Dye Sensitized Solar Cells

Subjects: Energy & Fuels | Engineering, Electrical & Electronic
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DSSCs are functional and efficient even in diffuse light, therefore they can generate electricity in the morning, evening and even indoors. Even as silicon prices fall and silicon-based photovoltaics become cheaper, DSSCs have great potential as they can be used in additional applications such as indoor and diffuse light. With a variety of fields of application, huge quantities of DSSCs could be produced in the future. With low production costs and no necessity for toxic compounds DSSCs are a potential product, which could circulate in the loops of a circular economy.

Keywords: dye sensitized solar cell ; recycling ; non-toxic materials ; circular economy ; healthy energy systems ; sustainability

1. Introduction

In order to reduce the temperature rise of the global climate, energy from renewable sources plays an important role [1]. In this context, interest in dye-sensitized solar cells (DSSCs) is increasing [2]. This technology could be integrated into windows, facades, cars, Internet-of-things devices or used as smart building blocks [3][4]. DSSCs are functional and efficient even in diffuse light, therefore they can generate electricity in the morning, evening and even indoors [5]. Even as silicon prices fall and silicon-based photovoltaics become cheaper, DSSCs have great potential as they can be used in additional applications such as indoor and diffuse light [6]. With a variety of fields of application, huge quantities of DSSCs could be produced in the future. Similar to the price decline in the photovoltaic market, the prices for industrially manufactured DSSCs will also fall [7]. Thinking ahead, this material will eventually end up in recycling processes. Applying the concept of the circular economy, there is now an opportunity to design DSSCs in such a way that they can be easily recycled at the end of their useful life. Since DSSCs have not yet reached the mass market, the potential for holistic design concepts is great. Around 70% of the environmental impact of a product is already predetermined in the design phase [8].

DSSCs with the highest efficiency are using materials like ruthenium, cobalt, silver and platinum [3], which are toxic or scarce [9]. Thus, these DSSCs pose high risk to people working with the cells, the environment in which they will be used and at the end, the toxic waste must be disposed of.

To develop a safe, recyclable and environmentally friendly technology, it is necessary to use only non-toxic materials. The use of toxic materials increases efficiency and stability but hinders recycling. A similar process can be seen today with CdTe cells. CdTe panels have some advantages, such as lower energy consumption in the production process than Si modules, and therefore lower CO_2 emissions. However, cadmium is a very toxic material and if the modules are not recycled or are recycled incorrectly, they pose a threat to human, aquatic and terrestrial life [10].

With a new product that is not yet in mass production, namely DSSCs, we have the opportunity to avoid waste, inspired by the circular economy. In the circular economy, it is important not to use harmful substances and to enable technical products that can be repaired, remanufactured or recycled. In this paper, we will take a closer look at the state of the art of DSSC recycling and show what research is underway to improve the recyclability of DSSCs. To close material loops, as for any other effective sustainable action in life, it is important to start with the end in mind. In this case, it is clear that more DSSCs will be in use in the future and will need to be recycled at the end of their useful life. Therefore, DSSCs must be designed to be non-toxic and to be able to be broken down into materials that are as pure as possible.

2. Using Recycled Material to Build DSSCs

One approach is to use recycled material to build DSSCs. The use of recycled material can reduce energy requirements and costs compared to the procurement of raw materials. For aluminum, energy savings of up to 95% can be achieved [11].

Daut et al. used recycled carbon from batteries for the counter electrode of DSSCs. They used the doctor-blade method to deposit thin homogeneous layers and achieved 0.33 V at an average solar irradiance of 693.69 W/m^2 at 44.4 °C [12]. Nair et al. compared two carbon sources for the counter electrode, pencil lead and recycled carbon from batteries. They concluded that the DSSC counter electrode with carbon from recycled batteries has a higher efficiency than cells with pencil lead [13]. Both options could improve the residual material stream for batteries or nearly spent pencils. However, carbon powder is not expensive and the recycling process of old batteries or pencils could therefore increase the price of future DSSCs. Using pencil lead as a carbon source is common, but does not result in the highest cell efficiencies [14]. Due to its formidable mechanical, optoelectronic, chemical and thermal properties, graphene-based DSSCs could become a sustainable solution [15].

Chen et al. took thin film transistor liquid crystal displays (TFT-LCD) and used the color filter glass to fabricate DSSC. These glasses are coated with indium tin oxide (ITO). Nevertheless, they had to improve the conductivity with copper nanowires. They point out that the conductive glass for a DSSC accounts for 30% of the total cost. With recycled material, costs could be reduced [16]. Ayaz et al. used old telephone screens as counter electrodes for DSSC production. They took the conductive screen, cleaned it and applied carbon to the glass with a candle flame [17].

Another approach by Zhu et al. could be to recover the valuable conductive glass and TiO_2 layer from old cells. In their case, they recycled the FTO TiO_2 glass from perovskite cells. They removed the top layers of the perovskite cell and applied fresh $CsPbIBr_2$ and carbon layers [18]. TiO_2 is commonly used in DSSCs because it is the best trade of between sustainability and efficiency [19]

3. Outlook and Development: Scaling up and Estimation of Recycling Material

While, relating to different studies the most important environmental problems concerning DSSCs are [3][20][21][22][23]: Use of critical raw materials or precious metals: this problem occurs when toxic and rare materials are used to increase cell efficiency. However, it is possible to use non-toxic, abundant materials. Therefore, this main problem can be addressed by designing DSSCs without toxic materials. Performance degradation due to electrolyte stability: the use of solid-state or quasi-solid-state electrolytes based on biopolymers could address this problem. High energy demand for producing transparent conductive oxide (TCO)/glass: This statement comes from life cycle analysis (LCA) with a cradle-to-gate perspective. Cradle-to-gate determines the scope of the life cycle assessment. Here, cradle stands for the extraction of the raw material. Further steps are the transport and processing of the product. Gate stands for the point at which the product leaves the company. In this LCA, all environmental impacts within the scope, from raw material extraction to product completion, were assessed. The impacts thereafter—the transport, the use phase and the disposal or a possible recycling process—were not considered. If it were possible to use recycled glass for DSSCs or even allow recycling of DSSCs, the energy requirement would decrease. A new LCA needs to be calculated to re-evaluate the environmental impact of glass-based DSSCs with a cradle-to-cradle approach. Sustainability aspects related to unsafe waste management: if non-toxic material is used, it is easier to define specific waste management as well as to close material loops and recycle DSSCs.

The main components of DSSCs are presented below to highlight important environmental aspects.

Peng et al. compared the greenhouse gas emissions of photovoltaic technologies and found that DSSCs are still no better than conventional solar cells [24]. However, they conclude that in the future, with higher efficiencies and lower material consumption, DSSCs could outperform conventional solar cells in terms of lower greenhouse gas emissions [24].

Finally, material recovery is becoming increasingly important and, in the case of silicone-based photovoltaics, is mandated by European legislation such as the WEEE (Waste Electrical and Electronic Equipment) declaration [25]. Furthermore, the recovery of critical raw materials through recycling is essential in order to become independent of finite fossil sources. This is particularly true for resource-poor countries such as Germany or Japan.

References

1. Baruch-Mordo, S.; Kiesecker, J.; Kennedy, C.M.; Oakleaf, J.R.; Opperman, J.J. Erratum: From Paris to Practice: Sustainable Implementation of Renewable Energy Goals. Environ. Res. Lett. 2019, 14, 024013.
2. Coverage, R. Dye Sensitized Solar Cell Market Growth Report, 2020–2027. 2021. Available online: https://www.Grandviewresearch.Com/Industry-Analysis/Dye-Sensitized-S (accessed on 19 June 2021).

3. Mariotti, N.; Bonomo, M.; Fagiolari, L.; Barbero, N.; Gerbaldi, C.; Bella, F.; Barolo, C. Recent advances in eco-friendly and cost-effective materials towards sustainable dye-sensitized solar cells. Green Chem. 2020, 22, 7168–7218.
4. Yuan, H.; Wang, W.; Xu, D.; Xu, Q.; Xie, J.; Chen, X.; Zhang, T.; Xiong, C.; He, Y.; Zhang, Y.; et al. Outdoor testing and ageing of dye-sensitized solar cells for building integrated photovoltaics. Sol. Energy 2018, 165, 233–239.
5. Kawakita, J. Trends of Research and Development of Dye-Sensitized Solar Cells. Sci. Technol. Trends 2010, 35, 70–82.
6. Trancik, J.E.; Cross-Call, D. Energy Technologies Evaluated against Climate Targets Using a Cost and Carbon Trade-off Curve. Environ. Sci. Technol. 2013, 47, 6673–6680.
7. van Sark, W.G.J.H.M.; Schoen, T. Photovoltaic System and Components Price Development in The Netherlands. In Proceedings of the 33rd European Photovoltaic Solar Energy Conference and Exhibition, Amsterdam, The Netherlands, 25–29 September 2017; pp. 2866–2869.
8. Rebitzer, G. Integrating Life Cycle Costing and Life Cycle Assessment for Managing Costs and Environmental Impacts in Supply Chains. Cost Manag. Supply Chain. 2002, 127–146.
9. Ehrmann, A.; Błachowicz, T. Solarstrom aus Früchtetee. Phys. Unserer Zeit 2020, 51, 196–200.
10. Vellini, M.; Gambini, M.; Prattella, V. Environmental impacts of PV technology throughout the life cycle: Importance of the end-of-life management for Si-panels and CdTe-panels. Energy 2017, 138, 1099–1111.
11. Kuchariková, L.; Tillová, E.; Bokůvka, O. Recycling and Properties of Recycled Aluminium Alloys Used in the Transportation Industry. Transp. Probl. 2017, 11, 117–122.
12. Daut, I.; Fitra, M.; Irwanto, M.; Gomesh, N.; Irwan, Y.M. TiO2 Dye Sensitized Solar Cells Cathode Using Recycle Battery. J. Phys. Conf. Ser. 2013, 423, 012055.
13. Gomesh, N.; Shafawi, M.; Irwanto, M.; Yusoff, M.I.; Fitra, M.; Mariun, N.; Nair, G. Performance Improvement of Dye Sensitized Solar Cell by Using Recycle Material for Counter Electrode. Appl. Mech. Mater. 2013, 446-447, 823–826.
14. Hölscher, F.; Trümper, P.-R.; Junger, I.J.; Schwenzfeier-Hellkamp, E.; Ehrmann, A. Application methods for graphite as catalyzer in dye-sensitized solar cells. Optik 2019, 178, 1276–1279.
15. Muchuweni, E.; Martincigh, B.S.; Nyamori, V.O. Recent advances in graphene-based materials for dye-sensitized solar cell fabrication. RSC Adv. 2020, 10, 44453–44469.
16. Chen, C.C.; Chang, F.C.; Liao, C.Y.; Paul Wang, H. Copper Nanowires on Recycled Conducting Glass for DSSC Electrodes; TechConnect Briefs: Danville, CA, USA, 2012.
17. Ayaz, M.; Khan Kasi, J.; Khan Kasi, A.; Ali, M. Toward Eco Green Energy: Fabrication of DSSC from Recycled Phone Screen. Open Access J. Resist. Econ. Int. J. Resist. Econ. 2016, 4, 2345–4954.
18. Zhu, W.; Chai, W.; Chen, D.; Xi, H.; Chen, D.; Chang, J.; Zhang, J.; Zhang, C.; Hao, Y. Recycling of FTO/TiO2 Substrates: Route toward Simultaneously High-Performance and Cost-Efficient Carbon-Based, All-Inorganic CsPbIBr2 Solar Cells. ACS Appl. Mater. Interfaces 2020, 12, 4549–4557.
19. Bai, Y.; Mora-Sero, I.N.; De Angelis, F.; Bisquert, J.; Wang, P. Titanium Dioxide Nanomaterials for Photovoltaic Applications. Chem. Rev. 2014, 114, 10095–10130.
20. Parisi, M.; Maranghi, S.; Vesce, L.; Sinicropi, A.; Di Carlo, A.; Basosi, R. Prospective life cycle assessment of third-generation photovoltaics at the pre-industrial scale: A long-term scenario approach. Renew. Sustain. Energy Rev. 2020, 121, 109703.
21. Gong, J.; Liang, J.; Sumathy, K. Review on dye-sensitized solar cells (DSSCs): Fundamental concepts and novel materials. Renew. Sustain. Energy Rev. 2012, 16, 5848–5860.
22. Mozaffari, S.; Nateghi, M.R.; Zarandi, M.B. An overview of the Challenges in the commercialization of dye sensitized solar cells. Renew. Sustain. Energy Rev. 2017, 71, 675–686.
23. Parisi, M.L.; Maranghi, S.; Basosi, R. The evolution of the dye sensitized solar cells from Grätzel prototype to up-scaled solar applications: A life cycle assessment approach. Renew. Sustain. Energy Rev. 2014, 39, 124–138.
24. Peng, J.; Lu, L.; Yang, H. Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems. Renew. Sustain. Energy Rev. 2013, 19, 255–274.
25. EUR-Lex—32012L0019—EN—EUR-Lex. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012L0019 (accessed on 8 June 2021).