

Overall efficiency of a power plant

$$\eta_{\text{overall}} = \eta_{\text{combustion}} \eta_{\text{thermal}} \eta_{\text{generator}} = \frac{\dot{W}_{\text{net,electric}}}{\text{HHV} \times \dot{m}_{\text{fuel}}}$$

- **Generator:** A device that converts mechanical energy to electrical energy.
- **Generator efficiency:** The ratio of the electrical power output to the mechanical power input.
- **Thermal efficiency of a power plant:** The ratio of the net shaft work output of the turbine to the rate of fuel energy input.

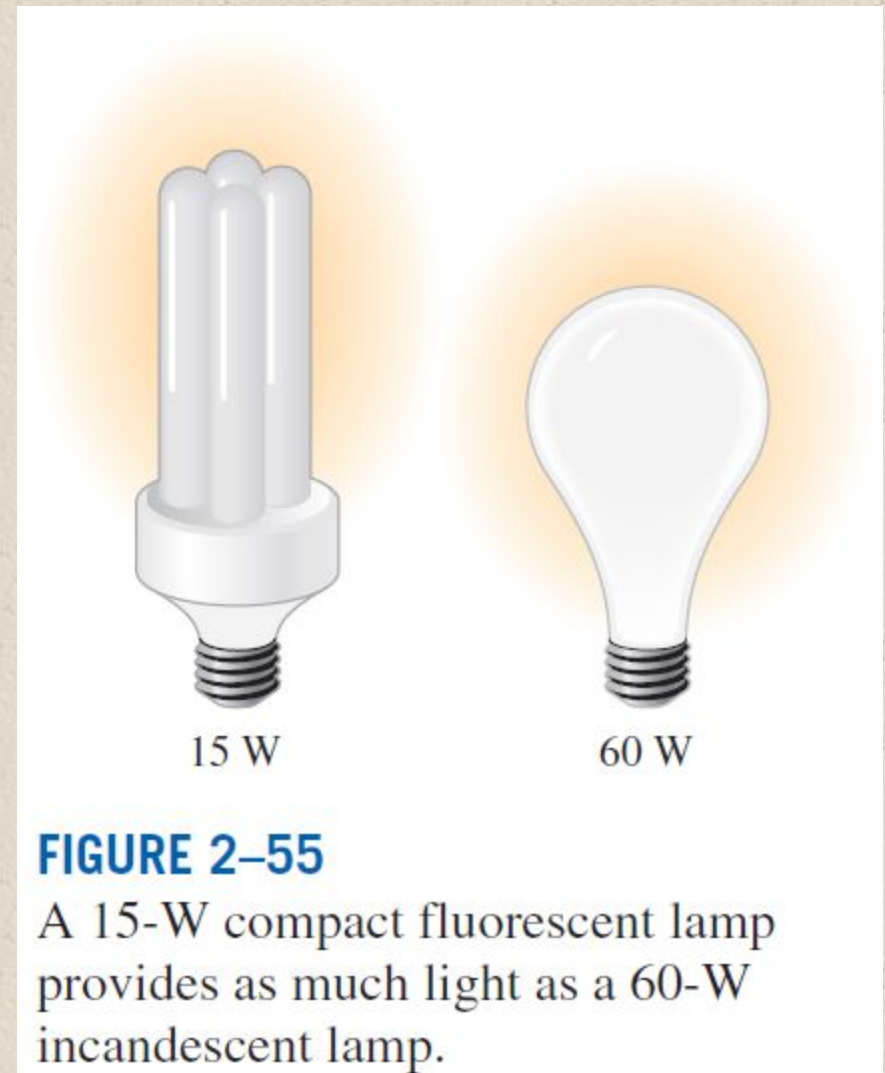


TABLE 2–1

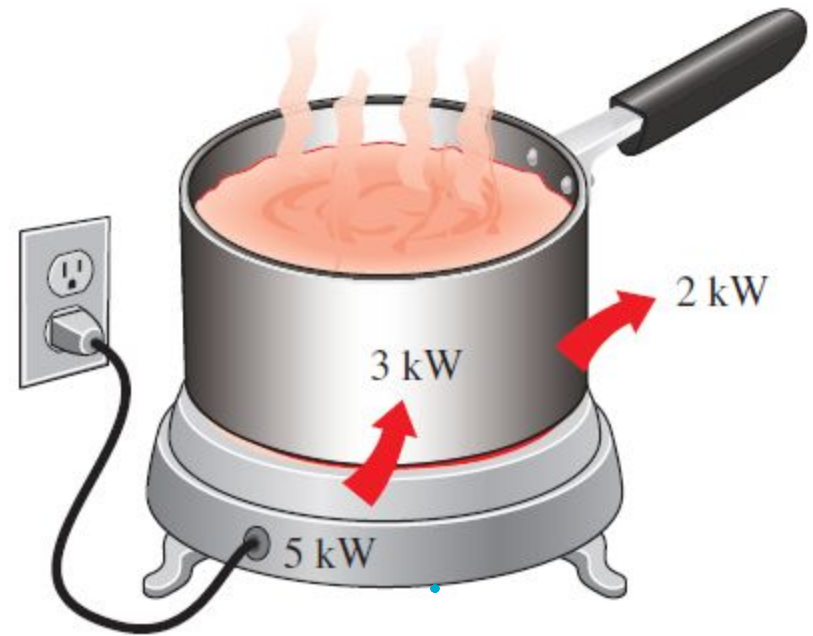
The efficacy of different lighting systems

Type of lighting	Efficacy, lumens/W
<i>Combustion</i>	
Candle	0.3
Kerosene lamp	1–2
<i>Incandescent</i>	
Ordinary	6–20
Halogen	15–35
<i>Fluorescent</i>	
Compact	40–87
Tube	60–120
<i>High-intensity discharge</i>	
Mercury vapor	40–60
Metal halide	65–118
High-pressure sodium	85–140
Low-pressure sodium	70–200
<i>Solid-State</i>	
LED	20–160
OLED	15–60
Theoretical limit	300*

Lighting efficacy: The amount of light output in lumens per W of electricity consumed.

*This value depends on the spectral distribution of the assumed ideal light source. For white light sources, the upper limit is about 300 lm/W for metal halide, 350 lm/W for fluorescents, and 400 lm/W for LEDs. Spectral maximum occurs at a wavelength of 555 nm (green) with a light output of 683 lm/W.

- Using energy-efficient appliances **conserve energy**.
- It helps the **environment** by reducing the amount of pollutants emitted to the atmosphere during the combustion of fuel.
- The combustion of fuel produces
 - **carbon dioxide**, causes global warming
 - **nitrogen oxides** and **hydrocarbons**, cause smog
 - **carbon monoxide**, toxic
 - **sulfur dioxide**, causes acid rain.



$$\text{Efficiency} = \frac{\text{Energy utilized}}{\text{Energy supplied to appliance}}$$

$$= \frac{3 \text{ kWh}}{5 \text{ kWh}} = 0.60$$

FIGURE 2-56

The efficiency of a cooking appliance represents the fraction of the energy supplied to the appliance that is transferred to the food.

TABLE 2-2**Energy costs of cooking a casserole with different appliances***

[From J. T. Amann, A. Wilson, and K. Ackerly, *Consumer Guide to Home Energy Savings*, 9th ed., American Council for an Energy-Efficient Economy, Washington, D.C., 2007, p. 163.]

Cooking appliance	Cooking temperature	Cooking time	Energy used	Cost of energy
Electric oven	350°F (177°C)	1 h	2.0 kWh	\$0.19
Convection oven (elect.)	325°F (163°C)	45 min	1.39 kWh	\$0.13
Gas oven	350°F (177°C)	1 h	0.112 therm	\$0.13
Frying pan	420°F (216°C)	1 h	0.9 kWh	\$0.09
Toaster oven	425°F (218°C)	50 min	0.95 kWh	\$0.09
Crockpot	200°F (93°C)	7 h	0.7 kWh	\$0.07
Microwave oven	"High"	15 min	0.36 kWh	\$0.03

*Assumes a unit cost of \$0.095/kWh for electricity and \$1.20/therm for gas.

Efficiencies of Mechanical and Electrical Devices

Mechanical efficiency

$$\eta_{\text{mech}} = \frac{\text{Mechanical energy output}}{\text{Mechanical energy input}} = \frac{E_{\text{mech,out}}}{E_{\text{mech,in}}} = 1 - \frac{E_{\text{mech,loss}}}{E_{\text{mech,in}}}$$

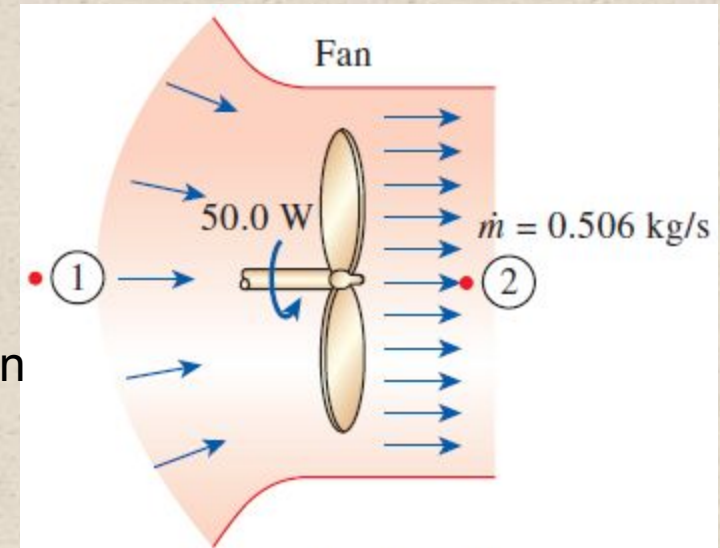
The effectiveness of the conversion process between the mechanical work supplied or extracted and the mechanical energy of the fluid is expressed by the **pump efficiency** and **turbine efficiency**,

$$\eta_{\text{pump}} = \frac{\text{Mechanical energy increase of the fluid}}{\text{Mechanical energy input}} = \frac{\Delta \dot{E}_{\text{mech,fluid}}}{\dot{W}_{\text{shaft,in}}} = \frac{\dot{W}_{\text{pump,u}}}{\dot{W}_{\text{pump}}}$$

$$\Delta \dot{E}_{\text{mech,fluid}} = \dot{E}_{\text{mech,out}} - \dot{E}_{\text{mech,in}}$$

$$\eta_{\text{turbine}} = \frac{\text{Mechanical energy output}}{\text{Mechanical energy decrease of the fluid}} = \frac{\dot{W}_{\text{shaft,out}}}{|\Delta \dot{E}_{\text{mech,fluid}}|} = \frac{\dot{W}_{\text{turbine}}}{\dot{W}_{\text{turbine,e}}}$$

$$|\Delta \dot{E}_{\text{mech,fluid}}| = \dot{E}_{\text{mech,in}} - \dot{E}_{\text{mech,out}}$$



$$V_1 \approx 0, V_2 = 12.1 \text{ m/s}$$

$$z_1 = z_2$$

$$P_1 \approx P_{\text{atm}} \text{ and } P_2 \approx P_{\text{atm}}$$

$$\begin{aligned} \eta_{\text{mech, fan}} &= \frac{\Delta \dot{E}_{\text{mech, fluid}}}{\dot{W}_{\text{shaft, in}}} = \frac{\dot{m} V_2^2 / 2}{\dot{W}_{\text{shaft, in}}} \\ &= \frac{(0.506 \text{ kg/s})(12.1 \text{ m/s})^2 / 2}{50.0 \text{ W}} \\ &= 0.741 \end{aligned}$$

FIGURE 2–58

The mechanical efficiency of a fan is the ratio of the rate of increase of the mechanical energy of air to the mechanical power input.

$$\eta_{\text{motor}} = \frac{\text{Mechanical power output}}{\text{Electric power input}} = \frac{\dot{W}_{\text{shaft,out}}}{\dot{W}_{\text{elect,in}}}$$

Motor
efficiency

$$\eta_{\text{generator}} = \frac{\text{Electric power output}}{\text{Mechanical power input}} = \frac{\dot{W}_{\text{elect,out}}}{\dot{W}_{\text{shaft,in}}}$$

Generator
efficiency

$$\eta_{\text{pump-motor}} = \eta_{\text{pump}}\eta_{\text{motor}} = \frac{\dot{W}_{\text{pump,u}}}{\dot{W}_{\text{elect,in}}} = \frac{\Delta\dot{E}_{\text{mech,fluid}}}{\dot{W}_{\text{elect,in}}}$$

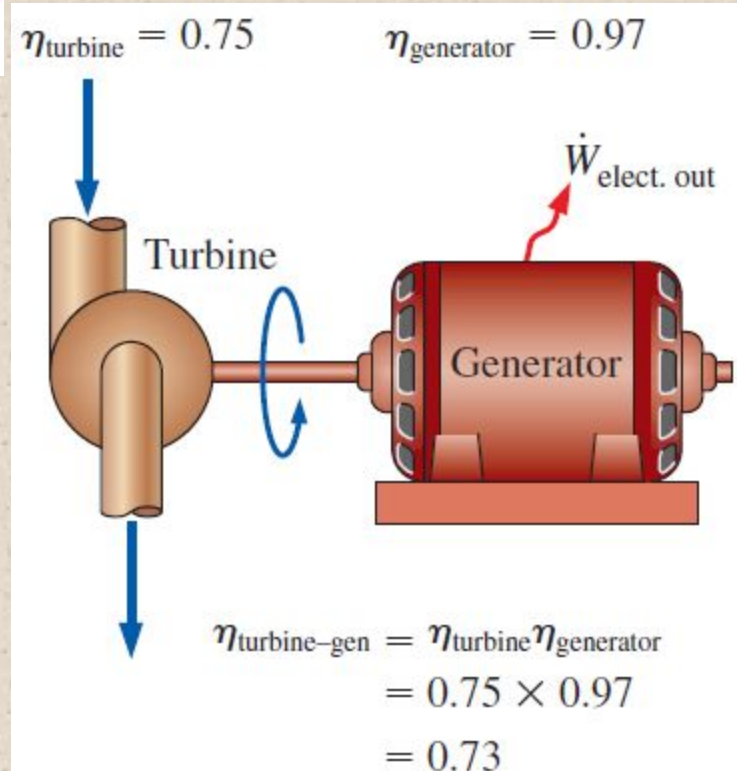
Pump-Motor
overall efficiency

$$\eta_{\text{turbine-gen}} = \eta_{\text{turbine}}\eta_{\text{generator}} = \frac{\dot{W}_{\text{elect,out}}}{\dot{W}_{\text{turbine,e}}} = \frac{\dot{W}_{\text{elect,out}}}{|\Delta\dot{E}_{\text{mech,fluid}}|}$$

Turbine-Generator overall efficiency

FIGURE 2–59

The overall efficiency of a turbine–generator is the product of the efficiency of the turbine and the efficiency of the generator, and represents the fraction of the mechanical power of the fluid converted to electrical power.



ENERGY AND ENVIRONMENT

- The conversion of energy from one form to another often affects the environment and the air we breathe in many ways, and thus the study of energy is not complete without considering its impact on the environment.
- Pollutants emitted during the combustion of fossil fuels are responsible for **smog, acid rain**, and **global warming**.
- The environmental pollution has reached such high levels that it became a serious threat to **vegetation, wild life**, and **human health**.



FIGURE 2-62

Energy conversion processes are often accompanied by environmental pollution.



FIGURE 2-63

Motor vehicles are the largest source of air pollution.

Ozone and Smog

- **Smog**: Made up mostly of ground-level ozone (O_3), but it also contains numerous other chemicals, including carbon monoxide (CO), particulate matter such as soot and dust, volatile organic compounds (VOCs) such as benzene, butane, and other hydrocarbons.
- **Hydrocarbons** and **nitrogen oxides** react in the presence of sunlight on hot calm days to form ground-level ozone.
- **Ozone** irritates eyes and damages the air sacs in the lungs where oxygen and carbon dioxide are exchanged, causing eventual hardening of this soft and spongy tissue.
 - It also causes shortness of breath, wheezing, fatigue, headaches, and nausea, and aggravates respiratory problems such as asthma.
- The other serious pollutant in smog is **carbon monoxide**, which is a colorless, odorless, poisonous gas.
 - It is mostly emitted by motor vehicles.
 - It deprives the body's organs from getting enough oxygen by binding with the red blood cells that would otherwise carry oxygen. It is fatal at high levels.
- Suspended **particulate matter** such as **dust** and **soot** are emitted by vehicles and industrial facilities. Such particles irritate the eyes and the lungs.

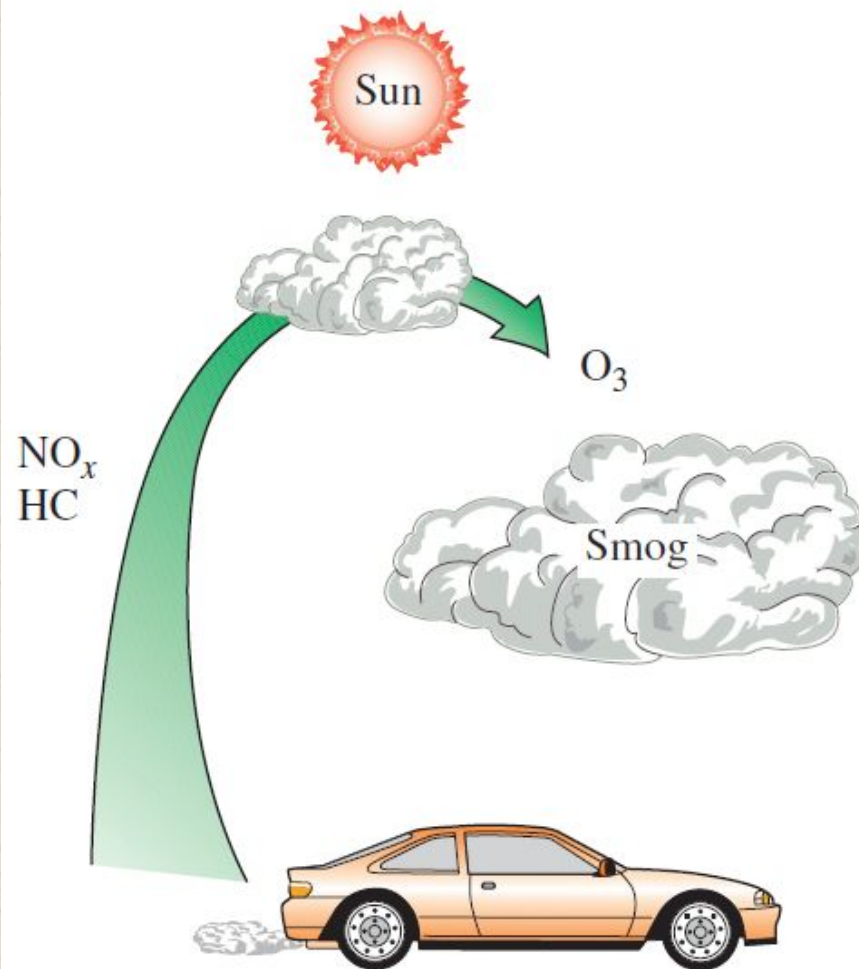


FIGURE 2-64

Ground-level ozone, which is the primary component of smog, forms when HC and NO_x react in the presence of sunlight in hot calm days.

Acid Rain

- The sulfur in the fuel reacts with oxygen to form sulfur dioxide (SO_2), which is an air pollutant.
- The main source of SO_2 is the electric power plants that burn high-sulfur coal.
- Motor vehicles also contribute to SO_2 emissions since gasoline and diesel fuel also contain small amounts of sulfur.
- The sulfur oxides and nitric oxides react with water vapor and other chemicals high in the atmosphere in the presence of sunlight to form sulfuric and nitric acids.
- The acids formed usually dissolve in the suspended water droplets in clouds or fog.
- These acid-laden droplets, which can be as acidic as lemon juice, are washed from the air on to the soil by rain or snow. This is known as **acid rain**.

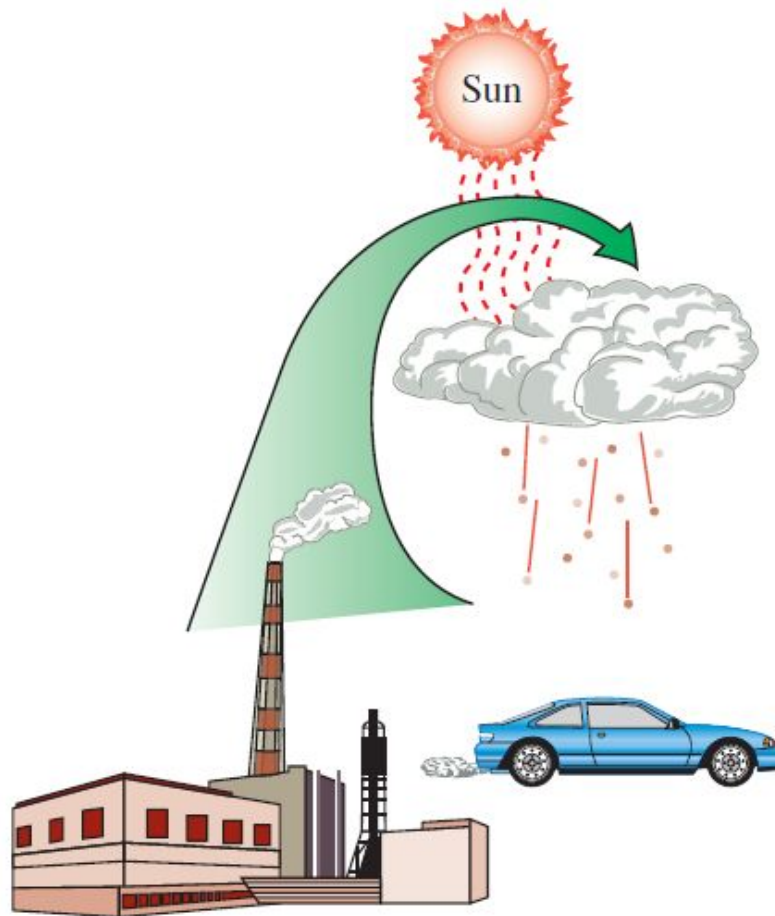


FIGURE 2-65

Sulfuric acid and nitric acid are formed when sulfur oxides and nitric oxides react with water vapor and other chemicals high in the atmosphere in the presence of sunlight.

The Greenhouse Effect: Global Warming and Climate Change

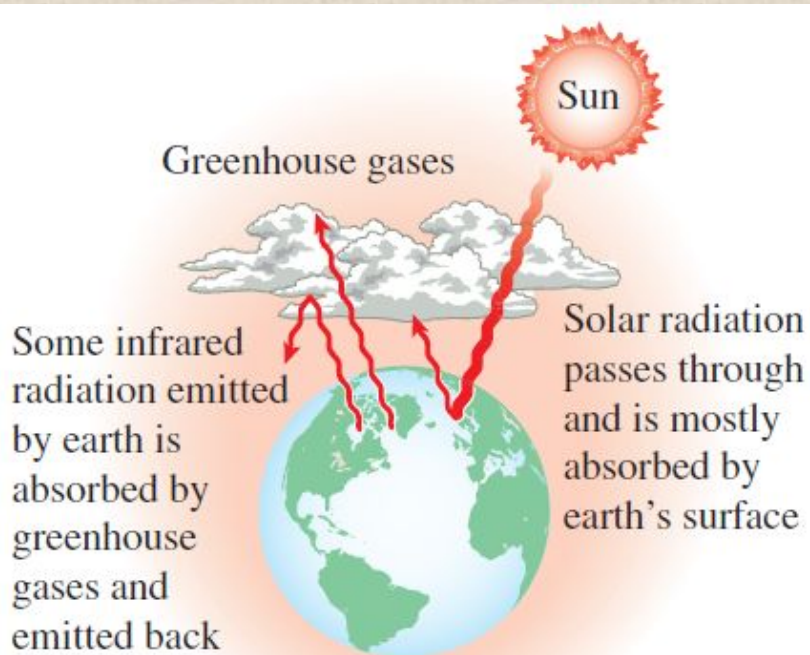


FIGURE 2-66

The greenhouse effect on earth.

- CO₂ is produced by the burning of fossil fuels such as coal, oil, and natural gas.

- **Greenhouse effect:** Glass allows the solar radiation to enter freely but blocks the infrared radiation emitted by the interior surfaces. This causes a rise in the interior temperature as a result of the thermal energy buildup in a space (i.e., car).
- The surface of the earth, which warms up during the day as a result of the absorption of solar energy, cools down at night by radiating part of its energy into deep space as infrared radiation.
- **Carbon dioxide (CO₂),** water vapor, and trace amounts of some other gases such as methane and nitrogen oxides act like a blanket and keep the earth warm at night by blocking the heat radiated from the earth. The result is **global warming.**
- These gases are called “**greenhouse gases,**” with CO₂ being the primary component.

- **A 1995 report:** The earth has already warmed about **0.5°C** during the last century, and they estimate that the earth's temperature will rise another **2°C** by the year 2100.
- A rise of this magnitude can cause **severe changes in weather patterns** with storms and heavy rains and flooding at some parts and drought in others, major floods due to the melting of ice at the poles, loss of wetlands and coastal areas due to rising sea levels, and other negative results.
 - Improved energy efficiency,
 - energy conservation,
 - using renewable energy sources
- help minimize global warming.



FIGURE 2–67

The average car produces several times its weight in CO_2 every year (it is driven 13,500 miles a year, consumes 600 gallons of gasoline, and produces 20 lbm of CO_2 per gallon).



FIGURE 2–68

Renewable energies such as wind are called “green energy” since they emit no pollutants or greenhouse gases.

Summary

- Forms of energy
 - ✓ Macroscopic = kinetic + potential
 - ✓ Microscopic = Internal energy (sensible + latent + chemical + nuclear)
- Energy transfer by heat
- Energy transfer by work
- Mechanical forms of work
- The first law of thermodynamics
 - ✓ Energy balance
 - ✓ Energy change of a system
 - ✓ Mechanisms of energy transfer (heat, work, mass flow)
- Energy conversion efficiencies
 - ✓ Efficiencies of mechanical and electrical devices (turbines, pumps)
- Energy and environment
 - ✓ Ozone and smog
 - ✓ Acid rain
 - ✓ The Greenhouse effect: Global warming and climate change