ARTICLE IN PRESS

Waste Management xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Global status of recycling waste solar panels: A review

Yan Xu [1], Jinhui Li *, Quanyin Tan *, Anesia Lauren Peters [1], Congren Yang [1]

State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing 100084, China

ARTICLE INFO

Article history:
Received 21 June 2017
Revised 13 January 2018
Accepted 25 January 2018
Available online xxxx

Keywords:
Waste solar panels
Crystalline silicon solar panels
Recycling
Policy

ABSTRACT

With the enormous growth in the development and utilization of solar-energy resources, the proliferation of waste solar panels has become problematic. While current research into solar panels has focused on how to improve the efficiency of the production capacity, the dismantling and recycling of end-of-life (EOL) panels are seldom considered, as can be seen, for instance, in the lack of dedicated solar-panel recycling plants. EOL solar-panel recycling can effectively save natural resources and reduce the cost of production. To address the environmental conservation and resource recycling issues posed by the huge amount of waste solar panels regarding environmental conservation and resource recycling, the status of the management and recycling technologies for waste solar panels are systemically reviewed and discussed in this article. This review can provide a quantitative basis to support the recycling of PV panels, and suggests future directions for public policy makers. At present, from the technical aspect, the research on solar panel recovery is facing many problems, and we need to further develop an economically feasible and non-toxic technology. The research on solar photovoltaic panels' management at the end of life is just beginning in many countries, and there is a need for further improvement and expansion of producer responsibility.

© 2018 Elsevier Ltd. All rights reserved.

Contents

1. Introduction

Solar, as a form of renewable energy, offers many advantages. It is safe, reliable, efficient, and non-polluting, and can be widely distributed. Solar energy—especially photovoltaic (PV) technology—has become a hot topic of global interest. The use of PV power

* Corresponding authors at: Room 805, Sino-Italian Environmental and Energy-efficient Building, School of Environment, Tsinghua University, Haidian District, Beijing 100084, China (J. Li). Room 825, Sino-Italian Environmental and Energy-efficient Building, School of Environment, Tsinghua University, Haidian District, Beijing 100084, China (Q. Tan).

E-mail addresses: jinhui@tsinghua.edu.cn (J. Li), tqytsinghua@foxmail.com (Q. Tan).

[1] Room 825, Sino-Italian Environmental and Energy-efficient Building, School of Environment, Tsinghua University, Haidian District, Beijing 100084, China.

https://doi.org/10.1016/j.wasman.2018.01.036
0956-053X/© 2018 Elsevier Ltd. All rights reserved.

Please cite this article in press as: Xu, Y., et al. Global status of recycling waste solar panels: A review. Waste Management (2018), https://doi.org/10.1016/j.wasman.2018.01.036

has skyrocketed during the past several decades, as part of the global effort to expand clean energy production, and it presents enormous market potential. PV power is expected to produce a significant portion of the energy consumed worldwide, and to become one of the primary global energy sources in this century (Bakhiyi et al., 2014). Developed countries, such as the United States, Japan, and Germany, have launched large-scale PV development plans to stimulate the PV industry (Chi et al., 2014). The global demand for PV power increased from 1 GW (GW) in 2004 to 57 GWs in 2015: an annual growth rate of more than 20%, faster than any other industry, including other emerging renewable energy industries. It has been suggested that PV power will the leading type of new energy development in the future (Luo et al., 2008; Winneker, 2013).

In China, the switch to solar energy may be an even more critical reform. In recent years, with the country's rapid economic growth, environmental conditions have been deteriorating (Duan et al., 2008, 2011). In Beijing, for example, air pollution has become a key issue, as it affects the livelihoods and health of residents. Since the extensive utilization of fossil fuels is one of the main sources of air pollution, the energy industry has a major share of responsibility for solving these environmental problems. Fortunately, though, the trends in energy reform are changing the structure of the energy system, reducing the proportion of coal in power generation, and promoting the development of new energy sources. It has been estimated that the solar-energy resource reserves in China are equivalent to 1700 billion tons of standard coal each year, indicating an enormous potential for the development and utilization of solar energy resources in China (Liu and Zhang, 2010).

Nevertheless, solar panels themselves present another environmental issue: when their useful life is over, they become a form of hazardous waste. Because solar panels have a long service life, the recycling of waste panels was not a concern during their first 25 years of development. A considerable number of the first batch of solar panels installed are now being retired, however, and sound management of end-of-life solar panels is gradually becoming an important environmental issue (Aman et al., 2015). Solar-panel recycling is particularly beneficial for environmental protection, because silicon production is a process of intensive energy consumption, and the energy and cost needed to recover silicon from recycled solar panels are equivalent to only one third of those of manufacturing silicon directly (Choi and Fthenakis, 2010) In addition, the heavy metals lead, tin, and cadmium also predominate in solar panels (Bakhiyi et al., 2014; Galan et al., 2005), and these heavy metals can pollute the environment and pose threats to human health. Therefore, the recovery of waste solar panels can reduce energy waste and environmental pollution (Cucchiella et al., 2015).

In July 2012, the European Union officially revised the waste electrical and electronic equipment (WEEE) directive, adding PV components as discarded electronic devices, so that they will be included under the ten categories of WEEE. Henceforth, solar PV elements will be included in the electronic waste management system, and must be collected and recycled (Bio Intelligence Service, 2011; McDonald and Pearce, 2010).

The newly launched PV waste management regulations require that all solar panels that have reached their end of life—whether from age or because they are damaged and their warranty period has expired—must be properly dealt with (Czanderna and Pern, 1996). Furthermore, all manufacturers of PV panels who supply components to the European market must pay a recycling fee. There are, however, few countries taking action outside the EU, primarily because there is an extremely low volume waste PV panels available for recycling, and the cost of recycling the panels is too high for the process to be cost beneficial (Yamashita et al., 2003; Wambach, 2004). There are only a handful of PV panel processing and recycling facilities around the world, and end-of-life solar PV panel management is a newly emerging field that needs further research and development.

The aim of this study was to provide an up-to-date review of the production and waste generation of solar panels and an outline of the present status of recovery efforts, including policies on end-of-life solar-panel management and recycling. This review also intends to provide a qualitative or semi-quantitative basis to support the recycling of PV panels, and to suggest future directions for public policymakers.

2. Types of solar panels and resources used in components

A typical solar-energy system consists of a solar panel, a solar controller, and a battery or group of batteries. If the output power is 220 V (AC) or 110 V, an inverter is also needed as part of the configuration (Fig. 1). Crystalline silicon solar panels are installed in solar arrays and have great recycling value.

Solar panels, also known as solar or photovoltaic modules (PV modules), work by using the photovoltaic effect of the semiconductor material in the panel to convert solar radiation directly into electrical energy. The solar panel is made up of several solar cells in series; these make up the key component of the system. The function of the battery group is to store the energy emitted by the solar panel when it is illuminated so that it can be supplied to the load at any time. The function of the controller is to automatically prevent overcharge of the battery. The function of inverter is to convert the direct current into alternating current.

Solar panels can be classified into three generations: (1) Crystalline silicon (monocrystalline or multi-crystalline); (2) thin film (amorphous silicon, cadmium telluride, copper indium gallium selenide - CIGS); and (3) concentrator photovoltaics and emerging technologies (CPV solar panels, dye-sensitized solar panels, organic solar panels, and hybrid panels). Since monocrystalline and polycrystalline silicon panels have higher conversion efficiency than thin film, they are presently (and will likely remain) the most widely used commercial solar-panel materials. Up until 2012, crystalline silicon panels accounted for about 90% of the global PV market, while third-generation solar panels have not yet been commercialized on a large scale.

Solar panels are the base power generation units of a solar energy system, and can be independently used. A typical panel includes an aluminum (Al) alloy frame, tempered glass, a battery piece, EVA (ethylene/vinyl acetate copolymer), and a backboard (TPT, Topotecan Hydrochloride) (Fig. 2) (Yin and Hao, 2009).

Tables 1 and 2 detail the PV panel composition and recyclable elements. After disassembly and extraction, the weight of the various resources from a typical solar panel is as follows: glass 54.7%, Al 12.7%, adhesive sealant 10%, silicon 3.1%, and other 19.5% (Cheng and Wang, 2007; Miles et al., 2005).

It can be seen that Al and glass account for a large proportion of PV panels, indicating that the loss of potentially reusable resources occurs across all types of PV panels. The loss of rare metals, in particular indium, gallium and germanium, is another effect of the non-recirculation of PV panels, which contain all of these rare metals. Indium is present in amorphous silicon and copper indium gallium selenide panels. Gallium is present in copper indium gallium selenide, concentrating photovoltaic (CPV) panels and emerging panel technologies. Germanium is present in amorphous silicon, concentrating photovoltaic (CPV) panels, and emerging panel technologies. While these rare metals account for only 1 percent of the PV panel volume, their value is significant.

After the recycling of PV panels, products can be obtained from reprocessing the components making up the Al frame, the silver

Please cite this article in press as: Xu, Y., et al. Global status of recycling waste solar panels: A review. Waste Management (2018), https://doi.org/10.1016/j.wasman.2018.01.036

Download English Version:

https://daneshyari.com/en/article/8869866

Download Persian Version:

https://daneshyari.com/article/8869866

Daneshyari.com