# 13.10: The E-Factor in Green Chemistry

Although atom economy, defined in Section 13.8, is a useful concept, one that is a more accurate measurement of environmental acceptability of a chemical manufacturing process is the **E factor** defined as the following:

$$\text{E factor} = \frac{\text{Total mass of waste from process}}{\text{Total mass of product}} \tag{13.10.1}$$

The E factor takes into account waste byproducts, leftover reactants, solvent losses, spent catalysts and catalyst supports, and anything else that can be regarded as a waste. Its calculation depends upon what is defined as waste. For example, water is a significant byproduct of many chemical processes and is generally harmless, so its mass is usually omitted from the total mass of waste in the calculation. However, it may be included in those processes in which it is severely contaminated and difficult to reclaim in a form pure enough to use or discharge to a publicly owned wastewater treatment facility. Leftover reactant that can be easily reclaimed and recycled to the process is not included as waste whereas reactant that cannot be salvaged is counted in the waste.

The ideal E factor is 0 and higher E factors are relatively less desirable. E factors that can be tolerated depend upon the value of the product and the amount of product produced. For bulk chemicals manufactured in amounts of hundreds of thousands to millions of tons per year, tolerable E factors typically range from 1 to 5. In the fine chemical and specialty chemical industry where annual quantities are typically measured as a few thousand tons per year E factors up to around 500 may be acceptable if the value of the product is high enough to justify the cost of treating and disposal of wastes. In the pharmaceutical manufacturing industry where annual quantities generated typically are measured in tens to several hundred tons per year, acceptable E factors may be up to about 4000.

Until recently, little attention had been given to amounts of wastes produced in pharmaceutical manufacturing because the prices of the products were so high and the total amounts of wastes produced were so low. However, with the realization that even the generation of a few hundred tons per year of waste can be undesirable and costly, the pharmaceutical industry is becoming a leader in the implementation of green chemical practice. It should be noted that,although they are not considered in the calculation of E factors for pharmaceutical manufacture, annual releases of post-consumer pharmaceuticals and their metabolites are not insignificant. Of greatest concern is contamination of wastewater, some of which gets back into drinking water supplies, by pharmaceuticals and their metabolites discharged with urine or simply flushed down the drain when no longer needed. By their nature, pharmaceuticals are metabolically active and their presence in drinking water can be a concern.

**The Nature of Wastes**

There are wastes, and then there are wastes. Production of a few thousand tons of carbon dioxide per year may be of little concern because it can be discharged to the atmosphere, contributing to the atmosphere's burden of greenhouse gases, but negligible compared to the millions of tons released by burning fossil fuels. However, generation of a few kilograms of heavy metal wastes can be a matter of concern because of heavy metal toxicity. So it matters *what kinds* of wastes are produced. Attempts have been made to assign an **environmental quotient**, **EQ**, to wastes where Q is a number assigned to a particular kind of waste which, multiplied times the E-factor provides in principle a means of weighting the potential harm of various kinds of wastes. Whereas E is easily measured by simple weighing, Q is a much more arbitrary number and subject to change as information is obtained regarding the potential harm of particular kinds of wastes.