## Course Learning Outcomes for Unit IV

Upon completion of this unit, students should be able to:

4. Evaluate pollution prevention strategies.
   4.1 Analyze source reduction options.
   4.2 Summarize recycling options.

| Course/Unit Learning Outcomes | Learning Activity |
|---|---|
| 4.1 | Unit Lesson<br>Chapter 19<br>Chapter 22<br>Unit IV Essay |
| 4.2 | Unit Lesson<br>Chapter 20<br>Chapter 22<br>Unit IV Essay |

## Required Unit Resources

**Chapter 19:** Source Reduction Options

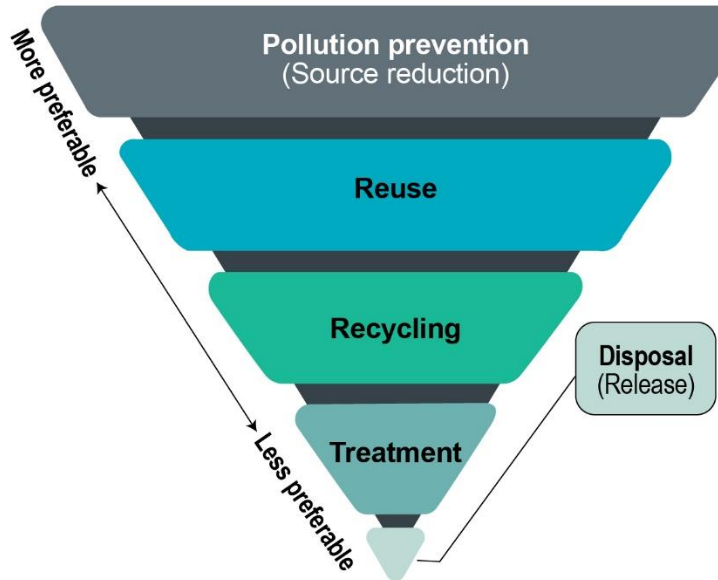
**Chapter 20:** Recycling Options

**Chapter 22:** General Applications

## Unit Lesson

**Introduction**

Welcome to Unit IV. We have learned about the foundation for pollution prevention (P2) by studying the laws, life cycle analysis, and audits. Our objective now is to evaluate source reduction options. Source reduction, reuse, and recycling—these are the #1, #2, and #3 most preferable P2 activities in the now familiar P2 hierarchy (see the image below as a reminder). Let’s go back to the fictitious company that was introduced in Unit I, SpecialtyParts, Inc. In Unit I, the P2 specialist acquainted the company’s division managers with P2. The P2 specialist led the managers through the P2 hierarchy and had each manager prepare a list of P2 possibilities within their departments.




P2 hierarchy
(Adapted from U.S. Environmental Protection Agency [EPA], n.d.)

As a part of the managers' investigations into P2 options for each of their divisions, several tasks were identified as having potential for cost reduction through P2. There were two tasks identified that needed further examination:

1. Reevaluate the wall thickness of plastic bottles that the company manufactures.
2. Consider purchasing aluminum beams to be installed horizontally to support vertically applied loads rather than steel beams as has been typical of the company in the past.

**Plastic Bottle Evaluation**

One of the many diverse products SpecialtyParts, Inc. manufactures is polyethylene (PET) plastic bottles for the beverage industry. The particular bottle that SpecialtyParts makes is for holding a carbonated beverage, such as soda pop. In the meeting with the P2 specialist, the plastics division manager suggested that the company might be able to save money and use less PET in this product line by reevaluating the wall thickness used in the PET bottle manufacturing process.

The PET bottle must be able to withstand an internal pressure of 75 psi (pounds per square inch) relative to the surrounding atmospheric pressure. The bottle has an inside diameter of 2.5 inches and a wall thickness of 0.03 inch. The beverage companies that purchase the bottles require the inside diameter of 2.5 inches, but they do not specify a wall thickness as long as a safety factor of 2.5 is used. Decades ago, the wall thickness of 0.03 inch was determined by SpecialtyParts because it met the safety factor requirement and is a wall thickness that SpecialtyParts' machinery could readily manufacture. With newer, more precise equipment used throughout the SpecialtyParts plant and the emphasis on P2, the plastics division manager suggested that reevaluating the wall thickness might be prudent.

The wall thickness of a hollow cylindrical container can be obtained by using the Barlow equation seen below (Riley et al., 2002).

$$t = F\frac{pD}{2s}$$

$t$ = Wall thickness, in inches
$F$ = Safety factor
$p$ = Inside pressure relative to outside pressure, psi (i.e., lb/in$^2$).
$D$ = Inside diameter of container, in inches
$s$ = Tensile strength of wall material, psi

The tensile strength of PET plastic is 10,200 psi, therefore:

$$t = (2.5)\frac{(75 \text{ psi})(2.5 \text{ inch})}{(2)(10{,}200 \text{ psi})} = 0.023 \text{ inch}$$

The cost for the raw PET pellets is \$0.70 per pound. The weight of a bottle when using a wall thickness of 0.03 inch was measured to be 0.05905 pound. A prototype bottle was made using the proposed wall thickness of 0.023 inch, and its weight was measured as 0.04357 pound.

The PET cost to make a 0.03-inch thick bottle is:

$$C_1 = (0.05905 \text{ lb})\left(\frac{\$0.70}{\text{lb}}\right) = \$0.04134 \text{ /bottle}$$

The PET cost to make a 0.023-inch thick bottle is:

$$C_2 = (0.04357 \text{ lb})\left(\frac{\$0.70}{\text{lb}}\right) = \$0.03050 \text{ /bottle}$$

The cost difference per bottle, $\Delta C_b$ is:

$$\Delta C_b = C_1 - C_2 = \$0.4134 - \$0.3050 = \$0.01084 \text{ / bottle}$$

To fulfill its contracts, SpecialtyParts has to produce 100,000 bottles per day. Using the smaller wall thickness for the bottles results in a cost savings on materials $\Delta C_d$ of:

$$\Delta C_d = \left(\frac{100{,}000 \text{ bottles}}{\text{day}}\right)\left(\frac{\$0.01084}{\text{bottle}}\right) = \$1084 \text{ / day}$$

For operations at 50 weeks per year and 5 days per week, the annual savings $\Delta C_a$ is:

$$\Delta C_a = \left(\frac{\$1084}{\text{day}}\right)\left(\frac{50 \text{ week}}{\text{year}}\right)\left(\frac{5 \text{ days}}{\text{week}}\right) = \$271{,}000 \text{ / year}$$

With such a significant savings each year, SpecialtyParts decided to make the switch to a thinner wall plastic bottle, which will meet the safety factor of the customer.

**Metal Beam Evaluation**

Many of the plant managers at SpecialtyParts have horizontal steel beams throughout their plant areas that are used to support thousands of pounds of weight hanging from each of them. Steel has been the beam material used due to decision-making decades ago. With the new P2 thought process instilled by the P2 specialist and the need for an additional 300 linear feet of new horizontal beams, the managers began discussing if a different material could be used for the beams at a lower cost with equal performance and less material.

The managers consulted their in-house team of engineers. The SpecialtyParts' engineers indicated that if a new material is being considered, it must have the same stiffness as the existing steel. Stiffness is the deflection (amount of bending) that a material undergoes due to an applied load. Though overall strength is an important consideration as well, the engineers indicated that only stiffness needs to be considered due to SpecialtyParts'' use of the beams. Due to a new nearby supplier of aluminum, the plant managers asked the company engineers to determine the amount of aluminum needed for an additional 300 linear feet of new beams. Then, the managers would contact the supplier for cost information to compare with the steel cost.

The engineers determined that the mass ratio between one material and another (in this case steel and aluminum) for equivalent stiffness is determined by the equation (Ashby, 2013):

$$\frac{m_a}{m_s} = \frac{\rho_a}{\rho_s}\sqrt{\frac{E_s}{E_a}}$$

$m$ = Mass
$\rho$ = Material density
$E$ = Elastic modulus. Elastic modulus is the ratio of the strength of a material to its strain (basically how much it will stretch due to a tensile load or shrink due to a compressive load)
Subscripts: $a$=aluminum, $s$=steel.

$\rho_a$ = 2710 kg/m$^3$ = 169 lb/ft$^3$.
$\rho_s$ = 7850 kg/m$^3$ = 490 lb/ft$^3$.
$E_a$ = 70 GPa, $E_s$ = 210 GPa.
kg = kilogram, lb = pound, ft = foot, m = meter, G = $10^9$, Pa = Pascal = Newton per square meter.

For the values, the ratio is evaluated:

$$\frac{m_a}{m_s} = \frac{\rho_a}{\rho_s}\sqrt{\frac{E_s}{E_a}} = \frac{2710\ \mathrm{kg/m^3}}{7850\ \mathrm{kg/m^3}}\sqrt{\frac{210\ \mathrm{GPa}}{70\ \mathrm{GPa}}} = 0.598$$

Since $m_a/m_s$ is a mass ratio, the units are equivalent to $m_a/m_s$ = 0.598 lb aluminum/lb steel.

The current steel beams weigh 22 lb/ft. The SpecialtyParts managers determined that they need an additional 300 linear feet of the same type of beams to support future loads within the facility. If the new beams are steel, the weight of the steel beams are:

$$m_s = (300\ \mathrm{ft})\left(22\,\frac{\mathrm{lb}}{\mathrm{ft}}\right) = 6600\ \mathrm{lb}$$

The alternative aluminum beams having an equivalent stiffness to the steel would have a required mass of:

$$m_a = m_s\left(\frac{m_a}{m_s}\right) = 6600\ \mathrm{lb}\ (0.598) = 3947\ \mathrm{lb}$$

The company is currently paying $0.7/lb for steel beams, so the proposed cost of the additional 300 ft of beams is:

$$P_s = (6600 \text{ lb})\left(\frac{\$0.7}{\text{lb}}\right) = \$4620$$

In contact with the new supplier and others, SpecialtyParts is able to obtain aluminum beams at $4/lb. The price for 300 ft of aluminum beams is:

$$P_a = (3947 \text{ lb})\left(\frac{\$4}{\text{lb}}\right) = \$15{,}800$$

While it was worth considering purchasing aluminum beams instead of steel ones, the price for 300 ft of steel beams is $4,620 compared to the much higher cost of aluminum beams at $15,800. Though the aluminum beams would have required less mass, the cost does not warrant the change.

**Conclusion**

The focus of this lesson was on P2 strategies. The lesson presented discussions within a fictitious company, SpecialtyParts, Inc. The P2 specialist encouraged the company's division managers to start thinking of P2 in all that they do. The idea is to use the principles of P2, mainly source reduction and chemical substitution, to reduce the amount of treatment and disposal conducted by SpecialtyParts. This lesson focused on two situations that the division managers presented following P2 reviews of their production areas.

The first scenario involved a product that SpecialtyParts manufactures—plastic bottles. After an engineering analysis, the managers determined that they could save the company $271,000 per year by using bottle wall thickness of 0.023 inch instead of the current 0.03 inch and continue to meet the customers' bottle specifications.

In addition, due to future expected expansion, the division managers identified the need for an additional 300 linear feet of horizontal beams throughout the facility. SpecialtyParts' engineering analyses showed that less aluminum mass would be needed to have the same stiffness as steel beams. However, the additional cost of aluminum compared to steel resulted in the continued use of steel.

**References**

Ashby, M. F. (2013). *Materials and the environment: Eco-informed material choice* (2nd ed.). Elsevier.

Riley, W. F., Sturges, L. D., & Morris, D. H. (2002). *Statics and mechanics: An integrated approach* (2nd ed.). Wiley.

U.S. Environmental Protection Agency. (n.d.). *Pollution prevention (P2).* https://www.epa.gov/p2

## Suggested Unit Resources

*In order to access the following resources, click the links below.*

To learn more about source reduction and recycling, access the following web pages.

U.S. Environmental Protection Agency. (n.d.). *Recycling basics*. https://www.epa.gov/recycle/recycling-basics

U.S. Environmental Protection Agency. (n.d.). *Source reduction activities reported*. https://www.epa.gov/trinationalanalysis/source-reduction-activities-reported