base-case conversion efficiency of 19.2%. Inherent in the comparison is also the difference in solar insolation applicable to the two technologies.

The required module prices in Figure 21.5 show a significant overlap of all of the cell technologies except Czochralski, which is consistently higher than the others. It is clear that the module-price, in $\$/W_p$, comparison among any of the four less-expensive modules depends greatly on the efficiency achieved. A horizontal line representing, for example, $\$1.20/W_p$ corresponds to about a 9% efficient single-junction amorphous module, but requires about 12% efficiency for the tandem-junction amorphous module, because the latter is more expensive to produce. The same rationale applies to the dendritic web and concentrator modules. The module price range for the Czochralski single-crystal wafer cells does not overlap the other cells, and, for the input data used in the study, it would always be more costly than the others. In hindsight, single-crystal and polycrystalline cells continue to be the most prevalent commercial technology, which perhaps is due to their having achieved more of their performance potential in volume production than have the other technologies. The wafer-cell technologies have simplicity on their side, even at the disadvantage of higher silicon use.

21.2.3.2 Cost of electricity for utility-scale PV plants

A study by the EPRI [4] encompassed both manufacturing-cost modeling and financial analysis for utility-scale PV plants. The study included three systems: a heliostat field focused on a central receiver incorporating a water-cooled silicon-cell array, a field of Fresnel lens concentrator arrays using silicon cells, and a field of fixed-tilt flat-plate module arrays using CIS cells. Brief results of the Fresnel system are given here to illustrate module-price analysis and system-cost development. Total energy costs for all three plants are also given later to illustrate the economic analysis for the three systems.

An extensive design study defined a 50-MW Fresnel system, and included specifications for a 500X Fresnel concentrator module having 48 Fresnel lenses per module, each lens being about 45-inches square with one back-contact Si cell mounted below it. A glass secondary lens was mounted between the Fresnel lens and the cell. The cell efficiency was taken as 27.4%, and module efficiency as 20.7%. Each cell had a passive heat dissipator on the back surface of the assembly. The basic module structural element was a molded plastic box supporting 4 cell/lens units, and 12 of these were assembled into a module (i.e. 48 cells/module). Sixty of these modules were mounted on a tracking structure to form an array. The total array field had 3390 arrays and the plant covered 700 acres.

Manufacturing of the cell and module assembly was modeled with the STAMPP program described previously. It was assumed that the modules would be produced over two years. The Stanford Advanced Back Contact cells were fabricated on 150-mm silicon wafers using conventional cell-fabrication processes. Table 21.4 summarizes the results of the module-cost modeling for a base case, whose results were input to the plant cost computation. The top section of the table shows some basic operating and financial parameters for the module business, and gives the computed module required price as \$320.08 each (1990\$), or $\$1.30/W_p$. Such a cost was indeed optimistic for the time the study was conducted, but it did represent a relatively high annual production volume. A significant amount of automation was employed, especially in the assembly of the module. A breakdown of module cost (taken from the income statement of the business) is shown in