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# Solar Cells and Solar Energy

Special Session: Energy

**Solar Cells and Solar Energy**

Prof. Dr. Klaus von Klitzing

Director, Max Planck Institute for Solid State Research, Stuttgart

In this discussion, I will focus on the topic of solar cells and solar energy. I have worked my entire life in the field of semiconductor physics, which is the basis of solar energy technology.

It has been predicted that there will be no life on Earth in 5 billion years. By that time, sunlight will irradiate the Earth directly and unfiltered, which will eliminate life as we know it. In other words, life on Earth is not sustainable on the time scale of billions of years. The question we face, however, is whether life will be sustainable in the next ten, one hundred or one thousand years. Moreover, we should focus on man-made environmental issues, not on natural phenomena. It has also been predicted that, in 5 billion years, thousands of new worlds will exist, so this gives us some time to deal with our environmental challenges, to communicate with beings on other planets, and to transfer our knowledge to other civilizations.

## New Global System of Measurement Units

There is something much more stable than life on earth, and that is the universal language of science. In the past, documented as far back as in the Bible, we used local units based on human dimensions to measure length and mass, such as ell, cubit, foot or grain. However, these measures differed throughout the world.

For the past 150 years, we have used standardized global units based on properties of the Earth to measure time, length, mass etc. For example, we use the rotation of the Earth as a basic time unit and the dimensions of our planet for units of length. However, in just two years' time, we will use a new global system of units that is independent of both humans and the Earth. Starting in 2019, we will have stable, universal units based on fixed values for constants of nature. Because just imagine, if the prototype of the kilogram in Paris were no longer to exist in some billions of years, we would still have a universally defined kilogram based on the fundamental Planck constant.

## Energy: The Driving Force behind (Borrowed) Prosperity

For the purpose of this discussion, let us consider a pragmatic definition of sustainability: To ensure a desirable planet for the next three generations. This is a near-term goal. First, to answer the question of what constitutes a "desirable" planet, we must recognize the crucial role played by sustainable energy. To wit, former UN Secretary General Ban Ki-moon has defined sustainable energy as "The golden thread that connects economic growth, increased social equity and an environment that allows the world to thrive." (Ki-moon, 2014). Energy, preferably electrical energy, is not only the driving force of economic wealth but also a necessity for a decent standard of living in a world with an increasing population. We have been lucky enough so far to have lived in this world of ever increasing energy consumption with growing affluence. But as we now realize, this has been at the expense of future generations. Two-thirds of the world's electrical energy used today is generated by burning fossil fuels (https://en.wikipedia.org/wiki/Electricity_generation). We must now also face the consequence that it will take us only a few more hundred years to destroy the reservoir of coal, oil and natural gas that took more than 70 million years to form. Therefore, the context of time must be an integral part of our sustainability discussions.

## Atmospheric CO2

It has been well established that the CO2 content in our atmosphere has increased from less than 320 ppm in 1960 to more than 400 ppm today, accompanied by a rise in global temperature. We need to curb these CO2 emissions. Although some progress has been made in this respect, if we extrapolate the current trend to the next few decades, there is no chance that atmospheric CO2 can be kept below the limit of 450 ppm, which is considered necessary in order to avoid global warming of more than 2 degrees Celsius by 2100 (https://www.esrl.noaa.gov/gmd/obop/mlo/). This means that radical changes must be made within the next five years.

The problem for some non-scientists, however, is that we cannot actually see $CO_2$, so it is easy to deny its impact on our environment. However, there are special cameras that can capture images of $CO_2$ emissions. We are emitting $CO_2$ into our atmosphere at an alarming rate. Many scientists – even many physicists – do not realize that burning just one liter of gasoline creates 2.33 kilograms of $CO_2$. These are huge amounts we are emitting constantly into our air, and we need to do more to educate the public about these emissions and their impact on the environment.

## Resources for Energy Production

Several natural energy reservoirs exist on our planet, but they have become depleted over time. These natural energy reservoirs include coal, natural gas, petroleum and uranium. In contrast, the amount of solar energy is truly huge. The sun emits more than enough energy to Earth in just one hour to meet our global energy demands for an entire year (http://www.asrc.albany.edu/people/faculty/perez/). All the other natural energy reservoirs are but secondary results of solar energy. It is of course well known that we have the technology to transform solar energy directly into electricity. However, the percentage of photovoltaic energy produced is still very small at less than 0.1% of the world's consumption at the beginning of this century. The excuses are as numerous as they are misguided: photovoltaic energy is too expensive, has no future, etc. Indeed, predictions for the use of photovoltaic energy have been pessimistic, but fortunately, this is changing. Nevertheless, the amount of solar energy being harnessed is still a very low percentage of the available resource. Fortunately, the cumulative photovoltaic capacity has increased exponentially and has always been much greater than predicted by the IEA's (International Energy Agency) World Energy Outlook (Schmalensee *et al.*, 2015). Clearly, we need to increase our production of solar energy greatly in order to take full advantage of this huge resource.

Let us also examine the economic factors involved. The cost per module of photovoltaic cells per Watt has fallen drastically from about $100 in 1976 to just $0.45 in 2016 (https://commons.wikimedia.org/wiki/File:Swansons-law.png). In 2008, more silicon wafers were used for solar cells than for microelectronic devices (Gunawan *et al.*, 2010). In other words, the huge global market for solar cells emerged in this century. More importantly, the costs of photovoltaic cells will soon become competitive with those of coal or natural gas, making them even more interesting from an economic perspective (Shenkleman & Martin, 2017). Therefore, it is only logical that, as the cost of photovoltaic panels has decreased, the global number of solar panel installations has risen accordingly.

## Silicon: The Backbone of Photovoltaic Mass Production

Although various materials are of interest in semiconductor physics, silicon is still the backbone not only of microelectronics but also of photovoltaics. In fact, 90% of the global photovoltaic technology market is covered by crystalline silicon for today's most efficient photovoltaic cells (20% efficiency). However, there are many other, possibly even more successful semiconductor materials such as cadmium telluride (CdTe), copper-indium-gallium-selenide (CuInGaSe) as well as perovskites. In fact, CdTe appears to be better attuned to the solar spectrum, making it a potentially important future candidate for photovoltaic technology. Ultimately, the market price will determine which materials will be successful. Special applications, such as for the aerospace industry, use very expensive semiconductors with a long lifetime known as III-V materials that encompass the entire solar spectrum. For example, three semiconducting materials that together cover the main part of the solar spectrum are gallium-indium-phosphide (GaInP), gallium-indium-arsenic (GaInAs) and germanium (Ge). Scientists are currently developing such high-efficiency, triple-junction solar cells based on III-V materials for the mass market. This technology allows us to concentrate the sun's radiation for record efficiencies of up to 46% (https://en.wikipedia.org/wiki/Solar_cell_efficiency). However, the effort to cover 15% of the global electricity production with solar energy is still in its infancy. To achieve that, we must increase investments into solar energy technology. Fortunately, the rapid introduction of photovoltaics globally is being fueled by the availability of cost-competitive, distributed energy producers. Some analysts predict that photovoltaic installations worldwide will generate 4,000 to 30,000 GW by the year 2050. For comparison, today's photovoltaic installations worldwide generate less than 300 GW.

Renewable electricity sources are not yet able to meet the growing global power consumption. Even if we increase the current amount of photovoltaic energy, we will not keep pace with future demands.

## Conclusion

In conclusion, primary and secondary renewable energy sources such as solar, wind and biomass will play a central role in the future energy transition. Ultimately, the greatest promise lies in combining large-scale solar power plants and small-scale, building-integrated solar energy generators (Perez, 2010). Clean energy technologies are already cheaper than traditional sources such as coal, and the economy is always a major driving force. Therefore, we can safely predict that clean energy has a bright future.

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