Concentrated Photovoltaic Power (CPV)

MECE E4211 – Energy Sources and Conversion
Supplemental
What are CPVs?

• Rationale:
  – Solar cells are expensive
  – Glass and plastic are cheap

• Solution: Use small solar cells and concentrate large amounts of light using optics

• Number of cells ↓ so we can afford to have cells with cost ↑ and efficiency ↑

• Only direct sunlight can be concentrated.
Methods of Concentration

- Lenses (Pyron Solar)
Methods of Concentration

- Lenses (Pyron Solar)
- Mirrors (Solar Systems)
Methods of Concentration

- Lenses (Pyron Solar)
- Mirrors (Solar Systems)
- Both (SolFocus)
Concentration Ratio (CR or X)

• Ratio of *aperture* area to cell area
• Optics can have several stages
  – For CR, use entrance optics and cell size
• \( I_{\text{cell}} = I_b \times \text{CR} \times \eta_o \)
  – \( \eta_o = \) optical efficiency
Example Problem

- A linear CPV system has a mirror aperture that is \(0.5 \text{ m} \times 4 \text{ m}\). Light is concentrated with 90% efficiency onto a line of 30% efficient cells of equal length but just 1 cm across.
  - What is the concentration ratio?
  - If the direct sunlight is shining at 800 W/m\(^2\), how much electricity will the unit produce?
Example Problem

• CR is the ratio in areas. Since the cell and the mirror are the same length,
  – CR = \frac{W_{aper}}{W_{cell}} = \frac{.5}{.01} = 50

• Now, find the amount of sunlight on the cell
  – I_{cell} = 800 \text{ W/m}^2 \times 50 \times .9 = 3.6 \text{ kW/m}^2
  – E_{cell} = 3.6 \text{ kW/m}^2 \times (.01 \text{ m})(4 \text{ m}) \times 30\% = \boxed{432 \text{ W}}
Heat Management

• Highest efficiency yet \( \approx 40\% \rightarrow \) electricity
• Remaining energy is necessarily converted to heat.

• **Heat must be dissipated.**
  – Low concentration can be passively cooled
  – Extra high (500x+) requires active cooling
  – Extracted heat can be used to run heat engine
Heat Transfer Modes (review)

- Conduction, thru stationary materials
  - \( q = k \times L \times (T_2 - T_1) \)
    - \( k \) = material conduction coefficient, \( L \) = length

- Convection, between solid and fluid
  - \( q = h \times A \times (T_2 - T_1) \)
    - \( h \) = convection coefficient, dependent on flow

- Radiation, electromagnetic
  - \( q = \varepsilon \times \sigma \times A \times (T_2^4 - T_1^4) \)
    - \( \varepsilon \) = surface emissivity, \( \sigma \) = Stefan-Boltzmann constant, 5.67 × 10^{-8} \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}, T = \text{temperature in Kelvin} \) for rad' n
Radiation and Concentration

- Neglecting convection and conduction, heat radiated is function of concentration
  \[ I_{\text{cell}} = I_b \times CR \times \eta_o, \quad q = \varepsilon \times \sigma \times A \left( T_2^4 - T_1^4 \right) \]

- Combining:
  \[ (1 - \eta_c)(I_b \times CR \times \eta_o) = \varepsilon \times \sigma \times A \left( T_2^4 - T_1^4 \right) \]

- When \( T_c > 2T_{\text{surr}} \), \( T_{\text{surr}} \) becomes insignificant.

\[
T_c = \left( \frac{(1-\eta_c)(I_b \cdot CR \cdot \eta_o)}{\varepsilon \sigma A} \right)^{1/4}
\]