production equipment, production facilities, and transportation of goods to and from the facility were excluded from the result. Using a solar insolation of 1700 kWh/m^2/year, and assuming an 80% correction for the system losses, the single-crystal silicon module had an energy payback of 4.1 years and the CIS module's payback was 2.2 years.

Given the predicted energy paybacks of, say, 1 to 5 years for PV systems, and their life of up to 30 years, payback is not a negligible factor in the overall energy-planning process, but neither is it a prohibitive one. Gradual improvements in conversion efficiency and improvements in manufacturing techniques can further reduce its impact over time.

The literature that addresses energy payback also addresses the contribution of PV systems in reducing greenhouse gases [7, 8]. "An average US household uses 830 kWh of electricity per month. On an average, producing 1000 kWh of electricity with solar power reduces emissions by nearly 8 pounds of sulfur dioxide, 5 pounds of nitrogen oxides, and more than 1400 pounds of carbon dioxide. During its 28 years of clean energy production, a rooftop system with 2-year payback and meeting half of a household's electricity use would avoid conventional electrical plant emissions of more than half a ton of sulfur dioxide, one-third of a ton of nitrogen oxides, and 100 tons of carbon dioxide." (Though not stated, we assume these comparisons are of solar versus coal-fueled generation.) Again, if the cost of removing these from the conventional emissions is quantified, the cost saving can be included in an economic assessment.

21.4 PROSPECTS FOR THE FUTURE

Photovoltaic cells, modules, and systems have undergone intensive development in the 25 years immediately prior to the twenty-first century. Significant improvements in performance and reductions in cost per unit area have been made. The variety of PV cells and module technologies commercially available or under development has expanded greatly, although crystalline-silicon technology still predominates. Cost-effective applications that capitalize on the unique characteristics of PV systems have been implemented. Many other applications have been installed that benefited from subsidies from utilities, government, or economic-development institutions. A lot of progress has been made, and yet PV supplies only a tiny fraction of the electric generation market.

A recent survey [9] by *Photon International* magazine puts the annual worldwide production of Photovoltaics at 401.4 MW_p in the year 2001. There are about 59 PV module manufacturers worldwide. However, the industry has lost more than US$3 billion over its first 25 years, according to the President and CEO of Siemens Solar in 1998[10]. He further states that two-thirds of the industry is still dependent on some kind of subsidy. Europe, Japan, and the United States each supply major portions of this production. The corporate landscape has been in a constant state of change over these years. Many small companies started up and a few large corporations entered the business. Many of the smaller firms have been absorbed by large corporate conglomerates, but a few have managed to stay in the business and grow. In recent years, some of the world's major corporations have become major players in the PV industry. The top ten producers in 2001 were listed as follows [9]:

1. Sharp (a major Japanese electronic-equipment maker, their solar cells are primarily integral to electronics products) 74.0 MW_p