The search for clean, renewable energy

Solar energy is an inevitable part of the solution

- Global Consumption (15 TW)
- Wind (870 TW)
- Geothermal (32 TW)
- Hydro (7.2 TW)

Available Power

2004 numbers
PV Land Area Requirements

All US Primary Energy

4.1 Terawatts with 10% modules

All US Electricity
800 Gigawatts with 10% modules
Unfortunately, solar cells are not very efficient

Silicon solar cells ~10%-20% (commercial)

In research ~25%. University of New South Wales (October 2008)

Theoretical limit ~30%
Intrinsic Losses in a semiconductor Solar Cell

When a photon is incident on a semiconductor:

- If $h\nu < E_g$, no absorption.
- If $h\nu > E_g$, thermalization loss.
- If $h\nu \geq E_g$, radiative recombination.
A single bandgap does not match the Solar Spectrum

- No absorption
- Radiative recombination loss
- Thermalization loss
Efficiencies of multi-band-gap Solar Cell
(Henry, C. H. J. Appl. Phys. 51, 4494)
Multi-junction cells convert more of the solar spectrum

- Lattice matching -> restricts choice of bandgaps

- Current matching -> each layer thickness & tunnel junction has to be optimized

- Maximum power points of each junction is different -> overall eff. is constrained

- # of bandgaps limited
Multiple bandgaps can boost efficiency significantly

<table>
<thead>
<tr>
<th># of bandgaps</th>
<th>Maximum efficiency</th>
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<tbody>
<tr>
<td>1</td>
<td>31%*</td>
</tr>
<tr>
<td>2</td>
<td>42%</td>
</tr>
<tr>
<td>3</td>
<td>48%</td>
</tr>
<tr>
<td>4</td>
<td>52%</td>
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optimum bandgaps (4) chosen to maximize efficiency

However, current multiple bandgap solar cells have problems...

- Fabrication is complex: lattice matching
- Maximum power points are constrained
- Not easily extendible beyond 3 junctions
- Current matching --> tunnel junction & cell thickness
Hybrid Photovoltaic & Thermal Power Generation
Thermophotovoltaic (TPV) Approaches

Early coaxial TPV design with optical filtering

A solar TPV design proposed by Swanson

primary parabolic mirror concentrator
~ 20,000 suns, temp ~ 2400K
Cassegrainian solar TPV system presented by Horne
Spectral-splitting in photovoltaics

(A) back-silvered coatings

(B) coolant can be passed through hollow interior.
Spectral-splitting in photovoltaics

PV cells of different bandgap values

Cavity receiver

Concentrated solar radiation

Photovoltaic cavity converter
Increasing bandgap PV cells

Prism spectrum splitting.
Spectrum Splitting via luminescent concentrators

Incident sunlight

PV 1

PV 2

Reflective coating

Thermal receiver

Luminescent concentrator plates coupled to PV cells
Spectrum Splitting via Holographic concentrators

Transmission and reflection holograms, splitting the sunlight into multiple bands for PV cells

Prism technologies Inc.
Polychroic mirror based spectral splitting

Unwanted diffraction orders, optical aberrations, angular sensitivity
Holographic lens for two-cell PV operation

Long wavelength focussing hologram

Short wavelength focussing hologram

PV 1

PV 2

Thermal absorber
Spectral bandwidth is typically limited (visible)

Lifetime issues with holographic material

Sensitivity to incident angle.

Single hologram avoids cross-coupling effects & minimizes aberrations.
Total solar co-generation system proposed by Soule

An implementation of this system is shown in Fig. 19 [124], where a tracking linear Fresnel lens is focusing light through a cylindrical plano-concave lens and onto a linear PV array which is thermally anchored to a copper substrate containing cooling channels. A spectrally selective heat-mirror positioned between the plano-concave lens and the PV receiver splits part of the beam off to an evacuated tube receiver, placed out of the path of the incident rays. Reflective wing secondary concentrators are provided at the aperture of both the PV and evacuated tube receivers for improved light collection. The optical losses could be substantial in this design, hence attention should be given to whether the concentration achieved will be sufficient for the efficient operation of both PV and thermal receivers.
Fig. 20A shows a transparent glass pipe enclosing the PV and thermal receivers, the upper half being of circular or elliptical cross section and the lower half of parabolic cross section. The lower half is coated with a thin aluminium layer to reflect long wavelengths onto a thermal receiver. A one-axis tracking mechanism aligns the collector in such a way that solar energy is approximately normally incident on a parabolic cold mirror located in the centre of the glass pipe. The cold mirror reflects the short wavelength component onto a PV receiver mounted on a rectangular water-cooled aluminium tube. The long wavelength component is transmitted to the lower half of the receiver and redirected onto an evacuated tube receiver. The evacuated tube is painted black for increased absorption and contains a heat transfer medium of low boiling point, producing vapour which eventually rotates a turbine for electricity generation.

Fig. 20B shows an alternative design, in which a Fresnel lens is positioned in the upper opening of a cylindrical collector of quadrilateral cross-section. Solar radiation is concentrated onto a convex parabolic cold mirror positioned above the heat tube receiver, and is split into two components for PV and thermal conversion.

In Fig. 20C, double-faced PV cells are employed in a sun-tracking panel assembly. Fresnel lenses converge the long-wave solar radiation onto evacuated tubes containing a black heat-transfer medium. A reflective aluminium plate is placed below the tubes to improve light utilization. The upper half of each evacuated tube is shaped like an inverted V and is coated with a semi-transparent thin film coating for short-wave reflection. The short wavelengths are directed onto the rear surfaces of double-faced solar cells, positioned on each side of the Fresnel lenses. The solar cells also receive direct solar radiation on their front surfaces. The waste heat extracted from cooling of the PV cells is suggested utilized in greenhouses to promote plant growth or for domestic hot water purposes.