technologies. Silicon requirements vary significantly with the choice of a cell technology and its associated cell-fabrication process. Cell-conversion efficiency is also significantly different among the cells made by different processes, and these efficiency differences are inherent in the cell structures. For example, the amorphous cells require much less silicon than Czochralski cells, but the latter have higher efficiency and require less module area to achieve the same rated capacity. How the module prices of the two cell technologies compare is also dependent on the cost of their fabrication processes. Some processing steps are unique to each cell or module as required by their structures and materials, but in other steps the processing is essentially the same. For example, the single- and tandem-junction thin-film cells have many common processing steps. Also, the encapsulation steps for several of these modules are the same.

The similarities and differences in the five cell/module technologies have important implications on cost, measured as $/$W_p$. In the case of cells fabricated from either Czochralski wafers or dendritic web substrates, the use of silicon for dendritic web cells is less than 20% of that used for Czochralski cells, and silicon is the single most costly material in both processes.

The dendritic web thickness was taken as about 5 mils, whereas the wafer thickness was 12 mils, and the wafers must be sawed from a boule with a kerf loss of 10 mils and an area loss because the boule is round. Dendritic webs are formed in a long strip with no kerf loss and very little area loss. The formation of the dendritic web substrate and the wafer is the primary difference in the two cell/module processes; the remaining steps to produce the cells and modules are essentially the same. The cell efficiency was taken as the same for the Czochralski and dendritic web modules.

Amorphous-silicon cells are produced by an entirely different process that results in a silicon cell that is about 1000 times thinner than the other two flat-plate cells. The "silicon" consumption (actually silane gas) is reduced to the point at which the glass substrate on which the cells are grown is the most costly item of material. However, a-Si cell efficiency has proved to be lower than that for the crystalline cells. In this study, base-case module efficiency using crystalline cells was taken as 15%, and the efficiency for the a-Si module was taken as 10%. For the tandem-junction a-Si cell/module, additional film-growth steps are added to the process, which consumes additional silane, but the material cost is still small. The efficiency for the tandem cell was taken as 15%. The module-fabrication steps are also different from the crystalline-cell modules because all of the cells for a module are deposited on one piece of glass, and cell interconnections are defined by scribing rather than soldering copper straps between cells.

For the concentrator module, the cell is fabricated on Si wafers on equipment comparable to the Czochralski flat-plate cell, but its fabrication was not modeled for this study. There are some cell-design differences that change the cell fabrication somewhat. Instead of modeling with STAMPP, a base-case cell cost of $2/cell was used for a 1-cm square cell. For comparison, the Czochralski and dendritic web cells were 10-cm square. The fabrication of the 48-cell Fresnel module was modeled as an automated parts fabrication and assembly operation. Since the concentration ratio for the module was 500X, the basic trade-off between the concentrator and flat-plate modules is the more complex mechanical structure of the concentrator with much less silicon-cell area compared to the simpler flat-plate structure with more silicon-cell area. The concentrator also had a