Maximum efficiency of solar cells

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The Shockley-Queisser limit only applies to conventional solar cells with a single p-n junction; solar cells with multiple layers can (and do) outperform this limit, and so can solar thermal and certain other solar energy systems. In the extreme limit, for a multi-junction solar cell with an infinite number of layers, the corresponding limit is 68.7% for normal sunlight,[4] or 86.8% using concentrated sunlight[5] (see solar-cell efficiency).

The Shockley-Queisser limit is calculated by examining the amount of electrical energy that is extracted per photon of incoming sunlight. There are several considerations:

Any material, that is not at absolute zero (0 Kelvin), emits electromagnetic radiation through the black-body radiation effect. In a cell at room temperature, this represents approximately 7% of all the energy falling on the cell.

Absorption of a photon creates an electron-hole pair, which could potentially contribute to the current. However, the reverse process must also be possible, according to the principle of detailed balance: an electron and a hole can meet and recombine, emitting a photon. This process reduces the efficiency of the cell. Other recombination processes may also exist (see "Other considerations" below), but this one is absolutely required.

(q being the charge of an electron). Thus the rate of recombination, in this model, is proportional to exp(V/Vc) times the blackbody radiation above the band-gap energy:

(This is actually an approximation, correct so long as the cell is thick enough to act as a black body, to the more accurate expression[7][8]

The difference in maximum theoretical efficiency however is negligibly small, except for tiny bandgaps below 200meV.[9])

The product of the short-circuit current Ish and the open-circuit voltage Voc Shockley and Queisser call the "nominal power". It is not actually possible to get this amount of power out of the cell, but we can get close (see "Impedance matching" below).

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