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PHOTOVOLTAICS COST ANALYSIS BASED ON THE LEARNING CURVE

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ABSTRACT

The historical cost reduction of photovoltaics is analyzed and the learning curve of the cost trend is found to have the 20 % cost improvement in each double accumulated production by Japanese data. This curve is combined with the market study of photovoltaics, which is shown with supply electricity cost and the accumulated market size. The market scale that is necessary to make photovolatcis cost effective is estimated from 1.4 Gw to 50 Gw depending on the future learning curve.

KEYWORDS

Photovoltaics; Learning curve; Market Study; Double Accumulated Production; Progress Index

INTRODUCTION

The photovoltaics is regarded as the most hopeful technology to be an economic energy supply source in the near future. And the demand analysis shows that the photovoltaics can be used in variety of end use. So it is sure that if the photovoltaics can be massively produced at lower cost, then it will begin to supply electricity in wide scale. However it is not known how much is the scale to begin cycle of mass production and cost effectivenes. This paper tries to analyse the scale of photovoltaics production based on the historical cost data, learning curve, and the market study.

PHOTOVOLTAICS COST

The research and development of photovoltaics succeeded in the cost reduction and the improvement of conversion efficiency in the last decade. Tab.1 shows the historical data of the production and the cost of photovoltaics in Japan. The accumulated production in the table is calculated from 1979 to 1988.

Here the cost is shown in Japanese Yen to keep consistency becasuse the exchange rate of Yen to Dollar has been largely fluctuated from 240 Yen In 1982 to 130 Yen in 1988 and the dollar conversion can not make analysis reliable.

Year	Module Cost (Yen/Wp)	Production (Kw/year)	Accumulated Production (Kw)
1979	7000	85.8	85.8
1980	4000	291.0	376.8
1981	3500	1024.0	2424.8
1982	2200	2123.0	4547.8
1983	1800	4826.0	9373.8
1984	1500	6918.0	16291.8
1985	1200	10800.0	27091.8
1986	1100	13400.0	40491.8
1987	1000	12450.0	52941.8
1988	900	13000.0	65941.8

Tab.1 The historical photovoltaics cost data in Japan

As shown in the table the module cost of phototvoltaics fell down from 7000 Yen per peak watt in 1979 to 900 Yen in 1988 and the production expanded from 78Kw in 1979 to 13000 Kw in 1988.

THE LEARNING CURVE

The industrial production process has a genaral characteristics of improving efficiency and cost effctiveness while the knowlege of production process is being accumulated. This process is expressed in mathematical form as the learning curve. The application of the learning curve to renewable energy system was seen in the SERI study on the solar thermal electricity system (Krawiec el al.,1980).

The general description of learning curve is as follows,

$$Y = a * X^{-b} \quad \text{or} \quad \log Y = \log a - b * \log X \tag{1}$$

Where,

Y : Unit production cost at X th production
X : The accumulated amount of production
a : Unit production cost at 1 st production
b : Parameter of learning

The parameter b can be expressed by each double accumulated production,

$$b = - \log F / \log 2 \quad \text{or} \quad F = -2 * \log b \tag{2}$$

The parameter F is called as the progress index, which shows the cost reduction rate at each double accumulated production. The progress index F for the mass products in the mechanical industry is nearly 0.75-0.85. It is known 0.7 approximately in the semiconductor industry in the last decade. This means that the cost of the semicondutor devices was reduced to 70 % at each time when the amount of the accumulated production was doubled.

THE LEARNING CURVE OF PHOTOVOLTAICS

The historical data of module cost and accumulated production in Tab.1 is used to regression analysis and the folowing relationship is caluculated,

$$\log Pm = 10.2445 - 0.30407 * \log N \tag{3}$$

$(R^2=0.96926)$

Where, Pm : Module cost of photovoltaics (Yen/Wp)
N : Accumulated production (KW)

This result shows that the cost of photovoltaics has been reduced nearly to 80% at each double accumulated production from 1979 to 1988 in Japan.

The future of this learning curve depends mainly on the technology such as single crystal, multi-crystal, amorphous, and multi-junction. Hoewever the cost reduction of the products can be described in a similar form to the learning curve for any technology used. And the leaning curve shows the tendency of the relationship between cost and the amount of production.

The future photovoltaics cost is shown in Fig.1 depending on the progress index, at which the equation (3) is rearranged to be consistent at the module cost in 1988 by changing the value a.

THE MARKET STUDY

In order to find the scale of the future application of photovoltaics, the potential market of electric power generation was surveyed by NEDO (NEDO,1985) The 70% of the present use of photovoltaics is not for electric power generation but for the portable small scale battery substitutes in the field of pocket calculator, pocket radio and watch. If these markets of battery substitute are included, then the future market of photovoltaics are larger than the result of this market study. But here we use the result of this market study.

The market study for electric power generation shows electricity supply price and market size as in Tab.2. In this table the author accumulated the respective market from the one with higher electricity price to the one with lower electricity price. This accumulated market size is assumed to be coresponding to the accumulated pdoduction in the learning curve concept.

Electricity Supply cost (Yen/Kwh)	Market (MW)	Accumulated Market (MW)	Application
90-50 (75)	20-40	30	Substitute for Diesel engine-electricity in remote area
28-36 (34)	3600- 5200	4430	Public use, Office building
27-31 (29)	17000-27000	26440	Residential use
15-29 (25)	10000-14000	38440	Industrial use

Tab. 2 The market of photovoltaics in Japan

The least square method is applied to the accumulated market size and the electricity supply price at average shown in the parenthes in Tab.2. The result is as follows,

$$\log Pe = 4.85686 - 0.15753 * \log Nm \tag{4}$$

$(R^2 =0.95713)$

where, Pe : electricity supply price (Yen/Kwh)

Nm : accumulated market size (MW)

THE BREAK EVEN POINT

The future production of photovoltaics can be calculated by the assumed production growth rate and the learning curve. This model was used to simulate the future energy supply and end use in Japan (Tsuchiya et al.1989).

If the cost reduction in a form of the learning curve can be used to estimate the cost and the market size in the future, then it is combined with the market study, and the break even point of the cost and the market size can be calculated. This point means that the photovoltaics can be cost effective, and will be widely used.

The relationship between the module cost of photovoltaics and the electricity supply cost in Japanese solar radiation is calculated assuming that the BOS cost including inverter system is at the same cost as module per peak watt.

$$Pe = c * Pm \qquad (5)$$

c : parameter 0.22 (Yen/Kwh / Yen/Wp)

$$N = Nm * 1000 \qquad (6)$$

Using equation (3),(4),(5) and (6), the break even point is calculated by repeating convergence method, and the result is shown in the Tab.3 and Fig.1 for respective progress index.

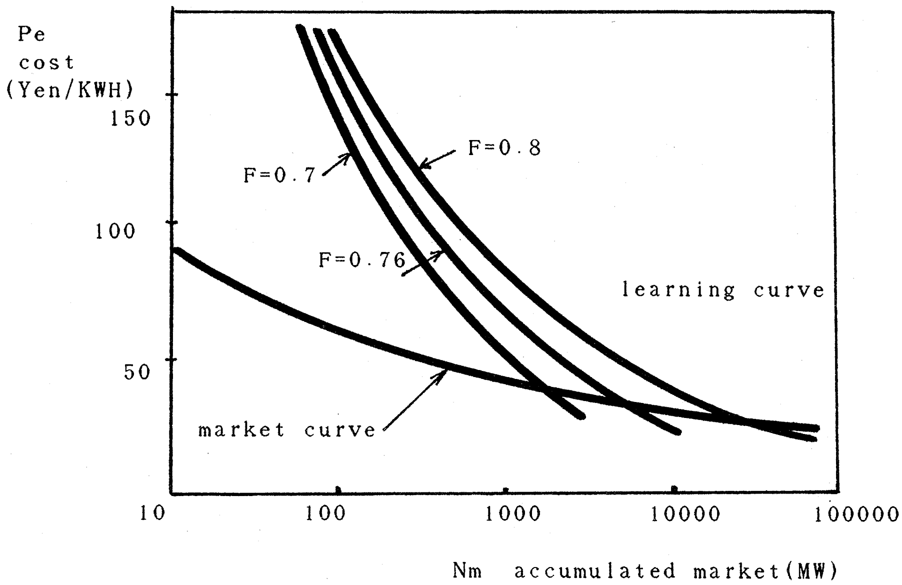

Fig.1 The break even point

The result shows that if F=0.8 as in the current trend, then 50 GW is needed to be cost effective, and if F=0.76 then 6.4 GW, and if F=0.7 as in the semiconductor industry today, then 1.4 GW is necessary for the break even point.However this analysis is based on the domestic production and market only.If the photovoltaic production and market in the global scale are included, then the result will be more favourable for the photovolatics industry.

F	b	Nm (MW)	Pe (Yen/KWH)	Pm (Yen/Wp)
0.90	0.1520	10^24	0.12	0.54
0.88	0.1844	10^16	0.49	2.23
0.86	0.2176	10^10	4.14	18.83
0.84	0.2515	10^7	10.93	49.69
0.82	0.2863	303992	17.69	80.41
0.80	0.3219	49166	23.55	107.03
0.78	0.3585	14852	28.40	129.10
0.76	0.3959	6435	32.49	147.67
0.74	0.4344	3366	35.87	163.05
0.72	0.4739	2059	38.76	176.19
0.70	0.5146	1393	41.21	187.31
0.68	0.5564	1012	43.34	196.22
0.66	0.5995	776	45.15	205.22
0.64	0.6439	619	46.81	212.79
0.62	0.6897	511	48.23	219.24
0.60	0.7370	433	49.51	225.03

Tab.3 The break even point of the market and the learnig curve.

CONCLUSION

The historical cost reduction data of photovoltaics is analyzed and combined with the market study to find the break even point of photovoltaics penetration in the future. The computational results show that it is necessary to continue production of photovoltaics to the scale of 1.4 Gw, if the learning curve is as steep as in semiconductor industry. This scale seems in the range of realistic reach for the future energy supply.

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