

### Example 8.1 Carbon Content of the Atmosphere

Estimate the tons of carbon in the atmosphere corresponding to a concentration of 360 ppm of  $\text{CO}_2$ . Assume the total mass of air equals  $5.1 \times 10^{18}$  kg. The density of air at standard temperature and pressure (STP,  $0^\circ\text{C}$ , and 1 atm) is  $1.29 \text{ kg/m}^3$ .

**Solution** One g-mole of  $\text{CO}_2$  contains 44 g ( $12 + 2 \times 16$ ), and each mole at STP occupies a volume of  $22.4 \times 10^{-3} \text{ m}^3$  (see Section 1.2). At 360 ppm, the concentration of  $\text{CO}_2$  (by weight at STP) is given by

$$\text{CO}_2 = \frac{360 \text{ m}^3 \text{ CO}_2}{1 \times 10^6 \text{ m}^3 \text{ air}} \times \frac{\text{mol}}{22.4 \times 10^{-3} \text{ m}^3 \text{ CO}_2} \times \frac{44 \text{ g}}{\text{mol}} = 0.707 \text{ g/m}^3$$

Since 44 g of  $\text{CO}_2$  contains 12 g of C, the total amount of carbon in the atmosphere is

$$\text{C} = \frac{0.707 \text{ g CO}_2}{\text{m}^3 \text{ air}} \times \frac{12 \text{ g C}}{44 \text{ g CO}_2} \times \frac{5.1 \times 10^{18} \text{ kg air}}{1.29 \text{ kg/m}^3 \text{ air}} = 7.62 \times 10^{17} \text{ g}$$

which, at  $10^6 \text{ g/ton}$ , is equivalent to  $762 \times 10^9$  tons or 762 gigatons (Gt)

# Calculation of Carbon footprints - Global Warming

- Replacing coal with gas or oil would reduce the Carbon dioxide emission i.e., Carbon footprints.
- Using solar energy and wind energy would reduce the carbon footprints as these have almost zero carbon dioxide emissions.
- Using hydrogen energy, fuel cells and cleaner electric energy would also reduce the carbon footprints.

# 5 CARBON EMISSION FACTORS FOR VARIOUS FUELS, AND 1985 WORLD FUEL AND EMISSIONS DATA

	Natural gas	Conventional oil	Coal	Synthetic fuels			Non-fossil fuel
				Oil from shale	Oil from coal	Gas from coal	
Quadrillion Btu	14.5	20.8	25.2	50.2	40.7	42.9	0
Emissions million tons	60	120	86	0	0	0	36
CO <sub>2</sub> emissions million tons	0.9	2.5	2.2	0	0	0	0

Data from Seidel and Keyes (1983) and EIA (1986).

**TABLE 8.5 CARBON EMISSION FACTORS FOR VARIOUS FUELS, AND 1985 WORLD FUEL AND EMISSIONS DATA**

Factor	Natural gas	Conventional oil	Coal	Synthetic fuels			Non-fossil fuel
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10 <sup>6</sup> ton C/quad	14.5	20.8	25.2	50.2	40.7	42.9	0
Quads/yr	60	120	86	0	0	0	36
Carbon emissions (Gt C/yr)	0.9	2.5	2.2	0	0	0	0

Source: Data from Seidel and Keyes (1983) and EIA (1986).

### ✓ Example 8.3 Replacing Coal-Generated Electricity with Direct Consumption of Gas

Suppose utilities generate electricity using 33-percent efficient coal-fired power plants. As a carbon-reducing measure, suppose electric water heaters that convert electricity into hot water with 100 percent efficiency are replaced with gas water heaters with a 70 percent conversion efficiency. By what fraction would carbon emissions be reduced?



**Solution** Let us approach this problem by imagining 1 quad of electricity being delivered to those electric water heaters, as suggested in Figure 8.16. Since the power plants are 33 percent efficient, 3 quads of heat would need to be delivered to the power plant. Using the emission factor for coal given in Table 8.5, the total carbon emissions would be

$$\text{Coal emissions} = 3 \text{ quads} \times 25.2 \times 10^6 \text{ ton C/quad} = 75.6 \times 10^6 \text{ ton C}$$

To get 1 quad of heat using 70-percent efficient gas-fired water heaters would require

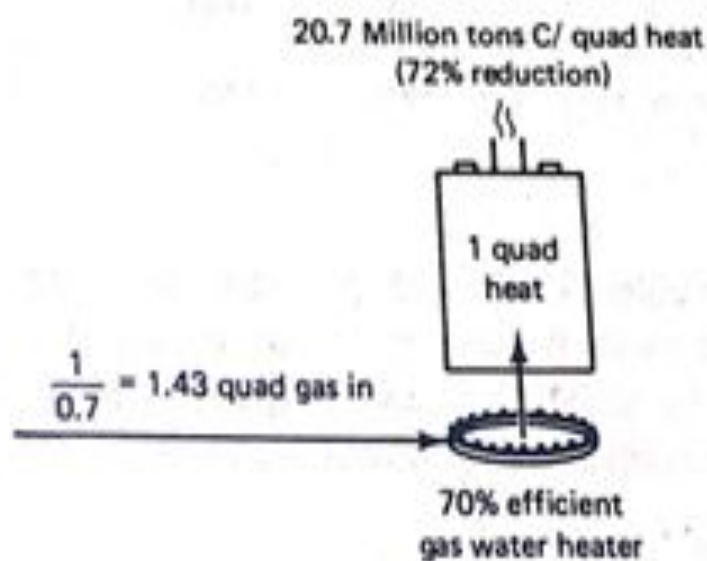
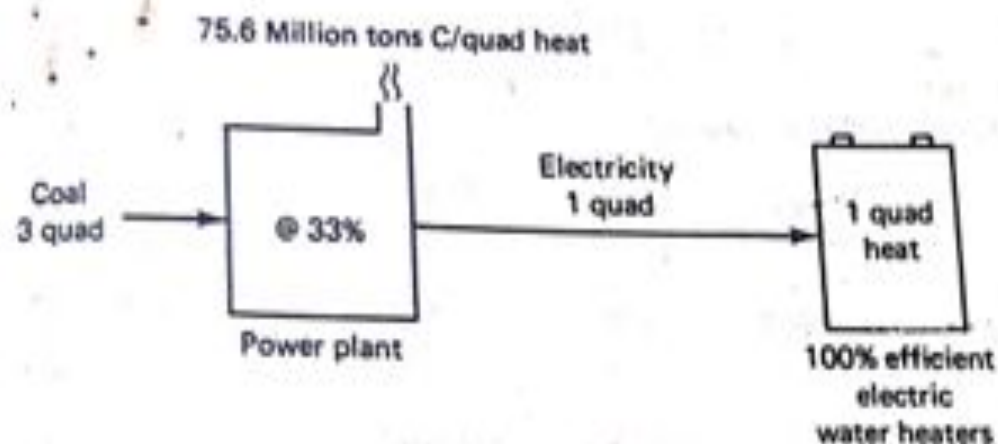
$$\text{Heat input} = 1 \text{ quad} / 0.70 = 1.43 \text{ quads}$$

Corresponding carbon emissions would be

$$\text{Gas emissions} = 1.43 \text{ quads} \times 14.5 \times 10^6 \text{ ton C/quad} = 20.7 \times 10^6 \text{ ton C}$$

That is, there would be a 73 percent reduction in emissions.

While Example 8.3 suggests that sizeable reductions in carbon emissions are possible by switching from coal to natural gas, it is unfortunate that most of the world's fossil fuel reserves and resources are in the form of coal. Recall the distinction between reserves and resources introduced in Chapter 3. Reserves are quantities that can reasonably be assumed to exist and that are producible with existing technology under present economic conditions; resources are amounts



Gas water heater is more expensive to install but cheaper to operate.

**Figure 8.16** Carbon emissions can be reduced by 73 percent when coal-fired electricity is replaced with gas used on site. A gas water heater is more expensive to install, but cheaper to operate. Numbers correspond to Example 8.3.

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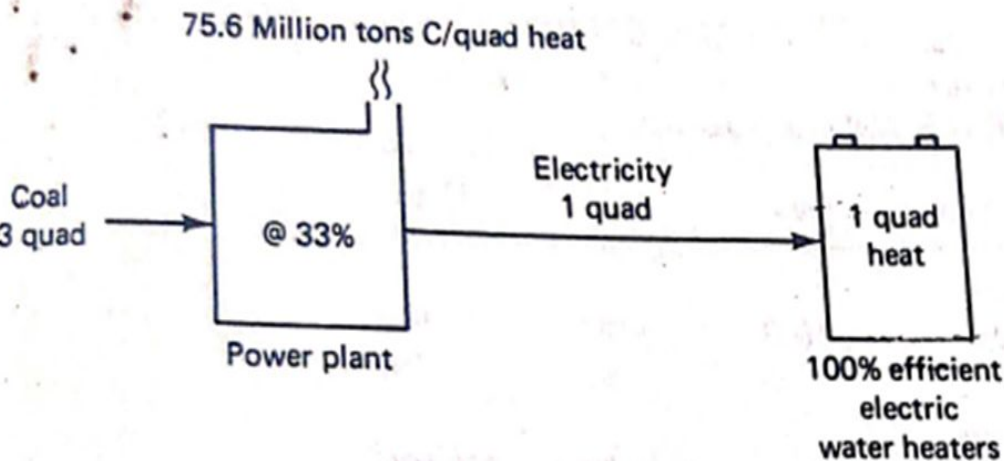
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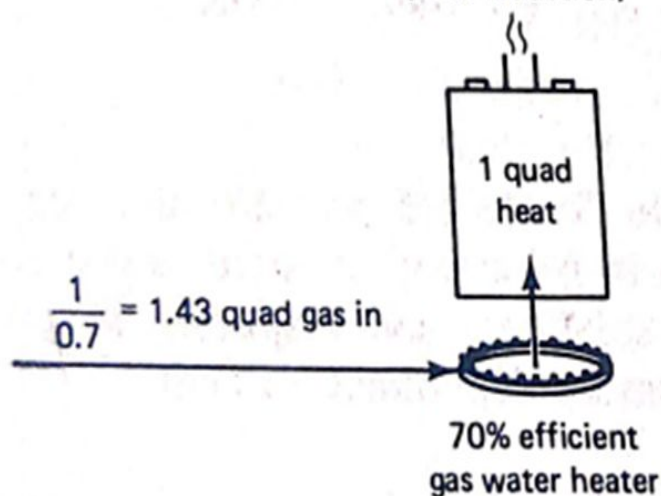
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20.7 Million tons C/quad heat  
(72% reduction)



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# REFERENCE

- A quad is a unit of energy equal to  $10^{15}$  (a short-scale quadrillion) BTU, or  $1.055 \times 10^{18}$  joule (1.055 exajoules or EJ) in SI units.
- REFERENCE FOR THESE NUMERICALS :
- Introduction to Environmental Engineering and Science by Gilbert M. Masters, Prentice Hall of India, 1991.