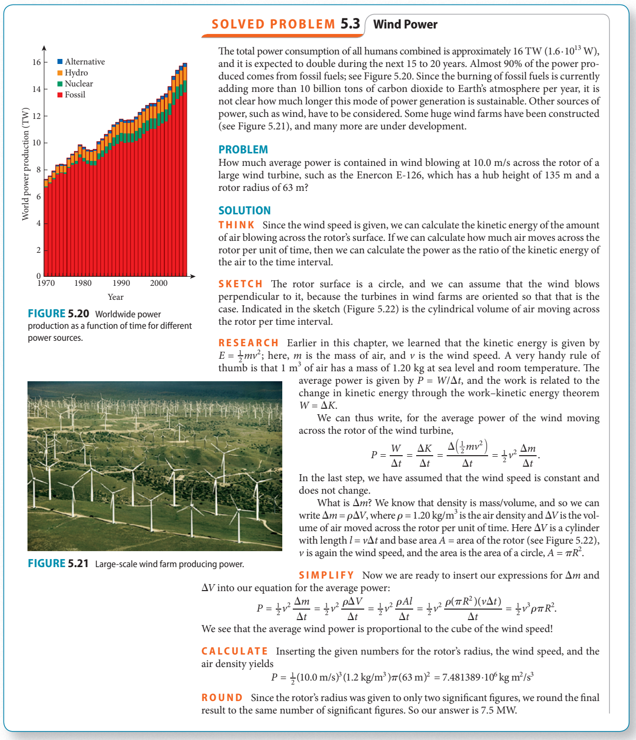
Seeing the Big Picture

Contemporary Examples

The authors have included recent physics research results throughout the text. Results involving renewable energy, the environment, aerospace, engineering, medicine, and technology demonstrate that physics is an exciting, thriving, and intellectually stimulating field. Available online at www.mhhe.com/bauerwestfall2e, the student resource center provides a number of items to enhance your understanding and help you prepare for lectures, labs, and tests.



SOLVED PROBLEM 5.3 Wind Power

The total power consumption of all humans combined is approximately 16 TW ($1.6 \cdot 10^{13}$ W), and it is expected to double during the next 15 to 20 years. Almost 90% of the power produced comes from fossil fuels; see Figure 5.20. Since the burning of fossil fuels is currently adding more than 10 billion tons of carbon dioxide to Earth's atmosphere per year, it is not clear how much longer this mode of power generation is sustainable. Other sources of power, such as wind, have to be considered. Some huge wind farms have been constructed (see Figure 5.21), and many more are under development.

PROBLEM
How much average power is contained in wind blowing at 10.0 m/s across the rotor of a large wind turbine, such as the Enercon E-126, which has a hub height of 135 m and a rotor radius of 63 m?

SOLUTION
THINK Since the wind speed is given, we can calculate the kinetic energy of the amount of air blowing across the rotor's surface. If we can calculate how much air moves across the rotor per unit of time, then we can calculate the power as the ratio of the kinetic energy of the air to the time interval.

SKETCH The rotor surface is a circle, and we can assume that the wind blows perpendicular to it, because the turbines in wind farms are oriented so that that is the case. Indicated in the sketch (Figure 5.22) is the cylindrical volume of air moving across the rotor per time interval.

RESEARCH Earlier in this chapter, we learned that the kinetic energy is given by $E = \frac{1}{2}mv^2$; here, m is the mass of air, and v is the wind speed. A very handy rule of thumb is that 1 m^3 of air has a mass of 1.20 kg at sea level and room temperature. The average power is given by $P = W/\Delta t$, and the work is related to the change in kinetic energy through the work–kinetic energy theorem $W = \Delta K$.

We can thus write, for the average power of the wind moving across the rotor of the wind turbine,

$$P = \frac{W}{\Delta t} = \frac{\Delta K}{\Delta t} = \frac{\Delta\left(\frac{1}{2}mv^2\right)}{\Delta t} = \frac{1}{2}v^2\frac{\Delta m}{\Delta t}.$$

In the last step, we have assumed that the wind speed is constant and does not change.

What is Δm? We know that density is mass/volume, and so we can write $\Delta m = \rho\Delta V$, where $\rho = 1.20$ kg/m^3 is the air density and ΔV is the volume of air moved across the rotor per unit of time. Here ΔV is a cylinder with length $l = v\Delta t$ and base area A = area of the rotor (see Figure 5.22), v is again the wind speed, and the area is the area of a circle, $A = \pi R^2$.

SIMPLIFY Now we are ready to insert our expressions for Δm and ΔV into our equation for the average power:

$$P = \frac{1}{2}v^2\frac{\Delta m}{\Delta t} = \frac{1}{2}v^2\frac{\rho\Delta V}{\Delta t} = \frac{1}{2}v^2\frac{\rho A l}{\Delta t} = \frac{1}{2}v^2\frac{\rho(\pi R^2)(v\Delta t)}{\Delta t} = \frac{1}{2}v^3\rho\pi R^2.$$

We see that the average wind power is proportional to the cube of the wind speed!

CALCULATE Inserting the given numbers for the rotor's radius, the wind speed, and the air density yields

$$P = \tfrac{1}{2}(10.0 \text{ m/s})^3(1.2 \text{ kg/m}^3)\pi(63 \text{ m})^2 = 7.481389\cdot 10^6 \text{ kg m}^2/\text{s}^3$$

ROUND Since the rotor's radius was given to only two significant figures, we round the final result to the same number of significant figures. So our answer is 7.5 MW.

FIGURE 5.20 Worldwide power production as a function of time for different power sources.

FIGURE 5.21 Large-scale wind farm producing power.

ConnectPlus eBook

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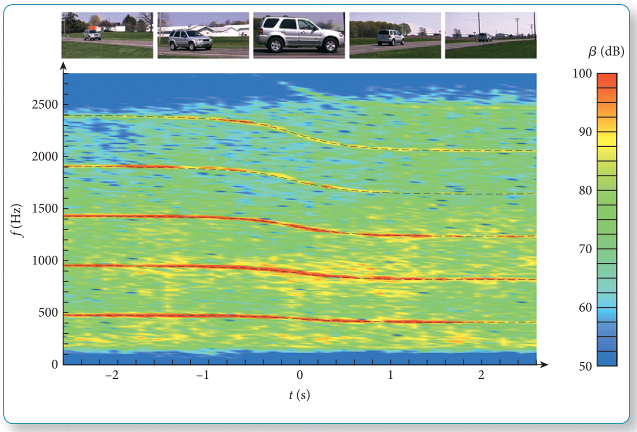
Visual Program

Familiarity with graphics and animation on the Internet and in video games has raised the bar for the graphical presentations in textbooks, which must now be more sophisticated to excite both students and faculty. Here are some of the techniques and ideas implemented in *University Physics:*

- Line drawings are superimposed on photographs to connect sometimes very abstract physics concepts to students' realities and everyday experiences.
- A three-dimensional look for line drawings adds plasticity to the presentations. Mathematically accurate graphs and plots were created by the authors in software programs such as Mathematica and then used by the graphic artists to ensure complete accuracy as well as a visually appealing style.



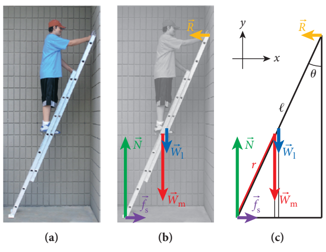


FIGURE 11.12 (a) Student standing on a ladder. (b) Force vectors superimposed. (c) Free-body diagram of the ladder.