Organic solar cells

Advantages, possibilities and limits of bulk heterojunction solar cells

Content

Motivation

Through the ages mankind needed more and more energy. At first for cooking and heating and later humanity used energy for all their manufacturing facilities, electric machines, lights and gadgets. Today the electricity consumption of the whole world is just about 18.921 TWh (1). To sustain all people with electricity, today million tons of coal, oil and gas are burned with the exception of the 13% of electricity produced by water, wind, nuclear and geothermic power (2). But how long can the non-renewable resources of the earth satisfy our unappeasable hunger? Oil, gas and coal will not last forever and it takes a number of years until new fossil fuels are formed.

Nevertheless the question is not how long will these sources still be readily available, finding a new source of energy supplying the whole earth with electricity is the task. But where can it be found - a source of energy which is inexhaustible, accessible nearly everywhere and easy to collect?

Every day the sun is rising over the horizon, circumnavigates the world and leaves $1.08 \cdot 10^{18}$ kWh (3) of energy behind. Much more than mankind will need to satisfy its hunger for electricity. It would be enough to convert 0.01% of this daily given energy into electricity to cover the energy consumption of one whole year.

So perhaps the sunlight could be this new source, shining in nearly every region of this earth. And a technology already exists for converting sunlight into electricity: solar cells.

Status quo

Today there are various types of silicon solar cells (SSC) with different costs and efficiency. Poly- and monocrystalline solar cells dominate the market (40% respectively 50% in 2002 (4)), amorphous, multijunction and thin photovoltaic cells branch off the remaining 10%. The overall market volume is about 3000 MWp (2007 (5)) whereby nearly half of this is installed in Germany.

But every type has different advantages and disadvantages. For example, the monocrystalline SSCs have a high efficiency but producing these cells costs a lot of energy and money, whereas gallium arsenide solar cells are extremely expensive but highly efficient, temperature-resistant and resistant against ultraviolet rays therefore they are used in spacecraft applications.

Type	**Subtype**	**Efficiency (in production/laboratory)**	**Costs per kWp**
silicon	monocrystalline (6)	15-20% (p)	3.000 €
	polycrystalline (7)	13-18% (p)	2.000 €
	amorphous	Ca. 8% (p)	
thin (8)	Copper Indium Gallium Selenide	11% (p)	1.000 €
	Cadmium telluride (9)	10% (p)	3.250 €
	Gallium arsenide (10)	30%(p)	50.000 €
Organic (11) (12) (13) (14)	Small molecule	4-8% (l)	
	Polymer solar cells	4-10% (p)	
	dye-sensitized	11% (l)	

Table 1: Efficiency and cost of solar cells (11) (12) (7) the costs per kWp are averaged over the found data.

The new Technology

Beside the well known semiconductor solar cells (15) used and evolved for more than 50 years, a new type of solar cell was developed during the last decade: Organic solar cells (or organic photovoltaic cells, called OPVC).

The difference to semiconductor (mostly silicon) solar cells is the material used to convert the sunlight into electricity. The basis of OPVC is the use of special conductive organic compound (16) with similar characteristics to amorphous semiconductors.

There are different types of OPVC: single layer, bilayer or bulk heterojunction photovoltaic cells and dye-sensitized solar cells (also called DSC) (17).

This assignment will focus on bulk heterojunction photovoltaic cells (BHPC), a technology already used to produce OPVC by an American company called Konarka (18).

Their solar cells consist of two main components: a polymer and a fullerene-like nanostructure combined into an active material called Polymer Blend. In this blend the polymer releases electrons when it is exposed to sunlight and they are escorted by the nanostructures away to an external electronic circuit where the electricity is used or stored (19) (20). To produce the so called Power Plastic® Konarka (and other companies producing this type of OPVC) coats sheets of plastic with the organic material and prints the electrodes with metallic inks (21).

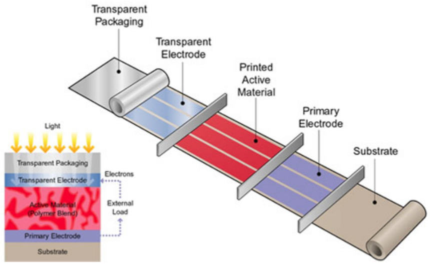

Figure 1: Power Plastic® Layers -
http://www.konarka.com/index.php/technology/our-technology/

Classification in the sustainability framework

Defined by Belz and Peattie (22) sustainable products satisfy customer needs while they represent a significant improvement with respect to social and environmental performance during the whole life cycle in comparison with existing competing or conventional products.

Customer satisfaction

OPVCs produce direct current which can be transformed with an inverter into alternating current satisfying the demand for electricity. And with this electricity mankind may satisfy different wants, for example producing food, cleaning clothes, light representing the needs for subsistence and protection.

Dual Focus

Providing energy with a recyclable product produced on very low energy costs and without toxic substances, OPVCs are an ecological product. One may also argue that they are touching also social aspects because they have the opportunity to provide cheap energy all over the world and especially in third world countries which have a lot of sun. And they enable them to produce enough energy in every little village independent of an expensive connection to the grid or dirty diesel generators through autarchic self-supply.

Life-cycle orientation

Made out of hydrocarbons (polymers and fullerene) the base for OPVCs is basically crude oil (23). With a view to all the problems around oil production, OPVCs may seem not very eco-friendly. As long they are not produced out of hydrocarbons, which are produced in a sustainable way, the OPVC technology has also some impact on the natural environment.

However, during the production of OPVCs much less energy is used than with the production of silicon or thin solar cells, because these types need high energy during the production.

Because of their small weight and material consumption, OPVCs have a much lower impact on the environment during production, installation and transportation.

And instead of an also energy-intensive recycling process for conventional solar cells OPVCs don´t need that much energy during their recycling whereby due to the short lifetime OPVCs are recycled more often than conventional solar cells.

Significant improvements

Until now the efficiency of OPVCs is lower than those of conventional solar cells (table 1) but once this factor increases above that of the conventional OPVCs they may replace inorganic solar cells due to the price and efficiency.

In the meantime, this technology can be used in areas where inflexible inorganic solar cells cannot be used.

Continuous improvement

Today, the OPVC technology is a sustainable technology but if OPVCs are used everywhere they may become nothing more than standard. But until then there are many different materials on which OPVCs are based so there are many possibilities for increasing the efficiency to the theoretical maximum of 30% (8) and a lot of possible areas, where they can be used. There could be other sources found for the organic material and material with a longer lifetime to reduce the impact of OPVCs on the environment

Competing offers

As already and later mentioned, nowadays OPVCs can only compete with their advantages in flexibility, weight, transparency and recyclability.

To sum it up one can classify OPVCs as a sustainable product albeit with some room for improvement, but the technology of organic solar cells may be classified as a sustainability technology.

Impact on the Nature

There are a lot of studies and papers published concerning the life-cycle of conventional solar cells (24) (25). For example cadmium telluride solar cells have the lowest carbon footprint (15g CO^2-eq/kWh), pollutant emissions (including cadmium) and energy payback time (EPBT = one year) of all current inorganic photovoltaic technologies. (26) Monocrystalline SSC, however, is the technology with the greatest impact on the environment (27) and with 40% of costs for installation and 60% for manufacturing the modules (65% of the module costs are for material) SSCs have huge impact on the environment.

In consideration of the fact that the OPVC technology is very new, there are few studies on the technology of DSC (28) and just one study recently published which proves that the overall used energy is less for organic solar cells compared with conventional inorganic solar cells. (29) (Unfortunately it cannot be read without paying for it.)

According to the fact that the EPBT for DSC is 0.5 to 1 year in Europe (28) one may assume that it is nearly the same for the BHPC while the SSCs have a much longer EPBT between 2 and 12 years.

Assuming the lighter the photovoltaic the lower the installation costs, OPVCs reduce the costs in installation and the minor demand for material reduces the costs and the impact (9).

Despite all this, during the use of every PV system they produce no noise, no toxics and no clime changing emissions.

In contrast to OPVCs the recycling for SSC and thin solar cells is very expensive and dangerous regarding heavy metals (3-5 times higher than normal waste and 35 times higher if thin film solar cells are disposed as hazardous waste (30)) and there is also a study saying that recycling gallium, tellurium, indium and selenium is impossible because it is much too dispersed (11).

Summarizing photovoltaic in general has lower impact on the nature than conventional energy production because it avoids emissions of CO_2, NO_X but it is much more expensive (31) (32). Even if SSCs and thin solar cells are much more ecological than conventional energy sources they still emit heavy metals during production and disposal and costs more material and energy than OPVCs that is why the few existing studies suggest that the OPVCs have a much lower impact on the environment than SSCs or thin solar cells have.

From Innovation to Integration

Market Entry

In the current state of development the OPVC technology is, according to Belz and Peattie (33), a type 2 innovation. It is no new product but a new type of product and reduces the environmental impact of conventional solar cells, but has not changed the habits, neither in production nor consumption.

The first segments for entering the market are those of consumer goods and outdoor poor light and curved or irregular surfaces because today with an efficiency of 4-10% OPVCs only have a chance in areas where the previous technologies could not be adopted: OPVCs are very thin and light so that they could be transported very easily and in combination with clothes or baggage a whole new market for OPVC applications is enabled. For example all portable appliances such as mobile phones, laptops can be recharged with OPVCs on the clothes or on the sleeve of the gadget. Beyond portable use they can be adopted on curved or irregular surfaces such as sunshades or asymmetric roofs and facades.

In consequence of these applications the initial customers for Konarka or other OPVC selling companies can be found in a B-to-B market. Therefore their objectives should be to find companies offering customer solutions which can be developed to much better customer solutions with OPVCs.

Existing Projects

The BHPC produced as PowerPlastic® by Konarka are used in some pilot projects: a transit shelter in Los Angeles and in cooperation with Traveller’s Choice a recharging bag (34). So Konarka already found some B-to-B partner to create a new customer solution and is at this moment engaged in the stage of introduction and has now to diffuse their product from the niche into bigger fields of application.

Possibilities

Once the efficiency increase over 12% and more OPVCs are produced with greater economies of scale producing, buying and using OPVCs will be more profitable. Greater output figures also enables more investments in research to develop OPVCs with a higher efficiency level (20) and based on other sources than oil, while the increasing number of producers causes competition on the market which causes more efficiency in producing and price.

Or as soon as they are made nearly completely transparent they could be used as windows to provide shading and electricity.

The technology of OPVCs may also represent a future function innovation (33) because combined with new types of energy storage this technology enables to produce electricity in a decentralized way without big and unsustainable power plants.

Advantages

Beside all the already mentioned advantages, such as lower impact on nature, less weight, no production in cleanrooms (23) and more flexible, a huge merit of OPVCs is that they produce also a significant amount of electricity in diffused light so that they can extrapolate a much larger scope than conventional solar cells. (10)

The easy production may allow production all over the world, especially in third world countries, where a lot of sun is shining, but the money and knowledge for building factories producing SSC is missing.

Compared to other renewable technologies such as wind, water and biomass photovoltaic systems they have the strongest argument that the sun is shining everywhere, everyday and inexhaustible (at least for the next four billion years (35)).

Limits

As long as OPVCs are produced with using crude oil they cannot be made in the further future and they are not completely sustainable, just if other sources for the hydrocarbons are found OPVCs may change the way in energy production.

They must always be competitive to the thin film technologies and other organic solar cells in terms of price per kWp and lifespan. However, a study by Dennler, Scharber, and Brabec shows that the lower lifetime and the lower efficiency of OPVCs can be compensated by the lower costs for production (36).

In consequence of their advantage of being made out of organic material OPVCs have a much shorter lifespan than SSCs, because the sunlight is also destroying the organic components of the OPVCs. But based on the fact that the OPVC technology is basically the same technology as organic LEDs some studies say that the theoretical lifespan of OPVCs might reach 11 years. (37)

Naturally every innovation has its technical limits: The single layer OPVCs can reach as maximum theoretical efficiency a level of about 30% while a tandem cell may reach a theoretical level of 49% and referring to Dennler, Scharber and Brabec the BHPC may reach maximum practical efficiencies between 20-25% (36) which is not much higher than the current efficiency of multilayer SSCs.

Resistance

But as always if a new technology is entering a market, there may be entry barriers built by customers and competitors. In the case of OPVCs customers will not be the greatest obstacles because OPVCs are cheap, easy to use and have no disadvantages according to the use by customers. As long as the customer sees his benefits by buying a product including an OPVC there might not be huge entry barriers. To replace SSCs in their use as electricity producer on roofs OPVCs producing companies have to dispel the fears and doubts of the customer by pointing out the advantages of OPVCs and offering the same or more service than the SSC producing companies do (38). One possibility might be to commission studies hopefully proving the advantages of OPVCs.

Indeed the existing competitors represented by the producers of silicon-based solar cells and also new market entrants at the start of their development cycle such as e.g. dye-sensitized solar cells will be strong entry barriers for the BHSC. To compete with the other OPVC technologies companies such as Konarka has to point out the advantages of the BHSC: Easier and faster production since exact epitaxy and stoichiometry is not necessary (37).

The silicon photovoltaic market is a very large market: 1.2 billions of Euros in 2007 (5). A new technology with the potential to replace this old one will be opposed by the producers of silicon solar cells for not losing their livings. That is why OPVC-producing companies have to face much pressure by big established companies.

Discussion questions

Assuming that mankind reaches the point that more energy than needed is produced by OPVCs (or maybe other types of solar cells); what about areas with less sunlight or the phases without sun (night or cloudy sky)? How can we transport or store all the energy converted from sunlight? To ensure that everybody always has enough energy, an intelligent or perfectly controlled system must be established that can control the flow of electricity.

Recharging organic solar panels on the clothes, on every house on nearly every surface in our modern world is very nice and convenient, isn´t it? But what about safety? If in everything we use in our everyday life, there are more electronics than in an average calculator these days couldn´t absolutely new problems arise e.g. electric smog, cable fire and accidents we can´t imagine today?

The access to an inexhaustible source of energy is very good, but it also guides mankind to energy consumption habits which are prodigal in a way we cannot imagine today, doesn´t it? If this technology is progressing in the future and dominates almost all other energy production technologies, then mankind might well become accustomed to universally available energy. That however may change the habits in energy consumption and may create huge rebound effects.

If crude oil is replaced by other sources such as e.g. corn to make the OPVC technology more sustainable, could it be possible that with a look to the whole life cycle this technology is not as sustainable as expected?

References

1. Energyconsumtion and production. [Online] 2010. http://www.vgb.org/daten_stromerzeugung.html.

2. [Online] http://en.wikipedia.org/wiki/World_energy_resources_and_consumption.

3. Energy of the sun - not to mention that a lot of energy is reflected by the atmosphere. [Online] http://de.wikipedia.org/wiki/Sonnenenergie.

4. Kristalline Silicium-Solarzellen - Marktanteile. [Online] http://www.fvee.de/fileadmin/publikationen/Themenhefte/th2003/th2003_02_01.pdf.

5. Marketbuzz . [Online] http://www.solarbuzz.com/Marketbuzz2008-intro.htm.

6. [Online] http://www.e2tac.org/News/index.cfm?InstanceID=841&step=show_detail&NewsID=339.

7. [Online] http://web.archive.org/web/20060916084611/http://oregonstate.edu/~ecclese/files/Term+Paper.pdf.

8. [Online] http://www.technik123.com/detail/B0035F6C04.

9. [Online] http://www.fvee.de/fileadmin/publikationen/Themenhefte/th2000-1/th2000-1_01_02.pdf.

10. [Online] http://www.konarka.com/media/pdf/konarka_info_sheet_remote.pdf.

11. Wikipedia Solarzelle. [Online] http://de.wikipedia.org/wiki/Solarzelle.

12. [Online] http://en.wikipedia.org/wiki/Thin_film_solar_cell.

13. [Online] http://en.wikipedia.org/wiki/Cadmium_telluride_photovoltaics.

14. [Online] http://www.nrel.gov/docs/fy05osti/37322.pdf.

15. Theory of solar cell. [Online] http://en.wikipedia.org/wiki/Theory_of_solar_cell.

16. Organische Solarzellen in der englischen Wikipedia. [Online] http://en.wikipedia.org/wiki/Organic_solar_cell.

17. Dye-sensitized solar cells by m. Grätzel. [Online] http://photochemistry.epfl.ch/EDEY/DSC_review.pdf.

18. Konarka at Wikipedia. [Online] http://en.wikipedia.org/wiki/Konarka_Technologies.

19. Mass Production of Plastic Solar Cells. [Online] http://www.technologyreview.com/energy/21574/?nlid=1435.

20. Organic solar cells: An overview. [Online] 2004. http://www.lios.at/Publications/2004/2004-021.pdf.

21. Konarka’s Paradigm-shifting Technolog. [Online] http://www.konarka.com/index.php/technology/our-technology/.

22. **Belz, Peattie.** *Sustainability Marketing, page 154.* 2009. ISBN 978-0-470-51922-6.

23. FAZ online. [Online] 2007. http://www.faz.net/s/Rub0E9EEF84AC1E4A389A8DC6C23161FE44/Doc~E416C2EB17C034549807C4344D3A3B472~ATpl~Ecommon~Scontent.html.

24. [Online] http://pubs.acs.org/doi/pdfplus/10.1021/es071763q.

25. PROGRESS IN PHOTOVOLTAICS: RESEARCH AND APPLICATIONS, VOL. 5, 287. [Online] 1997. http://deepblue.lib.umich.edu/bitstream/2027.42/35191/1/169_ftp.pdf.

26. Study by CENER for First Solar Solar cells. [Online] 2010. http://www.firstsolar.com/Downloads/pdf/SummaryReport_CENER_CdTe_NA.pdf.

27. First Solar Abstract Emmisions of PV. [Online] http://www.firstsolar.com/Downloads/pdf/Abstract_Emissions_from_PV_Life_Cycles_NA.pdf.

28. OrgaPVnet. [Online] 2009. http://isos-2.wikispaces.com/file/view/OrgaPVNet_Roadmap_2009.pdf.

29. Innovations report. [Online] September 2010. http://www.innovations-report.de/html/berichte/energie_elektrotechnik/research_team_assesses_environmental_impact_organic_161920.html.

30. PROGRESS IN PHOTOVOLTAICS: RESEARCH AND APPLICATIONS. [Online] 2000. http://www.calepa.ca.gov/CEPC/2010/AsltonBird/AppAEx7.pdf.

31. [Online] 1999. http://css.snre.umich.edu/css_doc/CSS99-02R2.pdf.

32. Emissions from Photovoltaic Life. [Online] 2008. http://pubs.acs.org/doi/pdf/10.1021/es071763q.

33. **Belz, Peattie.** *Sustainability Marketing, page 139.* 2009. ISBN 978-0-470-51922-6..

34. Konarka Applications. [Online] http://www.konarka.com/index.php/power-plastic/power-plastic-applications/.

35. Evolution of the sun. [Online] http://de.wikipedia.org/wiki/Sonne#Entwicklung_der_Sonne.

36. [Online] 2009. http://www.gfct.fisica.uminho.pt/referenciasfct-2/Ref._1.pdf.

37. Results of a study concerning OPVC . [Online] 2003. http://www.pv-uni-netz.de/img/Jahrestagung2003/uv_4_organische_01.pdf.

38. First Solar Recycling Programm. [Online] http://www.firstsolar.com/Downloads/pdf/Flyer_CollectionRecyclingProgram_DE.pdf.

39. PDF file with statistics by the IEA. [Online] http://www.iea.org/stats/surveys/mes.pdf.

40. worl electricity consumption. [Online] http://www.bine.info/index.php?eID=tx_cms_showpic&file=typo3temp%2Ffcf5c75bae.jpg&width=600&wrap=%3Cdiv%20class%3D%22popup_header%22%3E%3Cimg%20src%3D%22fileadmin%2Ftemplate%2Fimages%2Fpopup_header.gif%22%20alt%3D%22Bine.info%22%3E%3C%2Fdiv%3E%0A%09%09%09.

41. Worl energy consumption. [Online] http://de.wikipedia.org/wiki/Weltenergiebedarf#cite_note-0.

42. Photovaltiac. [Online] http://knightsathome.de/photovoltaik/html/funktion.html.

43. [Online] http://www.tagdertechnologie.rlp.de/fileadmin/Dateien/Downloads/Technologieportal/TagDerTechnologie/Christopher_Roesner.pdf.

44. [Online] http://www.solarnenergy.com/research_file/613173.pdf.

45. [Online] http://user.chem.tue.nl/janssen/SolarCells/Organic%20%20Solar%20Cells%202010.pdf.

46. [Online] http://crg.postech.ac.kr/korean/files/2009_12_am_jskim_end_functional.pdf.

47. [Online] http://www.sciencedaily.com/releases/2006/09/060918201621.htm.

48. A Review of Risks in the Solar Electric Life-Cycle. [Online] 2005. http://www.nrel.gov/pv/thin_film/docs/fthenakis_lca_brussels_nov_05.pdf.

49. Solarserver. [Online] http://www.solarserver.de/solarmagazin//download/farbstoff_solarzellen_solar_report_1109.pdf.

50. BMWi Entwicklung der Energiemärkte. [Online] 2005. http://www.bmwi.de/BMWi/Navigation/Service/publikationen,did=65014.html.

51. BINE . [Online] 2004. http://www.bine.info/hauptnavigation/publikationen/.

52. [Online] 2010. http://www.gsk.de/fileadmin/gsk.de/assets/Veranstaltungen/PDF/Pr%C3%A4sentation_Herr_Deibel.pdf.