Life-Cycle Environmental Impact of Thin-Film Silicon Solar Cells

Abstract: Photovoltaic, or solar electricity, is a promising renewable energy technology that is rapidly becoming more viable for widespread use. Ongoing technological improvements in the solar cell industry continue to enhance performance and reduce costs. However, like any industrial product, photovoltaic panels are also associated with certain environmental impacts.This paper addresses major environmental concerns related to solar PV systems, including the energy required for their manufacture (especially photovoltaic cells), end-of-life management, and the use or generation of toxic and other potentially harmful materials during production. Due to advancements in cell processing technologies and PV panel manufacturing, energy payback times have decreased significantly and now typically range from 2 to 5 years, with thin-film technologies at the lower end of this range.For silicon-based technologies, there are clear opportunities to further reduce energy input, and an energy payback time of about one year may be achievable in the near future. This study focuses on the negative environmental impacts throughout the entire life cycle of thin-film solar cells, from production to final disposal.

Keywords: Photovoltaic, Environmental Impact, Energy pay-back.

1. Introduction:

Photovoltaic (PV) technologies have distinct environmental advantages for generating electricity over conventional technologies. The operation of photovoltaic systems does not produce any noise, toxic-gas emissions, or greenhouse gases. Photovoltaic electricity generation, regardless of which technology is used, is a zero-emissions process.

However, as with any energy source or product, there are environmental, health and safety (EHS) hazards associated with the manufacture of solar cells. The PV industry uses toxic and flammable-substances, although in smaller amounts than many other industries, and use of hazardous chemicals can involve occupational and environmental hazards[1]. The most significant environmental, health and safety hazards are associated with the use of hazardouschemicals in the manufacturing phase of the solar cell and improper disposal of solar panels at the end of their useful life.

In this paper our potential concernof discussion is the energy required in the whole PV life-cycle and environmental impact of toxic & other potentially harmful materials used or created in the production of PV panels/cells.

2. Life-Cycle Energy Utilization & Environmental Performance of PV Panels:

The environmental life cycle assessment (LCA) of an energy technology considers the impact analysis of all stages of production from "cradle to grave," that is, from fuel production to decommissioning (Figure 1). In the case of PV energy, the stages are shown in Figure 1as

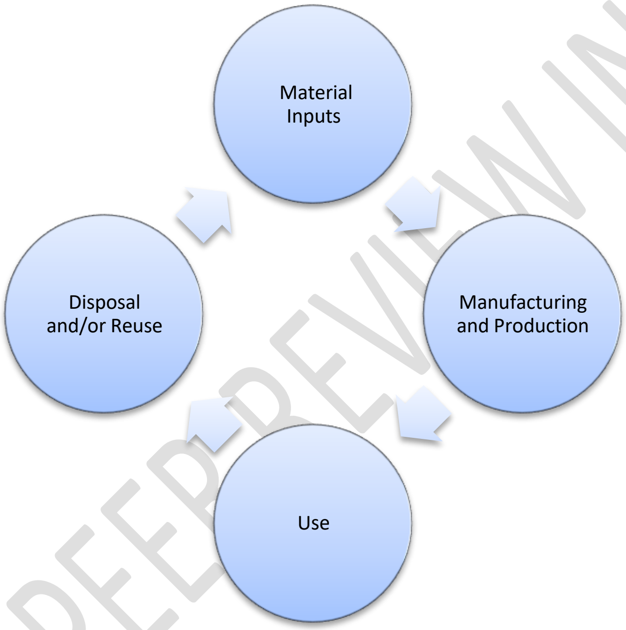

Figure 1: Life-cycle Assessment of PV panels

This cycle starts with material input stagethat consists of the extraction and processing of raw materials that are then used inthe production of solar panels. In manufacturing stage toxic & other potentially harmful materials are used and some hazardous by-products which are released to the air. Installation and use of PV panel stage has minimum environmental impact on the other hand last stage proper decommissioning and recycling of solar panels both ensures that potentially harmful materials arenot released into the environment and reduces the need for raw materials.

2.1 Raw material extraction and refining for solar panels

Crystalline silica is the primary raw material (assand or quartz) input for the manufacture of monocrystalline solar panels.The extraction process varies bylocation, but typically involves some combination of crushing, milling, washing, andscreening to separate the crystalline silica particles from other minerals and impurities and to achieve the desired grain size[2] called silica sand. Upgrading silica sand to metallurgical grade silica to finally polysilicon is subjected to distillation process.

Impacts: This process involves multiple potentially hazardous materials and byproducts that without propersafeguards can pose a significant risk to human and environmental health. Chlorosilanes and hydrogenchloride are toxic and highly volatile, reacting explosively with water. Chlorosilanes and silane can alsospontaneously ignite and under some conditions explode[3]. Silicon tetrachloride can cause skin burnsand is also an eye and respiratory irritant.[4]

2.2 Manufacturing and assembly of solar panels

Solar cells are made by transforming polycrystalline structure to ingots then it is sliced into thin wafers. Next, a textured pattern is imparted to the surfaceof the wafer in order to optimize the absorption of light. The wafer is then subjected to high temperaturesin the presence of phosphorous oxychloride in order to create the physical properties required to produceelectricity. Next an anti-reflective coating of silicon nitride is applied to the top surface of the cell tominimize reflection and increase efficiency of light absorption. Finally, metallic electrical conductors arescreen printed onto the surface wafer to facilitate the transport of electricity away from the cell.[5]

Impacts: Silicon panel production can include fluorine, chlorine, nitrates, isopropanol, sulfur dioxide, nitrogen oxide, carbon dioxide, silica particles, echants, acids and solvents, some of which are considered to pose acute and/or chronic hazards to occupational safety[6]. Individual solar cells are typically soldered together with copper wire coated with tin. Some solar panelmanufacturers utilize solders that contain lead and other metals that if released into the environment canpose environmental and human health risks.

2.3 Installation and Use

Installed silicon-based cells pose minimal risks to human health or the environment according to reviewsconducted by the Brookhaven National Lab and the Electric Power Research Institute[7].

Impacts: Solar cells require very little maintenance, though they can be difficult to repair when maintenance is needed due to the risk of electrical shock.

2.4 Disposal and/or Reuse

The outer glass cover constitutes thelargest share of the total mass of a finished crystalline photovoltaic module (approximately 65%), followedby the aluminum frame (~20%), the ethylene vinyl acetate encapsulant (~7.5%), the polyvinyl fluoridesubstrate (~2.5%), and the junction box (1%). The solar cells themselves only represent about fourpercent (4%) of the mass of a finished module.[8]

The amount of waste generated by retired panels is currently very small. By 2030, this developing industry will produce a growing PV waste stream. Proper decommissioning and recycling of solar panels both ensures that potentially harmful materials arenot released into the environment and reduces the need for raw materials.

3. Energy Pay back of PV Systems:

Producing electricity with photovoltaic (PV) emits no pollution, produces no greenhouse gases, and uses no finite fossil fuel resources. These are great environmental benefits, but just as we say that it takes money to make money, it also takes energy to save energy. This concept is captured by the term "**energy payback time (EPBT)**," or how long a PV system must operate to recover the energy—and associated generation of pollution and CO_2—that went into making the system in the first place [9].The intent is to recycle the materials, particularly the toxic materials, into new products. This approach reduces the potential for release of toxic materials into the environment and reduces the quantity of new resources that must be obtained.

Two parameters determine the EPBT: (1) how it is producedand (2) how it is implemented. The energy needed toproduce a product (specific energy) includes both theenergy consumed directly by the manufacturer duringprocessing and the energy embodied in the incoming raw.Implementation refers primarily to location, whichdetermines the solar insolation and therefore the electricaloutput of the PV panel, but could extend to installationdetails (fixed tilt or tracking, grid-connected or stand-alone,etc.) or balance of system ("BOS") requirements such asmounting structure, inverter, or batteries.

Energy Payback Time = $(E_{mat}+E_{manuf}+E_{trans}+E_{inst}+E_{EOL}) / (E_{agen}-E_{aoper})$ [10]

where,

E_{mat}: Primary energy demand to producematerials comprising PV system
E_{manuf}: Primary energy demand to manufacture PV system
E_{trans}: Primary energy demand to transportmaterials used during the life cycle
E_{inst}: Primary energy demand to install the system
E_{EOL}: Primary energy demand for end-of-life management
E_{agen}: Annual electricity generation in primary energy terms
E_{aoper}: Annual energy demand for operation and maintenancein primary energy terms

Palz&Zibetta [11] reported payback time of less than two years for polycrystalline ormulticrystalline ("mc-Si") modules. Keoleian& Lewis [12]focus on amorphous silicon ("a-Si") thin films, providingsome good data and a comprehensive approach, but appearto overstate the 2-7 year payback time (they combineprimary energy input and electrical energy output), andseem to have an arithmetic error (“best available” total isless than the “low” estimate). Aulich[13] provides usefuldata for raw materials use and alternate silicon productionand wafering processes as well as potential module designs,yielding energy payback of 8 years for the then-currenttechnology, with estimates for all-plastic modules withvarious silicon sheet casting methods, all below 2 years.

All air emissions are routed to pollution control equipment and covered under a Department of Environmental Quality (DEQ) air permit. All wastewater is treated and monitored prior to discharge under a DEQ water permit.Recycling technologies for reusing silicon from solar cells (from production waste or after module decommissioning) are not yet commercially available in the United States. According to the European Photovoltaic Industry Association and PV Cycle, it will take 1/3 of the energy to make a solar panel from a recycled one rather than using new materials, such as silicon [14]. End-of-life management strategies are being developed by the PV industry to recover silicon, glass, EVA foil and aluminum from solar panels. Currently, some panel manufacturers are harvesting silicone from recovered computer chips.As the PV industry vigilantly and systematically approaches these issues and mitigation strategies, the risk to the industry, the workers, and the public will be minimized.

4. Conclusion:

In this paper we have studied energy consumption and material used (or byproducts) in the whole life of a PV system. The manufacture of photovoltaic modules uses some hazardous materials which can present health and safety hazards, if adequate precautions are not taken. Routine conditions in manufacturing facilities should not pose any threats to health and the environment. Such hazards arise primarily from the toxicity and explosiveness of specific gases. If we choose safer technologies, processes, and materials, better use of materials, and by employee training, safety procedures and follow some quality parameters, its negative impacts is minimized.For silicon technology which is most developed technology is a clear prospects for areduction of energy input exist, and an energy pay-backof 1 year may be possible within a few years. Our further work is to optimized each stage of life cycle of PV system and calculate energy payback time in India. So the life cycle of photovoltaics starts from the extraction of raw materials(cradle) and ends with the disposal (grave) or recycling and recovery (cradle) of the PV components.

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