reality, typical production modules of a-Si and CdTe are in the 7 to 8% range while Cu(InGa)Se_2 is 9 to 10%.

Why has so much capital been invested to develop a-Si technology over CdTe and Cu(InGa)Se_2? A major factor was that a-Si had a stronger worldwide scientific research base, which ensured that the relation between deposition conditions and fundamental material and device properties were well characterized. In contrast, CdTe and Cu(InGa)Se_2 are "orphans" because they have no real application outside of photovoltaics. Therefore, the entire knowledge base and technical infrastructure had to be developed mostly by underfunded industrial groups and a small number of university and government research labs. This shows that translating research-grade champion cell performance into production modules coming off-the-line day after day is a very challenging task. Figure 13.23 in Chapter 13 shows the time delay in translating efficiency achieved in the lab for a small area cell to a prototype large area module for the Cu(InGa)Se_2 technology. Delays of six to eight years are typical. To conclude, the highest efficiency technology is not always going to be the best choice for a low-cost, high-yield process, at least not until much of the technical background is in place.

Recognizing that the ideal PV technology would have some of the merits of c-Si but be deposited as a thin film a few microns thick, several groups have elected to try to achieve the "best of both worlds" by developing thin films of multi-Si deposited on a substrate. This is the subject of Chapter 8. At present, the best thin-film multi-Si solar cells have the same efficiency as their $CuInGaSe_2$, CdTe, or a-Si based predecessors. This is partly because multi-Si thin-film photovoltaics also inherits some of the problems of both c-Si and thin films. In particular, passivation of grain boundaries and surfaces seems to be a major problem, yet many of the well-established passivation methods from c-Si are not applicable to multi-Si thin films.

But there are new thin-film technologies such as the dye-sensitized solar cell that operate on a very different principle than an all-solid-state solar cell, almost more like photosynthesis than photovoltaics. This fascinating new solid–liquid technology, not free of challenges either, is described in Chapter 15.

1.10 CONCENTRATION PV SYSTEMS

If solar cells are expensive, focusing concentrated sunlight onto fewer solar cells was considered from the earliest times as a way of reducing costs. For example, instead of a typical 100 cm^2 solar cell absorbing 100 cm^2 worth of sunlight, one could focus the sunlight from 100 cm^2 onto a 1 cm^2 of solar cell, thus reducing the solar cell cost by 99% while still utilizing the same amount of sunlight. This neglects the cost of the optical focusing elements and other special equipment needed for concentrator technology. Of course, two conditions were required. One is that the optical surface collecting the light and redirecting it to the cells had to be cheaper than the cell area it replaced and the second is that the efficiency of the cells under concentrated sunlight should not decrease substantially. The first condition is generally fulfilled if we consider only the optical surfaces. However, keeping the cells constantly in focus requires a moving structure to keep the optics pointing at the sun as it moves across the sky, which adds cost to the system. As for the cell efficiency, there are fundamental reasons (see Chapter 3) why