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A comprehensive review of the impact of dust on the use of solar energy: History, investigations, results, literature, and mitigation approaches

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ABSTRACT

The energy delivery of a solar-energy system is generally associated with the sun's available irradiance and spectral content, as well as a variety of environmental and climatic factors and inherent system and component performances. However, other external factors relating to geographical location and conditions can have even greater impacts on system performance. Among these, soiling is a commonly overlooked or underestimated issue that can be a showstopper for the viability of a solar installation. This paper provides a comprehensive overview of soiling problems, primarily those associated with "dust" (sand) and combined dust–moisture conditions that are inherent to many of the most solar-rich geographic locations worldwide. We review and evaluate key contributions to the understanding, performance effects, and mitigation of these problems. These contributions span a technical history of almost seven decades. We also present an inclusive literature survey/assessment. The focus is on both transmissive surfaces (e.g., those used for flat-plate photovoltaics or for concentrating lenses) and reflective surfaces (e.g., mirrors or heliostats for concentrating power systems).

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1. Introduction

Renewable energy technologies are a focus for meeting current concerns regarding energy security, the environment, and global climate change in developed and developing nations. Among these clean-energy approaches, solar technologies continue to grow in residential, commercial, agricultural, and industrial applications. For electricity generation, photovoltaic (PV) and concentrating solar–thermal power (CSP) systems are the main technologies used to convert the sun's abundant radiation. Design of these solar-energy systems encompasses wide-ranging material science and engineering, as well as innovative approaches to maximize system performance and lower cost. For both PV and CSP, the sun's electromagnetic radiation must interface (via transmission or reflection) with an intermediate surface before the energy can be transformed into useful energy. For PV modules, this intermediate surface is typically a glass or polymer module cover or concentrating lens; for CSP, highly reflective mirrors redirect light onto a central focal point. Research has been directed primarily to improve the components of the system. Fig. 1 shows one indication of the success of this research investment—the improvement of solar-cell conversion efficiencies over time. These improvements, some of which are only fractions of a percent from device to device, have been foundational in lowering the costs of the PV system through better area utilization and balance-of-systems investments.

A substantial amount of time and money have been invested to bring solar-system performance to its current credible position and to ensure reasonable system and component reliability (e.g., encapsulations commensurate with 30-year lifetimes, developing qualification tests and accelerated-lifetime testing procedures). However, far less time and money have been invested in addressing externalities that can be showstoppers for technology deployment. One such externality not generally considered in deploying and operating most solar systems is the impact of sedimentation (i.e., dust or dirt particles) on intermediate or exposed surfaces. Dust inherently disrupts the intended function

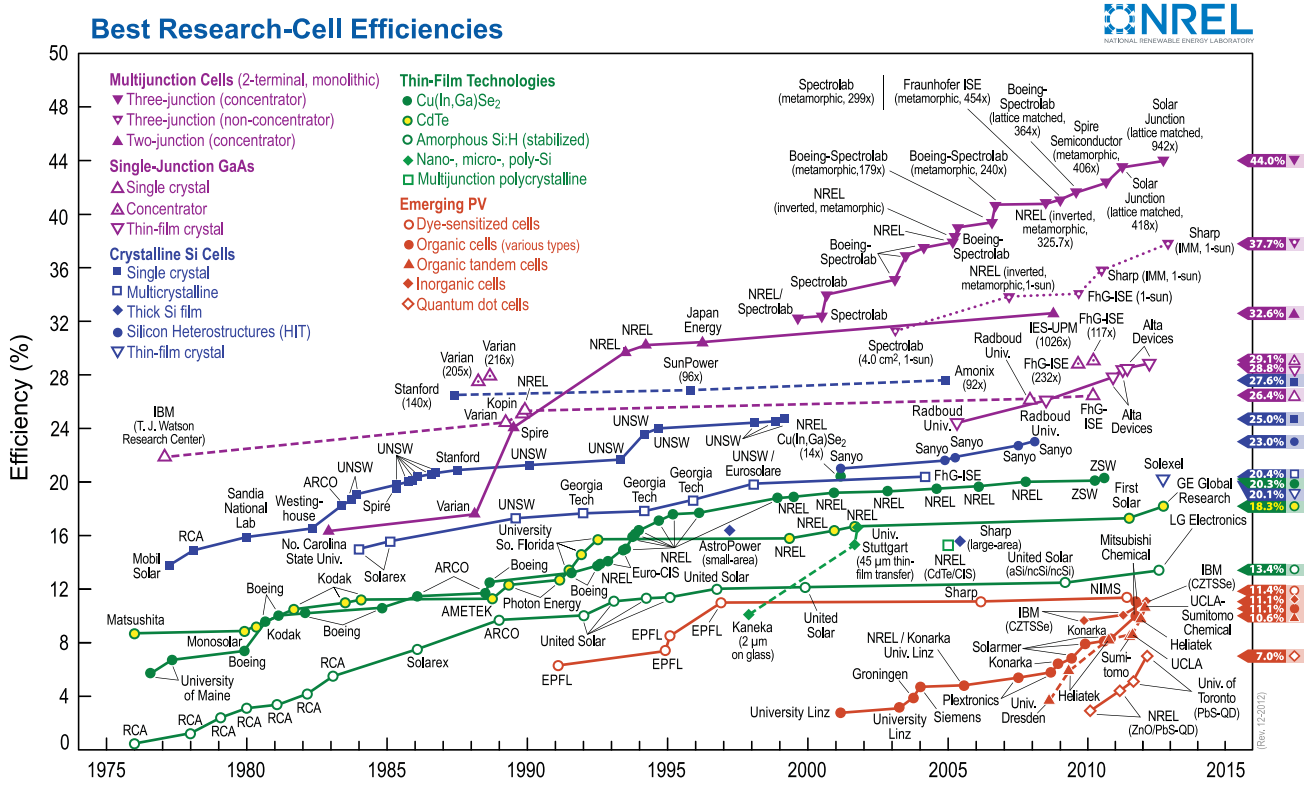

Fig. 1. Research solar cell efficiencies for various technologies measured under standard conditions. This chart has been maintained by L.L. Kazmerski at the National Renewable Energy Laboratory since 1984. Because progress continues at a rapid pace, this figure represents a snapshot of the status in March 2013. The reader is referred to www.nrel.gov and http://en.wikipedia.org/wiki/Solar_cell for the latest version.