Photovoltaics: an overview of technologies and market potentials

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Photovoltaic solar energy's contribution to the energy transition

Photovoltaic solar energy (PV) is a vital part of future sustainable energy supply and, slowly but surely, is becoming a mature source of energy. In an ambitious scenario PV covers 20% of global electricity consumption by 2040[a]. Already in 2020 PV may contribute to the reduction of CO_2-emissions by an equivalent of 75 coal-fired power plants or 45 million cars. A total solar generating capacity of more than 4400 MWp is currently installed in industrialised countries[b,c]. In developing countries and emerging economies, solar energy systems provide more than a million households with electricity. World production of photovoltaic modules increased by more than 50% in 2005, compared with the previous year, to more than 1800 MW_p[c]. Photovoltaic solar energy has a variety of unique characteristics, which give this option a leading role in every scenario for a sustainable energy supply.

- It is the only sustainable energy source with virtually unlimited potential.
- It is available worldwide, also at high latitudes.
- The product, electricity, is suitable for all applications.
- Due to its wide geographical availability, it is the preferred solution for rural areas.
- Because of the absence of moving parts, emissions and noise generation, it is suitable for use in heavily populated areas.
- Since it can be integrated into buildings and infrastructure, it uses little space.
- Solar electricity enjoys widespread public support.

Although reliable PV systems are commercially available and widely applied, ambitious further development of PV technology is crucial to enable PV to become a major source of sustainable energy and to strengthen the position of the PV industry sector. The current price level of PV systems allows solar electricity to compete with peak power in grid-connected applications and with alternatives like diesel generators in stand-alone applications, but it does not yet allow direct competition with consumer or wholesale electricity prices. A drastic further reduction of turn-key system prices is therefore needed and fortunately possible. This was emphasized in the document A Vision for Photovoltaic Technology, published by the Photovoltaic Technology Research Advisory Council (PV TRAC) in 2005[d]. Further development is also required to enable the PV industry to maintain and strengthen its position on the global market, which is highly competitive and characterized by rapid innovation.

Solar electricity generation costs

For grid-connected applications, a number of break-even points will be reached in the near future, as a result of which the associated market segments will take a leap forward. Roughly speaking, we are referring here to energy-generating costs in the range between peak rates and consumer prices (including taxes) on the one hand and the fuel costs for large-scale generation on the other. In Southern Europe, a break-even with consumer prices will come within a few years. For Middle European countries, with the predicted fall in the cost of solar electricity and a conservative estimate of increasing consumer prices, break-even will be reached between 2015 and 2020. If electricity prices rise faster than shown, that point will obviously come earlier. From then on, the cost of solar electricity will continue to fall until it is eventually comparable with wholesale prices – that is, about €0.05 per kWh.

These expectations are based on an extrapolation of the price evolution of solar electricity over the past 40 years. The potential for reductions in the cost of modules and complete systems is huge. In the past ten years, module prices have halved – a trend which is expected to continue for the next decades. The historic link between price and cumulative production volumes can be shown in a so-called learning curve (Fig. 1). The gradient of this double-logarithmic curve reflects the learning factor: the average reduction in price when cumulative volume produced doubles. For photovoltaic modules, that reduction has averaged 20% since 1976. The prices of other system components and the cost of installation show similar falls, which means that the turnkey cost of complete systems is also coming down. It is important to note that the price reductions revealed by the learning curve result from a combination of research and technological development on the one hand and, on the other, market growth and experience in production and implementation. Without technological advances, prices fall only slowly; without market growth, the results of those advances do not find their way in practical use and no experience is acquired, again causing prices to stagnate.

Solar electricity's economic contribution

Long before solar electricity starts to make a substantial contribution to a sustainable energy supply, it will already be an important source of economic activity. The global PV sector has grown by an average 25% over the past two decades and by 45% per annum over the past five years, predominantly due to the rapid expansion of the market segment of grid connected systems (Fig. 2). This has become possible by successful market development in an increasing number of countries. In Europe, such programs now exist in Germany, Spain, Portugal,

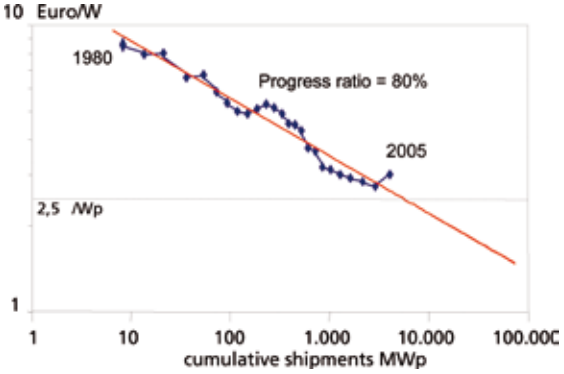


Figure 1

Learning curve for photovoltaic modules. This shows that module prices fall by approximately 20% every time the cumulative volume produced doubles[e]

France, Italy, Greece and Belgium with more countries considering such a program. Outside Europe, Japan, Korea and the USA provide good examples of well-developed or emerging markets. An investment report published in 2004 by Credit Lyonnais Security Asia forecasts that the photovoltaics sector has a realistic potential to expand from € 5.8 billion in 2004 to € 25 billion in 2010 corresponding to 5.3 GWp in annual sales[f]. The world-wide photovoltaic industry has the potential to create more than 2 million jobs by 2020[c]. The total number of jobs in the PV sector in Europe was estimated to be 40,000 in 2005, of which 30,000 in Germany and 6,300 in Spain[g,h]. Although the labor intensity will decrease with decreasing system prices, the rapid market growth will guarantee a strong increase in the number of jobs in Europe. Electricity generated with photovoltaic systems has additional positive benefits for the European economy in the long run. First, with increasing installations of photovoltaic systems, the generated electricity can help to reduce the dependency of the European Union on energy imports. Second, electricity from photovoltaic systems is generally produced during times of peak demand when electricity is most expensive.

Technology development

Research (or rather, R&D) is crucial for further development of photovoltaics. PV modules and other system components have experienced impressive progress in terms of price, performance, reliability and environmental aspects such as energy pay-back time over the past decades. This is evidenced by the price reductions shown in learning curves (Fig. 1), by the increase of power conversion efficiencies and energy yields, by enhanced system availabilities, by strongly shortened system energy pay-back-times, and by a variety of other indicators. Nevertheless, PV technology has by no means demonstrated its full potential yet. Only to give a rough impression of where PV was 25 years ago, where it stands today and whereto it may develop over the next 25-50 years, Table I gives some typical (rounded), tentative figures. Figures mentioned as long term potential need to be analyzed in more detail.

Table 1

PV technology fingerprints as a function of time. Figures rounded and indicative only, see comments below. Modified from the Strategic Research Agenda of the EU PV Technology Platform (2007)[i]

	1980	Today	2015	2030	Long term potential
Typical turn-key system price (2007 €/Wp, excl. VAT)	>30	5	2.5	1	0.5
Typical electricity generation costs Middle Europe (2007 €/kWh)	>2	0.30	0.25 (competitive with retail electricity)	0.10 (competitive with wholesale electricity)	0.05
Typical commercial module efficiencies (total area)	up to 8%	up to 15%	up to 20%	up to 25%	up to 40%
Typical system energy pay-back time Middle Europe (yrs)	>15	3	1.5	0.75	<0.50

An overview of commercially available photovoltaic technologies with their respective market shares is given in Figure 3. Wafer-based crystalline silicon, including multicrystalline silicon, monocrystalline silicon and silicon ribbons, is the dominant PV technology by far with a market share of 93% in 2005 and the main vehicle for price reduction. Although its market share is still marginal (<7% of total PV shipments in 2005), the current silicon feedstock shortage has led to a renewed interest in thin film photovoltaics. Manufacturers thus far almost exclusively focused on wafer-based crystalline silicon are now investing in thin film silicon production. Many new companies are involved in development and implementation of CIGS-, thin-film silicon- or CdTe production technology. On the longer term, thin-film photovoltaics will become competitive with crystalline silicon technology through major improvements in efficiency, stability and cost reduction. At present, thin-film photovoltaics are already successfully implemented in specific PV markets not served by crystalline-silicon due to their specific properties (light weight, homogeneous appearance, flexible, semi-transparent). Figure 4 illustrates current thinking as regards the development of commercially available module technologies. The technology families are developing in parallel, in the sense that cost per Wp is falling and efficiencies are improving.

New technologies, such as organic-based photovoltaics, may first enter certain market niches, based on their unique properties, but may eventually take over some market share from the established PV technologies. What the diagram does not show is the system costs and the quality-related improvements, which also play a part in the pricing of solar power: lifetime, aesthetics, environmental properties and so on.

Concluding remarks

Photovoltaic solar energy is world-wide the renewable energy source with the largest potential contribution. In the long term (from 2030 on) it will

Figure 2

Market growth per application area in megawatt-peak (MWp) added installed PV power

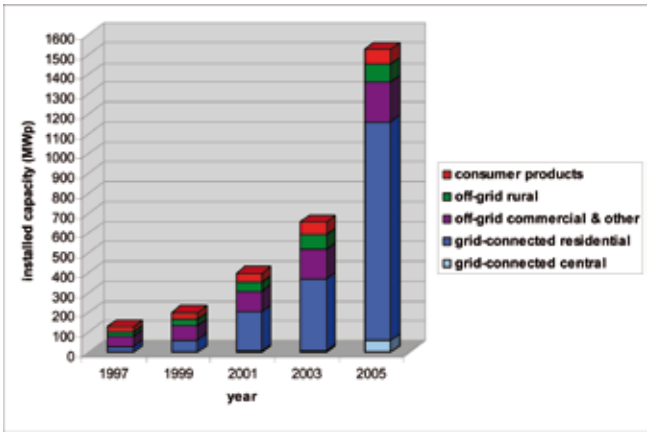
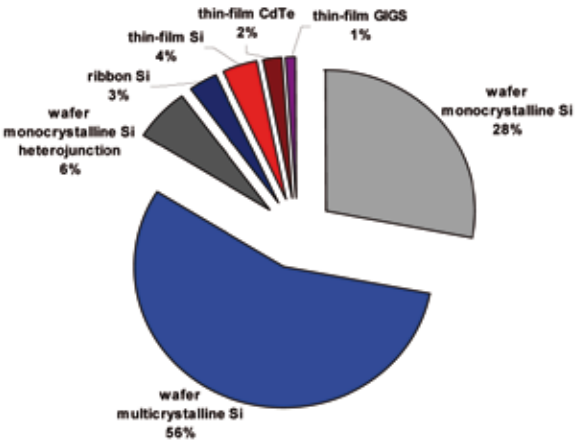


Figure 3

PV market segments by technology in 2005 [i]



contribute significantly and increasingly to CO_2 reduction. The already significant economic sector related to application of photovoltaics will grow enormously (larger than the semiconductor industry) and offer unique opportunities to the industry. Generation costs for solar electricity will reach the level of consumer electricity prices (grid parity) within the next 10 years for countries in southern and middle Europe.

Reference

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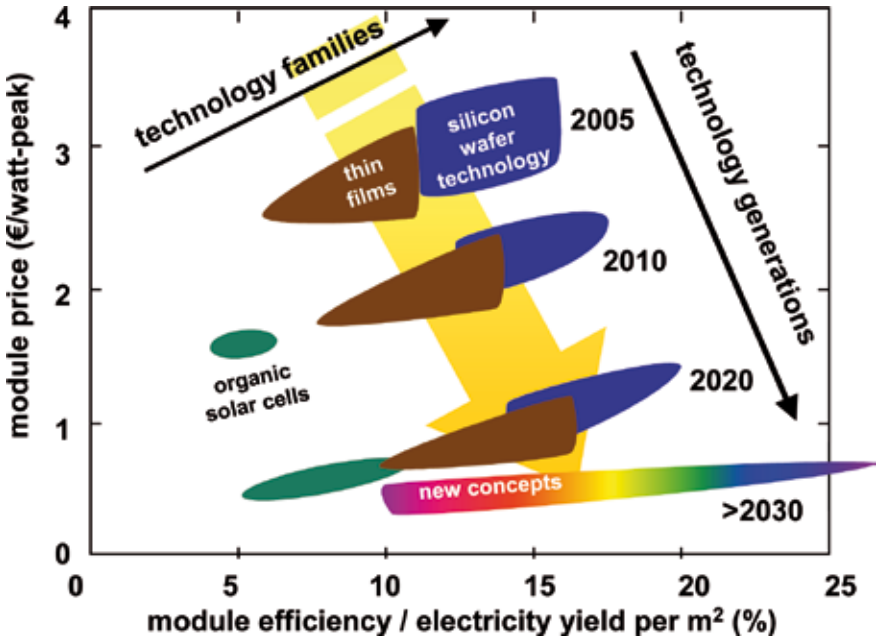

Figure 4

Comparative positioning and development of module technologies (freely adapted from W. Hoffmann, Schott Solar)