack cost could be comparable with internal combustion engine today if it is massively manufactured.

The analysis of cost structure shows that bipolar plates and electrodes have large share of stack cost and would be very significant even at the mass production stage. The power density improvement is essential to reduce overall stack cost, because it would decrease the resource use of other materials per unit power output. The share of platinum cost increases to nearly 7-11 % for different scenarios when cumulative production would approach to 5 million vehicles.

Tab.1 Present, future and bottom line cost of each element

Element	Present	Future	Bottom line
Proton exchange membrane	Nafion 100micron $500/m^2$ (Du Pont)	Thickness 20-50 micron $50/m^2$ at mass production	60 cents /m2 for thickness 50 micron
Platinum	2-4g/m^2 \$32-\$64/m^2	0.5g/m^2 \$7.7/m^2	Platinum cost is assumed constant as \$15.4/g
Electrode	Total thickness is 0.8 mm for single cell. \$1423/m^2	Roll sheet production. \$96/m^2	\$2.58 /m^2
Bipolar plates	Total thickness for single cell is 4mm. \$1650/m^2	Improved molding \$35/m^2.	\$13.6/m^2 for 4 mm thickness
Peripheral parts	End Plates, Thrust bolts, Plastic Frame. 0.5kg/m^2, \$15.4/m^2	Ordinary materials 0.5 kg/m^2	\$3.46 /m^2
Assembly	Hand assembly \$385/50kW	Automatic Assembly. Roll supply of membrane and electrodes. Stacking by Robotics	Assuming a production line \$94/50kW, \$1.88/kW

Tab.2 Fuel Cell Stack Cost (\$/kW) and the share of platinum cost by Learning Curve

Scenario		High Power Density (H) 2 to 5kW/m2 F=94.5%		Medium Power Density (M), 2 to 4kW/m2, F=96%		Low Power Density (L) 2 to 3kW/m2 F=97.5%	
	Progress Ratio /Pt loading	Fuel Cell stack cost (\$/kW)	Share of Platinum Cost (%)	Fuel Cell stack cost (\$/kW)	Share of Platinum Cost (%)	Fuel Cell stack cost (\$/kW)	Share of Platinum Cost (%)
Rapid (A)	F=78% Pt :0.4 to 0.05mg/cm2	88 15	5.9 10.8	103 19	5.9 11.1	121 25	5.9 11.4
Moderate (B)	F=82% Pt :0.4 to 0.1mg/cm2	143 30	5.1 9.7	167 38	4.9 9.8	196 49	5.1 9.9
Slow (C)	F=88% Pt :0.4 to 0.2mg/cm2	285 88	3.9 6.7	334 114	4.0 6.8	392 145	4.0 6.8

(Upper numbers for 2010, 50 thousands cumulative vehicles and lower numbers for 2020, 5 millions cumulative vehicles)

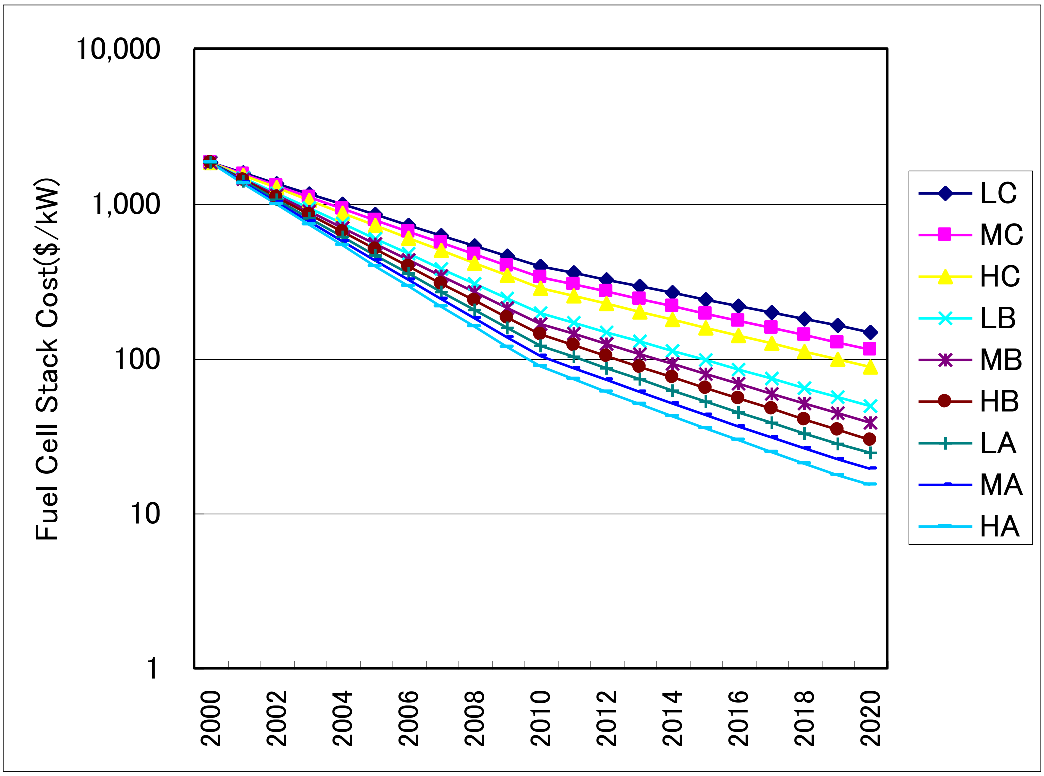

Fig.1 Learning Effects of Nine Scenarios