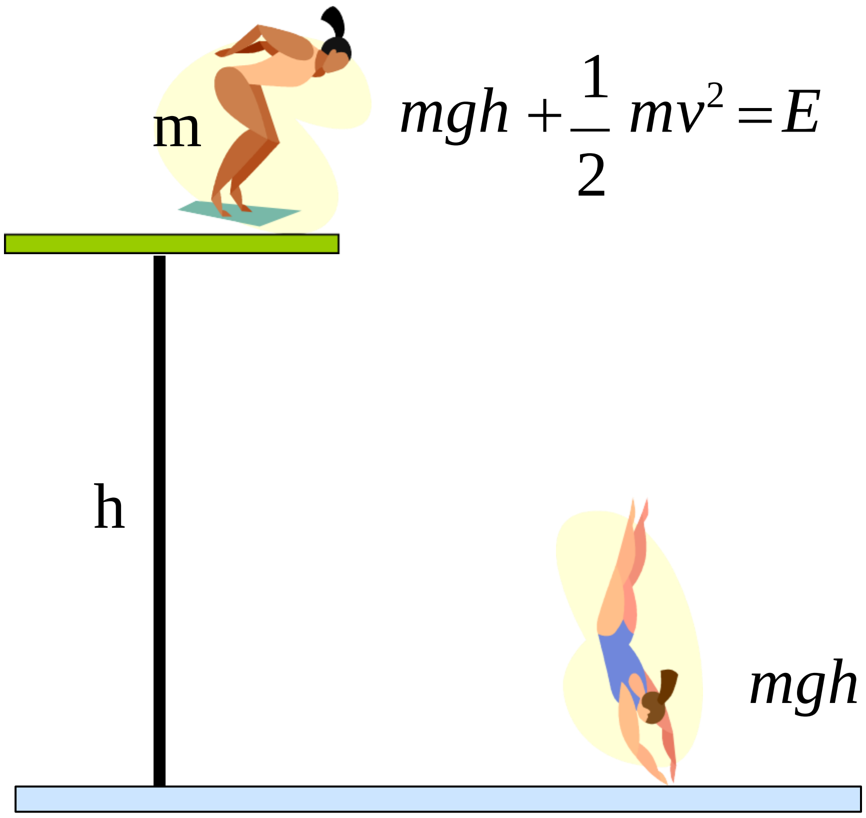
Types of Energy

- Potential & Kinetic Energy



$$mgh + \frac{1}{2}mv^2 = E \qquad \frac{1}{2}mv^2 = 0$$

$$mgh + \frac{1}{2}mv^2 = E \qquad mgh = 0$$

Types of Energy

- Thermal Energy

$$Q = mc\Delta T$$

$m : mass\,(g)$

$\Delta T : change\ in\ temperature\,(K)$

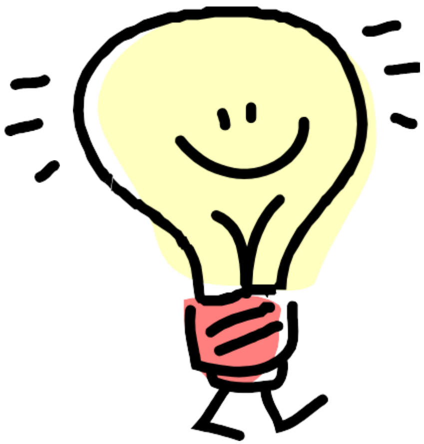
$c : specific\ heat\ capacity\,(cal / g \times K)$

Heat capacity: The thermal energy required to raise the mass of a substance by one degree; 1 cal: 4.184 J 1 J: 0.24 cal

1 cal: the amount of energy required to increase the temperature of 1g of water by ^oC.

Types of Energy

- Electric Energy



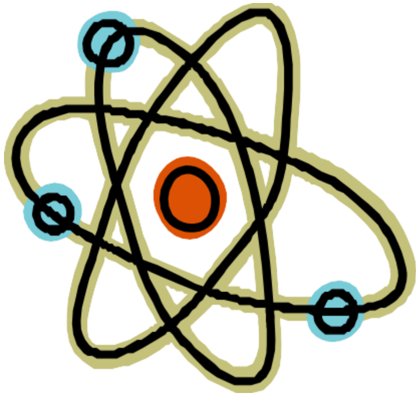
$$E = CV$$

$$1eV = 1.6 \times 10^{-19} J$$

1 eV:
the energy required to move one electron through an electric potential, 1V.

Types of Energy

- Nuclear Energy



$$E = mc^2$$

$$\Delta E = \Delta mc^2$$

ex) nuclear weapon and nuclear reactor

Small mass loss during the nuclear reaction appears as the large amount of energy

Types of Energy

- Photon Energy (E)

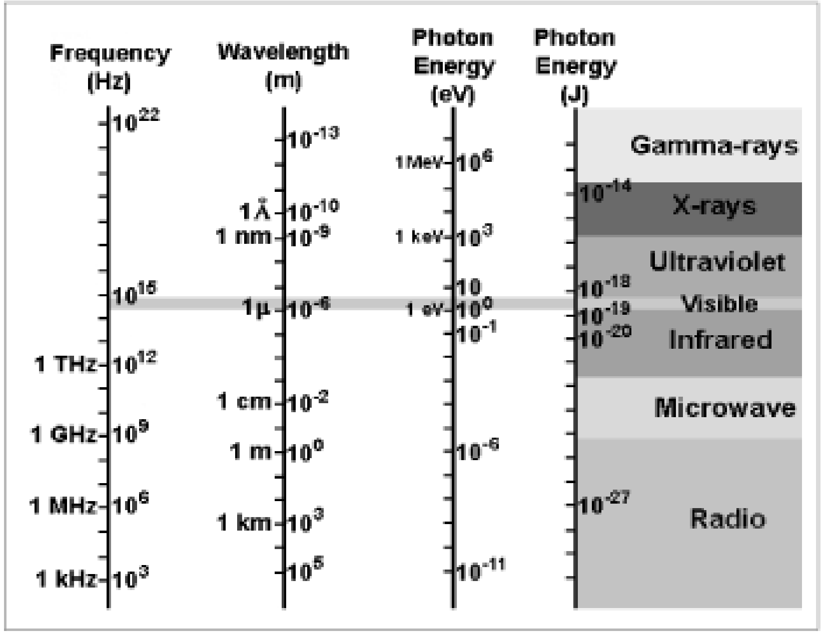
$$E = h\nu = \frac{hc}{\lambda}$$

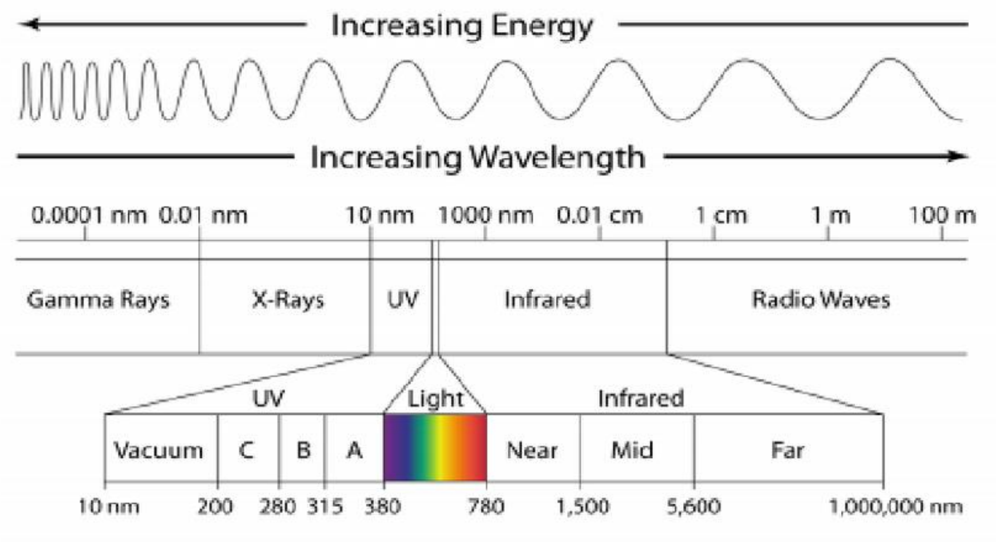
$$\text{h} = \text{planck's contant}(6.626 \times 10^{-34} J \bullet \text{sec})$$

$h\nu$	- Smallest amount of energy for the light with the frequency (ν) - Quantum of energy for light. - Energy of a photon.

Types of Energy

- Photon Energy (E) : The energy carried by a single photon
  - ✓ Gamma rays - higher energy photons
  - ✓ Radiofrequency region – lower energy photons

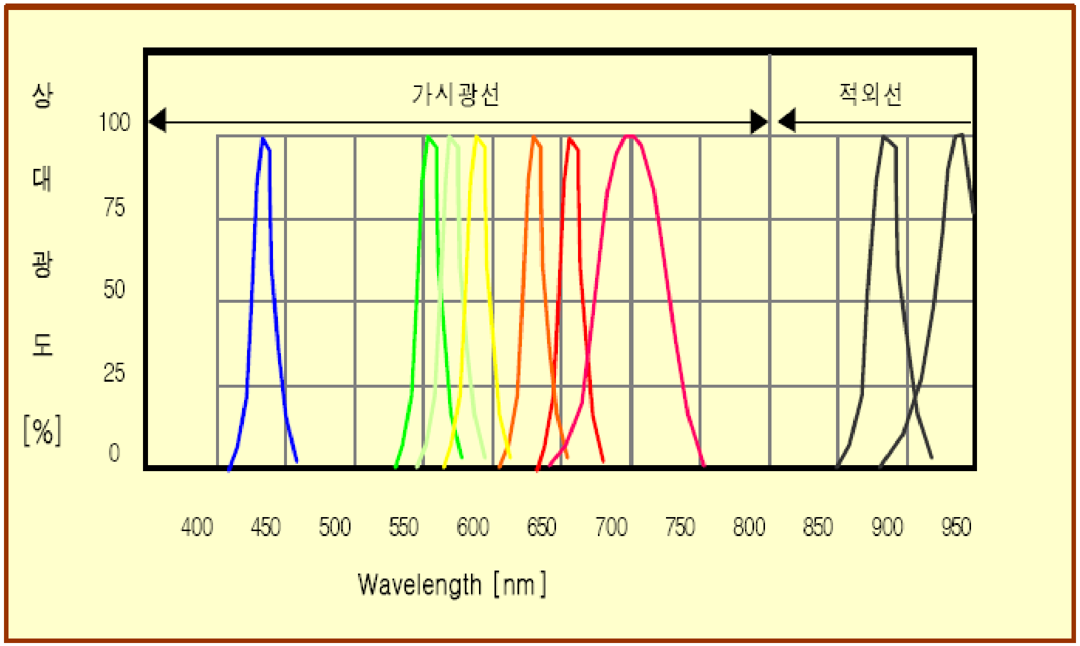


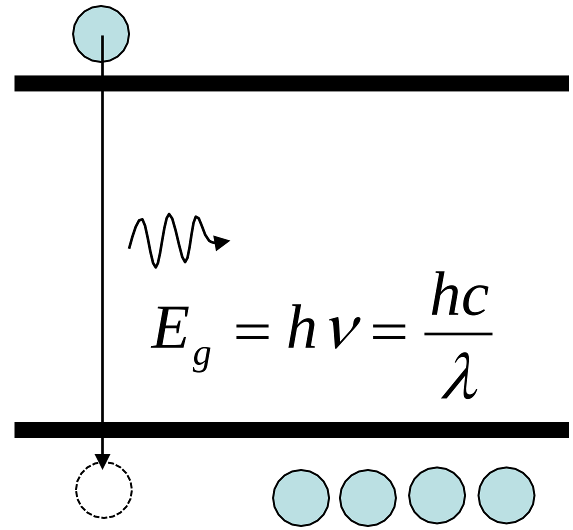


UV light is distinguished into several sub-ranges such as UVA (315-400nm), UVB (280-315nm), UVC (200-280nm) and Vacuum UV (100-200nm)

Types of Energy

- ❑ Photon Energy



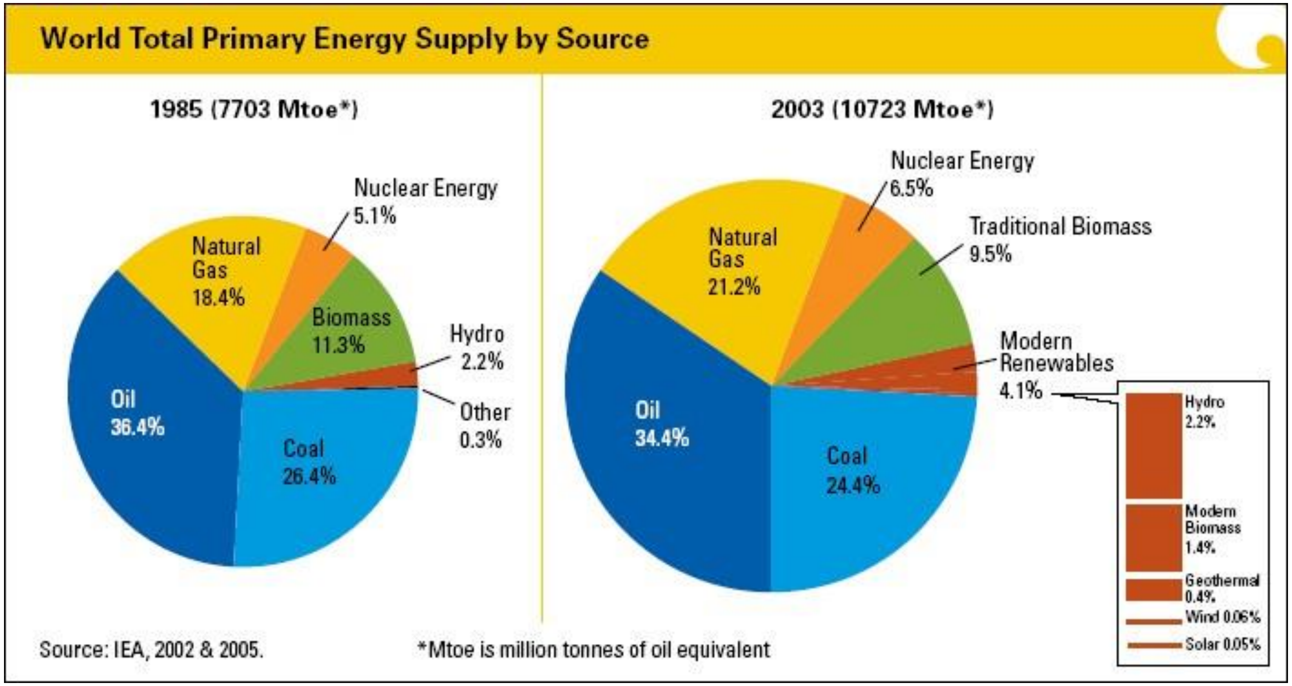


$$E_g = h\nu = \frac{hc}{\lambda}$$

$$E = \frac{1240\,nm}{\lambda}$$

Photon energy at 1 µm wavelength, the wavelength near **IR**, is ~ 1.240 eV

Global Energy Resource

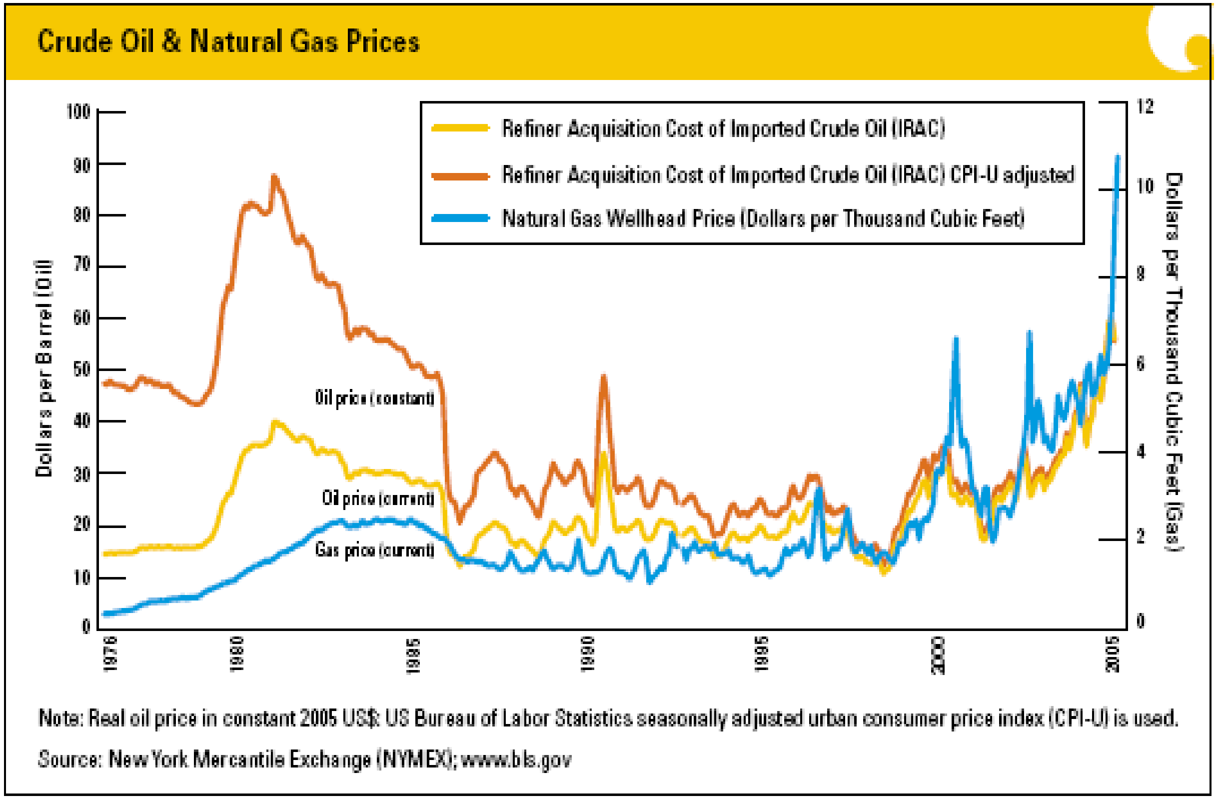


-Fossil fuels dominate energy supplies.

-From 1971 to 2003, global oil consumption in transport increased four times faster than consumption in industry.

-Renewables other than hydro and biomass, including geothermal, solar and wind energy, are growing faster than any other energy source, but still account for only a tiny fraction of global energy supply.

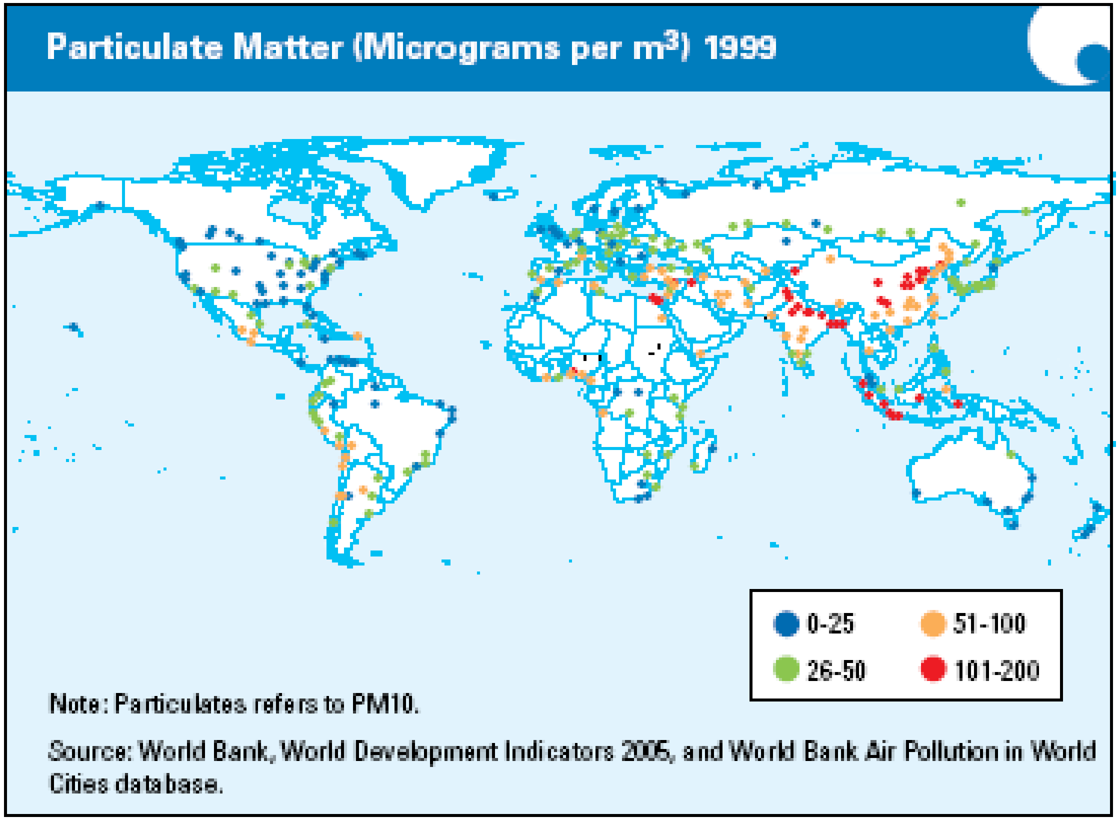
Global Energy Resource



-Higher energy prices are promoting energy efficiency but also causing concerns.

-High prices are promoting energy conservation and efficiency efforts and making alternative energy sources, such as renewable energy, more competitive.

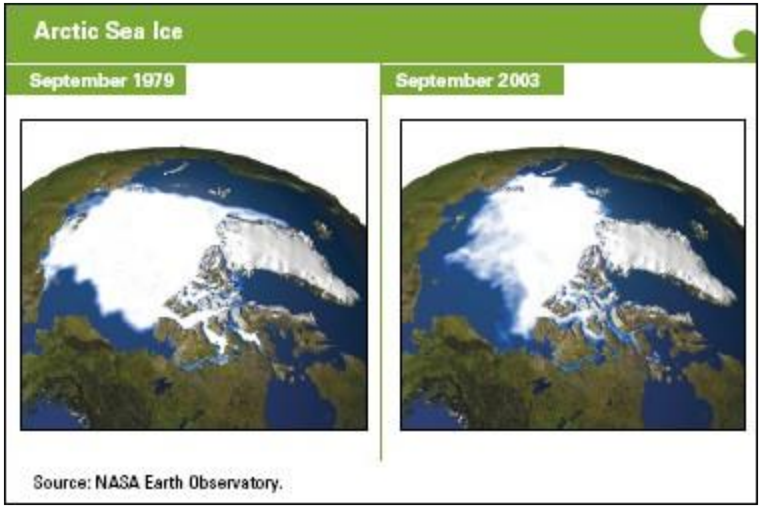
Atmosphere & Air Pollution



-Particulate air pollution has been reduced worldwide but remains high in large cities in developing countries

-Despite some improvement, in many Asian cities air pollution levels are an order of magnitude higher than in major developed country cities.

Climate Change



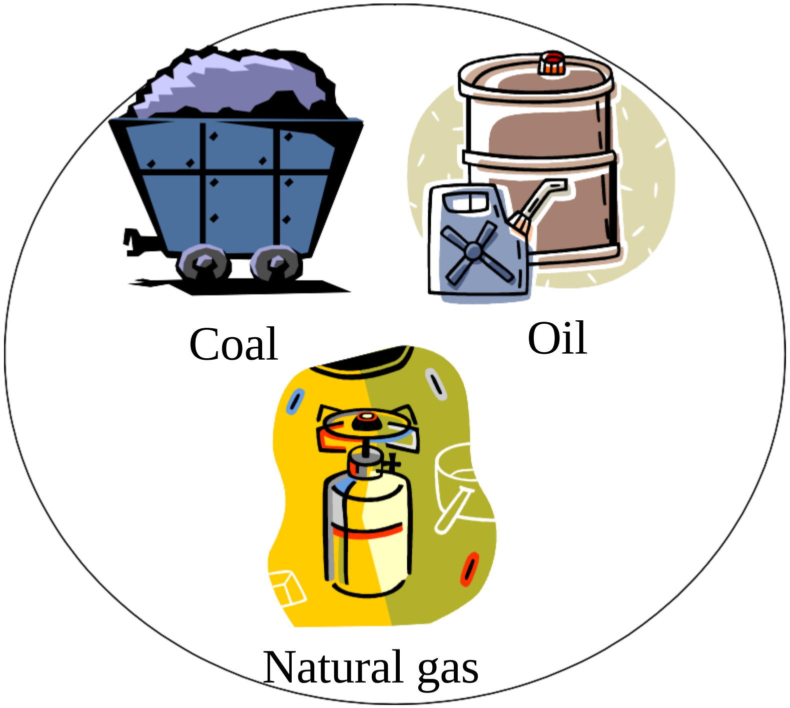
-Historical and current pictures of Arctic sea ice and tropical glaciers indicate the extent of warming and melting that has occurred over the past 25-35 years.

-Recent evidence indicates that current atmospheric CO_2 concentrations are high compared with levels over the last million years.

-Global warming is currently raising sea-levels by almost 2 cm per decade, and that rate is expected to increase with rising atmospheric CO_2 concentrations, leading to flooding of low-lying coastal areas.

Nonrenewable Energy

Nonrenewable energy: finite resources that will eventually dwindle, becoming too expensive or too environmentally damaging to retrieve.



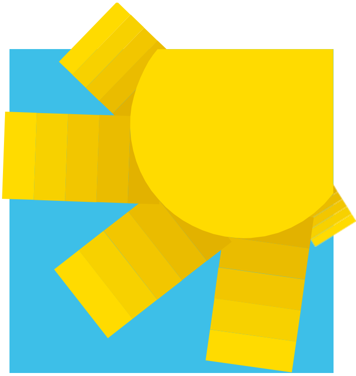
Fossil Fuel

Nuclear Fission

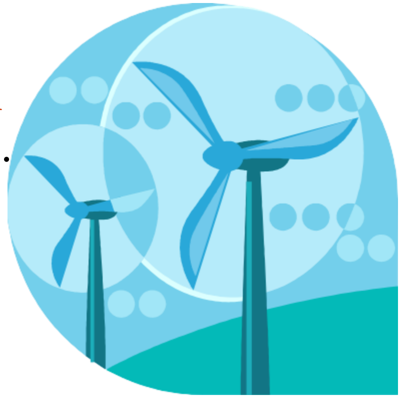
Is nuclear energy Renewable?

Renewable Energy

Renewable energy: resources—such as wind and solar energy—are constantly replenished and will never run out.



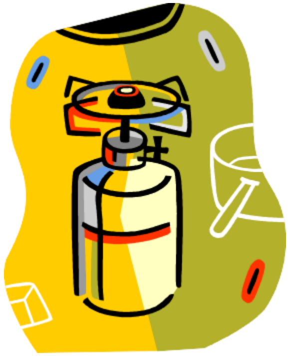
Solar: Most renewable energy comes either directly or indirectly from the sun. Sunlight, or solar energy, can be used directly for heating and lighting homes and other buildings, for generating electricity, and for hot water heating, and a variety of commercial and industrial uses.



Wind: The sun's heat also drives the winds, whose energy is captured with wind turbines. Then, the winds and the sun's heat cause water to evaporate. When this water vapor turns into rain or snow and flows downhill into rivers or streams, its energy can be captured using hydropower

Renewable Energy

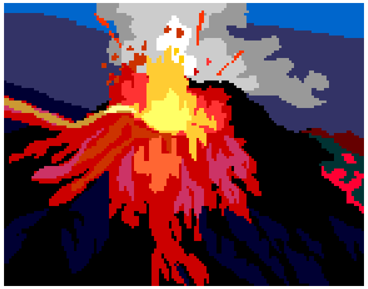
Biomass: Along with the rain and snow, sunlight causes plants to grow. The organic matter that makes up those plants is known as biomass. Biomass can be used to produce electricity, transportation fuels, or chemicals. The use of biomass for any of these purposes is called biomass energy.



Hydrogen: Hydrogen also can be found in many organic compounds, as well as water. It's the most abundant element on the Earth. But it doesn't occur naturally as a gas. It's always combined with other elements, such as with oxygen to make water. Once separated from another element, hydrogen can be burned as a fuel or converted into electricity.

In a flame of pure hydrogen gas, burning in air, the hydrogen (H_2) reacts with oxygen (O_2) to form water(H_2O) and releases energy.

$2H_2(g) + O_2(g) \rightarrow 2H_2O(g) + \text{energy}$



Geothermal: Not all renewable energy resources come from the sun. Geothermal energy taps the Earth's internal heat for a variety of uses, including electric power production, and the heating and cooling of buildings.

Renewable Energy

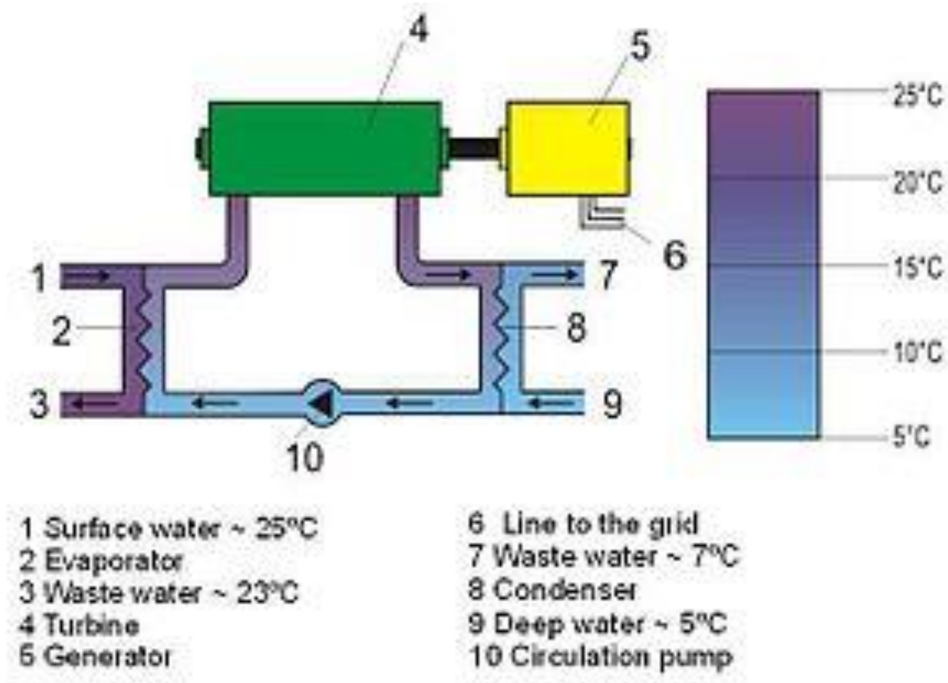
Ocean: The ocean can produce thermal energy from the sun's heat and mechanical energy from the tides and waves.

Oceans cover more than 70% of Earth's surface, making them the world's largest solar collectors.

Ocean thermal power: This works best when the temperature difference between the warmer, top layer of the ocean and the colder, deep ocean water is about 20°C (36°F). These conditions exist in tropical coastal areas, roughly between the Tropic of Capricorn and the Tropic of Cancer. This power could produce billions of watts of electrical power.

Ocean tide power: For those tidal differences to be harnessed into electricity, the difference between high and low tides must be at least five meters. There are only about 40 sites on the Earth with tidal ranges of this magnitude.

Hydropower: Flowing water creates energy that can be captured and turned into electricity. This is called hydroelectric power or hydropower.


4
5
25°C
20°C
6
15°C
1
7
2
8
10°C
3
9
5°C
10
1 Surface water ~ 25ºC
2 Evaporator
3 Waste water ~ 23ºC
4 Turbine
5 Generator
6 Line to the grid
7 Waste water ~ 7ºC
8 Condenser
9 Deep water ~ 5ºC
10 Circulation pump

Renewable Energy

Biomass

Source of Biomass

·We have used biomass energy or "bioenergy"—the energy from plants and plant-derived materials—since people began burning wood to cook food and keep warm.

•Wood is still the largest biomass energy resource today, but other sources of biomass can also be used. (food crops, grassy and woody plants, residues from agriculture or forestry, and the organic component of municipal and industrial wastes)

Use of Biomass

· Biofuel: Converting biomass into liquid fuels for transportation.

· Biofuels are in theory carbon-neutral because the carbon dioxide that is absorbed by the plants is equal to the carbon dioxide that is released when the fuel is burned.

·Biopower: Burning biomass directly, or converting it into gaseous or liquid fuels that burn more efficiently, to generate electricity

·Bioproduct: Converting biomass into chemicals for making plastics and other products that typically are made from petroleum

Benefits of Biomass

· Potential to greatly reduce greenhouse gas emissions.

· Reduce dependence on foreign oil because biofuels are the only renewable liquid transportation fuels.

·Biomass energy supports agricultural and forest-product industries. For biomass fuels, the feedstocks are corn (for ethanol) and soybeans (for biodiesel), both surplus crops.

Renewable Energy

Solar Energy

Technology of Solar Energy Utilization

·Concentrating solar power systems — Using the sun's heat to produce electricity.

·Passive solar heating and daylighting — Using solar energy to heat and light buildings.

·Photovoltaic (solar cell) systems — Producing electricity directly from sunlight.

· Solar hot water — Heating water with solar energy.

Renewable Energy

Concentrating solar power: Many power plants today use fossil fuels as a heat source to boil water. The steam from the boiling water rotates a large turbine, which activates a generator that produces electricity. However, a new generation of power plants, with concentrating solar power systems, uses the sun as a heat source.

Passive Solar: The south side of a building always receives the most sunlight. Therefore, buildings designed for passive solar heating usually have large, south-facing windows. Materials that absorb and store the sun's heat can be built into the sunlit floors and walls. The floors and walls will then heat up during the day and slowly release heat at night, when the heat is needed most. This passive solar design feature is called direct gain.

Thousands of years ago, the Anasazi Indians in Colorado incorporated passive solar design in their cliff dwellings.

Renewable Energy

Photovoltaics: Solar cells, also called photovoltaics (PV) by solar cell scientists, convert sunlight directly into electricity. They are made of semiconducting materials similar to those used in computer chips. When sunlight is absorbed by these materials, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity. This process of converting light (photons) to electricity (voltage) is called the photovoltaic (PV) effect.

Solar Hot Water: The sunlight can heat the water. The sun can be used in heating water used in buildings and swimming pools. This system consists of a solar collector and a storage tank. A flat-plate collector consists of a thin, flat, rectangular box with a transparent cover that faces the sun. Small tubes run through the box and carry the fluid to be heated. The storage tank then holds the hot liquid. It can be just a modified water heater, but it is usually larger and very well-insulated. Solar water heating systems can be either active or passive, but the most common are active systems. Active systems rely on pumps to move the liquid between the collector and the storage tank, while passive systems rely on gravity and the tendency for water to naturally circulate as it is heated.

Renewable Energy

Wind Energy: From old Holland to farms in the United States, windmills have been used for pumping water or grinding grain. Today, the windmill's modern equivalent—a wind turbine—can use the wind's energy to generate electricity.

Wind turbines, like windmills, are mounted on a tower to capture the most energy. At 100 feet (30 meters) or more aboveground, they can take advantage of the faster and less turbulent wind. Turbines catch the wind's energy with their propeller-like blades. Usually, two or three blades are mounted on a shaft to form a rotor.

Properties of Sun Light

- Energy of a Photon

$$E = h\nu = \frac{hc}{\lambda}$$

- where h is Planck's constant and c is the speed of light.
- $h = 6.626 \times 10^{-34}$ joule·s and $c = 2.998 \times 10^{8}$ m/s
- When dealing with "particles" such as photons or electrons, a commonly used unit of energy is the electron-volt (eV) rather than the joule (J).
- An electron volt is the energy required to raise an electron through 1 volt, thus 1 eV = 1.602×10^{-19} J.

hc = (1.99×10^{-29} joules·m) x (1ev/1.602×10^{-19} joules) = 1.24×10^{-6} eV·m

- Further, we need to have the units be in μm:

hc = (1.24×10^{-6} eV·m) x(1.0×10^{6} μm/ m) = 1.24 eV·μm

$$E = \frac{1.24}{\lambda(\mu m)} eV$$

Properties of Sun Light

- Photon Flux

$$\Phi = \frac{\#\ of\ photons}{\sec \cdot m^2}$$

  - The photon flux is defined as the number of photons per second per unit area:
  - The photon flux is important in determining the number of electrons which are generated, and hence the current produced from a solar cell.
  - Since the photon flux gives the number of photons striking a surface in a given time, multiplying by the energy of the photons comprising the photon flux gives the energy striking a surface per unit time, which is equivalent to a power density.
  - To determine the power density in units of W/m², the energy of the photons must be in Joules.

$$H\left(\frac{W}{m^2}\right) = \Phi\left(\frac{\#}{\sec \cdot m^2}\right) \times \frac{hc}{\lambda}(J) = q\Phi\ \frac{1.24}{\lambda(\mu m)}$$

Properties of Sun Light

- Spectral Irradiance
  - The spectral irradiance as a function of photon wavelength (or energy), denoted by F, is the most common way of characterising a light source. It gives the power density at a particular wavelength.
  - The units of spectral irradiance are in $Wm^{-2}\mu m^{-1}$. The Wm^{-2} term is the power density at the wavelength λ(μm). Therefore, the m^{-2} refers to the surface area of the light emitter and the μm^{-1} refers to the wavelength of interest.
  - The spectral irradiance is power density divided by the given wavelength.

$$F\left(\frac{W}{m^2\mu m}\right) = q\Phi\frac{1.24}{\lambda^2(\mu m)} = q\Phi\frac{E^2(eV)}{1.24}$$

Where:

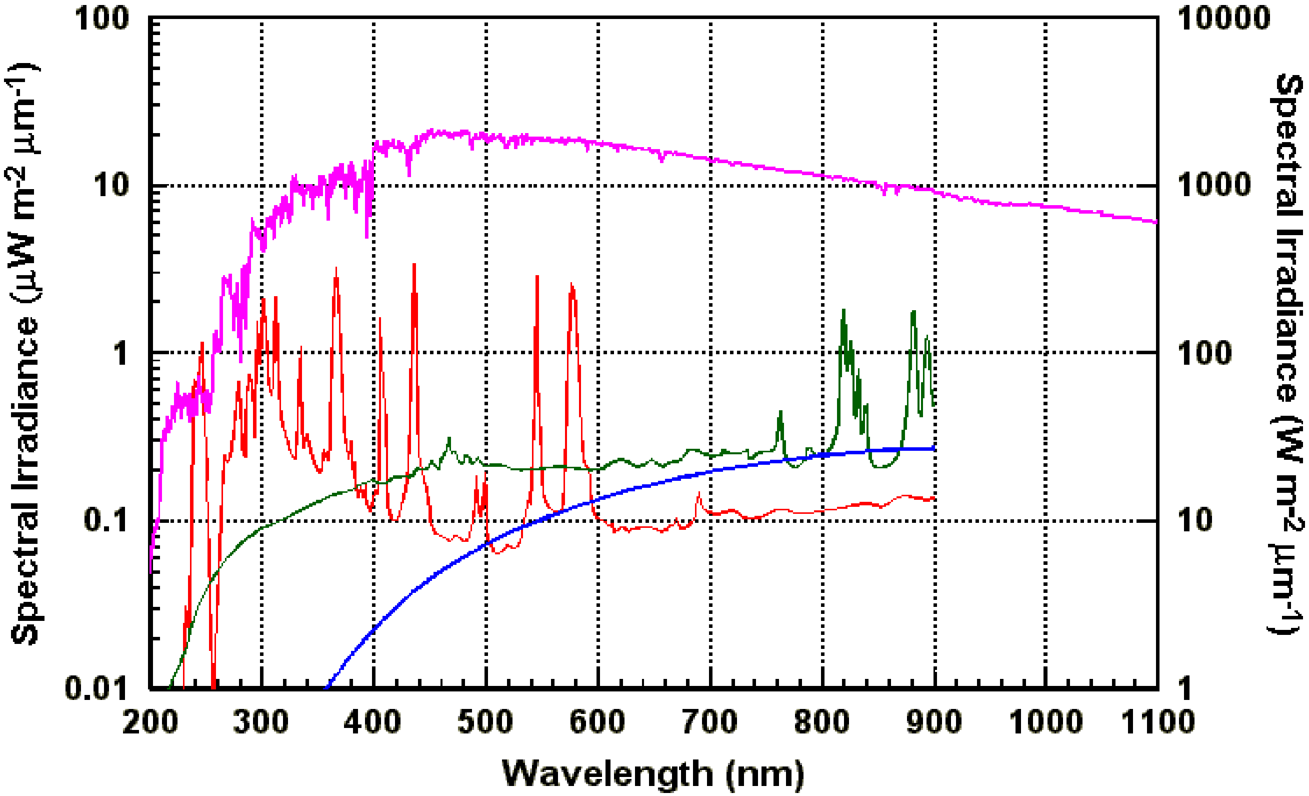
F: the spectral irradiance ($W/m^2\mu m$)

Φ: the photon flux ($\#/m^2 sec$) q, h and c: constants,

q: is the value of electronic charge $1.6*10^{-19}$

Properties of Sun Light

- Spectral Irradiance



The spectral irradiance of xenon (green), halogen (blue) and mercury (red) light bulbs (left axis) are compared to the spectral irradiance from the sun (purple, which corresponds to the right axis).

Properties of Sun Light

- Radiant Power Density
  - The total power density emitted from a light source can be calculated by integrating the spectral irradiance over all wavelengths or energies of interest.

$$H = \int_0^{\infty} F(\lambda) d\lambda = \sum_{i=0}^{\infty} F(\lambda) \Delta\lambda$$

where :

H: the total power density emitted from the light source in Wm^{-2}.

F(λ): the spectral irradiance in units of $Wm^{-2}\mu m^{-1}$

- The measured spectral irradiance must be multiplied by a wavelength range over which it was measured, and then calculated over all wavelengths.

Properties of Sun Light

- Blackbody Radiation
  - Many commonly encountered light sources, including the sun and incandescent light bulbs, are closely modelled as "blackbody" emitters.
  - A blackbody absorbs all radiation incident on its surface and emits radiation based on its temperature.
  - The blackbody sources which are of interest to photovoltaics, emit light in the visible region.
  - The spectral irradiance from a blackbody is given by radiation law, shown in the following equation:

$$F(\lambda) = \frac{2\pi h c^2}{\lambda^5\left(\exp\left(\frac{hc}{k\lambda T}\right)-1\right)}$$

  - The simplest is to use SI units so that *c* is in m/s, *h* is in joule·seconds, *T* is in kelvin, *k* is in joule/kelvin, and *λ* is in meters. This will give units of spectral irradiance in Wm^{-3}. Dividing by 10^6 gives the conventional units of spectral irradiance in $Wm^{-2}\mu m^{-1}$.

Properties of Sun Light

- The **Boltzmann constant** (k_B or k) is a **physical constant** relating the average relative **kinetic energy of particles** in a **gas** with the **temperature** of the gas
- **Planck's law of black-body radiation** and **Boltzmann's entropy formula**
- It is the **gas constant** R divided by the **Avogadro constant** N_A: R/N_A
- 1.380649×10^{-23} J/K

- The **Stefan–Boltzmann law** describes the power radiated from a **black body** in terms of its **temperature**
- Specifically, the Stefan–Boltzmann law states that the **total energy** radiated per unit **surface area** of a black body across **all wavelengths** per unit **time** (also known as the black-body *radiant emittance*) is directly **proportional** to the fourth power of the black body's **thermodynamic temperature** T:

Properties of Sun Light

- The total power density (W/m²)from a blackbody is determined by integrating the spectral irradiance over all wavelengths which gives:

$$H = \sigma T^4 \qquad \sigma = \frac{2\pi^5 k^4}{15c^2 h^3} = 5.670373 \times 10^{-8}\,\mathrm{W\,m^{-2}K^{-4}},$$

where σ is the Stefan-Boltzmann constant and T is the temperature of the blackbody in kelvin. .

- An additional important parameter of a blackbody source is the wavelength where the spectral irradiance is the highest, or, in other words the wavelength where most of the power is emitted.
- The peak wavelength of the spectral irradiance is determined by differentiating the spectral irradiance and solving the derivative when it equals 0.
- The result is known as Wien's Law and is shown in the following equation:

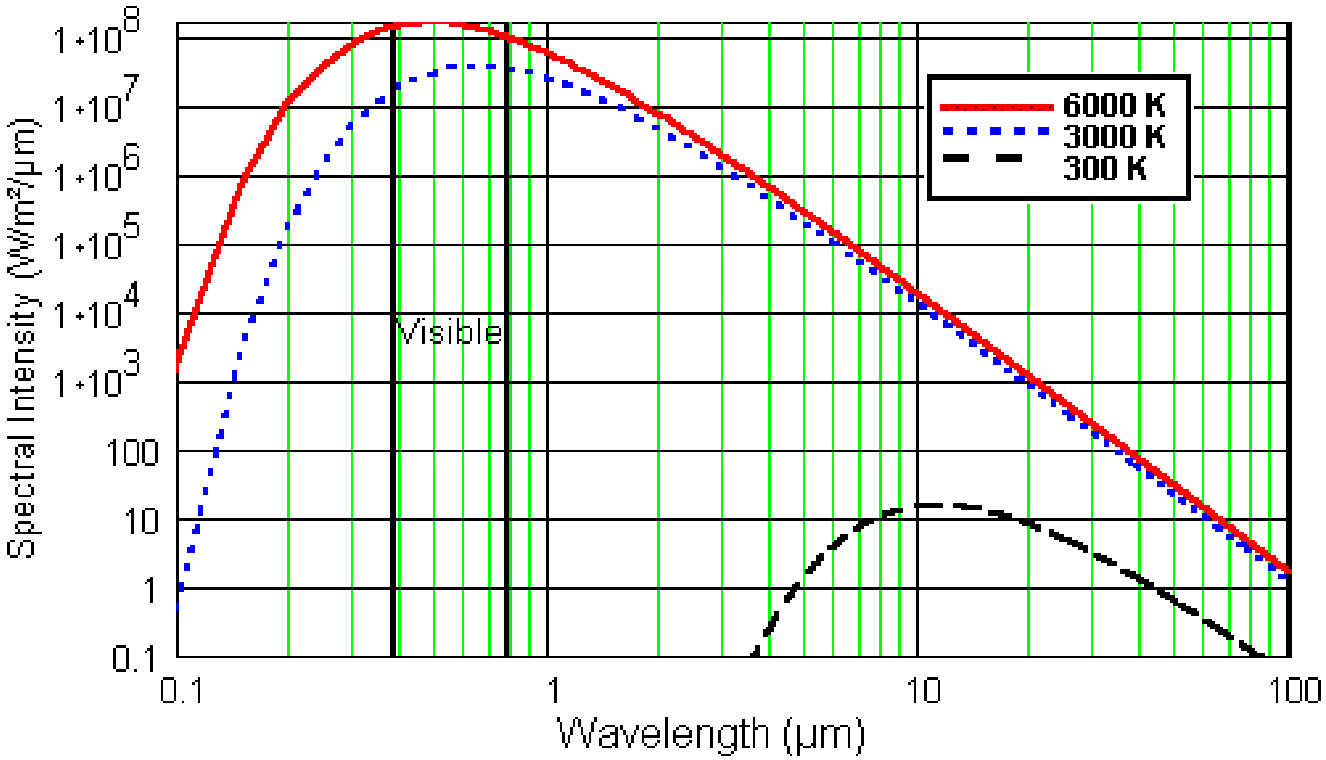
$$\lambda_p(\mu m) = \frac{2900}{T}$$

Wien's displacement **law** states that the black-body radiation curve for different temperature peaks at a wavelength is inversely proportional to the temperature.

where λ_p is the wavelength where the peak spectral irradiance is emitted and T is the temperature of the blackbody (K).

Properties of Sun Light

- Blackbody radiation



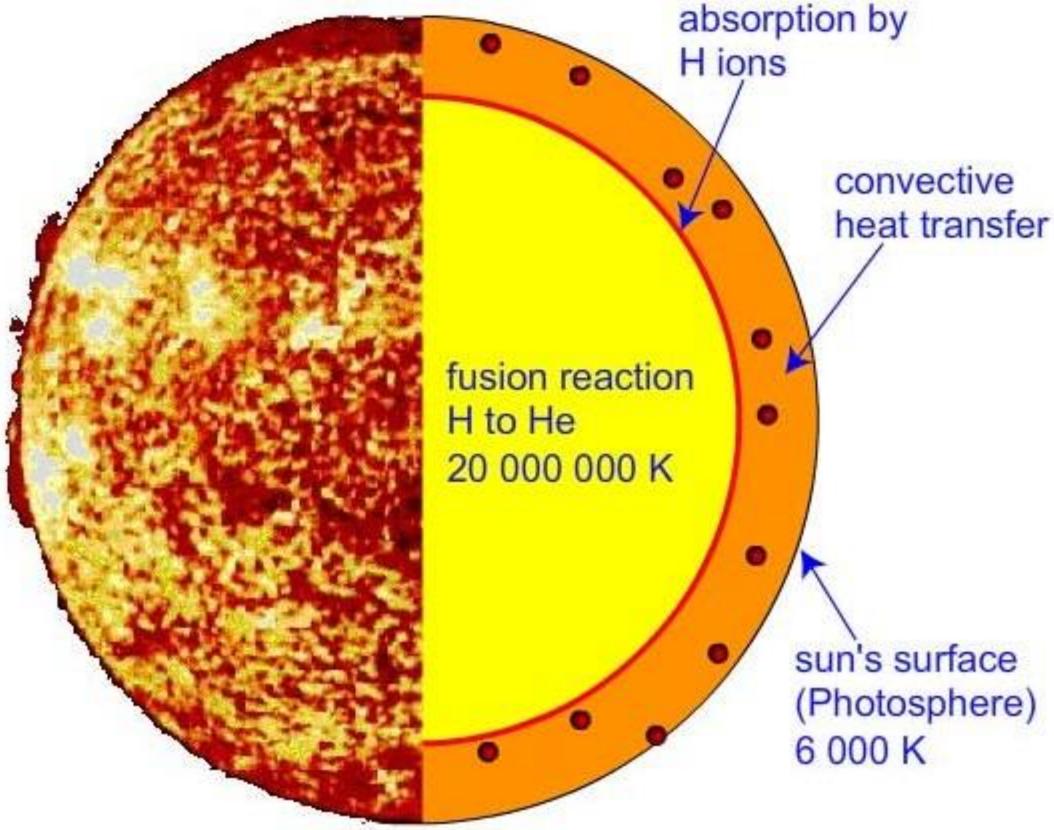
Spectral intensity of light emitted from a black body on a log-log scale. At room temperature the emission is very low and centered around 10 μm.

Properties of Sun Light

- The Sun
  - The sun is a hot sphere of gas whose internal temperatures reach over 20 million degrees kelvin due to nuclear fusion reactions at the sun's core which convert hydrogen to helium.
  - Heat is transferred through this layer by convection.
  - The surface of the sun, called the photosphere, is at a temperature of about 6000K and closely approximates a blackbody.
  - For simplicity, the 6000 K spectrum is commonly used in detailed balance calculations but temperatures of 5762 ± 50 K and 5730 ± 90 K have also been proposed as a more accurate fit to the sun's spectrum.
  - T=5762 K, λ_{peak}=0.5033, and $H=6.25\times10^{7}$ W/m^2
  - The total power emitted by the sun is calculated by multiplying the emitted power density by the surface area of the sun which gives 9.5 x 10^{25} W.

Properties of Sun Light

- The Sun



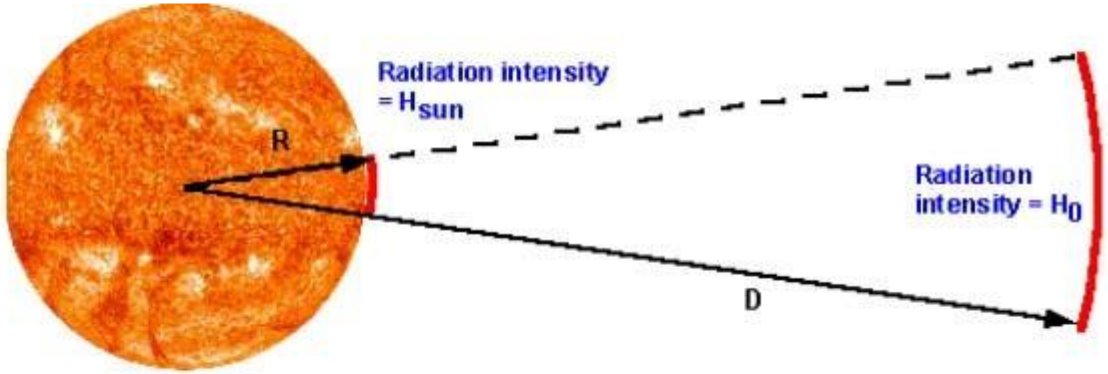
Properties of Sun Light

- Solar Radiation in Space
  - Only a fraction of the total power emitted by the sun impinges on an object in space which is some distance from the sun.
  - The solar irradiance (H_0 in W/m^2) is the power density incident on an object due to illumination from the sun.
  - At the sun's surface, the power density is that of a blackbody at about 6000K and the total power from the sun is this value multiplied by the sun's surface area.
  - However, at some distance from the sun, the total power from the sun is now spread out over a much larger surface area and therefore the solar irradiance on an object in space decreases as the object moves further away from the sun.

Properties of Sun Light

- The solar irradiance on an object some distance D from the sun is found by dividing the total power emitted from the sun by the surface area over which the sunlight falls.
- The total solar radiation emitted by the sun is given by σT^4 multiplied by the surface area of the sun ($4\pi R^2_{sun}$) where R_{sun} is the radius of the sun
- The surface area over which the power from the sun falls will be $4\pi D^2$. Where D is the distance of the object from the sun.
- Therefore, the solar radiation intensity, H_0 in (W/m^2), incident on an object is:

$$H_0 = \frac{R_{sun}^2}{D^2} H_{sun}$$



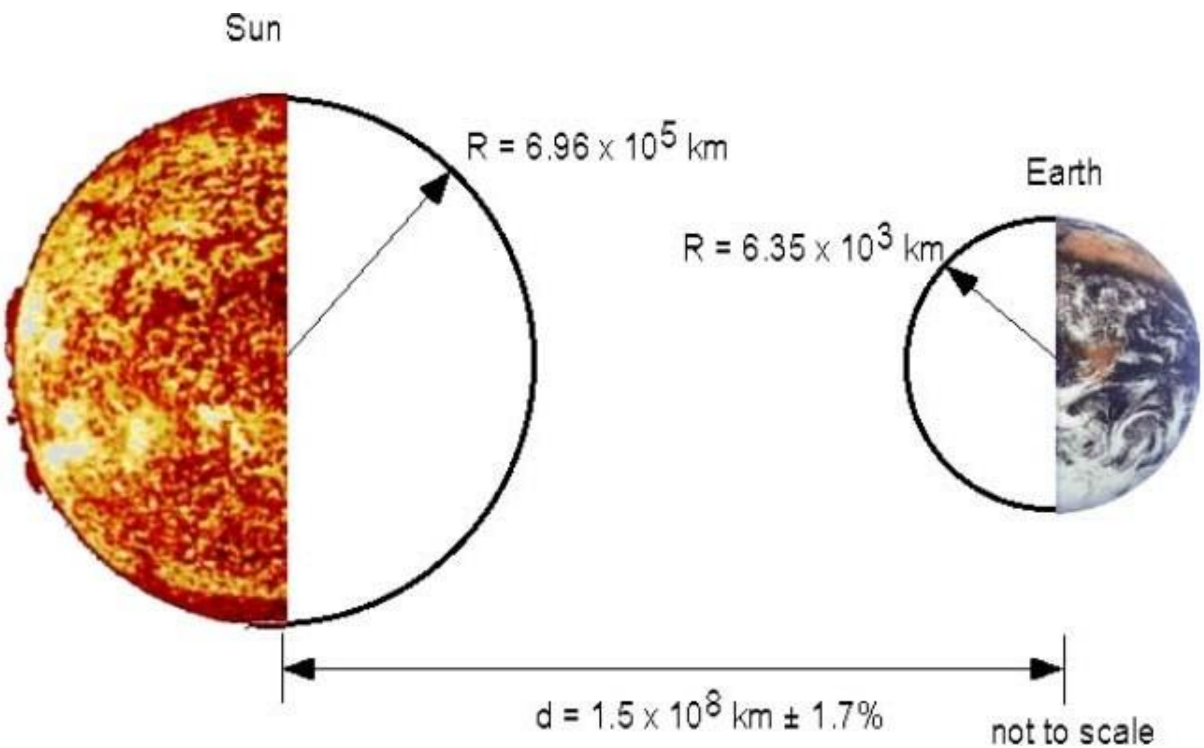
At a distance, D, from the sun the same amount of power is spread over a much wider area so the solar radiation power intensity is reduced.

Properties of Sun Light

Planet	Distance (x 10^9 m)	Mean Solar Irradiance (W/m^2)
Mercury	57	9116.4
Venus	108	2611.0
Earth	150	1366.1
Mars	227	588.6
Jupiter	778	50.5
Saturn	1426	15.04
Uranus	2868	3.72
Neptune	4497	1.51
Pluto	5806	0.878

Properties of Sun Light

- Solar Radiation Outside the Earth's Atmosphere
  - The solar radiation outside the earth's atmosphere is calculated using the radiant power density (H_{sun}) at the sun's surface (5.961×10^7 W/m^2), the radius of the sun (R_{sun}), and the distance between the earth and the sun.
  - The calculated solar irradiance at the Earth's atmosphere is about 1.36 kW/m^2.



Geometrical constants for finding the Earth's solar irradiance. The diameter of the Earth is not needed but is included for the sake of completeness.

Properties of Sun Light

- The actual power density varies slightly since the Earth-Sun distance changes as the Earth moves in its elliptical orbit around the sun, and because the sun's emitted power is not constant.
- The power variation due to the elliptical orbit is about 3.4%, with the largest solar irradiance in January and the smallest solar irradiance in July.
- An equation which describes the variation through out the year just outside the earth's atmosphere is:

$$\frac{H}{H_{constant}} = 1 + 0.033 \cos\left(\frac{360(n-2)}{365}\right)$$

where:

H is the radiant power density outside the Earth's atmosphere (in W/m^2);
$H_{constant}$ is the value of the solar constant, 1.353 kW/m^2; and
n is the day of the year.

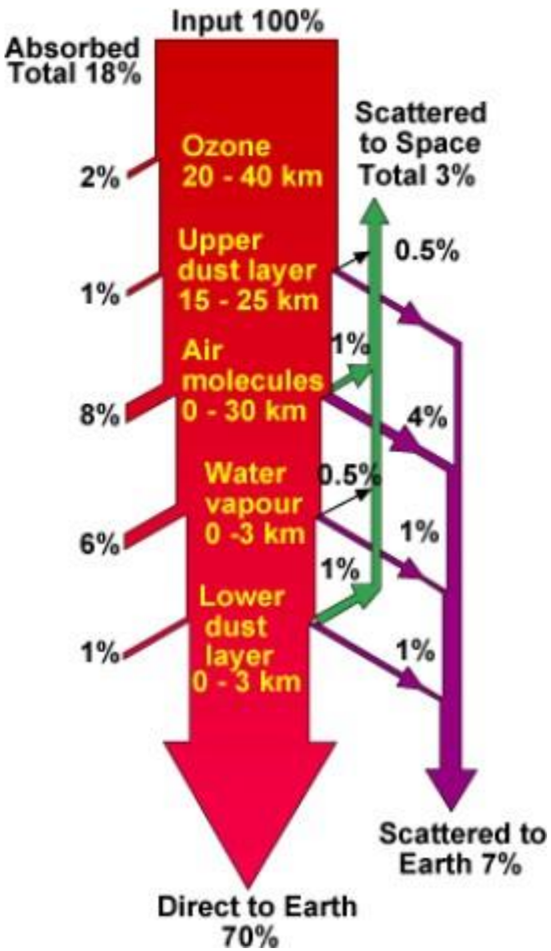
- These variations are typically small and for photovoltaic applications the solar irradiance can be considered constant.
- The value of the solar constant and its spectrum have been defined as a standard value called air mass zero (AM0) and takes a value of 1.353 kW/m^2.

Properties of Sun Light

- Atmospheric Effects
  - Atmospheric effects have several impacts on the solar radiation at the Earth's surface. The major effects for photovoltaic applications are:
    - ✓ a reduction in the power of the solar radiation due to absorption, scattering and reflection in the atmosphere;
    - ✓ a change in the spectral content of the solar radiation due to greater absorption or scattering of some wavelengths;
    - ✓ the introduction of a diffuse or indirect component into the solar radiation; and
    - ✓ local variations in the atmosphere (such as water vapour, clouds and pollution) which have additional effects on the incident power, spectrum and directionality.

Properties of Sun Light

- Atmospheric Effects



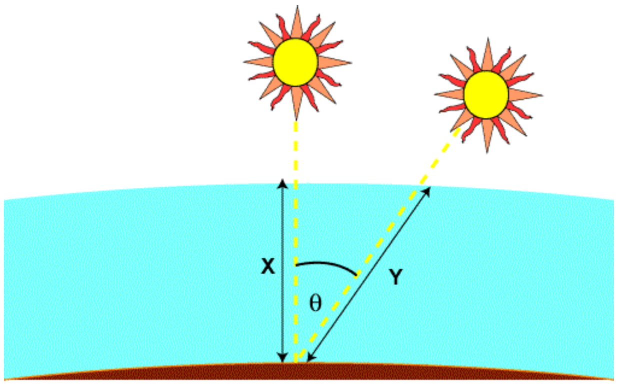
Typical clear sky absorption and scattering of incident sunlight

Properties of Sun Light

- Air Mass
  - The Air Mass is the path length which light takes through the atmosphere normalized to the shortest possible path length (that is, when the sun is directly overhead).
  - The Air Mass quantifies the reduction in the power of light as it passes through the atmosphere and is absorbed by air and dust.
  - The Air Mass is defined as:

$$AM = \frac{1}{cos(\theta)}$$

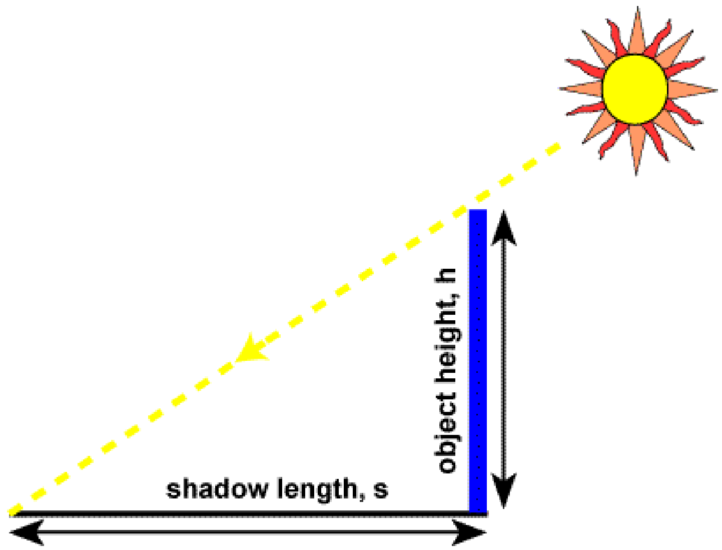
  - where θ is the angle from the vertical (zenith angle). When the sun is directly overhead, the Air Mass is 1.



The air mass represents the proportion of atmosphere that the light must pass through before striking the Earth relative to its overhead path length, and is equal to Y/X.

Properties of Sun Light

- Air Mass
  - An easy method to determine the air mass is from the shadow of a vertical pole.



  - Air mass is the length of the hypotenuse divided by the object height h, and from Pythagoras's theorem we get:

$$AM = \sqrt{1 + \left(\frac{s}{h}\right)^2}$$

Properties of Sun Light

- Air Mass
  - Because of the curvature of the atmosphere, the air mass is not quite equal to the atmospheric path length when the sun is close to the horizon.
  - An equation which incorporates the curvature of the earth is

$$AM = \frac{1}{\cos\theta + 0.50572(96.07995 - \theta)^{-1.6364}}$$

  - The efficiency of a solar cell is sensitive to variations in both the power and the spectrum of the incident light.
  - To facilitate an accurate comparison between solar cells measured at different times and locations, a standard spectrum and power density has been defined for both radiation outside the Earth's atmosphere and at the Earth's surface.
  - The standard spectrum at the Earth's surface is called AM1.5G, (the G stands for global and includes both direct and diffuse radiation) or AM1.5D (which includes direct radiation only).

Properties of Sun Light

- The intensity of AM1.5D radiation can be approximated by reducing the AM0 spectrum by 28% (18% due to absorption and 10% to scattering).
- The global spectrum is 10% higher than the direct spectrum.
- These calculations give approximately 970 W/m^2 for AM1.5G. However, the standard AM1.5G spectrum has been normalized to give 1kW/m^2 due to the convenience of the round number and the fact that there are inherently variations in incident solar radiation.
- The standard spectrum outside the Earth's atmosphere is called AM0, because at no stage does the light pass through the atmosphere. This spectrum is typically used to predict the expected performance of cells in space.

Properties of Sun Light

- Intensity Calculation based on The Air Mass
  - The intensity of the direct component of sunlight throughout each day can be determined as a function of air mass from the experimentally determined equation

$$I_D = 1.353 \cdot 0.7^{\left(AM^{0.678}\right)}$$

where I_D is the intensity on a plane perpendicular to the sun's rays in units of kW/m^2 and AM is the air mass.

  - The value of 1.353 kW/m^2 is the solar constant and the number 0.7 arises from the fact that about 70% of the radiation incident on the atmosphere is transmitted to the Earth.
  - The extra power term of 0.678 is an empirical fit to the observed data and takes into account the non-uniformities in the atmospheric layers.
  - Even on a clear day, the diffuse radiation is still about 10% of the direct component. Thus on a clear day the global irradiance on a module perpendicular to the sun's rays is:

$$I_G = 1.1 \cdot I_D$$