Yet, in all these alloy systems, material quality and device performance degrades substantially for band gaps exceeding 1.4 to 1.6 eV, depending on the materials (see Chapter 13). A very productive area for research will be to either improve these materials when they are produced with high band gaps or to develop new alloys. Any multijunction process must be sequentially compatible from beginning to end.

Besides the multijunction effort, other concepts are in place for attempting a better utilization of the solar spectrum, such as the Intermediate Band (IB) concept [81], which is described further in Chapter 4. A band, with electron states in the center of the band gap, would permit the passage of electrons from the valence band to the conduction band by means of two low-energy photons, one pumping electrons from the valence to the intermediate band and the other pumping the electron from this band to the conduction band. This concept presents a potential behavior which is somewhat better than the multijunction cell stack with two semiconductors. Nanotechnology is a means of producing this intermediate band [82], and the basic effect sketched above seems to have been proved already by using quantum dots [83]. Quantum dots are droplets of one material in a host of another material of higher band gap. The droplets are very small and exhibit quantum effects among which is the appearance of intermediate bands or levels. Alloys might also be found with intermediate band [84], but no practical realization of this concept has been shown so far. Other new type devices, although not easy to realize today, are also envisioned. The theoretical basis of all these new devices can be found in Chapter 4.

Finally, solar cells have been constructed which do not operate on the photovoltaic effect but on charge transfer between molecular orbitals, as in photosynthesis. Their potential for efficient absorption of the spectrum depends on "tuning" the chemistry of organic dyes, as described in Chapter 15. Presently the subject of much research, dye-sensitized solar cells have achieved $>10\%$ efficiency but have many challenges regarding stability and manufacturability.

1.13 CONCLUSIONS

Photovoltaics constitutes a new form of producing electric energy that is environmentally clean and very modular. In stand-alone installations, it must use storage or another type of generator to provide electricity when the sun is not shining. In grid-connected installations storage is not necessary: in the absence of sunlight, electricity is provided from other (conventional) sources.

PV electricity is highly appreciated by the public. It is unique for many applications of high social value such as providing electricity to people who lack it in remote areas. Often, international donor agencies are providing the funding, as many of the users are very poor. Photovoltaics is very suitable as the power supply for remote communication equipment. Its use is increasing rapidly to produce electricity in grid-connected houses and buildings in industrialized countries, despite a 5 to 10 times higher cost than conventional electricity. Often, publicly funded programs are required to enable photovoltaics to compete by partially offsetting its higher costs.

Largely, because of grid-connected PV applications such as homes and businesses, the expansion of the PV market has been very rapid in the last years of the twentieth