Photovoltaics the Basis for Sustainable Energy Systems and Industrial Innovations

Honory Lecture by the Becquerel Prize Winner

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Mr. Chairman, Ladies and Gentlemen, dear Friends,

thank you very much for awarding me with the prestigious Becquerel prize. I feel very honoured.

This prize is – as I see it – also recognition of the tremendous effort of the entire Fraunhofer ISE in developing new and optimised PV technologies and in dedicating scientific work to the vision of a sustainable future. Thus sincere thanks to the whole staff of our institute.

Today photovoltaic is in an excellent situation. A strong market (figure 1), growing industries creating new employment and good conditions for R&D underline this fact.

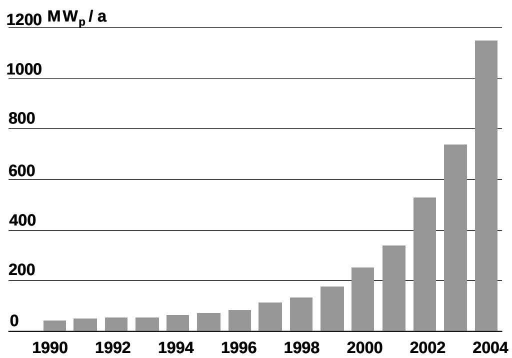

Figure 1: Growth of the global market for photovoltaic modules. 2004 more than 1000 MW of PV modules have been installed world wide.

On the other hand the pronounced and partly unforeseen extremely strong growth has now resulted in difficulties that have to be explained to the public and especially to the political sector.

Today the main problem in PV is the shortage in silicon feedstock and resulting from this a strongly reduced market growth (figure 2) and an increase in module prices (figure 3).

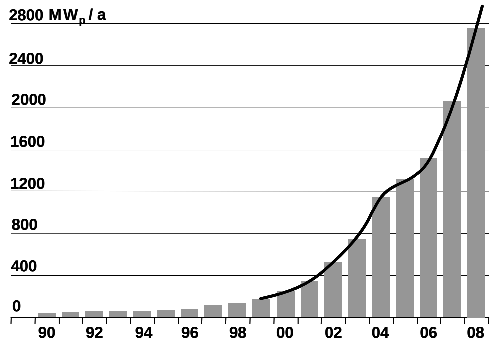

Figure 2: A likely scenario for the development of the global PV market. 2005 and 2006 will see a market growth of approximately 15% (mainly due to a better exploitation of the material – e.g. utilisation of thinner wafers). Starting 2007 new silicon feedstock will be available and the market will recover its strong growth (30%/a is assumed in the graph).

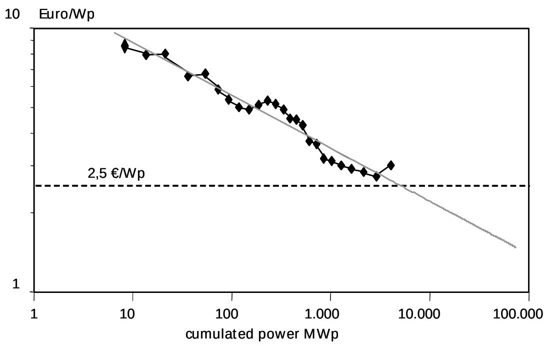

Figure 3: Price experience curve (learning curve) for flat plate PV modules. Mean world market prices are shown as a function of the total (accumulated) shipment (both scales logarithmic). The latest increase in prices is due to the actual silicon feedstock shortage. Most probable the price curve will recover its long term trend after sufficient silicon will be available again (1€ = 1,2US$ assumed).

The increase in module prices will result most probably in unpleasant discussions in the public and in the political arena - at least in Germany.

But there are very good arguments why (i) PV will cope with these problems in a short time and why (ii) it is necessary to continuously increase the efforts in order to develop PV to its full power - as the basis of a sustainable energy system.

In my lecture I will elaborate on four of such arguments.

Statement 1:

Photovoltaic has the potential to supply a quasi unlimited quantity of electricity in a sustainable way.

Since electricity (in conjunction with hydrogen) will become the most important final energy carrier, a future sustainable energy system will have to rely strongly on solar electricity. Furthermore photovoltaic is ideally suited for eradicating energy poverty in developing countries.

There exists a plethora of scenarios showing possible sustainable futures of the global energy system. The scenario shown as an example in figure 4 has been developed by the Advisory Council to the German Government on Global Change, I had the honour to be a member of this panel.

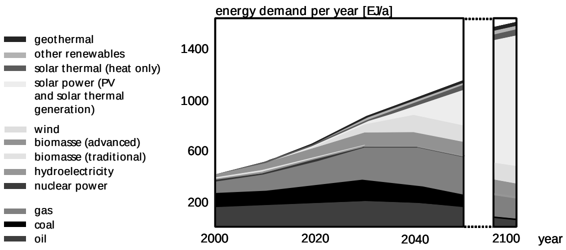

Figure 4: Exemplary Energy Path of the Advisory Council to the German Government on Global Change. This scenario [1] is based on strict sustainability criteria where sustainability is understood in a broad sense.

The scenario is based (i) on efficient use of energy, (ii) the restricted use of fossil fuels including carbon sequestration and, increasingly important, (iii) on solar electricity – mostly PV.

The reason for the long-term dominant role of solar electricity is the fact that solar radiation is the only high quality renewable energy source having a quasi unlimited potential. Wind energy or the energetic use of biomass have – compared with today's energy demand – huge potentials, but eventually these potentials are limited if strict criteria of sustainability are applied (figure 4, [1]).

Thus PV electricity will be on the long run the main basis of a sustainable global energy supply. This statement applies to that part of global energy that is traded on a market.

Though the PV market grows quasi exponentially since several years (figure 1) the contribution of solar electricity is not visible in figure 4 before 2030/2040 where according to the scenario installation rates of TW/a have been reached. From this it becomes clear that we have to guarantee for many years of quasi exponential growth in order to exploit the full potential of solar electricity. This means we can not accept any persistent reduction in today's growth rates.

Statement 2

Strong cost reductions in PV are necessary and feasible.

This may be achieved through higher efficiencies in (i) material exploitation, (ii) in production and (iii) in PV energy conversion. In this lecture I will address the last point only.

The graph in figure 5 is the result of a theoretical analysis of efficiency limits in PV energy conversion. At constant illumination level the maximum efficiency depends on the physical principle and the architecture of the PV device (for example the number of cells in stacked PV devices).

Besides this efficiency increases logarithmically with the concentration of solar radiation – via an increase in the separation of the quasi Fermi levels in the absorber material.

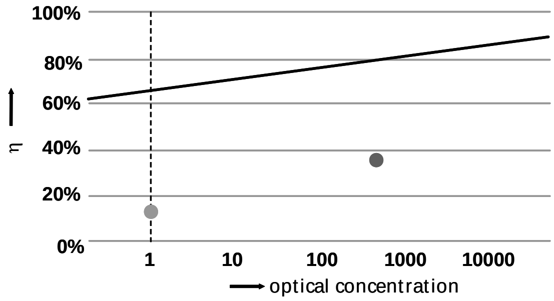

Figure 5: Theoretical limits of photovoltaic energy conversion. The efficiency of PV is shown as a function of the optical concentration of solar radiation (logarithmic scale). Concentration 1 is equivalent to an irradiation of 1 kW/m^2. The radiation characteristics of the sun has been approximated by a black body source of 5 777 K; cell temperature is 300 K.

The dot in the lower left of figure 5 is the value for today's Si cells on the market, the dot in the centre/right part gives the value for the best laboratory triple junction III/V cell (Spectrolab) under an optical concentration of 500.

With this graph I have the intention to show that there is – especially compared with other energy conversion technologies – an impressive large potential for efficiency improvement and most probably for cost reduction in PV.

Statement 3

Photovoltaic is high technology and thus especially suited for regions with high cost of labour and there is not just one PV technology.

This leaves much room for technological innovations, industrial activities and employment in PV. Thus PV offers considerable strategic chances for industry and governments – especially when seen on a long term time scale.

Figure 6 summarises today's available PV technologies. As I see it, in the near future there will be a parallel evolution of silicon wafer, thin film and III/V technologies. There is no evidence that we will have different generations of photovoltaic technologies each following another.

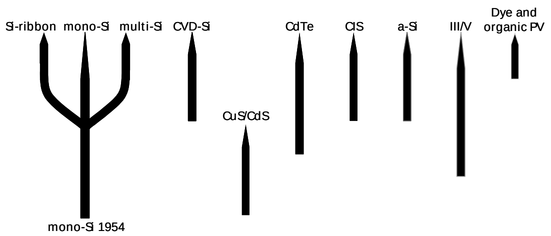

Figure 6: Evolution of photovoltaic technologies. The vertical direction in the graph gives a rough orientation in time. At present wafer Silicon has the lion’s share of the market.

The feasibility of the technologies shown in figure 6 has already been established. In addition to this there is a variety of exciting new ideas concerning photovoltaic energy conversion. Figure 7 shows examples of such conversion paths that are investigated at present in research institution world wide (figure 7). On some of these topics we had excellent presentations this morning, here in Barcelona.

Up and down conversion of photon energy

Multi-bands cells

Quantum well structure

Electromagnetic antenna

Auger excitation

Extraction of hot carriers

Thermophotonics

Figure 7: Compilation of some new principles of photovoltaic energy conversion being today under scientific investigation.

If you consider these examples as being too futuristic please keep in mind that we are talking about 2015 and even 2050. For the near future we should seriously consider e.g. optoelectronics in PV: Multijunction III/V cells operating under an optical concentration of 1000 (figure 8). Assembly of primary and secondary optics, heat sink and contact structures being realised by pick and place robots.

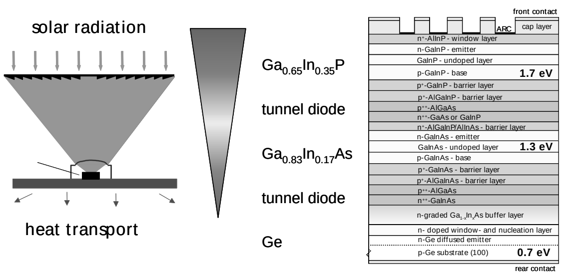

Figure 8: Optoelectronics in PV. Small size PV cells (square millimetres) equipped with primary and secondary (directly above the cell) optics will convert solar radiation under an optical concentration of 1000 or even higher. The semiconductor device including optics and heat sink will be manufactured using optoelectronic technologies. Right side of the figure: A structure of a triple junction semiconductor device for photovoltaic energy conversion. Such structures can be automatically produced on manufacturing machines developed for optoelectronics (MOVPE).

Photovoltaic – ladies and gentlemen – means today and tomorrow high technology.

Statement 4

Photovoltaic is not only semiconductor technology. It generates professional activities and employment in many areas of the broad added-value chain.

This may be seen from figure 9.

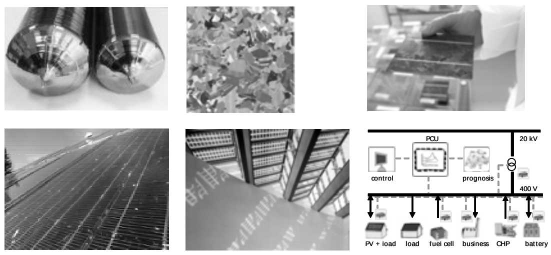

Figure 9: The added-value chain of photovoltaics. Photovoltaic comprises metallurgy, crystal growth, wafering, cell production, packaging and integration into the energy supply scheme - from buildings to grids, the latter including power electronics, information technologies and energy distribution.

These – ladies and gentlemen, dear colleagues - where just 4 arguments showing that PV is both: The basis for a future sustainable energy system and at the same time a great chance for innovative industrial activities.

In order to continue effectively with the activation of the immense potentials of PV it is most important that PV activities will continue to be embedded in long term strategies of our societies. That is: Especially the European Commission and the national governments have to concentrate on this issue in a dedicated way.

In closing I would like to thank once again the prize giving committee, all my collaborators and friends of Fraunhofer ISE and my wife.

REFERENCES

[1] German Advisory Council on Global Change (WBGU), World in Transition - Towards Sustainable Energy Systems, 2003, www.wbgu.de.