Research and Development Needs for Renewable Energy Technology in Industrialized Countries

Abstract

With a large number of users and high volumes of production, renewable energy technologies will be typical industrial mass products. Using photovoltaics as the example, we show that the most important research and development (R&D) function of industrialized countries in renewable energy is to focus on the reduction of cost per unit of power output. Reducing the cost / power ratio of renewables relies on the ability of developed countries to conduct advanced R&D.

Renewable energy – a large-volume industry

Renewable energy generation must be large to have impact on the global energy supply. Renewable energy will have many users, will produce large quantities of electrical or thermal energy or fuel, will use large quantities of material for their construction, and will require large investments of capital. These characteristics are typical of mass-produced industrial goods.

Therefore, renewable energy sources are following a path that is characteristic of modern industrial products like the automobile or the microprocessor. The widespread use of these was made possible by low cost, per passenger or per logic gate, of very advanced products. For the widespread use of renewable energy, low cost per unit of power or energy will be equally essential. For the eventual adoption of renewable energy by private users the cost of energy must be low. Its renewable character will be a secondary attractor for the vast majority of users in developed countries that we want to engage.

This argument applies to all sources of renewable energy produced in large quantity, whether in distributed or in central, bulk, form. Taking advantage of our own experience we employ photovoltaics (PV) as the vehicle for making our point. The present cost of PV is $ 3 /W of module, and $ 6 /W or more for the whole system. $ 3 /W systems cost is the target for opening large markets for distributed systems. A system cost

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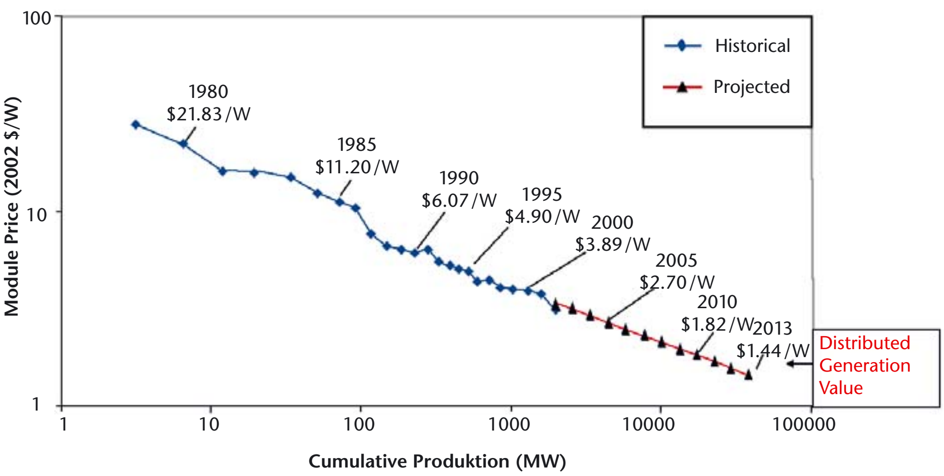

Figure 1
The experience curve for photovoltaic module price, and its extrapolation to the year of 2013.

The module cost of $ 1.44/W will open a large commercially viable market for distributed generation of photovoltaic electricity. From ref. [1].m ref. [1].

of $1.30/W is expected to introduce PV to the bulk power market. (We use $/W here to denote the cost per Watt of output power under peak insolation, which corresponds approximately to $0.25/We, the average output of a conventional power plant.)

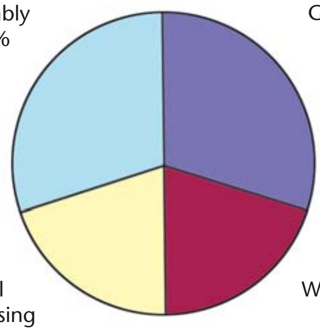

Figure 2
Main components of crystalline silicon PV module cost. From ref. [1].

Renewable energy cost reduction to date – the photovoltaic example

Like many mass-produced products, solar electric modules have come down in price with manufacturing experience. On average, the panel price has dropped to 81% of its value at the beginning of each period of doubling of cumulative production. The cumulative production counts all modules ever produced. This historical record is illustrated by *Fig. 1*, which also includes a projection of cost reduction anticipated over the next ten years. [1] (It is assumed but not assured that future cost will follow the historical trend of *Fig. 1*). While economists do not yet understand the semi-logarithmic dependence shown by this "experience curve," it is clear that the cost is coming down in part by R&D.

To understand the role of R&D in past cost reduction, and its leverage on cost reduction in the future, let us look at the components of module cost. The four main steps of module fabrication are reflected in the pie chart of *Fig. 2* on cost components of a PV module. These are (i) silicon refining and crystal growth, (ii) wafer cutting, (iii) cell fabrication, and (iv) module assembly. *Tab. 1* illustrates how each of these steps has contributed to the cost reduction depicted in *Fig. 1*. The manufacturing processes of all four steps have been improved.

Improving the cell efficiency is particularly important to cost reduction because of its leverage on the cost of the entire system. Raising the cell efficiency brings down the cost (per Watt) of the entire system, that is, it reduces the cost per watt of all manufacturing steps and of the balance-of-system.

Prognosis for further cost reduction – the photovoltaic example

The silicon solar cell roadmap foresees further improvements in cell and manufacturing efficiency, with module cost projected to reach $1.50/W by the year 2012. PV manufacturers are confident that the necessary technology can be developed. Cost reductions are anticipated in all steps of module manufacture, as described in the rightmost column of *Tab. 1*. Taking the balance-of-systems cost to be equal to the module cost, in 2012 the PV systems cost will become competitive for distributed application of PV. In other words, at this cost distributed PV no longer will need subsidies because it will be profitable.

Table 1
Improvements in silicon PV module manufacturing: history and projection

Process step	Material/process	Improvement to date	By2012
Silicon crystal	Polysilicon price	$300/kg → $30/kg	
	Larger diameter	75 mm → 150 mm	**200 mm**
Wafer Cutting	Wire sawing	< $ 0.25/W	
	Thinner Wafers	375 µm → 150 µm	**120 µm**
Cell fabrication	Higher efficiency	10% → 16%	**23%**
	Volume manufacturing	1 MW → 100 MW annual production	**500 MW**
Module assembly	**Automation**	**None → some**	**More**

The forecast for reaching the goal of PV to bulk power generation is less certain. For competitive bulk power generation the module cost will have to drop to $0.65/W, and the systems cost to $1.30/W. The scientific and technical path to this goal is not known, and finding it will need new discoveries, inventions, and manufacturing techniques.

Renewable technologies are complex products of advanced industrial societies

The preceding sections illustrate our main point: Because of their large numbers and extreme cost constraints, distributed systems for the generation of renewable power will have to be industrial mass products. Their introduction will follow that of other mass products made by demanding technologies, such as automobiles and microprocessors. They are invented, engineered, made, and first used in developed countries. In the past such advanced industrial products first have been imported to developing countries as status symbols of the wealthy. Because they turned out to meet basic societal needs and became affordable, large markets opened up for them in developing just as in developed countries. These markets were supplied with standardized products, which were adapted to local conditions in a kind of mass customization. When local markets in developing countries became sufficiently large, developed countries manufactured products tailored for export. Local manufacture in developing countries followed, which entrained the buildup of local base of suppliers. This flow of technological development that eventually becomes mutual is laid out in *Tab. 2*. Until sufficient income is generated locally from renewable energy sales, much of the sequence is financed by capital from developed countries.

How much subsidy is needed to make distributed PV power commercially viable?

Extrapolating the experience curve of *Fig. 1* shows that the commercially competitive module price of $1.50/W is attained when the cumulative production has reached 30,000 MW. *Fig. 1* allows to calculate the subsidy needed for reaching commercially viable distributed PV power. Assuming that manufacturers and installers are subsidized to receive $6/W of system, the total subsidy for bring systems cost to $3/W is $25 billion. This amount suggests that PV financing also will remain in the domain of the industrialized countries for some time to come. It is plausible that this need for subsidies, and their source, extends to several other renewable energy technologies.

Industrialized countries →
Exploratory research → invention → applied research →
→ product development → pilot production → field test
→ manufacture →
→ systems development → applications development → use
← Developing countries

Table 2
Entry points and growth directions in renewable energy industries of developed and of developing countries.

R&D entry for developing countries

While the need for mass production at low cost places the burden of development and financing renewable technology squarely on the shoulders of the industrialized countries, many developing countries have technology bases that enable them to make significant R&D contributions to renewables. *Tab. 3* lays out one possible approach.

Developing countries →
Energy conservation → heating/cooling → wind power
→ liquid fuels → PV electricity

Table 3
A possible division of labor in the development of renewable energy technology

Consequences on the division of labor in research and training

The preceding discussion served to highlight the most important need in R&D on renewable energy technology: to reduce its cost to a commercially viable level. Low cost is the key to successful market development. Once cost is low self-motivated and self-financed markets will spring up in developing countries, which then will begin moving in the direction from application to manufacture to R&D.

Reduction of the cost/power ratio must drive the research agenda for developed countries. This agenda will cover all aspects of the renewable technology, ranging from materials to physical function, to manufacturing, to systems development and installation. In technologies without local expertise in developing countries, developed countries will train local experts for applications and customization of systems. Where local expertise in renewable applications already exists, developing countries can help best by strengthening their R&D capability that helps local entry to cost effective manufacturing.

Reference

[1] "A Vision for Crystalline Silicon PV," R.M. Swanson, Materials Research Society Spring 2004 Meeting, Symposium A on Amorphous and Nanocrystalline Silicon Science and Technology-2004, paper A7.4. San Francisco, CA, 14 April 2004.