of the relative significance of various factors. These assumptions and model parameters may not apply to some immature or as-yet undeveloped technologies. Yet, these exercises can be useful to decision makers, especially if complemented by sensitivity studies (as in Chapter 21).

As a final comment, the costs presented in this section are final costs calculated by a detailed account of all the elements utilized in a plant or module and an estimation of the performances achieved. In contrast, the costs in Section 1.5 are based on fundamental economic laws that are found empirically to occur regardless of technological details, yielding costs as a function of the time. Thus, the costs, as calculated in the present section, may be considered as a point of that curve, to occur somewhere in the future.

Of course, all components in the system have some parasitic power loss. Yearly average AC efficiencies of 10% are common in a well-managed grid-connected system with modules starting at 14%. Much of this loss can be attributed to temperature: cells operate at 20 to 30°C over the ambient which reduces their efficiency and output since efficiency decreases with temperature (except for a-Si). Additionally, 8 to 10% relative losses are expected for the DC–AC conversion in the inverter. Round trip battery losses (charge–discharge) in stand-alone applications can be an additional relative 10 to 20%.

1.12 FUTURE OF EMERGING PV TECHNOLOGIES

The solar resource is huge although its energy density is rather low. However, it is not so low as to lose any hope of massive utilization but it is not high enough to make it easy.

Obviously, the proper strategy for recovering a dispersed resource is to do it with high efficiency at a low cost per area. But the standard PV-effect, as described in this chapter, only delivers to the external circuit with high efficiency those charge carriers generated by the few photons with energy close to the band gap. The excess energy of photons whose energy is greater than the band gap is typically wasted as heat. Even worse, all of the energy of the photons whose energy is below the band gap is wasted since they are not absorbed and therefore generate no charge carriers.

Thus, as described in detail in Chapter 4, the maximum efficiency that can be obtained under the best conditions from a single junction solar cell is in the range of 40%. The best efficiency so far obtained for single-junction solar cells is 27.6%, with GaAs research-type cells [75] under concentrated sunlight of 255 suns, that is, of 255 times the unconcentrated standard power density (i.e. at 255 $\mathrm{kW/m^2}$). Typical commercial silicon cell efficiency is $\sim$15% measured at standard conditions (input optical power density of 1 $\mathrm{kW/m^2}$, 25°C and standard terrestrial solar spectrum).

One way of extracting more power from the sun is to use stacks of cells of semiconductors having different band gaps. Higher band gap semiconductors are located on top of the stack allowing photons of energy less than their band gap to pass through, where they can be absorbed by inner cells of lower band gap. The limit efficiency of these stacks, as presented in Chapter 4, with infinite number of cells of different band gap is 86%, as compared with the 40% of the single band gap cells. Efficiencies up to 32% (under standard unconcentrated terrestrial solar spectrum) have been achieved for a monolithic three band gap stacked cells of GaInP/GaAs/Ge [76].