How Long Does it Take for Photovoltaics To Produce the Energy Used?

BY VASILIS FTHENAKIS

In the July 2011 *PE* magazine article "Why We Need Rational Selection of Energy Projects," the author stated that "photovoltaic electricity generation cannot be an energy source for the future" because photovoltaics require more energy than they produce (during their lifetime), thus their "Energy Return Ratio (ERR) is less than 1:1." Statements to this effect were not uncommon in the 1980s, based on some early PV prototypes. However, today's PVs return far more energy than that embodied in the life cycle of a solar system (see Figure 1).

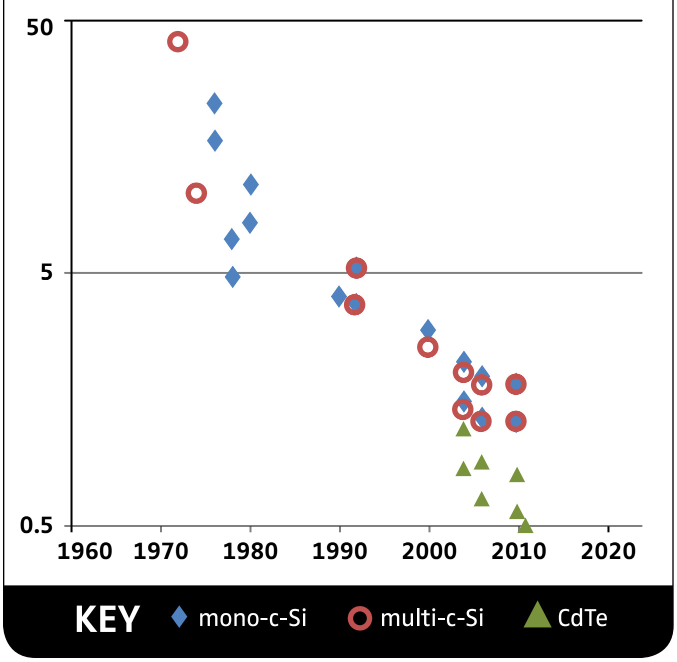
Their energy payback times (EPBT)—the time it takes to produce all the energy used in their life cycles—currently are between six months to two years, depending on the location/solar irradiation and the technology. And with expected life times of 30 years, their ERRs are in the range of 60:1 to 15:1, depending on the location and the technology, thus returning 15 to 60 times more energy than the energy they use. Here is a basic tutorial on the subject.

Life Cycle of PV and Energy Payback Times

The life cycle of photovoltaics starts from the extraction of raw materials (cradle) and ends with the disposal (grave) or recycling and recovery (cradle) of the PV components (Figure 2). The mining of raw materials such as quartz sand for silicon PVs, and copper, zinc, and aluminum ores for mounting structures and thin-film semiconductors, is followed by separation and purification stages. The silica in the quartz sand is reduced in an arc furnace to metallurgical-grade silicon, which must be purified further into solar-grade silicon (i.e., 99.9999% purity), requiring significant amounts of energy. Metal-grade cadmium and tellurium for CdTe PV is primarily obtained as a byproduct of zinc and copper smelters, respectively, and further purification is required for solar-grade purity. Similarly, metals used in CIGS PV are recovered as byproducts: indium and gallium are byproducts of zinc mining, while selenium is mostly recovered from copper production.

(FIGURE 1)

EPBT OF PV SYSTEMS HAVE BEEN REDUCED FROM ABOUT 40 TO 0.5 YRS FROM 1970 TO 2010



The raw materials include those for encapsulations and balance-of-system components, for example, silica for glass, copper ore for cables, and iron and zinc ores for mounting structures. Significant amounts of energy are required for the production, processing, and purification of all these materials, as well as for the manufacturing of the solar cells, modules, electronics, and structures, and for the installation, sometimes the operation, and eventually the dismantling and recycling or disposal of the system components. Thus, the EPBT is defined as the period required for a renewable energy system to generate the same amount of energy (in terms of primary energy equivalence) that was used to produce the system itself.

Energy Payback Time =

$$(E_{mat}+E_{manuf}+E_{trans}+E_{inst}+E_{EOL}) / (E_{agen}-E_{aoper})$$

where,

E_{mat}: Primary energy demand to produce materials comprising PV system

E_{manuf}: Primary energy demand to manufacture PV system

E_{trans}: Primary energy demand to transport materials used during the life cycle

E_{inst}: Primary energy demand to install the system

E_{EOL}: Primary energy demand for end-of-life management

E_{agen}: Annual electricity generation in primary energy terms

E_{aoper}: Annual energy demand for operation and maintenance in primary energy terms

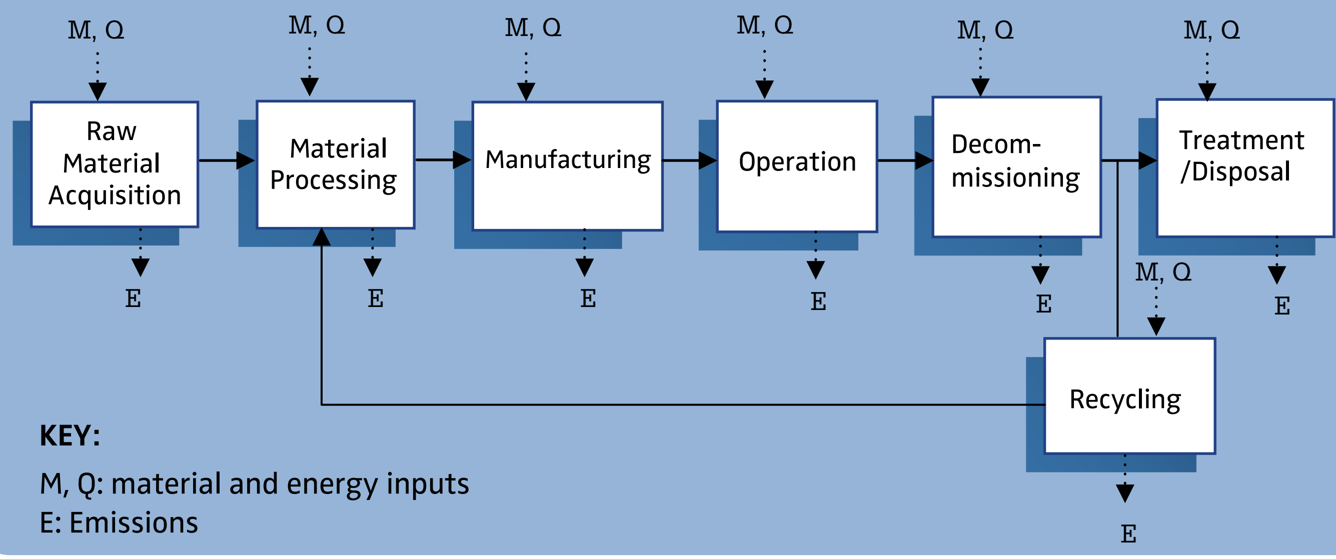
The traditional way of calculating the EROI of PV is EROI = lifetime/EPBT, thus an EPBT of one year and life expectancy of 30 years corresponds to an EROI of 1:30.

Results

Figure 3 gives the energy payback times of three major commercial PV module types: mono-Si, multi-Si, and cadmium telluride. These results are based on detailed process data obtained through collaborations with 13 European and U.S. PV manufacturers. The

(FIGURE 2)

FLOW OF THE LIFE-CYCLE STAGES, ENERGY, MATERIALS, AND EFFLUENTS FOR PV SYSTEMS



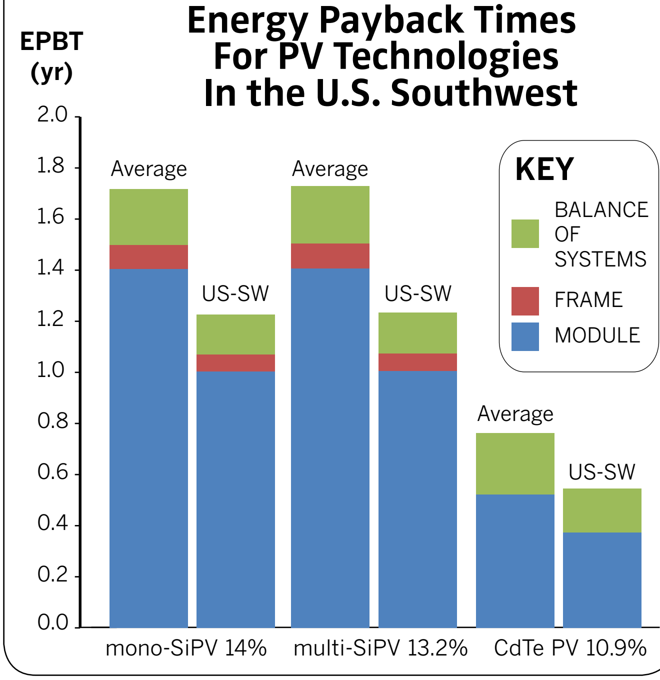
EPBT for the same type of systems installed in the U.S. Southwest are decreased in proportion to the solar irradiation ratio (1700/2380) between the U.S. average and Southwest solar conditions. Thus, for Southwest irradiation the EPBTs for the three PV technologies shown in Figure 3 are 1.2, 1.2, and 0.5 years and the corresponding EROIs are 0.04, 0.04, and 0.02, thus 50 times better than stated in the July *PE* article. And these EROI keep improving as systems and material utilization efficiencies continue to improve.

It is noted that several PV LCA studies with differing estimates can be found in literature. Such divergence reflects different assumptions about key parameters, like product design, solar irradiation, performance ratio, and lifetime. The estimates also differ because of the different types of installation used, such as ground mounts, rooftops, and façades. Also, assessments often are made from outdated information in the literature collected from antiquated PV systems.

To resolve these inconsistencies, the International Energy Agency PVPS Task 12 has published "Methodology Guidelines on Life Cycle Assessment of Photovoltaic Electricity" (www.bnl.gov/pv). These guidelines reflect a consensus among experts in the U.S., Europe, and Asia for conducting balanced, transparent, and accurate life-cycle assessments. The results presented in Figure 3 are produced according to these guidelines.

(FIGURE 3)

Energy Payback Times For PV Technologies In the U.S. Southwest



Vasilis Fthenakis is a senior chemical engineer and director of the Photovoltaics Environmental Research Center at Brookhaven National Laboratory. He also holds a joint appointment with Columbia University as professor of earth and environmental engineering and the founder and director of the Center for Life Cycle Analysis. He is the author of 300 publications, member of the Editorial Boards of Progress in Photovoltaics and the Journal of Loss Prevention. He is a Fellow of the American Institute of Chemical Engineers and a Fellow of the International Energy Foundation. He can be reached at vmf@bnl.gov.