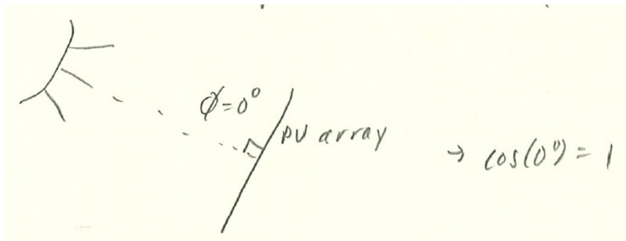
Tuesday, 9/26/23

Capturing Sunlight

1. Pointing the PV Array at the Sun

In bright sunlight, maximum solar energy is obtained when the array is pointed directly at the sun.



Consider the effects of pointing error:

Φ (degrees)	Cos(Φ)
0°	1
± 5°	0.996
± 10°	0.984
± 15°	0.966

This shows that small pointing errors have little effect on output power.

Keep in mind, though, that in cloudy areas, diffuse sunlight may more than compensate for pointing errors.

2. Motion of the Sun

The sun's high point in the sky is called "solar noon."

(1) In the northern hemisphere

From spring equinox (~ March 21) to summer solstice (~ June 21), the sun moves 23.45° higher in the sky to its annual peak elevation angle.

From summer solstice (~ June 21) to winter solstice (~ December 21), the sun moves 46.9° lower in the sky to its annual minimum elevation angle.

The opposite effect happens in the southern hemisphere.

(2) Latitude Effect

Consider the figure below:

https://mspalmersclassroom.weebly.com/mapping-our-world.html

At the equinox dates (spring ~ 3/21, fall ~ 9/21): elevation angle = 90° – latitude.

Example: Auburn, AL: latitude = N 32.597684.

Equinox elevation angle = 90° – 32.597684 = 57.402°.

Summer solstice elevation angle = 57.402° +23.45° = 80.852°.

Winter solstice elevation angle = 57.402° – 23.45° = 33.952°.

Notice that in Auburn, AL, the sun is *never* directly overhead!

The sun, however, is directly overhead in the tropics;

Between latitudes S 23.4378° (Tropic of Capricorn) and N 23.4378° (Tropic of Cancer).

Consider the Arctic Circle (N 66.5622), which is the northern latitude where:

At the winter solstice: elevation angle = 90° – 66.5622 – 23.45 = 0°.

Here, the sun is on the horizon at solar noon!

The Antarctic Circle (S 66.5622) is the southern hemisphere equivalent of the Arctic Circle: but 6 months out of phase.

3. Ramifications for PV Systems

   (1) In the topics, horizontal PV arrays on flat rooftops are often fine.

   (2) In northern and southern latitudes close to the Arctic or Antarctic Circles, vertically mounted PV arrays are often fine

       This could include vertically mounting on the side of a wall.

   (3) In in-between latitudes, an appropriate tilt angle for the PV array should be chosen for optimal performance.

   (4) Cloud cover (i.e. leading to a significant diffuse light component) based on seasonal variation should be considered in selecting the optimal tilt angle.

   (5) The seasonal albedo (reflected) sunlight component (such as from seasonal snow cover) should be considered.

   (6) Seasonal shading effects need to be considered:

       a. From structures: chimneys, power poles, antennas, etc.

       b. Trees: foliage (spring-fall), tree trunks/limbs (in winter due to the sun's low elevation angle), fallen leaves (fall), pollen accumulation (spring).

   (7) The efficiency of SC Si and MC Si PV decreases as temperature increases.

   (8) The PV array's tilt angle can be selected to match the higher power needs in a particular time of year (summer fishing cabin, winter ski chalet, etc.).

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Consider the figure from the textbook below:

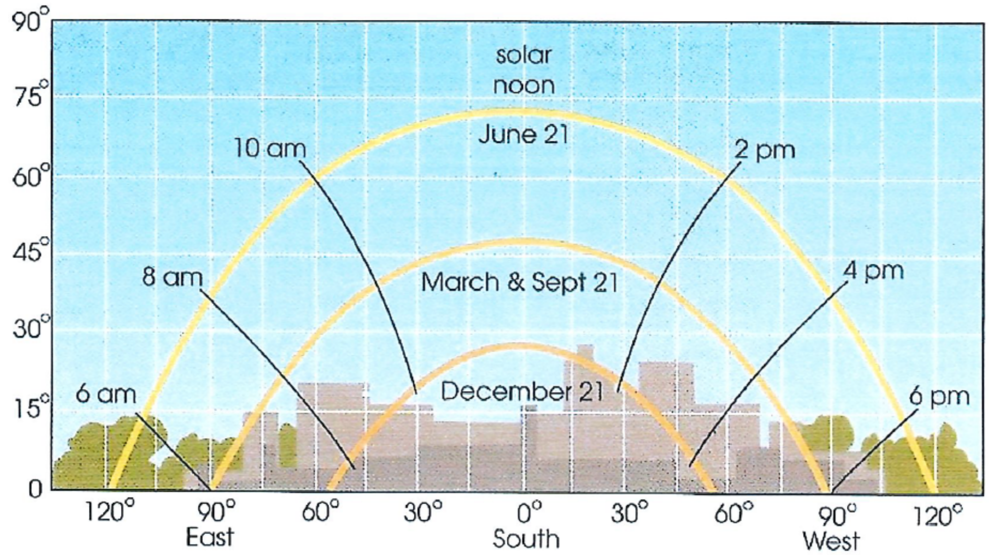
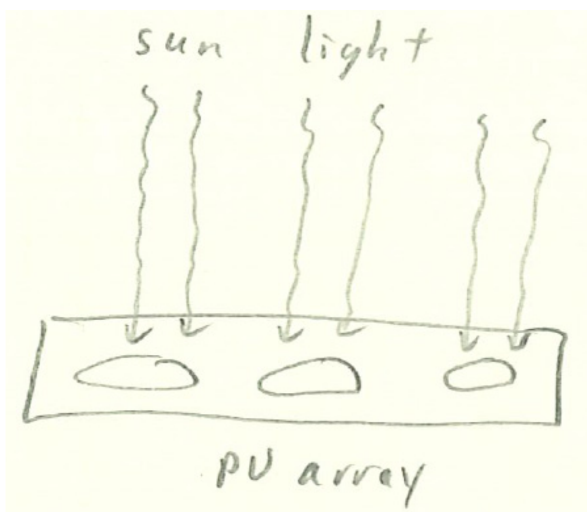


Figure 3.9 Shading effects.

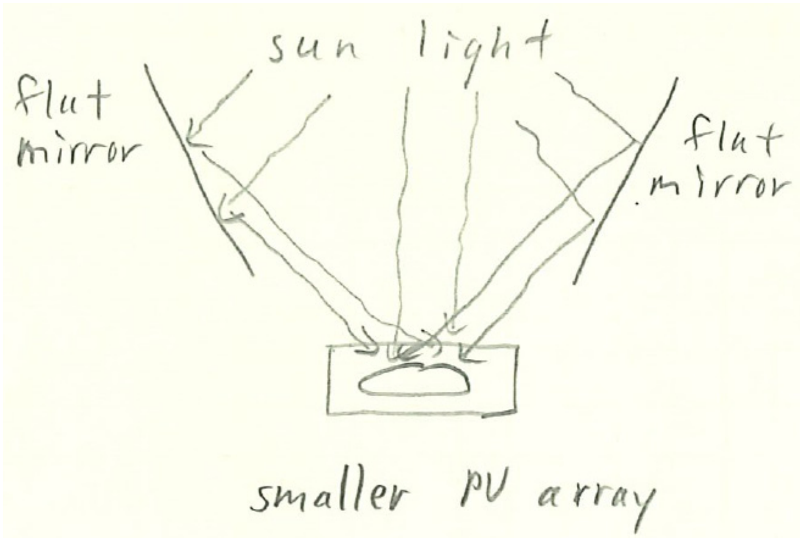
Concentrating Sunlight onto A PV System

1) Methods of Concentration

a. Without solar concentration:



b. With flat mirror concentration:



c. Parabolic dish mirror concentration:

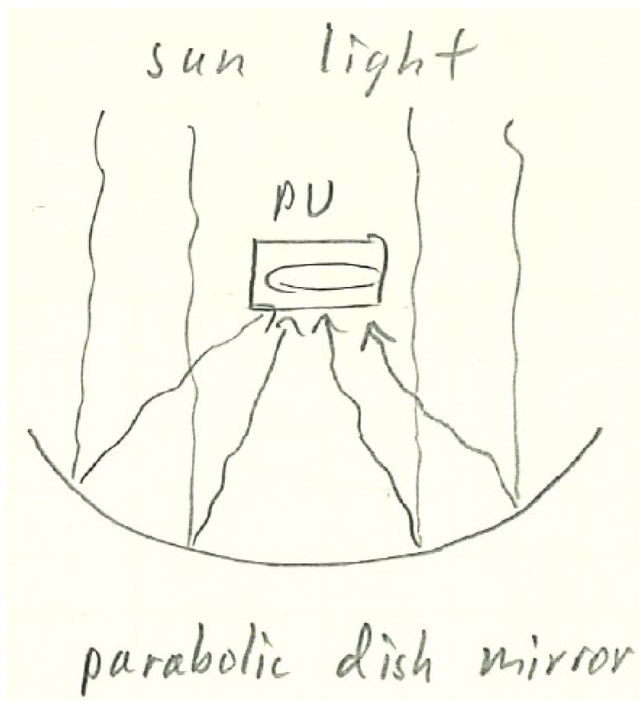
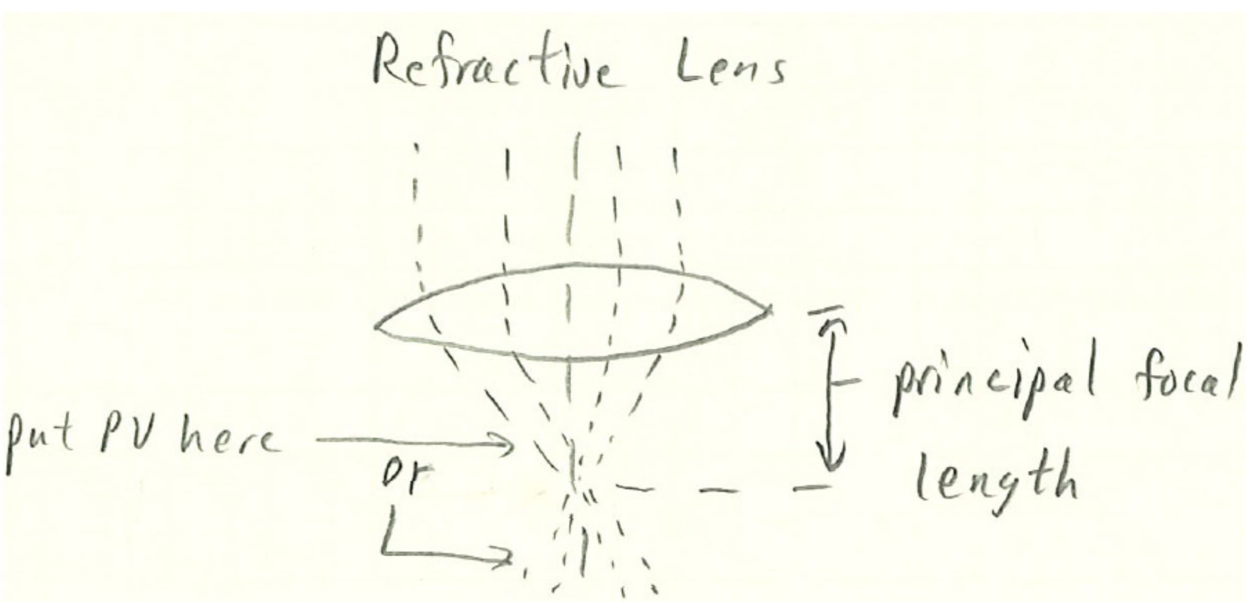


Figure 3.18 The *Euclides* 480 kW$_p$ system on the island of Tenerife (Spain) comprises a series of 14 linear parabolic trough mirrors 84 m long (EPIA/BP Solar).

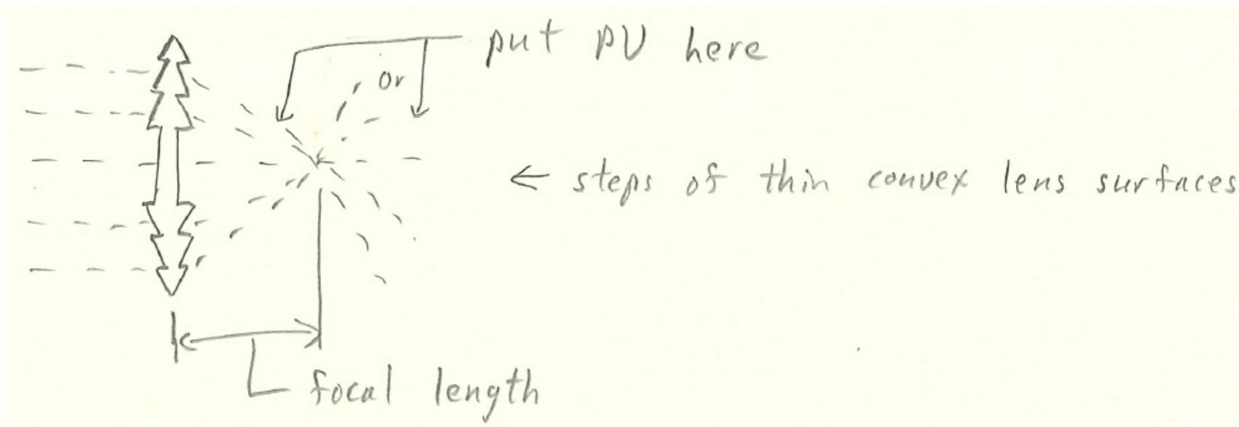
d. Refractive lens concentration:

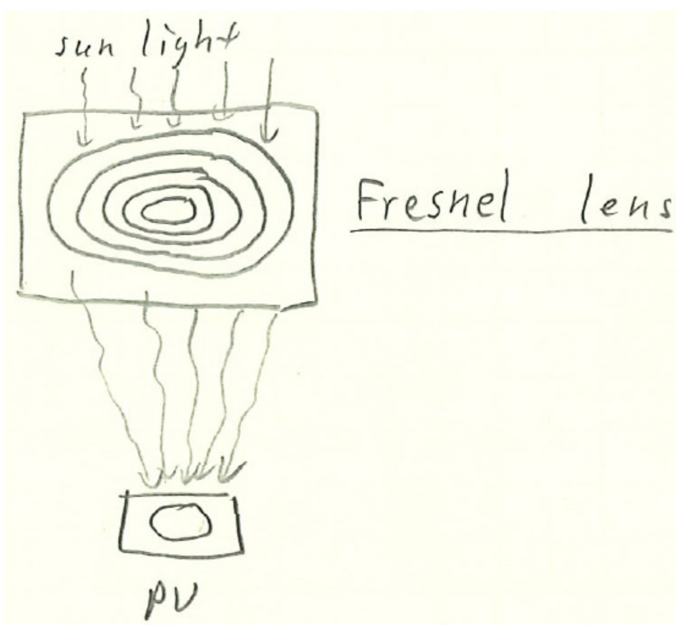


The PV cell does not go at the focal point, but rather at a position in front of or behind the focal point where the focused light shines over the entire PV cell, to have uniform illumination over the entire PV cell.

e. Fresnel lens concentration:

A Fresnel lens is better than a refractive lens for large diameters (> 10 cm) due to the large thickness (and weight) of large refractive lenses.





Fresnel lenses have been used in lighthouses since 1823.

http://beachbum.homestead.com/lighthouses/lenses/photosoflenses.html

Fresnel lens used in a lighthouse

Simple Fresnel lenses can be quite inexpensive:

Opticlens Brand (2) Pack Full Page 3x Magnifier / Plastic Magnifying Sheet Fresnel Lens, 7" X 10.25"
$6.95 at Amazon.com

Fresnel Lens focusing sunlight to melt a brick:

http://peswiki.com/index.php/Directory:Charles_Shults%27_Fresnel_Solar_Design

2) Degree of Concentration

The degree of concentration by a lens or a mirror in commonly expressed in "suns."

$$\#suns = \frac{intensity\ of\ incoming\ light}{standard\ insolation\ (i.e.\ 1000\,\frac{W}{m^2})}$$

Example: 100 suns = 100 kW/m^2 = 10 W/cm^2.

Typically, the focused light intensity on the PV cell is about 85% direct light and 15% diffuse light, even under clear skies. Note: this is because all bright sunlight on earth is about 85% direct and 15% diffuse. Geometrical optics *cannot* concentrate diffuse light!

Example: a 100 sun concentrator would typically produce 8.5 W/cm^2 at the PV cell.

3) Advantages of Solar Concentration

(1) Reduced required area of the PV cells.

(2) PV cells designed for high-quality concentrated sunlight can achieve higher conversion efficiencies than standard PV cells.

4) Disadvantages of Solar Concentration

(1) Lenses and/or mirrors are required, and they cost money.

(2) Above a certain level of concentration, sun-tracking must be added to keep the focused sunlight on the PV cell as the sun moves across the sky.

(3) High concentration is effective for the direct sunlight component, but not for diffuse or albedo components.

(4) Concentration equipment must <u>also</u> last ~ 25 years → adding maintenance costs.

(5) Concentration is not suitable for building-integrated PV systems if tracking is required.

(6) There are safety issues: concentrated sunlight can start fires, large mirrors can be problematic for airplane pilots, and birds and insects can be roasted by flying through concentrated sunlight:

NATURE

This Solar Plant Accidentally Incinerates Up to 6,000 Birds a Year

JOSH HRALA

15 SEPTEMBER 2016

A rare and unusual type of <thermal> solar power plant that concentrates sunlight in California is accidentally killing up to 6,000 birds every year, with staff reporting that the birds keep flying into its concentrated beams of sunlight, and spontaneously bursting into flames.

https://www.sciencealert.com/this-solar-plant-accidentally-incinerates-up-to-6-000-birds-a-year

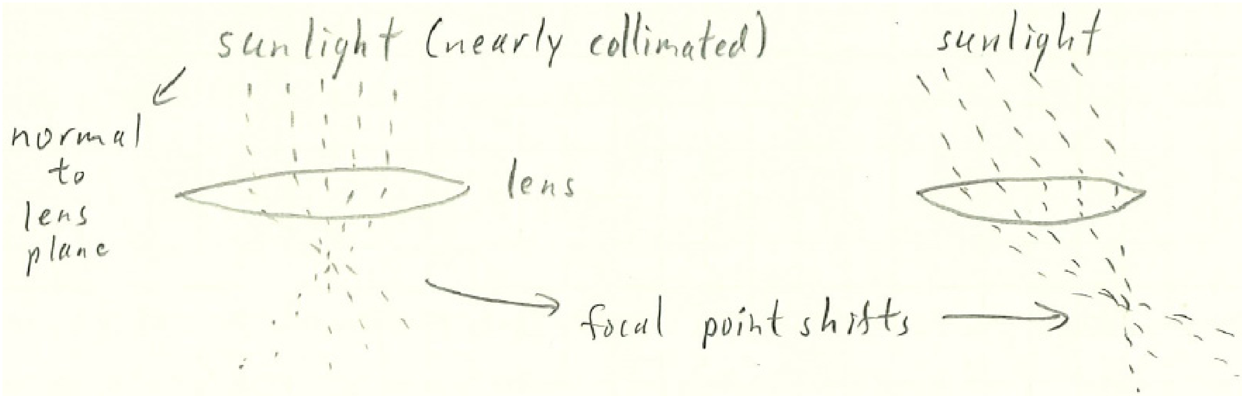
Note: higher priced GaAs PV cells (~ 40% efficiencies) are good candidates for concentrated PV systems.

Tracking the Sun

For concentration of 6-8 suns or less, tracking is generally not needed.

For concentration of greater than 6-8 suns, tracking is useful and may increase electricity output by up to 40%.

The Acceptance Angle is the angular range over which a concentrator can accept light:



To track the sun as it moves across the sky, the optics or the PV or both may be moved to track the sun's movement.

a. Simple Tracking

With this system, a person manually points the PV array at the sun 4 times a day.

This increases the yield to > 90% of what an automated tracking system can achieve.

This is limited to small, typically home-use PV systems.

b. One-Axis Automated Tracking

This is adequate for non-concentrating PV systems.

This is useful for concentrating PV systems up to about 40 suns.

This system uses a gimbaled platform with actuator(s) and a control system:

(1) Bright-spot-in-the-sky sensor.

(2) Preprogramed for time of day and day of the year.

With the one-axis system, the gimbaled axis could be the horizontal axis or the polar axis:

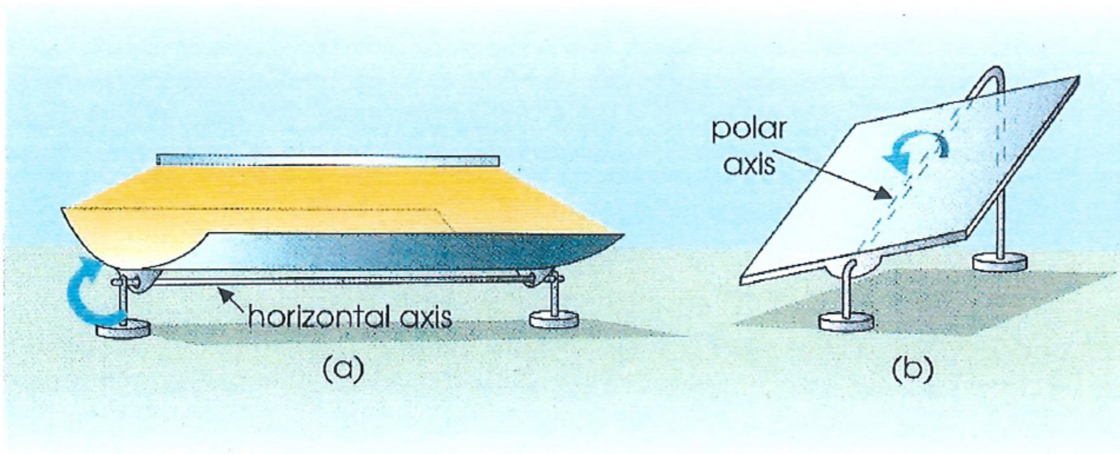


Figure 3.19 One-axis tracking.

c. Two-Axis Automated Tracking

Two-axis tracking is required for high concentration systems (> 40 suns).

This is usually used at high power commercial solar power plants.

There are various implementations:

(1) Azimuth axis and elevation axis.

(2) Tilt axis and roll axis.

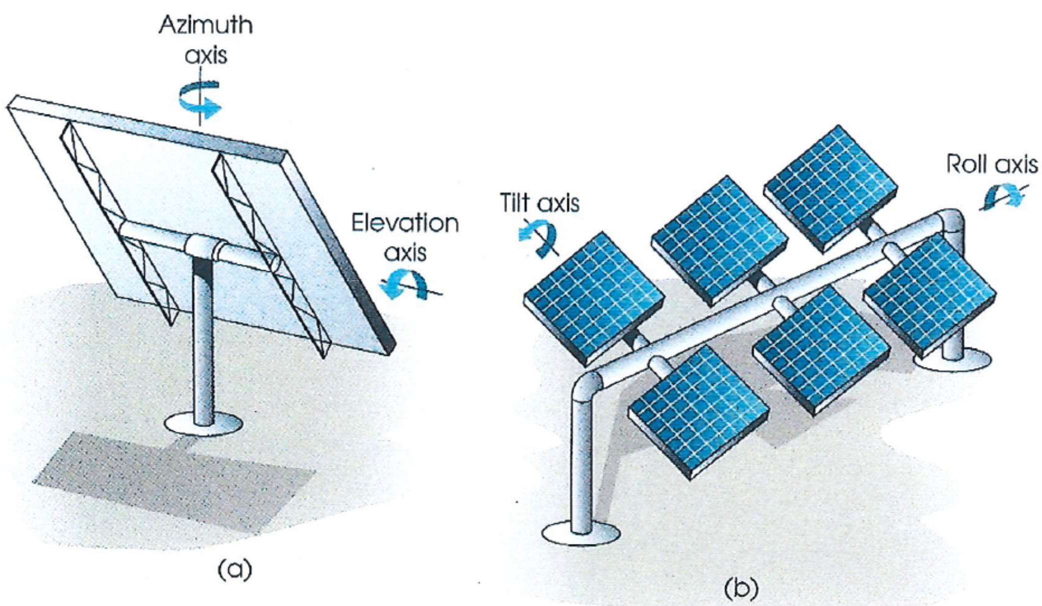


Figure 3.20 Two-axis tracking.

Consider this 53 kW_p GaAs 2-axis gimbaled PV system:

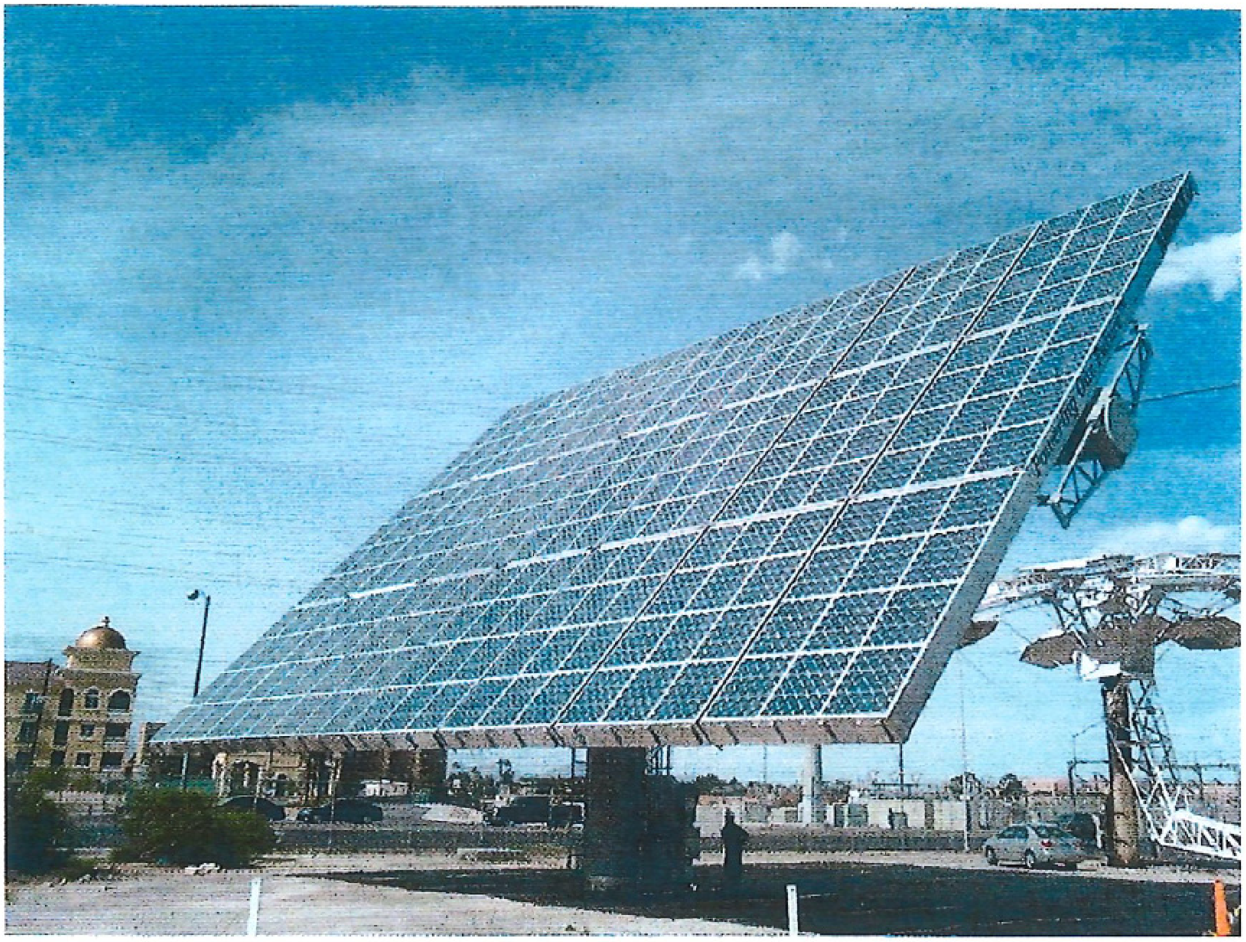


Figure 3.21 This impressive two-axis tracker in Las Vegas, USA, supports multiple point-focus concentrator modules housing multijunction GaAs solar cells and is rated at 53 kW_p (Amonix Inc.).