cost Si modules. The most costly GaAs technology (SJ/GA-SC), even at its highest projected efficiency of 30%, has an LEC of $0.192/kWh compared to the LEC of the Si technology of $0.142/kWh. The least-costly GaAs technology (TJ/Ge-PC) has an LEC of $0.118/kWh at its highest efficiency of 35%, which is less than the Si LEC. The slightly more costly TJ/GA-SC technology still has a lower LEC ($0.124/kWh at 35%) than the Si module, and this GaAs structure using the single-crystal wafer is more likely to achieve the 35% efficiency than the polycrystalline wafer cell.

21.3 ENERGY PAYBACK AND AIR POLLUTION REDUCTION

PV systems convert the free solar energy resource into valuable electric energy. However, it has long been noted that energy is consumed in the manufacture of PV conversion hardware. That is, there is an energy cost to produce energy. The mining, refining, and purification of semiconductor materials is energy intensive, and energy is consumed in the manufacture of all the other materials in a PV system, such as glass, steel, aluminum, copper, and plastic. In addition to the energy content of the materials incorporated directly in the module, support structures, and balance of system (BOS) components, there is an energy content in the equipment that produces all the PV system components. Energy is also consumed in transporting and erecting a PV system at its operating site. During the life of a PV system, usually taken as 20 to 30 years, energy is produced as a return on the energy "invested" in its creation. The long-raised question is: how much more energy does the PV system generate than it takes to produce it; or, is there a net energy benefit to society from PV systems? The answer is usually stated as "energy payback," which is the number of years that is required to repay the energy content of the PV system with its delivered electricity. Energy payback for PV systems, measured in years, should ideally be a small fraction of the system life in years. In fairness to PV, it should also be noted that fossil energy systems, in addition to the energy consumed as they operate to produce electricity, also have an energy content in their power-plant hardware. In addition, the fuel itself has an energy content associated with the exploration, development, recovery, and transportation to the generation site. Thus, the terms of comparison for energy payback between PV and other systems need to be carefully defined if they are to be meaningful.

The energy-payback question needs to be differentiated from whether a PV system pays for itself economically (financially), which is a primary subject of this chapter. The question of economic benefit is adequately answered when the cost of all materials, equipment of production, and capital are accounted for. These costs include the cost of the energy content of all the elements of the system. Given that economic criteria are met, the energy payback question is essentially an ecological one; that is, does the creation of PV systems that generate substantially more energy than is consumed to produce them represent a wise use of fossil resources? A related issue is the reduction in greenhouse gases that results from the generation of electricity with PV rather than with fossil-fuel-based generation. If governments impose financial penalties on fossil generation or give credits for solar generation, then financial benefits can be introduced into the economic evaluation. To a degree this is implicit in the process when, for example, the cost of exhaust scrubbers for fossil plants is included in the economic comparison. Moreover, if solar energy is the source for producing PV systems, the ecological consequences are