Solar Energy Primer

- The Earth’s surface receives about 89 petawatts ($89 \times 10^{15}$ W) of solar radiation (insolation) – 100 mW/cm$^2$ → AirMass1.5 conditions
- In one year, the total solar energy absorbed by Earth's atmosphere, oceans and land is approximately 3,850 zettajoules ($10^{21}$ J)
- More solar energy strikes the earth in 1 hr ($4.3 \times 10^{20}$ J) than all the energy consumed on the planet in 1 yr ($4.1 \times 10^{20}$ J in 2001)
- The world energy consumption rate was 13.5 terawatts ($10^{12}$ W) in 2001, and is expected to grow to 27 TW by 2050.
- The US consumption of total power (gas, electricity) was 3.34 TW in 2005. The US electricity consumption was about 0.7 TW (winter 2006-2007)
- A half day of sunlight (in winter) striking the US ($9 \times 10^{15}$ watts) can provide all the US energy for a year (29,000 TW-hr).
Solar Energy Primer

- Solar irradiance spectrum above atmosphere and at surface

Solar Radiation Spectrum

- Sunlight at Top of the Atmosphere
- 5250°C Blackbody Spectrum
- Radiation at Sea Level
A newly established low band gap for indium nitride means that the indium gallium nitride system of alloys ($\text{In}_{1-x}\text{Ga}_x\text{N}$) covers the full solar spectrum.
• 1 Gallon of Gasoline = 37 KW-h (125,000 BTUs in a gallon of gas divided by 3,400 BTUs in 1 KWH)

• 1 Gallon of Gasoline = 500 hours of human work: 50 people in a 10 hour day (37 KWH in 1 gallon of gas ÷ human work in agriculture of .074 KW)

• Sometimes energy units are in “quads” → 1 quad = 1 quadrillion (10^{15}) BTU (heat to raise 1 pound of water 1°F) = 1.055 exajoules (1.055 \times 10^{18} J) = 290 terawatt-hr

• The most efficient solar cells convert over 23% of illumination power to electric power (record is about 42%)
Solar Energy Primer

• The sale price of converted electrical energy should pay back the initial cost of the solar energy system over 30-yrs. At 10% efficiency, and $3/W (peak) (or $300 per m²) typical of Si-based modules, an electricity price of $0.35 /[kW-hr] is required

• At the end of 2007, according to preliminary data, cumulative global photovoltaic production was 12,400 megawatts

• The 14 MW Nellis Solar Power Plant is the largest solar photovoltaic system in North America, at Nellis Air Force Base northeast of Las Vegas. It generates 25 million kilowatt-hours of electricity annually and supplies 25 percent of the base’s power

• The world's largest photovoltaic (PV) power plant is a 60 MW unit in Spain
Solar Energy Primer

• Calculate land area needed to supply US electric peak power during daylight hours.

• Solar illumination under AM1.5 conditions is 1KW/m². At 20% cell efficiency (sold by Sanyo in 2008), the available peak power is 200W/m². To obtain the US peak electric usage of 1 TW, we need:
  \[ \text{Area} = \frac{\text{peak power}}{\text{conversion density}} = \frac{1 \text{ TW}}{0.2 \text{ KW/m}^2} = 5 \times 10^9 \text{ m}^2 = 5 \times 10^3 \text{ km}^2 = (71 \text{ km})^2 = (44 \text{ mi})^2 . \]
  This is 0.05% of the US land area of 9,161,923 SQ KM (not 3 % as in some textbooks!)

• So a region of south western desert, 44 miles square, would provide the US with peak power during the day (about 6 hours). Maybe quadruple this to get a full 24 hours worth, plus storage would be needed. Year 2008 module price is about $5/W (peak) with efficiency near 20% for Si-based modules.
Solar Energy Primer

• Photovoltaic cell cross section

• Textured surface produces longer photon path: “light trapping”
Solar Energy Primer

- Reported timeline of solar cell energy conversion efficiencies (from National Renewable Energy Laboratory, USA)
• Wikipedia – that wonderful website.
• “Powering the planet: Chemical challenges in solar energy utilization,” Nathan S. Lewis and Daniel G. Nocera