diminished. Given the small amount of PV generation capacity in service today relative to other electric generation capacity, the primary concern for energy payback is in long-term energy planning in relation to ecological impact.

The issue of energy payback has been examined quantitatively, and a good bibliography is given in [6]. Energy payback is determined by the four basic factors mentioned below:

- The design of the PV system, including all components
- The location of the system
- The life of the PV system
- The portion of the manufacturing energy-consumption chain included in the payback.

System design determines the system conversion efficiency and system power level, as well as defining the energy content of the hardware. The system location determines the incident energy for the system, which, coupled with the system life, determines the total energy delivered by the PV system. The total energy content of the PV system depends on just how far back in the energy chain the analysis goes. For example, does the chain go back to the mining, transportation, refining, and fabricating of a material, and include every piece of equipment used at every link of the chain? In most cases, PV material energy content is based on prior studies of the energy content of basic materials. Special considerations are sometimes incorporated; for example, much of the crystalline PV production is currently based on using scrap-refined Si from the microelectronics industry, so it may be reasonable to ignore the energy content of the scrap material.

In a summary of energy payback studies, the US National Renewable Energy Laboratory (NREL), states that "(E)nergy payback estimates for rooftop PV systems boils down to 4, 3, 2, and 1 years: 4 years for systems using current multicrystalline-silicon PV modules, 3 years for current thin-film modules, 2 years for future multicrystalline modules, and 1 year for future thin-film modules." These data assume a 30-year life. Multicrystalline modules have a longer energy payback because they have a much larger content of silicon than thin-film modules. Shorter payback for future modules is predicated on improved manufacturing processes and higher efficiencies.

NREL credits these results to the Dutch researcher Erik Alsema [7]. His data are based on estimates of 600 kWh/m^2 for the near-future, frameless, single-crystal silicon PV modules and 420 kWh/m^2 for multicrystalline modules. With a 12% conversion efficiency and a solar insolation level of 1700 kWh/m^2/year, Alsema calculated the 4-year payback for current multicrystalline modules. The future payback of 2 years for multicrystalline modules was based on a 14% efficiency and solar-grade silicon feedstock.

For thin-film modules, amorphous-silicon paybacks are a good proxy for all material systems (including copper indium diselenide, cadmium telluride) because the major energy content is in the substrate, usually glass, and the deposition process plus other facilities. The films are so thin that they have relatively little energy content [8].

Knapp and Jester [6] examine the energy payback for both actual copper indium diselenide (CIS) and single-crystal silicon processes and modules produced using measured data. The data that were collected from plants operated by Siemens Solar Industries and reported in [6] assume that the CIS plant operated at capacity. Energy content of