Lecture 15: Solar Energy

Course: MECH-422 – Power Plants

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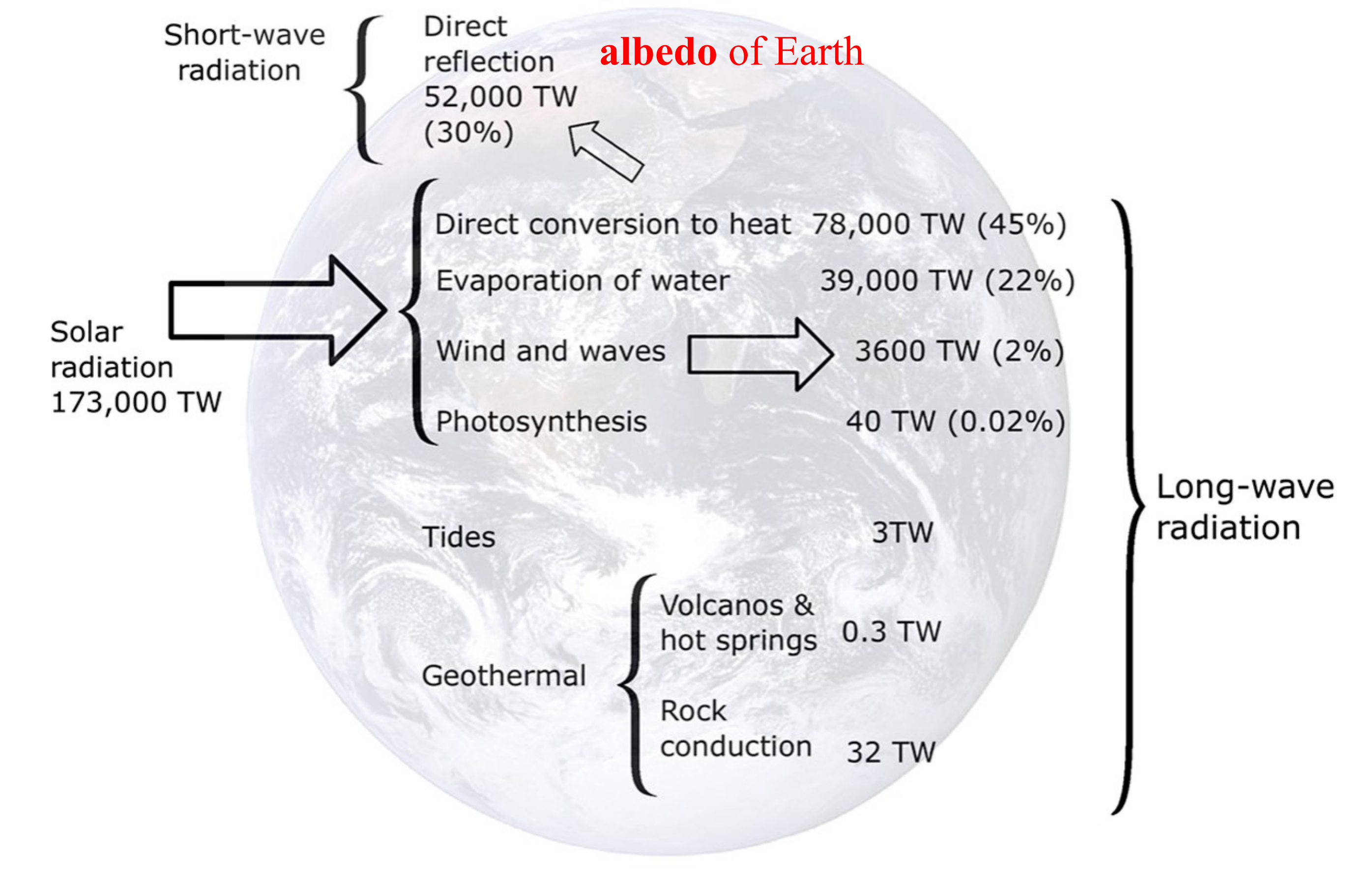
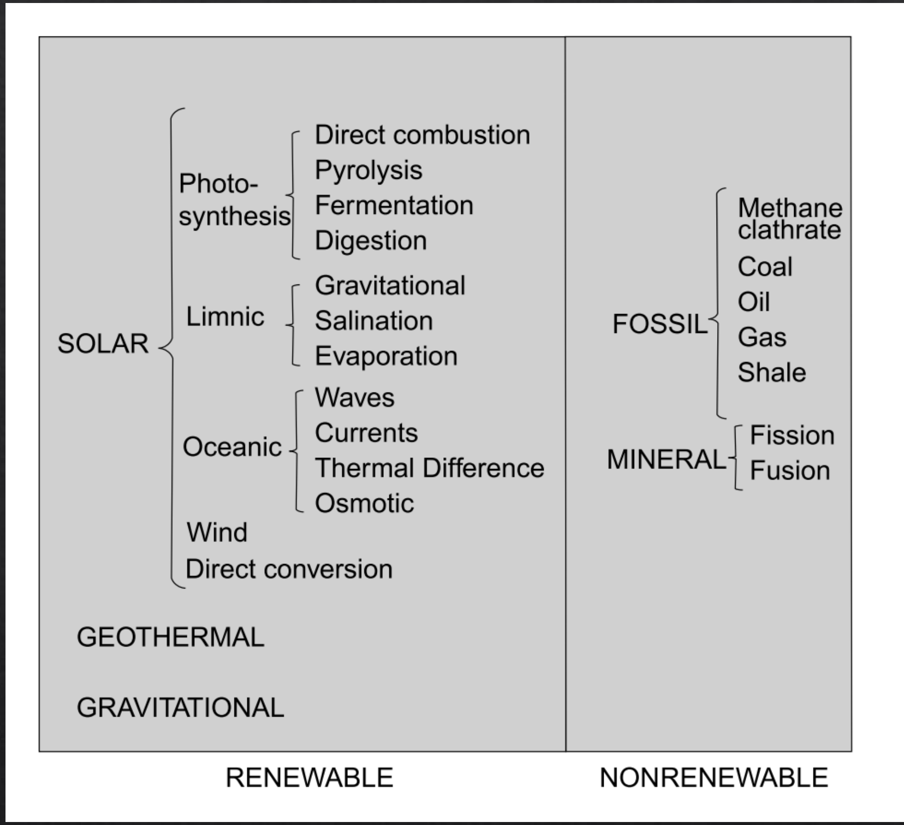
Term: Fall 2021

BUITEMS – DEPARTMENT OF MECHANICAL ENGINEERING

Planetary Energy Balance





Solar Energy

- **Solar irradiance**, also called **solar energy flux or intensity (**W/m^2**)**
- is defined as the incident solar energy or power, also referred to as insolation, received by a unit of area.
- The amount of solar irradiance varies with both time and location.

Solar Energy

- To understand how solar irradiance varies on Earth,
- We will evaluate the following factors:
    - Solar energy production on the Sun
    - Solar radiation traveling from the Sun to Earth (extraterrestrial radiation as received above the atmosphere)
    - Geometric relationship between the Sun and Earth
    - Solar radiation traveling through the atmosphere

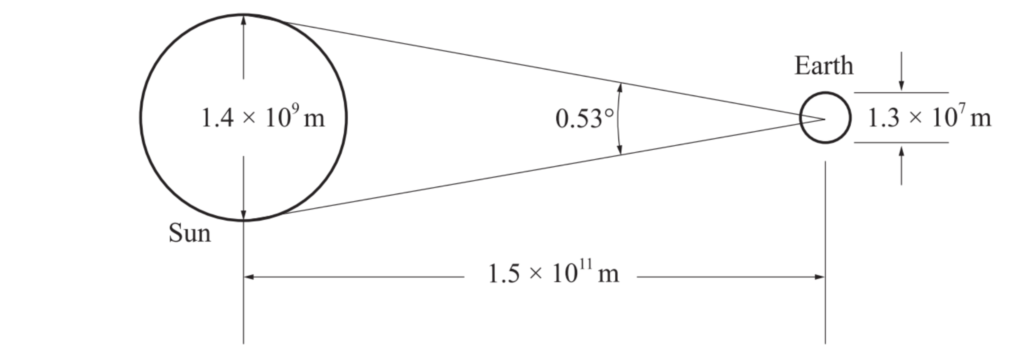
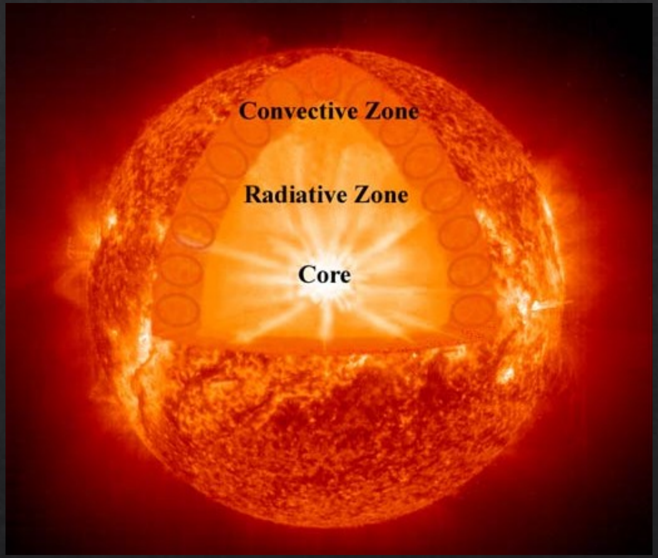


FIGURE 11.1
Dimensional relationship between Earth and the Sun.

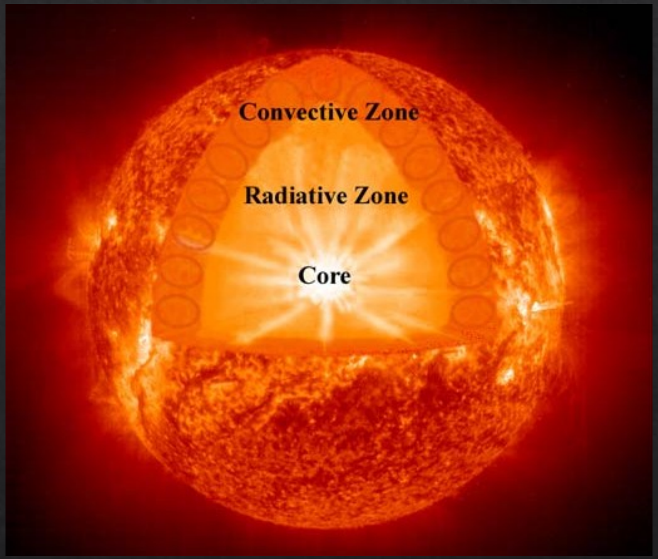
Solar Energy

- Energy in sun is generated by the thermonuclear reactions at its core where hydrogen atoms are fused into helium.
- While most known elements exist in the Sun,
  - the great majority of the Sun is made of hydrogen and helium (with the ratio of about three to one).
- The energy produced at the center of the Sun is estimated at about 3.8 × 1026 W.
- The Sun is so massive that it takes tens of thousands of years for the thermal energy created at its core to transfer to its surface.



Solar Energy

- While it is estimated that the temperature of the core of the Sun is over 15 million degree Celsius
- This temperature gradually reduces through many layers of gases.
- On the surface of the Sun, the temperature is about 5500°C.
- This high-temperature surface is where the solar radiation is originated from.



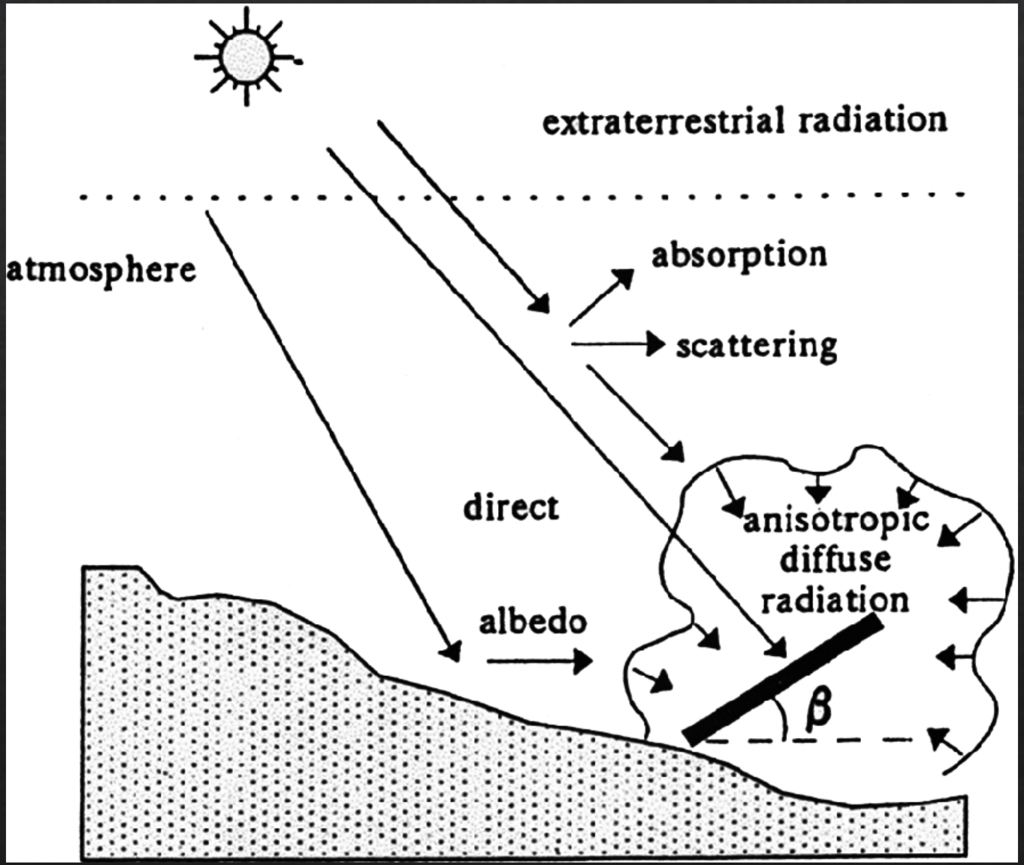
Solar Energy

Example 11.1

If the energy generated in the fusion reaction on the Sun is 3.8×10^{26} W, determine the rate of the conversion of mass to energy on the Sun in kg/s.

Extraterrestrial Radiation

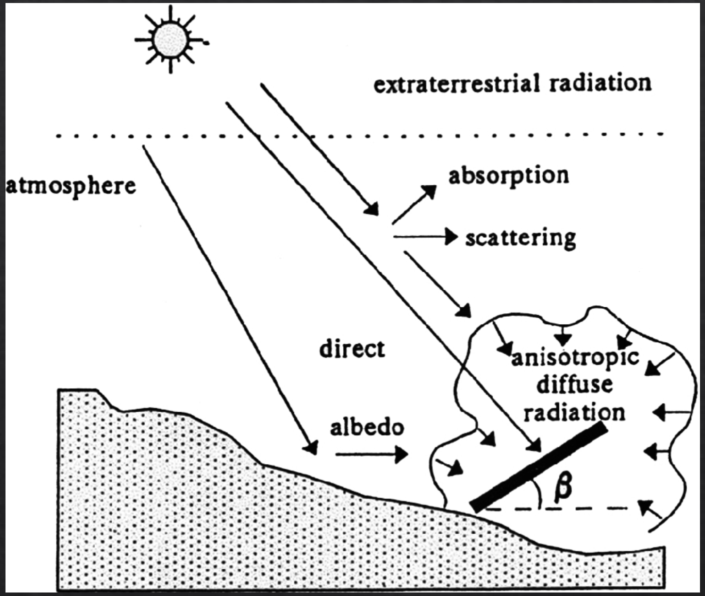
- Solar radiation generated by the surface of the Sun travels the void between the Sun and Earth unaltered.
- The average distance between the Sun and Earth is about 1.5×10^{11} m (93 million mi)
  - Which is also referred to as one astronomical unit (1 AU).



Extraterrestrial Radiation

Solar Constant

- The value of solar irradiance outside Earth's atmosphere when the distance between the Sun and Earth is approximately one AU is called the solar constant
- Note that the solar constant (sometimes referred to as GSC) is not a fixed physical constant (such as the gravitational constant or the speed of light)
- A range of values has been reported for it, from 1360 to 1370 W/m^2.
- Because of this variation, some references stop using the term solar constant and now use the term total solar irradiance (TSI)

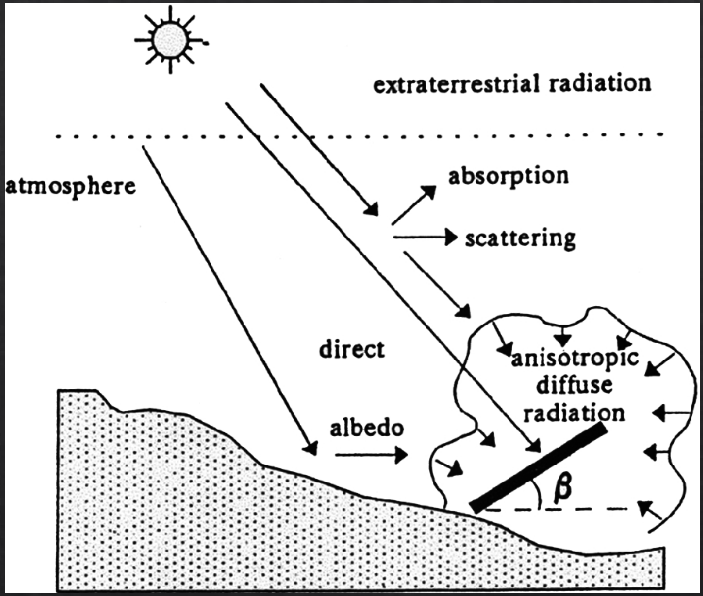


GSC = Global Solar Constant

Extraterrestrial Radiation

Solar Constant

- The current estimated value for the solar constant by NASA is 1360.8 ±0.5 W/m^2



Example 11.2

We know that the Sun releases 3.8×10^{26} W of radiation. If the average distance between the Sun and Earth is 1.5×10^{11} m, determine the solar power received on Earth per unit of area (solar irradiance in W/m^2).

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Solution

When solar radiation arrives at Earth's atmosphere, it is uniformly distributed on the surface of a sphere with the radius of the average distance between the Sun and Earth.

$$I = \frac{\text{Total solar radiation}}{\text{Surface of sphere}} = \frac{P_{\text{Sun}}}{4\pi r^2} = \frac{3.8 \times 10^{26}}{4 \times 3.14\left(1.5 \times 10^{11}\right)^2} = 1345 \text{ W/m}^2 \quad (11.2)$$

If we repeat the calculations with more accurate values of solar radiation and the Sun and Earth distance, a much more accurate value of 1361.8 W/m^2 can be achieved.

In the examples, we assumed Earth rotates around the Sun in a circle with the radius of the average distance of the Sun and Earth. However, Earth's orbit around the Sun is slightly elliptical (with the eccentricity of 0.0167), which means Earth is sometimes farther away from the Sun than the

Example 11.5

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Solution

The area that intercepts solar radiation on Earth is equal to the area of a disk with the radius of Earth.

$$\text{Area of a disk with radius of Earth} = \pi r_{\text{Earth}}^2 = 3.14\left(6.371 \times 10^6\right)^2 = 1.27 \times 10^{14}\ \text{m}^2$$

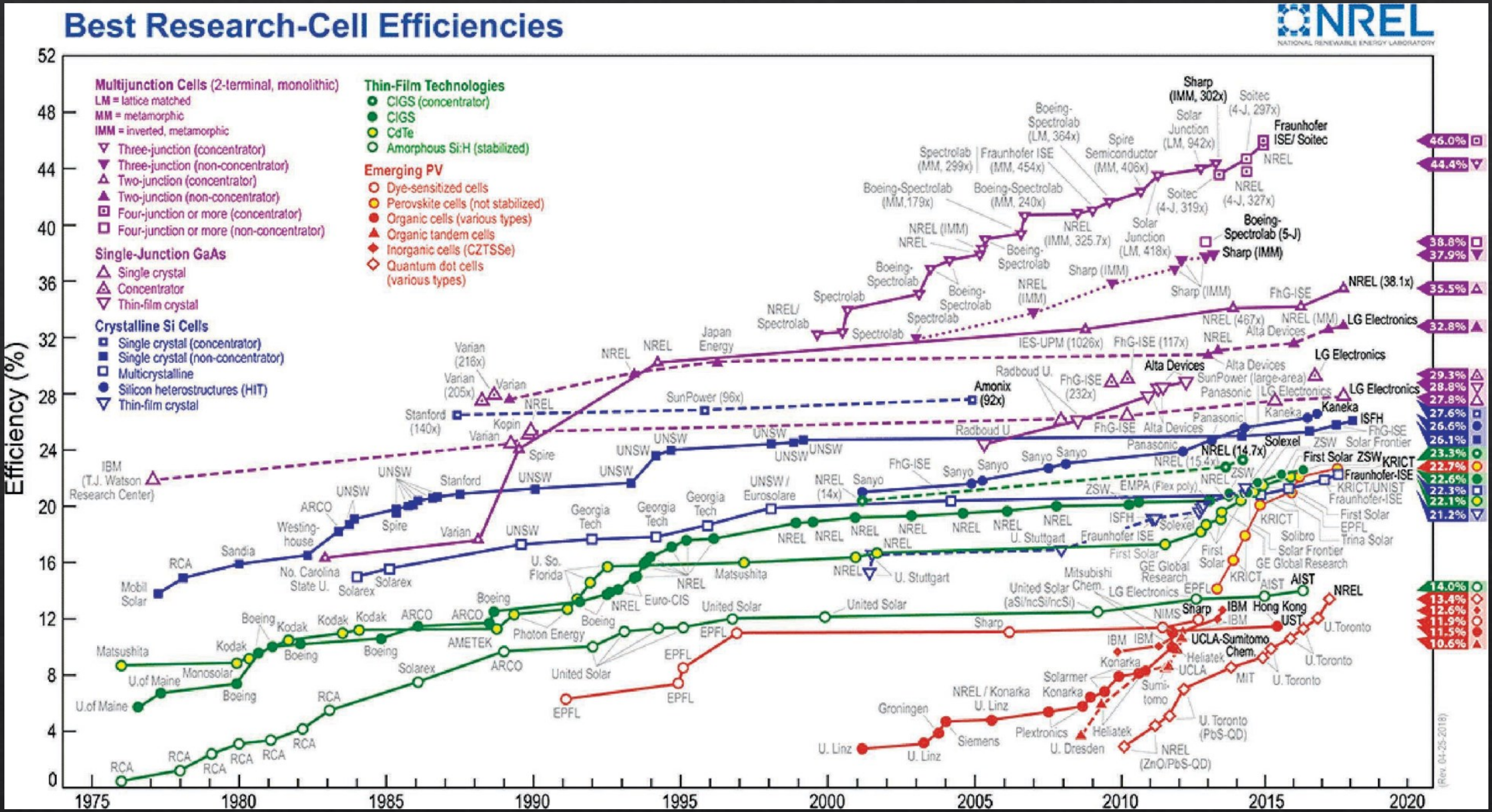
$$\text{Radiation intercepted by Earth} = 1361.8 \times 1.27 \times 10^{14} = 1.74 \times 10^{17}\ \text{W}$$

$$\text{Percentage of the Sun's total radiation intercepted by Earth}$$

$$= \frac{\text{Radiation intercepted by Earth}}{\text{Total solar radiation}} = \frac{1.74 \times 10^{17}}{3.828 \times 10^{26}}$$

$$= 4.53 \times 10^{-10} = 4.53 \times 10^{-8}\,\%$$

- DNI
- GHI
- DHI



Efficiency of various solar cell technologies between 1975 and 2018. (Source: NREL, https://www.nrel.gov/pv/assets/images/efficiency-chart.png)

Example 11.6

The area of the solar array installed on Juno orbiting Jupiter is $72\,m^2$. Determine the amount of solar radiation intercepted by this satellite when it orbits Jupiter. What if it orbits Earth, Mars, or Saturn? The Sun releases 3.828×10^{26} W of radiation. The average distance between the Sun and Jupiter, Earth, Mars, and Saturn is 5.2, 1, 1.52, and 9.5 AU, respectively.

End of Lecture!