Energy Payback: Clean Energy from PV

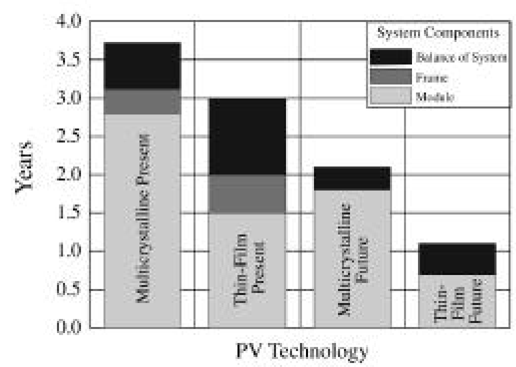
Producing electricity with photovoltaics (PV) emits no pollution, produces no greenhouse gases, and uses no finite fossil fuel resources. These are great environmental benefits, but just as we say that it takes money to make money, it also *takes energy to save energy*. This concept is captured by the term "energy payback," or how long a PV system must 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 rooftop PV systems boil down to 4, 3, 2, and 1 years: 4 years for systems using current multicrystalline-silicon PV modules, 3 years for current thin-film modules, 2 years for future multicrystalline modules, and 1 year for future thin-film modules. With energy paybacks of 1–4 years and assumed life expectancies of 30 years, 87% to 97% of the energy that PV systems generate will be free of pollution, greenhouse gases, and depletion of resources. Let's take a look at how the 4-3-2-1 paybacks were estimated for current and future PV systems.

What is the 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-consumptive 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 building.

4-3-2-1 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. In addition, Swiss researchers Dones and Frischknecht found that the small green-house-gas emissions required to make PV systems are comparable to non-power-plant energy requirements for fossil-fuel electricity such as mining, transporting, and refining.

- Because today's PV industry generally recrystallizes any of several types of "off-grade" silicon from the microelectronics industry, and because estimates for the energy used to purify and crystallize silicon vary widely, energy payback calculations are not straightforward. Until the PV industry begins to make its own silicon—which it could do in the near future—key assumptions must be made to calculate payback for crystalline PV.

- To calculate payback, Dutch researcher Erik Alsema reviewed previous energy analyses and did not "charge" for the energy that originally went into crystalizing microelectronics scrap. His "best estimates" of energy used to make near-future, 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 1700 kWh / m^2 per year of available sunlight energy (the U.S. average is 1800), 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 generally support Alsema's figures. Based on a solar-grade feedstock, Japanese researchers Kazuhiko Kato *et al.* calculated a multicrystalline payback of about 2 years (adjusted for the U.S solar resource). Palz and Zibetta also calculated energy payback of about 2 years for current multicrystalline silicon PV. For single-crystal silicon—which Alsema did not calculate—Kato calculated payback of 3 years when he did not charge at all for off-grade feedstock.

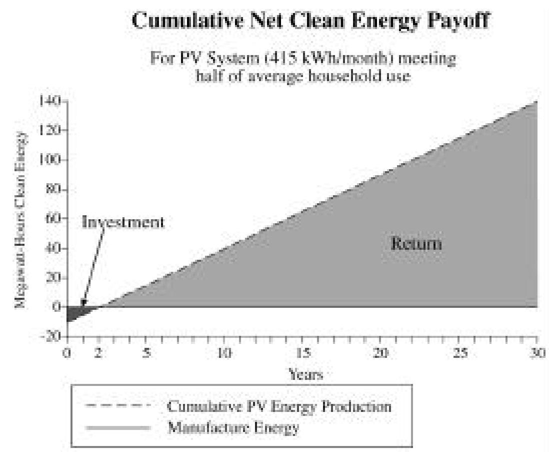
What is the Payback for Thin-Film PV Systems?

- 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. These energy costs are similar for all thin-film technologies (copper indium diselenide, cadmium telluride, amorphous silicon), varying only in the film deposition processes themselves, so amorphous silicon is a representative technology.

- Alsema estimated that it takes 120 kWh / m^2 to make near-future, frameless, amorphous-silicon PV modules. He added another 120 kWh / m^2 for a frame and a support structure for a rooftop-mounted, grid-connected system. Assuming 6% conversion efficiency (standard conditions) and 1700 kWh / m^2 per year of available sunlight energy, Alsema calculated a payback of about **3 years** for current thin-film PV systems. Kato and Palz calculated shorter paybacks for amorphous silicon, each ranging from 1-2 years.

- Deleting the frame, reducing use of aluminum in the support structure, and assuming a conservative increase to 9% efficiency and other improvements, Alsema projected the payback for thin-film PV ten years from now to drop to just **1 year**.

- So, for an investment of from 1 to 4 years worth of their energy output, PV systems can provide as much as 30 years or more of clean energy. Note that these figures are for rooftop systems. Support structures for ground-mounted systems—as might be found more advantageous for central utility generation—would add about another year to the payback period.



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.

How Much CO_2 and Pollution Does PV Avoid?

- An average U.S. household uses 830 kilowatt-hours of electricity per month. On average, producing 1000 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 2-year 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. PV is clearly a wise energy investment with great environmental benefits!

Where Can I Find More Detailed Information?

- Alsema, E. (1999). "Energy Requirements and CO_2 Mitigation Potential of PV Systems." *Photovoltaics and the Environment*. Keystone, CO, July 1998, Workshop Proceedings. Brookhaven National Laboratory, Report Number BNL-52557.

- Dones, R.; Frischknecht, R. (1997). "Life Cycle Assessment of Photovoltaic Systems: Results of Swiss Studies on Energy Chains." Appendix B-9. *Environmental Aspects of PV Power Systems.* Utrecht, The Netherlands: Utrecht University, Report Number 97072.

- Kato, K.; Murata, A.; Sakuta, K. (1997). "Energy Payback Time and Life-Cycle CO_2 Emission of Residential PV Power System with Silicon PV Module." Appendix B-8. *Environmental Aspects of PV Power Systems.* Utrecht, The Netherlands: Utrecht University, Report Number 97072.

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❑ Palz, W.; Zibetta, H. (1991). "Energy Pay-Back Time of Photovoltaic Modules." *International Journal of Solar Energy*. Volume 10, Number 3-4, pp. 211-216.

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