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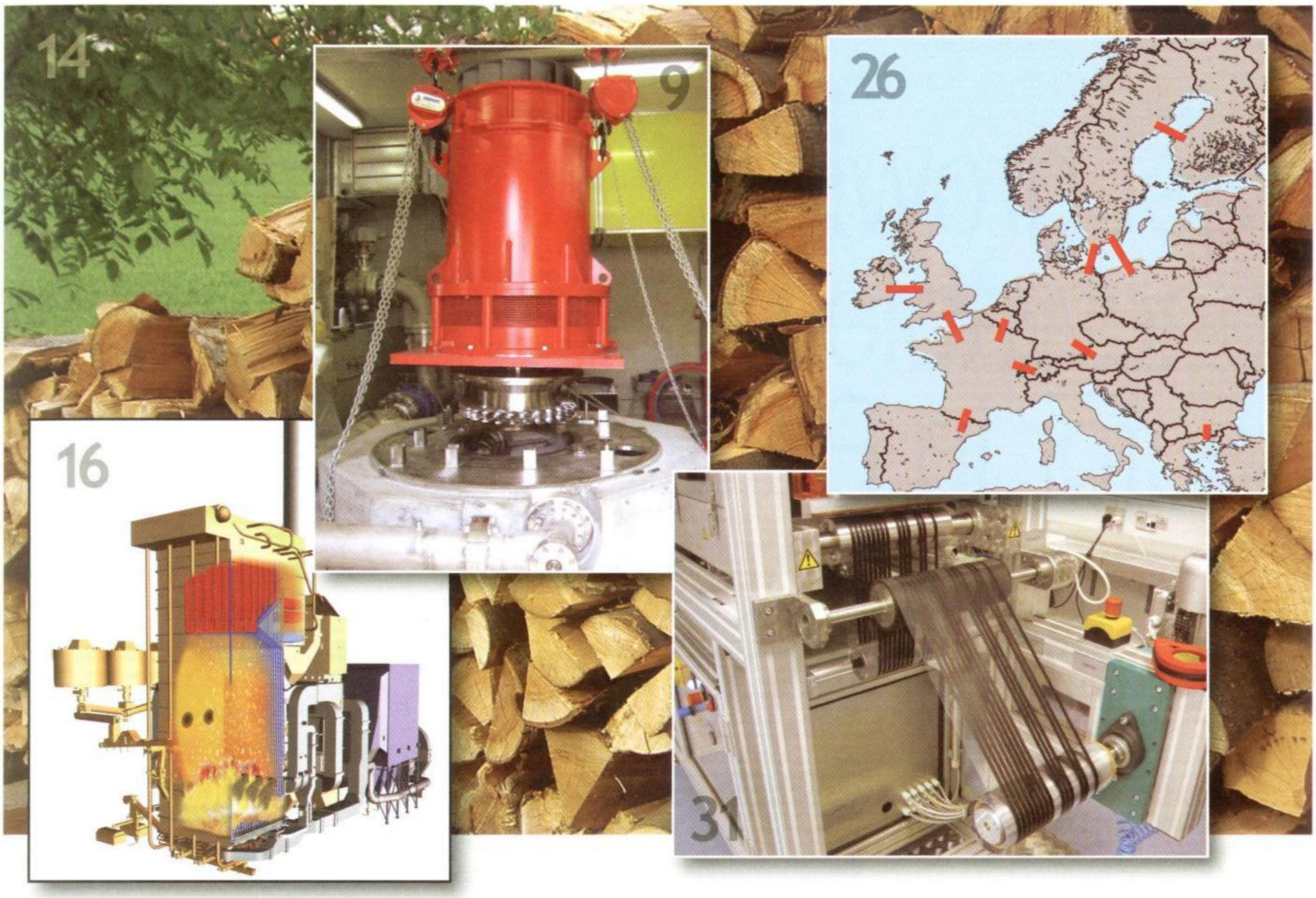
CONTENTS



Grid parity: Holy Grail or hype?

These are exciting times for solar energy. The Secretary of Energy in the new Obama administration is Steve Chu; co-winner of the Nobel Prize in Physics in 1997, but even better known as a very powerful advocate for solar energy. The USA may therefore rapidly catch up with Europe, the current world leader in this area. The heat is on!

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Solar energy has a huge global and European potential for sustainable generation of electricity, heat and fuels. Photovoltaic solar energy conversion (PV) and concentrating solar power (CSP) are the two options for electricity generation. In the longer term they may also be used to generate sustainable fuel, especially hydrogen, if that would turn out to be useful in the total energy mix. Because of the different nature of the PV and CSP conversion processes and the related distinctive features, they can be considered largely complementary. Clearly, the combination of the two absolutely makes a winning team and may form (or even has to form) the basis of our future sustainable energy system. This is for instance illustrated by the "exemplary transformation path" that was published by the German Advisory Council on Global Change (WBGU) in 2003[1].

Photovoltaic solar energy and competitiveness

PV has the unique features of being modular, very low maintenance and quiet, which makes it the technology of choice for a wide range of applications, from consumer products and stand-alone systems for rural use to grid-connected building-integrated systems and large-scale ground-based power plants.

It is widely acknowledged that further price reduction is a prerequisite for very large scale implementation of PV. Although PV system prices and generation costs have come down rapidly, they do not yet allow direct competition with most other electricity generating options, whether conventional or renewable. The concept of 'competitiveness', however, requires a sophisticated approach in the case of PV. PV is used in very different applications and the reference varies strongly with these applications. In other words, it is important to consider not only the *cost* of electricity generated by PV, but also its *value* in the specific application environment.

In the case of a stand-alone PV system for rural use (e.g. a so-called solar home system), the reference may be the cost to provide the same service with a diesel generator. 'Service' may apply to lighting, television, mobile phone, etc. In addition to the cost, the quality and reliability of the service may play an important role. Absence of noise and smell, and low maintenance often speak in favour of PV.

For grid-connected systems, the reference is always electricity from that grid, but here as well the concept of 'competitiveness' is not straightforward. Apart from the fact that PV is a renewable and very-low-CO_2 technology[2] while conventional sources are not sustainable, which is not taken into account in a simple comparison, reference prices of electricity from the grid vary with the connection point considered and often with the time of the day. If a building-integrated PV system would supply electricity during hours of peak consumption and high spot prices, e.g. due to air conditioning, the value could be quite high. PV then acts as 'peak shaver'; a potential value that was recognised many years ago. This may also apply on a macro level, i.e. for the total generating capacity of PV in the total electricity system in a country. On the other hand, if a ground-based PV power plant (or the collective PV systems in a country) would only replace base load power, the value of the electricity is probably a lot lower. It is noted that these examples are meant to illustrate the complexity of the comparison, but also the market opportunities and possible incentive models that arise from it.

From turn-key system price to electricity generation cost

For reasons of easy comparison, it is often more useful to consider the costs of electricity generation with PV (EUR per kWh) than the costs associated with the investment in a turn-key system (EUR per watt-peak[3] of system power), although the latter can be determined more easily and accurately. The conversion of turn-key system cost (or rather 'price' from the viewpoint of the owner/investor) to electricity generation costs is often done using a so-called Levelised Energy Cost (LEC) method (also referred to as Levelised Cost of Energy, LCoE).

Although the calculation involved is very straightforward, it requires assumptions and estimates of parameters which may not be made in a straightforward manner. More precisely, besides the turn-key investment price in Euros per watt-peak, we need a value for the operation and maintenance costs (normally expressed as a percentage of the investment per year), the system economic lifetime (depreciation period), the discount rate (interest rate) and the specific electricity yield (kWh per year per watt-peak of system power). The latter parameter is primarily dependent on the amount of sunlight available at the geographical location and orientation[4] of the system (the insolation) and to a much lesser extent on system design, technology used, etc.

Without explicit information on the assumptions made, comparisons between different PV systems and between PV and other energy technologies have no meaning whatsoever.

Unfortunately, such comparisons are frequently made. Table 1 on page 36 presents a set of calculation examples to show the effect of typical ranges of parameters. Turn-key prices of grid-connected systems currently range from less than four Euros per watt-peak to eight Euros per watt-peak or more, for different system types and sizes, and countries. A value of five Euros per watt-peak is sometimes used as a reference[5].

It is expected that system prices will drop to (less than) two Euros per watt-peak in 2020, (less than) one Euro per watt-peak in 2030 and perhaps even less in the longer term[5]. Specific electricity yields for high-quality, well-oriented systems roughly range from 0.8 kWh/watt-peak per year for north-west Europe to 1.6 kWh/watt-peak per year for the most southern parts of Europe. Combining a low (future) system price with a high insolation and reasonable values for other parameters gives an indication of what PV may be capable of in the longer term: electricity generation at five Eurocents per kWh. Clearly, if this can be reached PV will be competitive with almost all other electricity options.

At current price levels, electricity from PV cannot yet compete with electricity from the grid

PV price reduction and grid parity

The concept of 'grid parity' has been presented in a transparent and useful way[6] by Dr Winfried Hoffmann, (among others) Vice-President of the European Photovoltaic Industry Association (EPIA). It has been used frequently and in different contexts in recent years. 'Grid parity' refers to the situation where the generation cost of PV, see previous section, is equal to the price of electricity at the point of connection. Note that it is common practice to speak about the *cost* of electricity from PV, because the point of grid parity does not assume a profit margin for the owner, while the comparison is made with the *price* of electricity from the grid, which again makes sense from the perspective of the owner/consumer.

At current price levels, electricity from PV cannot yet compete with electricity from the grid, except in selected situations like peak power consumption. This, however, will soon change[5]

Table 1: Levelised cost of electricity for a range of turn-key system prices, geographical locations and other parameters. Numbers serve as examples. See text for details.

Turn-key system price (€/Wp)	Depreciation time (yrs)	Energy yield (kWh/Wp.yr)	Interest rate (%)	O&M + other costs (% of initial investment/yr)	Levelized electricity cost (€/kWh)
5.00	20	0.80	4	1	0.52
2.00	20	0.80	4	1	0.21
1.00	20	0.80	4	1	0.10
5.00	**30**	0.80	4	1	0.42
5.00	**20**	0.80	4	1	0.52
5.00	**10**	0.80	4	1	0.83
5.00	20	**0.80**	4	1	0.52
5.00	20	**1.20**	4	1	0.35
5.00	20	**1.60**	4	1	0.26
5.00	20	0.80	**8**	1	0.70
5.00	20	0.80	**4**	1	0.52
5.00	20	0.80	**2**	1	0.44
5.00	20	0.80	4	**0.5**	0.49
5.00	20	0.80	4	**1**	0.52
5.00	20	0.80	4	**2**	0.58
1.00	20	1.60	4	1	**0.05**

(see Table 2). This table shows some key historic, current and projected future parameters; 'fingerprints' of PV technology as a function of time. In a few years from now grid parity with retail electricity will be reached in Southern Europe, while in 2020 grid parity may have been achieved in most of Europe. The latter is the overriding short-term goal of the EPIA and the EU PV Technology Platform. It is noted that according to recent estimates, this goal may perhaps even be reached before 2020.

In the past decades, the price of electricity from PV has come down tremendously by a smart combination of research and technology development (innovation) and economies of scale in all parts of the value chain (see Table 2). Together they form the basis of the well-known learning curve ('price-experience curve'), which shows that the market price of solar modules drops by 20 per cent for each doubling of the cumulatively produced volume (100 per cent minus 20 per cent = 80 per cent is the so-called progress ratio). Since modules constitute only a part of a complete (turn-key) system, it is important to also consider the progress ratio of the Balance-of-System (BoS) price, i.e. the price of the turn-key system *excluding* the modules.

Studies have indicated that in selected cases, a progress ratio of roughly 80 per cent also applies to the BoS, and thus to turn-key systems, although this is no proof of future developments. Market development and the resulting increase in production volume are clearly essential to progress along the learning curve. It is *because* of the market development in several EU countries (especially in Germany and Spain) that PV is in its present, rather advanced state.

It is also crucial to realise, however, that constant innovation is *implicit* in the learning curve. In other words, the effects of volume only would be much smaller than the combined effects of innovation and volume. Moreover, innovation is also necessary to enable efficient up-scaling. Without innovation, up-scaling would involve a simple multiplication of existing technologies and manufacturing practices, which is obviously not the

Table 2: Evolution of PV technology over time, adapted from the Strategic Research Agenda of the EU PV Technology Platform, see ref. 5.

Rounded figures	1980	2008	2020	2030	Long term potential
Typical turn-key system price (2008 €/Wp, excl. VAT)	>30	5 *(range 4~8)*	2.0	1	0.5
Typical electricity generation costs Southern Europe/NL (2008 €/kWh)	>2 / >3	0.30 / 0.50	0.12 / 0.20 *(competitive with retail electricity) retail electricity)*	0.06 / 0.10 *(competitive w wholesale electricity)*	0.03 / 0.05
Typical commercial *flat-plate* module efficiencies (total area)	up to 8%	up to 15%	Up to 20%	up to 25%	up to 40%
Typical commercial *concentrator* module efficiencies	(~10%)	up to 25%	Up to 30%	up to 40%	up to 60%
Typical system energy pay-back time Southern Europe (yrs)	>10	2	1	0.5	0.25

PV is a renewable and very-low-CO_2 technology

optimal approach. To reach the point of grid parity with retail electricity prices, it is thus necessary to continue to combine market (volume) development with research and development. Nevertheless, there is wide consensus in the PV community that the 2020 targets can be met using advanced and strongly improved versions of technologies already available today. In other words, there is no need for a breakthrough in the traditional sense of the word. Moreover, the fact that there is a portfolio of PV technologies rather than just one candidate makes the development perspective of PV very robust and attractive. It is not really the question *whether* PV will be successful, but merely *in which form(s)*.

The significance and limitations of grid parity

The concept of grid parity as it is presently used has been very effective to communicate that competitiveness of PV is not many decades away, but actually within reach for the specific, but very relevant case of retail electricity. Since it does not account for any profit on the side of the PV owner/investor and it does not consider costs or benefits related to (avoided) grid transport, back-up power, etc., it is not an accurate indicator of competitiveness in the broad sense of the word. Neither is reaching grid parity a sufficient condition to create a self-sustained market. Last but not least, it is important to note that retail electricity prices especially may contain a significant portion of taxes, i.e. price components *not directly* related to generation, transport, etc. These taxes differ per market segment and per country. Although part of those taxes could perhaps be seen as a compensation for environmental damage caused by electricity generation, it is clear that taxes further complicate the comparison between electricity from the grid and electricity from PV. Nevertheless, grid parity with retail prices is a very important stepping stone on the road to full competitiveness. When 'net metering'[7] applies, grid parity marks the situation that the owner of a PV system can recover the investment solely by avoided purchase of electricity and by the income generated by selling electricity to the grid. After that, as PV prices decrease further, financial market incentives like feed-in tariffs may be gradually eliminated. A similar line of reasoning applies to grid parity in other electricity markets, such as commercial or industrial electricity.

Conclusion

Grid parity is a rather simplified indicator of the competitiveness of PV. It is nevertheless very useful, since it assumes the viewpoint of a potential investor in a PV system and has thus helped to define potential markets. Moreover, the concept *does* roughly illustrate how long it takes PV to reach competitiveness in different segments of the electricity market. It may not be the Holy Grail, but it is certainly no hype either. When used with care, it is one key to the success of PV. ✓

References

1. *World in Transition; Towards Sustainable Energy Systems, German Advisory Council on Global Change (WBGU), Earthscan, London (2003); see www.wbgu.de/wbgu_jg2003_engl.html*
2. *The so-called system energy pay-back (EPBT) time is currently roughly two years in sunny regions, on a technical lifetime of typically 30 years. Moreover, the EPBT decreases with improvements of the technology. When PV systems are manufactured and installed using conventional energy, the ratio of the EPBT to the lifetime is a measure of the (very low) equivalent CO_2 emissions related to PV electricity generation*
3. *The term 'watt-peak' refers to the power that is generated at full sun, or more precisely, under standard test conditions. It is used to enable comparison between different system types, sizes and technologies*
4. *Very useful and attractively presented information on insolation can be found on http://sunbird.jrc.it/pvgis/*
5. *See, for instance, A Strategic Research Agenda for Photovoltaic Solar Energy, EU PV Technology Platform (2007), www.eupvplatform.org*
6. *An updated version of Hoffmann's original figure can be found on page 41 of Solar Generation V, European Photovoltaic Industry Association EPIA and Greenpeace (2008), see www.epia.org*
7. *'Net metering' refers to the situation where electricity generated by PV may be sold to the grid at the same price as electricity bought from the grid*

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