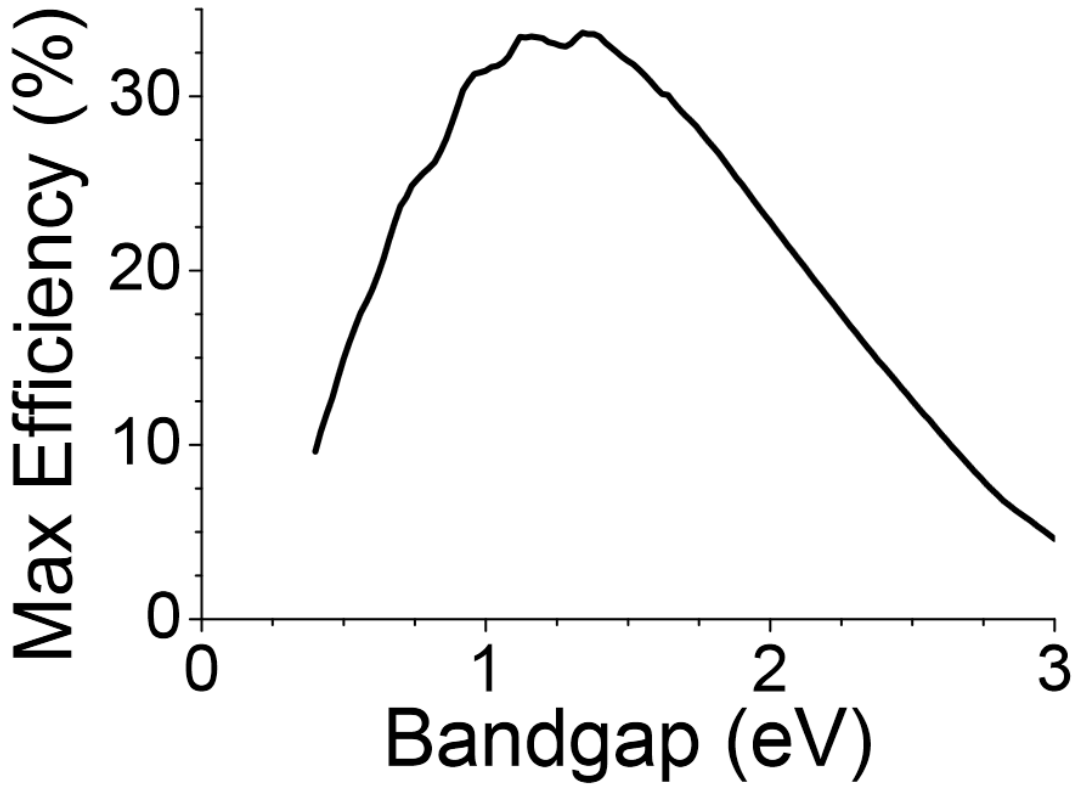
The Shockley-Queisser limit

Shockley–Queisser limit or **detailed balance limit** refers to the calculation of the maximum theoretical efficiency of a solar cell made from a single pn junction. It was first calculated by William Shockley and Hans Queisser:

William Shockley and Hans J. Queisser, "Detailed Balance Limit of Efficiency of p-n Junction Solar Cells", *Journal of Applied Physics*, Volume 32, pp. 510-519 (1961)

The Shockley–Queisser limit is calculated by examining the amount of electrical energy that is extracted per incident photon.

The calculation places maximum solar conversion efficiency around **33.7%** assuming a single pn junction with a band gap of 1.4 eV (using an AM 1.5 solar spectrum). Therefore, an ideal solar cell with incident solar radiation will generate 337 Wm^{-2}. When the solar radiation is modelled as 6000 K blackbody radiation the maximum efficiency occurs when the bandgap energy ***Eg*=1.4 eV**.



The maximum efficiency of a single-junction solar cell as calculated by the Shockley–Queisser model as a function of bandgap energy. The incident solar spectrum is approximated as a 6000 K blackbody spectrum.(From Shockley–Queisser limit Wiki pages)

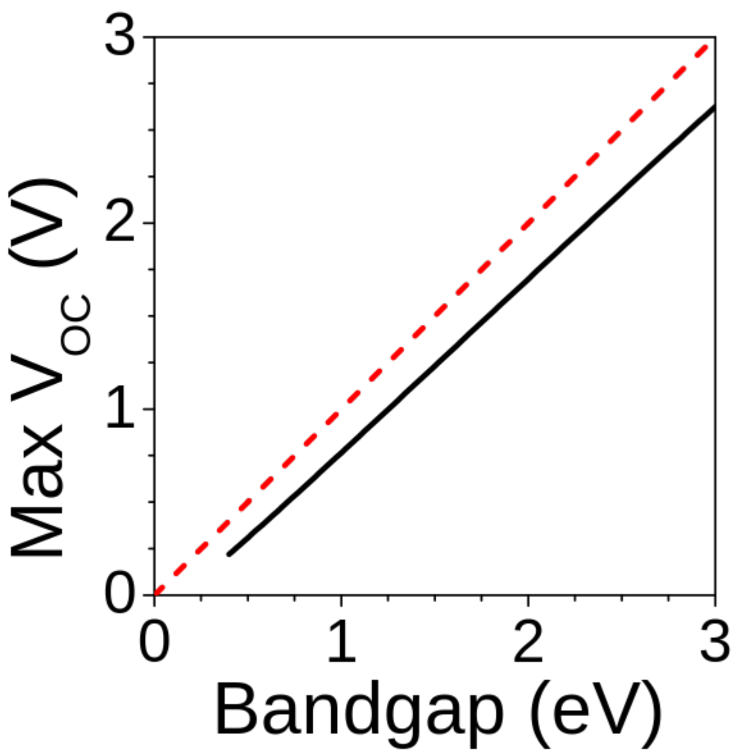
There are three primary considerations in the calculation.

1. Blackbody radiation

The blackbody radiation from solar cell at room temperature (300 K) cannot be captured by the cell, and represents about 7% of the available incoming energy. **Energy lost in a cell is generally turned into heat**, so any inefficiency in the cell increases the cell temperature when it is placed in sunlight. As the temperature of the cells increases, the blackbody radiation also increases, until equilibrium is reached. In practice this equilibrium is normally reached at temperatures as high as 360 K, and cells normally operate at lower efficiencies than their room temperature rating.

2. Recombination

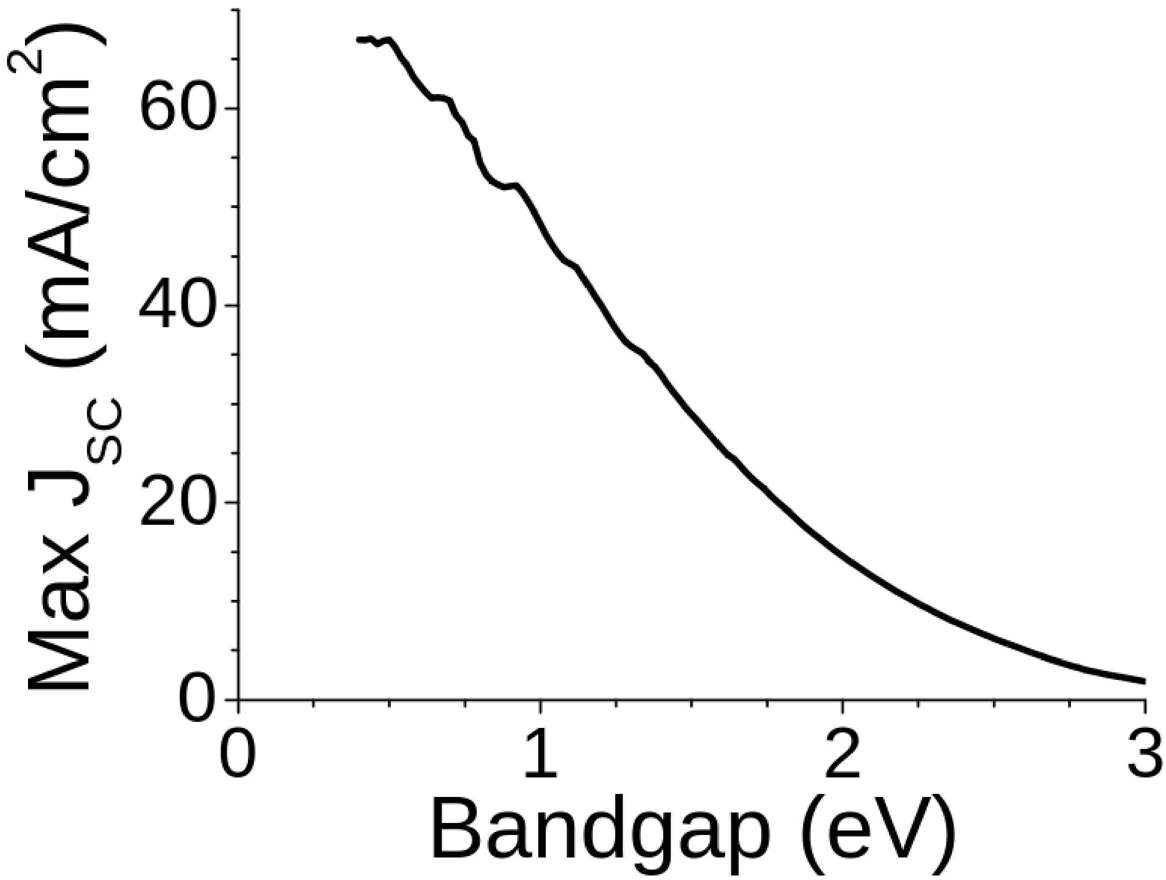
Recombination places an upper limit on the *rate* of electron-hole production. In silicon this reduces the theoretical performance under normal operating conditions by another 10% over and above the thermal losses. V_{oc} is limited by recombination.



The limit for the maximum open-circuit current of a solar cell within the Shockley-Queisser model. The red dotted line is V_{oc}=E_g. .(From Shockley–Queisser limit Wiki pages)

3. Spectrum losses

The limit for short-circuit current density (i.e., current density at zero voltage). This assumes that each solar photon gets converted into an electron that flows through the circuit. At higher bandgaps, there are fewer photons above the bandgap, and therefore the current density decreases.

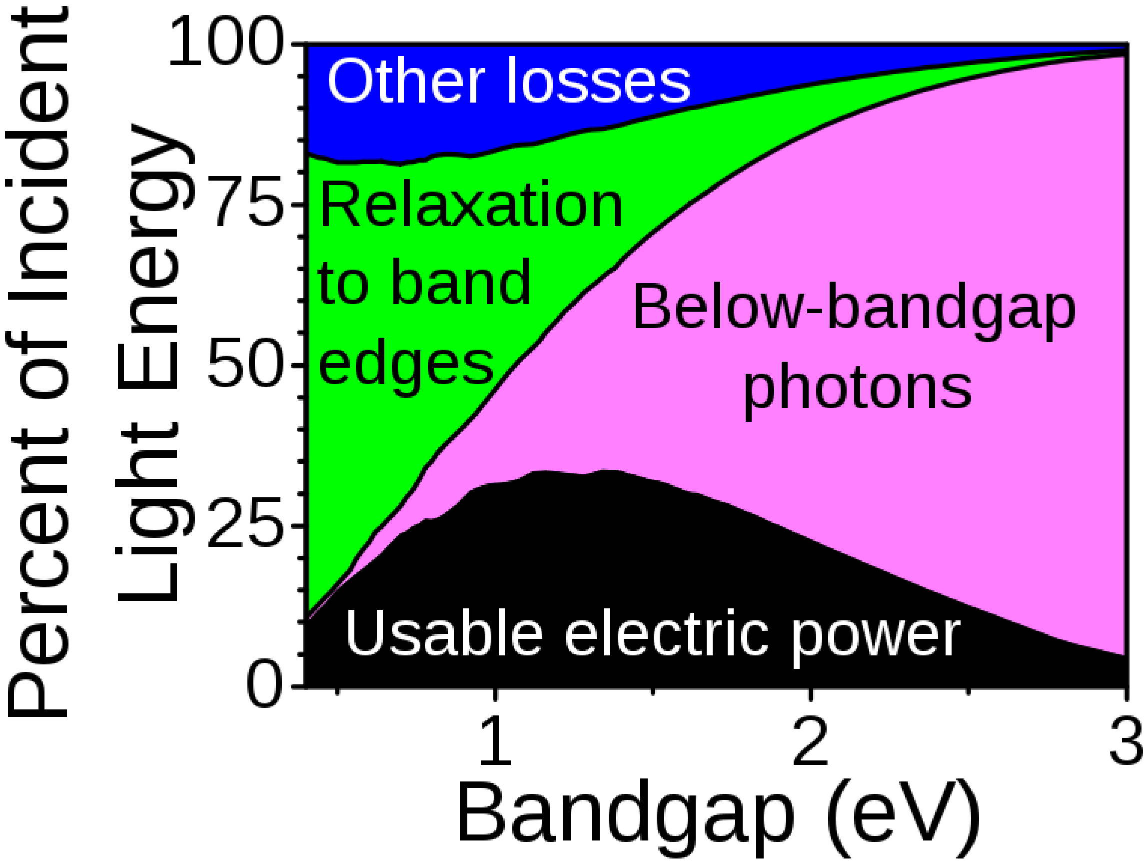


(From Shockley–Queisser limit Wiki pages)

Of the 1,000 W/m² in AM1.5 solar radiation, about 19% of that has less than 1.1 eV of energy, and will not produce power in a silicon cell.

This accounts for about 33% of the incident sunlight, meaning that from spectrum losses alone there is a theoretical conversion efficiency of about 48%, ignoring all other factors.

Summary:



(From Shockley–Queisser limit Wiki pages)

<u>Solar cells: environmental impact</u>

No greenhouse gasses
No pollutants
No moving parts
Some hazardous materials: Cd, As,...
Lifetime ~30 years
Energy payback time (EPBT) = energy used in manufacture equal to energy produced under normal operating condition.

- 7 years for single-junction crystalline silicon cells
- 5 years for multi-junction crystalline silicon cells,
- 3 years for amorphous silicon cells
- 1.5 years for CdTe cells

Possible project (essay) themes:

- How is the energy used in manufacture calculated?
- The economics of solar cells (photovoltaics): how is the cost per kWh calculated?
- Strategies for improving the efficiency of silicon solar cells
- Organic solar cells: efficiency and EPBT
- Thermo-photovoltaic cells: what are they and how do they work?