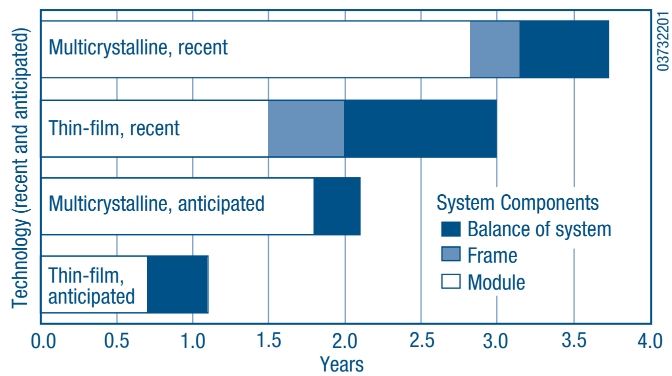
PV FAQs

What is the energy payback for PV?

Producing electricity with photovoltaics (PV) emits no pollution, produces no greenhouse gases, and uses no finite fossil-fuel resources. The environmental benefits of PV are great. But just as we say that it takes money to make money, it also takes energy to save energy. The term "energy payback" captures this idea. How long does a PV system have to operate to recover the energy—and associated generation of pollution and CO_2—that went into making the system, in the first place?

Energy payback estimates for both rooftop and ground-mounted PV systems are roughly the same, depending on the technology and type of framing used. Paybacks for multicrystalline modules are 4 years for systems using recent technology and 2 years for anticipated technology. For thin-film modules, paybacks are 3 years using recent technology, and just 1 year for anticipated thin-film technology (see Figure 1). With assumed life expectancies of 30 years, and taking into account the fossil-fuel-based energy used in manufacture, 87% to 97% of the energy that PV systems generate won't be plagued by pollution, greenhouse gases, and depletion of resources.

Figure 1. Energy Payback for PV Systems



Reaping the environmental benefits of solar energy requires spending energy to make the PV system. But as this graphic shows, the investment is small. Assuming 30-year system life, PV systems will provide a net gain of 26 to 29 years of pollution-free and greenhouse-gas-free electrical generation.

Based on models and real data, the idea that PV cannot pay back its energy investment is simply a myth. Indeed, researchers Dones and Frischknecht found that PV-systems fabrication and fossil-fuel energy production have similar energy payback periods (including costs for mining, transportation, refining, and construction).

What is the Energy Payback for Crystalline-Silicon PV Systems?

Most solar cells and modules sold today are crystalline silicon. Both single-crystal and multicrystalline silicon use large wafers of purified silicon. Purifying and crystallizing the silicon are the most energy-intensive parts of the solar-cell manufacturing process. Other aspects of silicon-cell and module processing that add to the energy input include: cutting the silicon into wafers, processing the wafers into cells, assembling the cells into modules (including encapsulation), and overhead energy use for the manufacturing facilities.

Today's PV industry generally recrystallizes any of several types of "off-grade" silicon from the microelectronics industry, and estimates for the energy used to purify and crystallize silicon vary widely. Because of these factors, energy payback calculations are not straightforward. Until the PV industry begins to make its own silicon, which it could do in the near future, calculating payback for crystalline PV requires that we make certain assumptions.

To calculate payback, Dutch researcher Alsema reviewed previous energy analyses and did not include the energy that originally went into crystallizing microelectronics scrap. His best estimates of electricity used to make frameless PV were 600 kWh/m^2 for single-crystal-silicon modules and 420 kWh/m^2 for multicrystalline silicon. Assuming 12% conversion efficiency (standard conditions) and 1,700 kWh/m^2 per year of available sunlight energy (the U.S. average is 1,800), Alsema calculated a payback of about 4 years for current multicrystalline-silicon PV systems. Projecting 10 years into the future, he assumes a solar-grade silicon feedstock and 14% efficiency, dropping energy payback to about 2 years.

Other recent calculations support Alsema's figures. Based on a solar-grade feedstock, Japanese researchers Kato et al. calculated a multicrystalline payback of about 2 years (adjusted for the U.S. solar resource). Palz and Zibetta also calculated an energy payback of about 2 years for current multicrystalline-silicon PV. For single-crystal silicon, which Alsema did not calculate, Kato calculated a payback of 3 years when he did not charge for off-grade feedstock. Knapp and Jester studied an actual manufacturing facility and found that, for single-crystal-silicon modules, the actual energy payback time is 3.3 years. This *includes* the energy to make the aluminum frame and the energy to purify and crystallize the silicon.

What is the Energy Payback for Thin-Film PV Systems?

Thin-film PV modules use very little semiconductor material. The major energy costs for manufacturing are the substrate on which the thin films are deposited, the film-deposition process, and facility operation. Because thin-film PV technologies all have similar energy requirements, we'll use amorphous silicon as our representative technology.

Alsema estimated that it takes 120 kWh/m^2 to make frameless, amorphous-silicon PV modules. He added another 120 kWh/m^2 for a frame and support structure for a rooftop-mounted, grid-connected system. Assuming 6% conversion efficiency (standard conditions) and 1,700 kWh/m^2 per year of available sunlight energy, Alsema calculated a payback of about 3 years for current thin-film PV systems with frames. Kato and Palz calculated shorter paybacks for amorphous silicon, each ranging from 1 to 2 years.

Aluminum is energy-intensive to manufacture. Deleting the frame, reducing use of aluminum in the support structure, assuming a conservative increase to 9% efficiency, and factoring in other improvements, Alsema projected the payback for thin-film PV that would drop to just 1 year by 2009.

$CuInSe_2$ and CdTe modules are already being sold in the 9%–12% efficiency range. Depending on design details, such as frames and mounting, their energy payback may be less than a year already.

Used in ground-mounted fields, does PV still offer a practical payback period?

Until recently, some analysts thought that PV for utilities would be limited because ground-mounting support structures, such as concrete foundations and heavy framing, would add years to the payback periods. However, a recent study by James Mason found that, not including modules, Tucson Electric Power's Springerville multicrystalline PV plant paid back the energy invested in its ground-mounted PV system in only 3 to 5 months. That's essentially the same as for a roof-mounted PV system. Tucson Electric did this by using simplified support structures that use less concrete and aluminum.

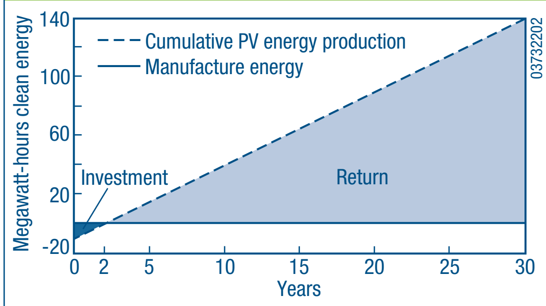
Extrapolating the costs and paybacks for thin-film modules, the paybacks would also be the same for ground-mounted versus roof-mounted PV (see Figure 1).

So, in answer to the question about the practicality of using PV for utility power generation—the answer is, yes, ground-mounted PV offers the same attractive energy payback.

How Much CO_2 and Pollution Does PV Avoid?

An average U.S. household uses 830 kWh of electricity per month. On average, producing 1,000 kWh of electricity with solar power reduces emissions by nearly 8 pounds of sulfur dioxide, 5 pounds of nitrogen oxides, and more than 1,400 pounds of carbon dioxide. During its projected 28 years of clean energy production, a rooftop system with a 2-year energy payback and meeting half of a household's electricity use would avoid conventional electrical-plant emissions of more than half a ton of sulfur dioxide, one-third a ton of nitrogen oxides, and 100 tons of carbon dioxide (see Figure 2). PV is clearly a wise energy investment that affords impressive environmental benefits.

Figure 2. Cumulative Net Clean Energy Payoff



PV systems can repay their energy investment in about 2 years. During its 28 remaining years of assumed operation, a PV system that meets half of an average household's electrical use would eliminate half a ton of sulfur dioxide and one-third of a ton of nitrogen-oxides pollution. The carbon-dioxide emissions avoided would offset the operation of two cars for those 28 years.

Note on Methodology

Most of the energy that goes into manufacturing a PV module is in the form of electricity (kWh). Payback calculations are based on paying back this electricity with PV electricity produced by installed modules. Thus, the equation energy payback is simply:

Energy used to make system (in kWh/unit area) ÷
Energy produced by system (in kWh/unit area-time).

This is the equation that is used to calculate the numbers quoted in this FAQ and in the referenced studies. The electricity from installed PV offsets the electricity that made the PV in the first place; it doesn't matter how that electricity was made or what fuel source was used.

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