Key Technical and Non-Technical Challenges for Mass Deployment of Photovoltaic Solar Energy (PV)

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Introduction

Photovoltaic solar energy (PV) is used for direct conversion of sunlight into electricity. It is not to be confused with low-temperature thermal solar energy (e.g. solar domestic hot water systems) and with solar electricity production using a conventional high-temperature steam cycle (using parabolic troughs or "power towers"). Important features of PV are:

- inherently renewable;
- sustainable if well designed, manufactured, used, and disposed;
- no moving parts, quiet;
- reliable if well designed and engineered;
- modular (from milliwatts to multi-megawatts);
- suitable for a wide variety of applications (stand-alone and grid-connected);
- large potential (regionally and globally);
- intermittent;
- capacity factor (ratio of average system power to installed (=peak) power) ≈0.08-0.24.

PV is among the major renewable energy technologies in all well known energy scenarios, although a substantial role in % of the total energy production can only be achieved on the long term (typically 40-60 years years). Fortunately, long before that the PV market may be a rapidly growing, multi-billion € business, providing enormous economic opportunities and many jobs.

PV technology, economy and applications[1]

PV systems are divided into stand alone and grid connected configurations. The former often consist of one or more modules, a charge regulator and a battery. The latter are built of (one to thousands) modules and one ore more inverters for dc/ac conversion. Commercial modules are available in several types (the last two on a pre-commercial or pilot scale):

- monocrystalline silicon (sc-Si)
- multicrystalline silicon (mc-Si)
- amorphous silicon (including amorphous silicon-germanium and microcrystalline silicon) (a-Si);
- copper-indium/gallium-difselenide/sulfide (CIGS);
- cadmium-telluride (CdTe).

In the laboratory, many new solar cell technologies are under development. Of these, dye-sensitised and organic (polymer or "plastic") cells are probably best known.
Energy conversion efficiencies of commercial modules are roughly between 5 and 15%, laboratory cells have efficiencies ranging from a few % up to 30% or slightly more. It is emphasised that the available efficiencies as such are already sufficient for widespread use of PV and that efficiency is by no means a measure of quality. It is primarily the price/performance ratio that needs to be improved further, as outlined in the following section. It is expected that maximum energy conversion efficiencies of PV modules will double or maybe even triple on the long term.

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[1] For a recent and comprehensive overview of the state-of-the-art (and expectations) of all energy technologies, see World Energy Assessment (UNDP, 2000), www.undp.org/seed/eap/activities/wea.

PV modules are only one part of a complete system, and therefore it is important to address the performance of other components and of the total as well. In modern, high-quality grid-connected systems, system-related losses have been reduced to a low value of ≈10%.

PV systems are presently able to compete directly with other electricity generating technologies in high-value applications. Well-known examples are "solar home systems" for rural electrification, and systems for telecom or leisure. For mass deployment of grid-connected systems, however, a further cost reduction (typically by a factor 2-4) is necessary. Alternatively (or rather: in addition) the economy of such systems may be improved by a variety of financial incentives: mainly subsidies, tax credits and feed-in tariffs. Somewhat more difficult to quantify, but also important is to make optimum use of the "added value" of PV. One can think of using PV modules as building elements with a double function. Finally, the application of PV may also benefit from non-financial incentives, for instance through building codes.
Turn-key system prices of the most common (i.e. roof-mounted & grid-connected) PV systems are typically between 4 and 8 €/watt-peak (Wp) excl. VAT, corresponding roughly to 0.20-0.80 €/kWh in EU countries[2]. Prices are expected to lower by 5-10% per year, depending on market growth and other conditions. The ultimate turn-key system price is estimated to be around 1 $ or € per Wp (with a technical lifetime of 20 years or more). This implies that PV generation costs are likely to remain always higher than today's minimum fuel cost of electricity generation. This should not be a major bottleneck, however.

Although the economy of PV systems is most favourable in stand-alone applications, recent market growth has mainly been in grid-connected applications. This is due to ambitious government programmes in several countries (particularly, but not only, in Germany and Japan), and to the fact that market development of rural applications in developing countries appears to be much more complex than anticipated a few years ago. Grid connected systems are either integrated in buildings and other objects in the physical infrastructure (sound barriers, etc.), or applied as ground-based power plants. Recent attention goes primarily to small to medium sized (typically 100 Wp to a few MWp) integrated systems and to large (roughly 10-100 MWp) ground-based systems. The latter exist mainly as concepts for future solar power production in deserts or other areas with a high insolation.

PV market development

Although there is little doubt that one day PV will play a major role in the global energy supply system, there is no consensus on how to achieve this. An analysis of the cost structure of today's PV systems clearly shows that cost reduction requires both economy-of-scale (or more precisely: volume) ánd technological innovations. This is true for the PV modules, but also for the Balance-Of-System (other system components and installation). Economy-of-volume can only be reached if the PV market grows substantially bigger than it is today. Moreover, technological innovations will not be implemented in production if the market grows slowly, since manufacturers will make use of existing capacity rather than making new investments. This puts market growth forward as the key issue to address. However, since PV can generally not yet compete directly with electricity from other generators, market growth is small if no extrinsic incentives are created. This is the (in)famous chicken-and-egg problem. Countries worldwide make very different choices in this respect. Germany has adopted a system of high feed-in tariffs (DM 0.99/kWh) in combination with loans on very favourable conditions. Japan has a system of investment subsidy. Since electricity prices are high, savings obtained by PV have a high value. The Netherlands has a system of investment subsidy for house owners, sometimes combined with net metering, and various fiscal incentives for commercial companies. In addition, PV contributes partly to lowering of the energy performance coefficient for buildings. The maximum allowed

[2] There is still considerable debate on the calculation method for translation of Wp to kWh, major issues being depreciation period, interest rate, and O&M + insurance cost.

coefficient is set by the government. In the United States a variety of financial incentives exist on state and city levels.
The PV module market has grown by approximately 20%/year over the past 2 decades, while the year 2000 showed an exceptional 40% growth compared to 1999 (2000: 280 MWp, worth almost 2 billion € of PV systems). Cumulatively, about 1400 MWp has been installed worldwide.
In addition to purely financial aspects, the earlier mentioned “added value” of PV plays an important role in decision making. An increasing number of systems is commissioned because PV can be used in aesthetically pleasing building designs and to strengthen the image of the owner.
A very strong impulse for PV market growth can come from sales of green electricity with a “yellow” component (i.e. solar electricity). By mixing low and high cost renewables in commercial products, they may stay affordable and still provide the desired boost in PV volume. This concept is now tested by some energy companies.

Added value of PV: system at a newly built sustainable office building (ECN, Petten, The Netherlands, 2001. Photo courtesy BEAR Architects). PV modules fulfil multiple functions: electricity generation, roofing and partial shading.

Key issues to address in mass deployment of PV
So far, PV systems make only a very small contribution to electricity generation. Therefore some key issues have not yet been addressed adequately, or at least not with a very high priority. The focus has been mostly on (module) technology development and on cost reduction. Now that the PV market grows rapidly, it becomes important to solve remaining problems for short and long term deployment. Some important aspects are described hereafter.

- <u>Quality assurance (components and installation) and guarantees</u>
  PV systems are meant to generate electricity for 20 years or more. PV modules come with a standard guarantee of 10-25 years, but other components and installation are generally in imbalance with this. Without jumping to conclusions on what should be done in this respect, clear statements on (a.o.) expected lifetime, required maintenance and preventive replacement of components are required in a professional market. In addition, the user would like to have an accurate prediction of the actual energy that will be

produced (not just information on the installed power). Finally, insurance companies and financiers do not yet know how to treat PV systems since there is little reliable and documented information on behaviour of representative systems over longer periods of time.

- <u>Norms and standards</u>
  International norms and standards are not yet available on all relevant aspects. This hampers development of the PV industry. It takes a long time and a lot of debate to agree, for instance, on requirements for protection against island operation of PV systems (if the grid fails, PV systems should switch off automatically).
  The building industry is rather country-specific and therefore using PV as building element poses a challenge to manufactures of PV components.

- <u>Environmental issues</u>
  Although PV systems generate renewable energy by nature, they are not automatically fully sustainable. Sustainability is partly dependent on energy, materials and processes used in production. Fortunately, the energy content of PV systems goes down rapidly as a spin-off of efforts focussed primarily on cost reduction. Energy pay-back times of complete systems are now typically in the range of 4-8 years (in Western Europe) and are expected to be reduced to 1-2 years in the near future. The PV industry and R&D institutes are paying increasing attention to materials use, but are faced with important questions. For instance, cadmium-containing PV modules (most CIGS, and CdTe) are allowed according to EU legislation, but not according to present national legislation in The Netherlands. The latter, however dates back to the pre-PV days. It is expected that the use of lead in soldering materials will have to avoided in the future. This has some important practical consequences for manufacturers.

- <u>Valuing, costing, and financing</u>
  There are huge differences between countries and even within countries concerning the way PV systems are treated by utility companies and other stakeholders. Feed-in tariffs vary from a very generous DM 0.99/kWh to avoided fuel cost or even zero, with net metering as an intermediate. In addition, there is no consensus on the very basic and important translation of turn-key system cost (and some other input parameters) into kWh generation cost. Although differences are likely to remain between countries and companies, it would be helpful to be clear on the philosophies applied. The same is true for the conditions under which money is made available for investment in a PV system (part of the mortgage or not, for instance).

- <u>Aesthetic quality</u>
  In a few decades from now, people will see PV systems whenever they look out of their window. To prevent the “not on my roof” syndrome, it is therefore essential that PV systems are pleasing to the eye and an enrichment of building design rather than a technology that has to be applied. Because emphasis is put entirely on low cost in some cases, systems are not as nice as they could (and should) be.

- <u>Electricity generation profiles</u>
  PV systems generate electricity whenever there is direct or diffuse sunlight. This makes PV an intermittent source of energy. In grid connected systems the fluctuations in production (actually, the differences between local production and local use) are buffered by the grid, which acts as a virtual storage. At low penetration levels of PV this is an elegant and acceptable method, but obviously we need another approach if PV is to be applied on a very large scale. Various options are under investigation, such as: demand-side management including local electricity storage, combined use of PV and micro-CHP with fuel cells or other technologies (buildings may then become micro baseload generators), and macro storage of energy (for instance as hydrogen).

The future of PV - conclusions

PV is considered to be one of the most promising renewable energy technologies. Well-known global energy scenarios sketch a future where renewables including solar energy have a major share around the middle of this century. It is important to note that a 10% contribution from PV in 2050 requires a continuous 20-25%/year market growth over half a century. This is indeed a huge challenge.

High-quality PV systems are already commercially available now and applied worldwide. True mass deployment of PV, however, is only possible when the cost of electricity generation with PV is reduced substantially. This, in turn, requires mass production of components and installation at a large scale. To break this vicious circle it is essential to make full use of the unique character of PV and not to focus on generation cost only. In the built environment PV is an indispensable element of energy-conscious design (low or zero energy concepts) and a material for architects to use in a variety of ways. Project developers may offer houses with PV included as a standard option (like is done in Japan and some European countries). Energy companies may offer green electricity with a PV component or even pure solar electricity to their customers. By using creativity and being ambitious in marketing and application of PV *now* we will make PV competitive in the future.