the major energy requirement. For thin films, the semiconductor layers are 100 times thinner, and deposited at ∼1000°C lower temperature, so their energy requirement is negligible, in comparison. Instead, it is the energy embodied in the glass or stainless steel substrate, which is the major energy sink. Also, a seemingly insignificant component, the cosmetic Al frame around the module, is responsible for a surprisingly large fraction of energy. In fact, this can be the dominant energy sink for thin-film a-Si or $Cu(InGa)Se_2$ modules [20, 21]. Although thin-film modules have a shorter energy payback, they also have lower efficiency, which means a larger BOS is needed to support the larger number of modules. Thus, a larger amount of energy is embodied in the BOS for thin-film photovoltaics compared to crystalline Si photovoltaics.

The case of concentrators is less studied, but again the use of semiconductor is reduced and the BOS becomes more important than even for the thin films because the concentrating structures are very massive. However, their efficiency is higher. In summary, we can guess that in this case the situation will be similar to the case of thin films.

1.4 HISTORY OF PHOTOVOLTAICS

The history of photovoltaics goes back to the nineteenth century, as shown in Table 1.2. The first functional, intentionally made PV device was by Fritts [22] in 1883. He melted Se into a thin sheet on a metal substrate and pressed a Au-leaf film as the top contact. It was nearly 30 cm^2 in area. He noted, "the current, if not wanted immediately, can be either stored where produced, in storage batteries, ... or transmitted a distance and there used." This man foresaw today's PV technology and applications over a hundred years ago. The modern era of photovoltaics started in 1954 when researchers at Bell Labs in the USA accidentally discovered that *pn* junction diodes generated a voltage when the room lights were on. Within a year, they had produced a 6% efficient Si *pn* junction solar cell [23]. In the same year, the group at Wright Patterson Air Force Base in the US published results of a thin-film heterojunction solar cell based on Cu_2S/CdS also having 6% efficiency [24]. A year later, a 6% GaAs *pn* junction solar cell was reported by RCA Lab in the US [25]. By 1960, several key papers by Prince [26], Loferski [27], Rappaport and Wysoski [28], Shockley (a Nobel laureate) and Queisser [29], developed the fundamentals of *pn* junction solar cell operation including the theoretical relation between band gap, incident spectrum, temperature, thermodynamics, and efficiency. Thin films of CdTe were also producing cells with 6% efficiency [30]. By this time, the US space program was utilizing Si PV cells for powering satellites. Since space was still the primary application for photovoltaics, studies of radiation effects and more radiation-tolerant devices were made using Li-doped Si [31]. In 1970, a group at the Ioffe Institute led by Alferov (a Nobel laureate), in the USSR, developed a heteroface GaAlAs/GaAs [32] solar cell which solved one of the main problems that affected GaAs devices and pointed the way to new device structures. GaAs cells were of interest due to their high efficiency and their resistance to the ionizing radiation in outer space. The year 1973 was pivotal for photovoltaics, in both technical and nontechnical areas. A significant improvement in performance occurring in 1973 was the "violet cell" having an improved short wavelength response leading to a 30% relative increase in efficiency over state-of-the-art Si cells [33]. GaAs heterostructure cells were also developed at IBM in