# Sustainability in Engineering Design and Construction

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J. K. Yates
Daniel Castro-Lacouture

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*This book is dedicated to the students who encouraged the authors to write it so they would be able to learn more about sustainable design and construction and to all of the youth who are interested in preserving the planet for future generations.*

*This book is also dedicated to Colten Guerra, the 4-year-old great nephew of Dr. Yates, who has a long battle ahead of him fighting cancer.*

*Dr. Castro-Lacouture dedicates this book to his wife Paula and his children Eva, Matias, and Camilo.*

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# Preface

The purpose of this book is to introduce sustainability and sustainable practices to members of the engineering and construction (E&C) industry and to provide insight into how to design and construct sustainable structures. Information is presented on why sustainable practices are being used, how they are being implemented, and what the potential benefits of their use are for members of E&C firms.

This book is unique because it not only addresses the sustainable aspects of buildings but also covers sustainable practices during engineering design and construction operations for all types of E&C projects. Many books focus on the sustainability certification rating systems used for evaluating buildings after they are complete, and these rating systems are mentioned in this book, but the main focus of this book is on providing information on how to address sustainability in all of the E&C industry sectors during engineering design and construction operations.

The first part of the book, Chapters 1 through 3, provides background information on sustainability, sustainable development practices, corporate social responsibility, supply chain management, early adopters of government sustainability objectives, barriers and drivers for implementing sustainable development practices, sustainability in the construction sector, domestic and foreign environmental regulations, sustainability global reporting initiatives, the social and community impact of projects, the environmental impact of production operations for construction materials, and global environmental management standards.

The first part of the book also includes information on the global treaties influencing the incorporation of sustainable practices into engineering design and construction operations such as the Kyoto Protocol Treaty, Basel Convention, Rio Declaration, and Stockholm Convention. It also presents information on clean development mechanisms, joint implementation practices, carbon sinks, and emissions credits. The environmental laws affecting E&C professionals working in the United States are covered to illustrate their impact on engineering designs and construction operations.

The middle part of the book, Chapters 4 through 10, presents information on sustainable designs; selecting sustainable sites; designing for passive survivability; designing for disassembly; and information on the ISO 14000 standard. It also discusses life-cycle cost assessment models and how to quantify all of the sustainable impacts on construction including the overall costs of materials taking into consideration cradle-to-grave economic and environmental costs. The middle section of the book also provides a summary of the results obtained from a research investigation into how sustainable practices are already being integrated into E&C firms and projects. Information is provided on how sustainability techniques are being used in the E&C industry, and on corporate- and project-level sustainability practices. The last part of the middle section of the book discusses global sustainability trends and implications and provides samples of some of the environmental degradation mitigation strategies being used throughout the world.

The third part of the book, Chapters 11 through 15, covers specific sustainability concepts and processes by including detailed information on sustainable construction materials and processes, heavy construction equipment, and traditional and alternative energy sources. It also provides background information on the Leadership in Energy and Environmental Design (LEED) Green Building Rating System and many other sustainability organizations and certification programs such as the International Green Construction Code, the Building Resource Energy and Environmental Assessment Model (BREEAM), Green Globes, Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) comprehensive assessment, Chartered Institute of Building's Sustainability and the Construction Industry in the United Kingdom Building for Environmental and Economic Sustainability (BEES) Stars, Green Advantage, Green Star, Green Guide to Specifications, British Standards Institute BES 6001, Responsible Sources Model, the Sustainable Sites Initiative, Design Quality Indicators, Civil Engineering Environmental Quality Assessment and Award Scheme, Los Alamos National Laboratory Sustainable Design Guide, the World Green Building Council, Green Guides to Specifications, United Nations Environment Programme, the Sustainable Building Alliance, GreenRoads, Green Building National Standard that incorporates NSI/ASHRAE/IES/USGBC Standard 189.1–2104, and others.

The last part of the book, Chapter 16, includes implementation resources developed during a research investigation funded by the Construction Industry Institute and conducted by Research Team 250, called Sustainable Industrial Engineering and Construction. The Research Team 250 members were from E&C firms and government agencies, and their names and affiliations are included in our "Acknowledgments" section. The implementation resources included in this book are a Sustainability Quick Start Guide, two Sustainability Maturity Models, a Sustainability Index Metric, and a Checklist for Evaluating the Sustainability of Construction Jobsite Operations. These implementation resources are used by members of E&C firms to help them implement sustainability programs and to evaluate the sustainability of engineering designs and construction operations. To illustrate how the checklist for evaluating the sustainability of construction jobsite operations is implemented on projects, Appendices D through F include three sample sustainability project execution plans developed using the checklist for actual construction projects located in Arizona, North Carolina, and Pennsylvania.

This book provides information on (1) definitions for sustainability terms, (2) sources for locating global sustainability requirements, (3) current sustainability issues and sustainable designs, (4) environmental laws related to sustainability and their implications, (5) sustainable design, (6) life-cycle cost assessment models, (7) sustainable practices currently being used in the E&C industry, (8) corporate-level sustainability practices, (9) project-level sustainability practices, (10) global sustainability trends and implications, (11) sustainable materials, (12) sustainable heavy construction equipment, (13) traditional and alternative energy sources, (14) the LEED Green Building Rating System, (15) sustainability organizations and certification programs, (16) sustainability implementation resources, and (17) a summary of sustainable engineering design and construction.

The end of each chapter contains a list of key terms, discussion questions, and references. Appendix A includes a list of commonly used acronyms and organizations related to sustainable practices along with their definitions. Other instructional materials and resources are available for educators, including PowerPoint lectures for each chapter, solutions to the discussion questions at the end of each chapter, and sample examination questions. These materials and resources are available at https://www.crcpress.com/product/isbn/9781498733915

The underlying theme of this book is to enhance the use of sustainability practices by providing information on how to incorporate sustainability practices into engineering designs and construction operations in all of the E&C industry sectors. Sustainability practices not only are evaluated after a structure is completed but they also need to be integrated into the designs, materials, processes, and operations used to build structures.

# Acknowledgments

Environmental consciousness increased during the last half of the twentieth century, and a resurgence of environmental concern occurred during the beginning of the twenty-first century. One of the major drivers for implementing sustainable practices at the beginning of the twenty-first century was the youth who came of age during this period. They are concerned about the state of the environment, and the environmental consequences they have inherited affecting their world.

It was university engineering and construction students who asked the authors to develop a course on sustainability in engineering design and construction so they could be more informed about their role in improving the environment for future generations. The discussions about sustainability that the authors had with students led to a research investigation on sustainability in the industrial construction sector that contributed to the body of knowledge already available for the building sector. Many aspects of the research were incorporated into lecture materials that the authors used in engineering and construction courses and the final result is this book, which captures for engineering and construction students and industry professionals information that helps them provide sustainable services to clients and improve the environmental aspects of society.

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# Authors

**J. K. Yates**, PhD, emeritus professor and currently a civil and construction engineering consultant, is a former dean of the College of Engineering Technology at Ferris State University, Big Rapids, Michigan, which is one of the largest colleges of engineering technology in the United States. She was also formerly the department head and the Joe W. Kimmel Distinguished Professor of Construction Management in the Department of Construction Management in the Kimmel School of Construction Management and Technology at Western Carolina University, Cullowhee, North Carolina. Dr. Yates was previously a professor and department chair in the Department of Construction Management and Engineering at North Dakota State University; in charge of the Construction Engineering and Management focus area in the Civil and Environmental Engineering Department at Ohio University; and program coordinator for the Construction Engineering program in the Civil and Environmental Engineering Department at San Jose State University in California. Dr. Yates was also a professor at New York University Polytechnic School of Engineering (formerly Polytechnic University and Brooklyn Polytechnic) and at Iowa State University, along with being a visiting professor at the University of Colorado for one year.

Dr. Yates earned a Bachelor of Science degree in civil engineering at the University of Washington and a PhD in civil engineering at Texas A&M University, College Station, Texas, with minors in global finance and management, global political science, business analysis, construction science, and archeology/anthropology.

Dr. Yates has worked for several of the top ranked domestic and global engineering and construction firms, as a consultant during legal cases, and on international contracts. Dr. Yates is the author of eight books and numerous refereed journal articles and is a former member of the American Society of Civil Engineers, Project Management Institute, and American Association of Cost Engineers International. Dr. Yates received the Distinguished Professor award from the Construction Industry Institute (CII) in 2010 and from Polytechnic University in 1994, the Associated General Contractor's Outstanding Construction Professor in America in 1997, one of the *Engineering News Records*' "Those Who Made Marks on the Construction Industry" in 1991, and in 2001 one of the principal investigators on a project that received the Ron Brown award for industry/academic collaborations with the Hewlett Packard Foundation. Dr. Yates has traveled for work and pleasure to 25 countries and worked in Bontang, East Kalimantan on the island of Borneo in Indonesia.

**Daniel Castro-Lacouture**, PhD, PE, is a professor and chair of the School of Building Construction, College of Architecture, Georgia Institute of Technology, Atlanta, Georgia. His overall area of interest consists of defining and deploying evaluation protocols for technology innovations in the built environment, focusing on areas affecting the built environment from both operational and sustainability perspectives. An Excellence in Civil Engineering Education (ExCEEd) Fellow, Georgia Tech Class of 1969 Teaching Fellow, and Colfuturo Scholar, Dr. Castro-Lacouture is a registered professional engineer and associate editor of *Automation in Construction*; he was chair of the American Society of Civil Engineers (ASCE) 2014 Construction Research Congress; and he has worked in construction engineering and management positions in both the public and private sectors.

Dr. Castro-Lacouture has been a member of governing boards and organizations at the local, national, and international levels, such as the Architecture/Construction/Engineering (ACE) Mentor Program of Atlanta, the American Society of Civil Engineers' Construction Institute North Georgia Chapter, the Green Advantage Certification Board, the International Council for Building (CIB) Working Commission W117 on Performance Measurement in Construction, and the International Association for Automation and Robotics in Construction (IAARC). He has taught 26 undergraduate and graduate courses and was corecipient of the best paper award at two international conferences. He earned his bachelor of science degree in civil engineering at the Universidad de Los Andes, Colombia; masters of science degree in construction management at the University of Reading, United Kingdom; and PhD in construction engineering and management at the School of Civil Engineering, Purdue University, West Lafayette, Indiana.

# 1 Introduction

Gaia Theory—the earth in its totality is very much a living entity. It is alive, it is fragile, and everything that is in it preserves a complex balance with everything else in a state of mutually beneficial equilibrium. Humankind's current disharmonious behavior is affecting this careful balance; there is a growing feeling that it must be changed radically and soon, if life on earth is to continue and flourish.

**John Lovelock (1979)**
*British chemist and environmentalist (Winchester 2005, p. 4)*

## 1.1 IMPORTANCE OF UNDERSTANDING SUSTAINABILITY IN ENGINEERING DESIGN AND CONSTRUCTION OPERATIONS

*Sustainability* in engineering design and construction operations is a significant twenty-first-century topic. In addition to first costs, clients are focusing on facility life-cycle costs and facilities where they are able to measure the benefits of green design and construction. Clients are including specific sustainability performance targets in requests for proposals, and this requires design professionals to know how to measure and quantify sustainable performance. When engineers and constructors provide suggestions to clients on incorporating sustainable practices early on during the design phase, it helps contribute to the success of sustainable designs.

Rather than merely evaluating buildings or other structures using a sustainability checklist, members of the engineering and construction (E&C) industry are moving toward performance-based evaluations to measure and track performance. This requires sustainability metrics that include scientific and administrative rigor for the evaluation of the carbon footprint of structures. The International Green Construction Code was released in 2012, and it is affecting sustainability certifications as municipalities throughout the United States adopt it. The code may motivate more clients to seek the *Leadership in Energy and Environmental Design* (LEED) Green Building Rating System or similar certifications for owners to demonstrate their compliance to the International Green Construction Code.

This chapter discusses sustainability in engineering design and construction operations from a historical perspective and includes insights about the incorporation of sustainable practices into projects. It explains the concepts of *sustainable development*, *corporate social responsibility*, the *Dow Jones Sustainability Group Index*, *key performance indicators*, *corporate sustainability,* and the *triple bottom line*. It also explores why members of the E&C industry are implementing sustainable practices and adopting green construction techniques. The last part of the chapter includes definitions of the sustainability terms and expressions used throughout this book. This chapter also introduces a research project that collected and analyzed the data incorporated into Chapters 7 through 9.

To assist readers in furthering their understanding of the material being presented in this book, each chapter contains key terms. At the end of each chapter, there is a list of the key terms for that chapter. These are words or phrases (and in many instances a definition is provided after the key terms) that readers may not be familiar with but should understand to progress through the material in each chapter.

## 1.2 SUSTAINABLE DEVELOPMENT

In the twenty-first century, there is increasing concern for the environment and in implementing sustainable development policies. Analyzing sustainability as it applies to engineering design and construction operations requires evaluating sustainability from both an environmental and a social impact perspective. The following are some of the primary engineering design and construction areas directly related to sustainability issues:

- Compliance with government environmental regulations
- Environmental footprint of structures
- Environmental impact of production operations
- Resource efficiency
- Responsible supply chains and procurement
- Social and community impacts of projects
- Supplier and vendor environmental and social responsibility
- Sustainable designs and materials

One definition for sustainable development by Samaras (2004, p. 1) is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs," and corporate sustainability is defined by Samaras (2004, p. 1) as "a business approach that creates long-term shareholder value by embracing opportunities and managing risks deriving from economic, environmental, and social developments."

## 1.3 CORPORATE SOCIAL RESPONSIBILITY

Corporate social responsibility is one of the major driving forces for the incorporation of sustainability concepts into the corporate strategies of firms. One of the original definitions of CSR by Bowen (1953, p. 6) refers to the obligations of corporations to "pursue those policies, to make those decisions, or to follow those lines of action which are desirable in terms of the objectives and values of our society." Another definition by Skruzmane (2005, p. 1) is "the success of a company's business is gained not only through the observance of laws and regulations but also through an approach that strikes a balance among economic, environmental, and social issues in ways that benefit citizens, the community, and society as a whole."

*Social responsibility investment* communities are another force driving the implementation of sustainable practices, as reflected by the increasing use of Dow Jones Sustainability Group Index, which tracks firms implementing sustainable practices. Social responsibility investment is defined by Uesugi (2004, p. 1) as "the supplying of funds to firms that fulfill social responsibilities through such means as stock investments and extension of loans." Environmental and social credibility is also influencing whether construction firms are able to secure investments or receive preferential treatment on bids.

Key performance indicators are incorporated into the design of structures and used to measure the level of implementation of sustainable practices. Key performance indicators are used for quantifying the success of an organization by developing a set of measurements used to evaluate the progress of the firm.

## 1.4 TRIPLE BOTTOM LINE

Executives from some E&C firms have adopted the triple bottom line as part of their corporate goals. The triple bottom line includes economic, environmental, and social values in design and construction, and it incorporates approaches such as "design for the environment, context sensitive designs, value engineering, life-cycle cost analysis, and LEED certification for projects. Sustainable construction techniques include implementing a sustainable design, meeting or exceeding sustainable design specifications, developing strategies to minimize and reuse construction waste and spoils, optimizing asset efficiency, and pursuing the highest level of LEED certification possible" (Samaras 2004, p. 1).

The term triple bottom line was first used by Elkington in 1997 in his consultancy Sustain–Ability. According to Paramanathan, Farrukh, Phaal, and Probert, in "Implementing Industrial Sustainability: The Research Issues in Technology Management," the "'health' of the global ecosystems represents the ultimate bottom line" (Paramanathan et al. 2004, p. 527).

## 1.5 SUSTAINABILITY IN ENGINEERING AND CONSTRUCTION OPERATIONS

The sustainable practices used in engineering design and construction operations predominately reflect the incorporation of alternative sustainable materials including reusable materials; materials using less resources during their extraction, manufacture, or transport; or materials that are recycled at the end of the useful life of a project. Sustainability considerations during the design stage of projects also include specifying sustainable materials to be used on a project. Another aspect of sustainability includes being able to reduce energy consumption during construction and operations or using alternative, renewable energy technologies. Sustainable practices in the area of waste management include producing less waste and recycling more waste. In the area of *pollution prevention*, the goals are to have less toxicity in the materials and products used during construction and to reduce noise and spatial pollution. To include sustainable practices while planning for deconstruction requires considering whether the materials removed from structures are recyclable or reusable when a structure is demolished at the end of its useful life (Yates 2008, 2013).

Building construction and demolition generates approximately 25% of the municipal solid waste and 50% of the hazardous waste in the United States.

Buildings use 40% of the total energy resources and 16% of available water (U.S. Green Building Council 2008). Indoor air pollution is one of the top five environmental risks to public health. Building-related activities are responsible for generating 35%–45% of the total *carbon dioxide* ($CO_2$) generated in the United States. Construction uses large quantities of stone, aggregate, sand, and steel and approximately 25% of virgin wood. Buildings use 75% of the polyvinyl chloride (PVC) manufactured worldwide. Manufacturing and fires are linked to emissions of a wide range of persistent bioaccumulative and toxic emissions including the release of *dioxin*, which is a highly toxic *carcinogen* (cancerous) (U.S. Green Building Council 2008).

Members of the E&C industry work closely with government agencies, owners, designers, and members of the manufacturing industry to help reduce environmental pollution. When engineers design projects, they are required by their professional code of ethics to recommend sustainable practices to clients. Engineers should evaluate the cradle-to-grave consequences and perform a life-cycle cost analysis for each project that not only includes the cost impact of their design but also evaluates the amount of pollution created during the extraction, manufacture, and transportation of construction materials. Engineers also need to consider recycling or reusing the materials removed from structures rather than disposing of them in landfills.

The *U.S. Green Building Council* (USGBC) and other organizations focusing on sustainability provide detailed information on the operational aspects of sustainable buildings; therefore, this book was written to provide engineers and constructors with guidelines on how to design and build *sustainable construction* projects and to focus on the incorporation of sustainability concepts during engineering design and construction operations.

When firms implement sustainable development practices during the design stage or construction operations, it benefits the environment, especially when sustainable materials are used on projects. Some of the sustainable practices incorporated into the design and construction phases of projects include selecting and incorporating reusable and recyclable materials, using materials requiring fewer resources to produce and transport; using equipment to install materials that consumes less energy; and using alternative renewable energy technologies.

Sustainable practices in the area of waste management include designing projects that produce less waste and allow for the recycling of more waste. Since the construction industry generates over 50% of the hazardous waste in the United States, in order to not produce as much hazardous waste less toxic materials should be used during construction (World Health Organization 2004).

There are numerous organizations creating rating systems used to evaluate the sustainable development practices incorporated into building construction projects, including residential, commercial, and institutional buildings. The U.S. Green Building Council developed the LEED Green Building Rating System, which is one of the rating systems being used in the United States for certifying building construction projects (U.S. Green Building Council 2008). Information about the LEED rating system is included in Chapter 14, and other sustainability organizations, publications, and certification systems are discussed in Chapter 15.

## 1.6 IMPLEMENTING SUSTAINABLE PRACTICES DURING ENGINEERING AND CONSTRUCTION PROJECTS

If engineers and constructors have access to detailed information on how to incorporate sustainable practices during both the design and the construction phases of projects, it helps promote the incorporation of additional sustainable practices. The reputation management of E&C firms is enhanced when members of firms are provided with information that helps generate more informed decisions on whether to implement sustainable practices on projects; how to determine the economic, social, and environmental impact of implementing sustainable practices; and how to determine whether the implementation of sustainable practices is warranted and beneficial to their clients.

When E&C projects are designed and built, the areas benefiting the most from implementing sustainable practices include

- Alternative energy sources
- Sustainable heavy construction equipment and fuel sources
- Complying with government environmental regulations
- Design modifications
- Material production
- Material transportation
- Resource efficiency
- Selecting environmentally neutral materials
- Social and community impacts of projects
- Supplier and vendor social responsibility
- Production operations

This book includes information on the sustainable practices being used by members of E&C firms during the design and construction of structures. The information provided helps increase the understanding of sustainable development practices. In addition, the first part of the book was written to assist engineers and constructors in

1. Determining the social and environmental benefits of incorporating sustainable practices
2. Determining the economic impact of implementing sustainable practices
3. Determining whether implementing sustainable practices has a positive effect on reputation management
4. Making more informed decisions on whether to implement sustainable practices

This book is applicable to buildings, but its main focus is on sustainable design and construction operations in the following sectors:

1. Heavy/highway
2. Manufacturing
3. Mining, minerals, and metals

4. Petrochemical
5. Power
6. Pulp and paper
7. Utilities

## 1.7 DEFINITIONS

This section includes definitions for the sustainable terms used throughout this book.

### 1.7.1 Sustainability and Industrial Sustainability

Cywinski (2001, p. 13) says, "Sustainability is said to be based on five pillars: conservation of nature, health and safety, reduced use of materials, social ecology, and cultural ecology." The last two issues are related to education and knowledge, ethics and culture, and values of heritage. Other areas of sustainability include "management and business practices, design technology and procedures, construction methods and equipment, materials and systems, and public and government policy. A list of sustainability linked environmental factors includes: energy; building ecology; air, water, landscaping; waste management; cultural change; and behavioral issues" (Cywinski 2001, p. 15).

In 2003, the Institute for Manufacturing at the University of Cambridge in England developed a definition for *industrial sustainability* "the conceptualization, design, and manufacture of goods and services that meet the needs of the present generation while not diminishing economic, social, and environmental opportunity in the long term" (Paramanathan et al. 2004, p. 528).

In 1999, a sustainable development strategy for the United Kingdom was created by the government, and a definition was developed for industrial sustainability by Paramanathan et al. (2004, p. 528), "The objectives are social progress which recognizes the needs of everyone, effective protection of the environment, prudent use of natural resources and lastly maintenance of high and stable levels of economic growth and employment."

### 1.7.2 Sustainable Development

In 1995, as a result of the formation of the World Business Council on Sustainable Development (WBCSD), sustainable development became a mainstream topic. This organization includes 160 global companies from more than 30 countries. Members of the WBCSD discovered that using eco-efficiency as a tool to measure environmental sustainability performance helps companies determine whether they are contributing to sustainable development or not (Bidwell and Verfaillie 2000). During this same period, a Swedish environmental organization, "The First Step," started promoting "organizational transformation as a key element for society to shift towards sustainable development" (Bradbury and Clair 1999, p. 65).

Sustainable development is defined in many ways, and one definition (United Nations World Commission on Environment and Development 1987, p. 43) characterizes it as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This definition was adopted and used in the Brundtland Report, which is also called *Our Common Future*. This report was written by the United Nations World Commission on Environment and Development in 1987. The report also provided seven strategies for sustainable development (Kirby et al. 1995, p. 9):

1. Changing the quality of growth
2. Conserving and enhancing the resource base
3. Ensuring a sustainable level of population
4. Meeting essential needs for jobs, food, energy, water, and sanitation
5. Merging the environment and the economy in decision making
6. Reorienting technology and managing risks
7. Reviving growth

Two definitions for sustainable development by Leadbitter (2002, p. 2197) are "a dynamic process which enables all people to realize their potential and to improve their quality of life in ways which simultaneously protect and enhance the earth's life support systems and the process of moving towards sustainability."

In Japan, sustainable development is referred to as *environmental symbiosis building*, or *environmental conscious building* (Cywinski 2001). In Finland, according to the Finnish National Commission on Sustainable Development (FNCSD), there are three practical dimensions to sustainable development: "1) ecological, 2) municipal, and 3) cultural" (European Commission Enterprise–Industry Sectors: Construction: Finland 2001a, p. 1).

Another definition for sustainable development by Cwyinski (2001, p. 13) is "a system of changes in public attitude and policy through which the population and vital activities of a community may be continued into the indefinite future without robbing the community of its usable resources." Another definition by Cwyinski (2001, p. 14) is "a process of change in which the direction of investment, the orientation of technology, the allocation of resources, and the development and functioning of institutions meet present needs and aspirations without endangering the capacity of natural systems to absorb the effects of human activities, and without compromising the ability of future generations to meet their own needs and aspirations." *Economic development* is defined by Chong et al. (2006, p. CT–007–1) as "ethical and wholesome economic growth."

### 1.7.3 CORPORATE SUSTAINABILITY AND CORPORATE SOCIAL RESPONSIBILITY

Corporate sustainability is defined by Wilson (2003, p. 1) as an organization that "recognizes that corporate growth and profitability are important, it also requires a corporation to pursue societal goals, specifically those relating to sustainable development–environmental protection, social justice and equity, and economic development." Another definition for corporate sustainability provided by 12MANAGE (2007, p. 1) is "a business approach by companies to consider not only economical needs in their strategies and practices, but also environmental needs. It is the opportunity for businesses to improve their profitability, competitiveness, and market share without compromising resources for future generations."

Coporate social responsibility is defined by Chong et al. (2006, p. 4) as "the responsibility of multinationals to behave fairly in host communities and to reduce the effects of industrial development in the host community." Another definition by Wilson (2003, p. 2) is "corporate social responsibility deals with the role of business in society. Its basic premise is that corporate managers have an ethical obligation to consider and address the needs of society, not just to act solely in the interests of the shareholders or their own self-interest."

### 1.7.4 SUSTAINABLE CONSTRUCTION AND GREEN BUILDING

According to Ofori (2000, p. 196), sustainable construction involves "creating construction items using best practice clean and resource-efficient techniques from the extraction of raw materials to the demolition and disposal of its components." According to the European Union publication *Proposals for a Response to the Challenges of Sustainable Construction* by the European Commission Enterprise (European Commission Enterprise–Industry Sectors: Construction: Finland 2001b, p. 1), sustainable construction "is the set of processes by which a profitable and competitive industry delivers built assets (buildings, structures, supporting infrastructure, and their immediate surroundings) that in turn

- Achieve higher growth while reducing pollution and maximizing the efficient use of resources.
- Contribute to sustainable development internationally.
- Enhance the quality of life and offer customer satisfaction.
- Improve towns and protecting the quality of the countryside.
- Increase investment in people and equipment for a competitive economy.
- Offer flexibility and the potential to cater to user changes in the future.
- Provide and support desirable natural and social environments.
- Share the benefits of growth more widely and more fairly. (European Commission Enterprise- Industrial Sectors Construction: Finland 2001b, p. 1).

The Conseil International du Batiment (CIB) defined the goal of sustainable construction as "… creating and operating a healthy built environment based on resource efficiency and ecological design" and introduced seven principles of sustainable construction (Kibert 2008, p. 6):

1. Apply life-cycle costing.
2. Eliminate toxins.
3. Focus on quality.
4. Protect nature.
5. Reduce resource consumption.
6. Reuse resources.
7. Use recyclable resources.

*Green building* is defined by Kibert (2008, p. 7) as "healthy facilities designed and built in a resource-efficient manner, using ecologically based principles."

### 1.7.5 SUPPLY CHAIN MANAGEMENT AND INTEGRATED CHAIN MANAGEMENT

One definition for *supply chain management* (SCM) by Lambert et al. (1998, p. 1) is "the integration of key business processes from end user through original supplier that provides products, services, and information that add value for customers and other *stakeholders* (those affected by the organization's actions, objectives and policies such as creditors, directors, employees, government agencies, owners/shareholders, suppliers, unions, and the community from which the business draws its resources)."

*Integrated chain management* has been defined by Heeres et al. (2004, p. 985) of the Task Force on Integrated Chain Management of the Dutch Environment Ministry as "the management of material flows, in chains caused by social activities, with respect to the environmental space boundaries." Managing material flow should lead to achieving the following three objectives (Heeres et al. 2004, p. 293):

- Keep renewable and nonrenewable resources as long as possible in material cycles, unless this is not environmentally desirable.
- Keep the balance in the process of use and production of renewable resources. This means making sure that one does not use more of a particular resource in a year than the amount of the resource produced in that same year.
- Reduce the use of nonrenewable resources (fossil fuels), and stimulate the use of sustainable energy as much as possible.

### 1.7.6 ENVIRONMENTAL COLLABORATIONS

*Environmental collaborations* are defined by Fiedler (2007, p. 410) as "two or more parties working together in relation to natural environmental issues, where at least one of the parties in an organization is from industry, and another, a nonprofit organization that has an objective of environmental conservation." One example of an environmental collaboration is Greenpeace, a nongovernmental organization with its coordinating body in Amsterdam, the Netherlands, working with private firms to create nuclear power plants that are environmentally acceptable to society. The objective of environmental collaborations according to the European Commission Enterprise (European Commission Enterprise–Industry Sectors: Construction 2001b, p. 1) is to build a better quality of life, and the main goals to achieve this objective are

- Adding to biodiversity
- Avoiding pollution
- Conserving water resources
- Designing for minimum waste
- Minimizing energy use throughout the life cycle
- Reusing existing built assets
- Respecting people and communities

### 1.7.7 Sustainability Stakeholders

Sustainability stakeholders, according to Paramanathan et al. (2004, p. 528), are "the individuals or groups that affect, or are affected by, an organization: those that have a legitimate interest in its activities and to whom the organization owes an account of its conduct."

### 1.7.8 Industrial Ecology

Another topic of concern related to sustainable development is *industrial ecology*, and it is defined by Basu and Van Zyl (2006, p. 299) as the "study of physical, chemical, and biological interactions and interrelationships both within and between industrial and ecological systems." According to Basu and Van Zyl (2006, p. 301) in the article "Industrial Ecology Framework for Achieving Cleaner Production in the Mining and Minerals Industry," "the aim of industrial ecology is to interpret and adapt an understanding of the natural system and apply it to the design of the manmade system, in order to achieve a pattern of industrialization that is not only more efficient, but that is intrinsically adjusted to the tolerances and characteristics of the natural system. The emphasis is on forms of technology that work with natural systems, not against them." Industrial ecology is an integrated management and technical program that includes the following (Basu and Van Zyl 2006, p. 301):

- Creation of industrial ecosystems
- Balancing industrial input and output to natural ecosystem capacity
- Dematerialization of industrial output
- Improving the metabolic pathways of industrial processes and material use
- Policy alignment with a long-term perspective of industrial ecosystem evolution

Basu and Van Zyl (2006, p. 303) summarize industrial ecology as "the means by which humanity is able to deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution. The concept requires that an industry system be viewed not in isolation from its surrounding systems, but in concert with them. It is a system view in which one seeks to optimize the total material cycle from virgin material, to finished material, to product, to waste product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital."

### 1.7.9 Pollution Prevention

Pollution prevention is defined by the Environmental Protection Agency (2007, p. 1) as "the use of materials, processes, or practices that reduce or eliminate the creation of pollutants or wastes at the source. It includes practices that reduce the use of hazardous materials, energy, water, or other resources and practices that protect natural resources through conservation or more efficient use."

### 1.7.10 Environmental Management

According to Ball (2002, p. 421), *environmental management* as used in the International Organization for Standardization (ISO) 14000 standards means "what an organization does to minimize harmful effects on the environment caused by its activities." In the ISO 14000 series of standards, there are standards specific to life-cycle cost assessment (LCCA), which means to "analyze the environmental impacts of a material from cradle to grave" (Ball 2002, p. 426).

### 1.7.11 Energy Auditing

*Energy auditing* is defined by the Australian Department of Primary Industries and Energy (1994, p. 1) as "a periodic examination of an energy system (or a part of a system) to ensure the most appropriate sources of energy are employed and this energy is used as efficiently as possible." Energy auditing is

> a systematic way of gathering and evaluating information with regard to the quantity and type of energy used, and is a specialized form of environmental auditing. It comprises the periodic survey, measurement, reporting, analysis and examination of an energy system for individual plants, a production process, or an entire organization. The goals of energy auditing are to promote energy efficiencies, to identify areas of potential savings in energy and its related expenditure, and to promote energy management to achieve, maintain, and recognize further potential savings. (Langston and Ding 2001, p. 263)

Additional information on energy auditing is provided in Chapter 13 in Section 13.17.

### 1.7.12 Embodied Energy

According to Calkins (2009, p. 6), "*Embodied energy* is the total energy required to produce and install a material or product during all stages of the life cycle." In addition to embodied energy, comparisons of materials should also "take into account other factors of production such as pollutants and toxins released, resources used, or habitat disturbed" (Calkins 2009, p. 6).

To obtain a true measure of embodied energy in a form for comparison purposes the embodied energy is divided by the time a product is in use, and this is a more accurate representation of the environmental impact of the product. This encourages the use of more durable products with higher embodied energy that last longer than other comparable products. The embodied energy of some common construction materials, as measured by megajoules per kilogram and by megajoules per cubic meter, is listed in Table 1.1.

### 1.7.13 Eutrophication and Acidification

*Eutrophication* is defined as "over enrichment of water bodies with nutrients from agricultural and landscape fertilizer, urban runoff, sewage discharge, and eroded stream banks. Nutrient over supply fosters algae growth, which blocks sunlight and causes underwater grasses to die. Decomposing algae further utilize dissolved oxygen necessary for the survival of aquatic species" (Kibert 2008, p. 41).

## TABLE 1.1
## Embodied Energy in Construction Materials

| Construction Material | Embodied Energy (MJ/kg) | Embodied Energy (MJ/m$^3$) |
|---|---|---|
| Aggregate | 0.1 | 150 |
| Aluminum | 227.0 | 5,700 |
| Aluminum (recycled) | 8.1 | 21,870 |
| Asphalt shingles | 9.0 | 4,930 |
| Brick | 2.5 | 5,170 |
| Carpet (synthetic) | 148.0 | 84,900 |
| Cellulose insulation | 3.3 | 112 |
| Concrete (30 MPa–4,350 psi) | 1.3 | 3,180 |
| Copper | 70.6 | 93,620 |
| Fiberglass insulation | 30.3 | 970 |
| Gypsum wallboard | 6.1 | 5,890 |
| Linoleum | 116.0 | 150,930 |
| Lumber | 2.5 | 1,380 |
| Mineral wool insulation | 14.6 | 139 |
| Paint | 93.3 | 117,500 |
| Particleboard | 8.0 | 4,400 |
| Plywood | 10.4 | 5,720 |
| Polystyrene insulation | 117.0 | 3,770 |
| PVC | 70.0 | 93,620 |
| Steel | 32.0 | 251,200 |
| Zinc | 51.0 | 371,280 |

*Source:* Data from Kibert, C., *Sustainable Construction: Green Building Design and Delivery*, John Wiley, Hoboken, New Jersey, 2008.

According to Kibert (2008 p. 41), *acidification* is the “process whereby air pollution in the form of ammonia, sulfur dioxide, and nitrogen oxides, mainly released into the atmosphere by burning fossil fuels, is converted into acids. The resulting acid rain is well known for its damage to forests and lakes and it also damages freshwater, and coastal ecosystems and soils.”

### 1.7.14 OTHER TERMS RELATED TO SUSTAINABLE DEVELOPMENT

Other terms used in relation to sustainable development include the following (Paramanathan et al. 2004, p. 527):

- Design for sustainability including
    - Full life-cycle concepts
    - Design for assembly and disassembly (DfD)
    - Design for extended life, and for reuse/remanufacturing/recycling

- Product development sustainability
- Design for manufacture
- Sustainable quality management (SQM)
- Quality function development (QFD)

Appendix A is a list of sustainability acronyms that are frequently used in the E&C industry and the terms they represent.

## 1.8 SUSTAINABILITY RESEARCH IN ENGINEERING DESIGN AND CONSTRUCTION OPERATIONS

Sustainability research projects were analyzed to determine the types of information applicable to engineering design and construction operations. This analysis determined that the following sustainability areas are the most pertinent to engineering design and construction operations:

1. Compliance with government regulations
2. Deconstruction and the recycling of the by-products of deconstruction
3. Environmental footprint of structures
4. Environmental impact of production operations
5. Environmental impact statements
6. ISO 14000 environmental management standards
7. Less toxicity in pollution or generating less pollution
8. Long-term effects of not considering sustainability during construction
9. Material cradle-to-grave ecological costs including whether materials are reused or recycled, and reducing energy use during the manufacturing and transporting of materials
10. Producing less waste
11. Recycling more waste during construction
12. Reducing noise and spatial pollution
13. Renewable energy
14. Resource efficiency including reducing energy consumption during construction
15. Social and community impact of projects
16. Supplier and vendor environmental and social responsibility including responsible supply chains and procurement
17. Sustainable design

After reviewing sustainability research projects, additional information was collected from E&C industry executives on the use of sustainable practices. Table 1.2 is a summary of the types of firms providing information along with company information about the firms. Some of the boxes in the columns are blank because there were not as many categories for that particular area. The information being presented in Table 1.2 is summarized by columns, not rows.

## TABLE 1.2
## General E&C Company Information from Survey

| Type of Industry | Type of Firm | Type of Contracts | Countries of Operation | Nature of Ownership | Size of Company | Average Size of Projects | Number of Employees |
|---|---|---|---|---|---|---|---|
| Building 11% | Arch. 7% | Cost plus % fee 20% | Africa 3% | Corporation 35% | $0–$10 Million 3% | $1–$10 Million 28% | 1–100 7% |
| Commercial 6% | Contr. 21% | Cost plus a fee 18% | No response 3% | Do not know 5% | $100–$500 Million 21% | $10–$50 Million 30% | 100–500 13% |
| Gas production 13% | Design/build 16% | Lump-sum 47% | North America 7% | Employee owned 13% | $500–$1 Billion 7% | $50–100 Million 7% | 500–1,000 10% |
| Heavy and highway 6% | Engr. 21% | Other 2% | South America 3% | N/A or other 5% | Over $1 billion 69% | $100–$500 Million 14% | 1,000–5,000 27% |
| Industrial construction 12% | No response 2% | Unit price 13% | United States 33% | Privately held 13% | | $500 Million to $1 billion 14% | 5,000–10,000 3% |
| Institutional 5% | Other 2% | | Worldwide 51% | Publically traded 29% | | Over $1 billion 7% | 10,000–50,000 40% |
| Manufacturing 5% | Owner 26% | | | | | | |
| Mining/metals 6% | Supplier 5% | | | | | | |
| Petrochemicals 13% | | | | | | | |
| Power 15% | | | | | | | |
| Pulp and paper 2% | | | | | | | |
| Residential 2% | | | | | | | |
| Utilities 11% | | | | | | | |

*Source:* Data from Yates, J.K., *Sustainable Industrial Construction*, Construction Industry Institute, Austin, Texas, 2008.

*Note:* N/A, not applicable.

The E&C industry experts participating in the research investigation provided information on the following:

1. Barriers to implementing sustainability programs
2. Drivers to the implementation of sustainable development practices
3. Economic benefits of sustainable development practices
4. How members of firms evaluate sustainability
5. How sustainability programs are implemented in their firms
6. How the benefits of using sustainable practices are measured on projects
7. How the waste generated during construction projects is recycled or reused
8. Pollution prevention techniques
9. Social conditions addressed during construction
10. Sustainability programs used in their firms
11. Sustainable alternatives to traditional construction materials
12. Techniques used to improve sustainable development
13. Using innovative sustainable designs or construction components
14. Whether their firm measures metrics related to sustainable objectives

Table 1.3 summarizes the results obtained from E&C industry experts, and Chapters 7 through 9 include a synopsis of the detailed information obtained from the industry experts.

**TABLE 1.3**
**Sustainability in Construction Survey Results**

| **Part II Questions**<br>**Corporate-Level Sustainability** | **Yes** | **No** | **Do Not Know** |
|---|---|---|---|
| Environmental considerations in design documents | 96% | 0% | 4% |
| Sustainability issues evaluated that could impact the completion of projects | 70% | 15% | 15% |
| Considerations due to regulatory compliance or other | Regulatory compliance: 48% | Beyond compliance: 52% | |
| Environmental sustainability considered when determining expected project life cycle | 63% | 18% | 19% |
| Evaluate sustainability social issues that impact the completion of projects | 70% | 15% | 15% |
| Structured approach used when designing and specifying materials that include sustainability | 58% | 23% | 19% |
| Have a corporate strategy on sustainability | 84% | 8% | 8% |

(*Continued*)

**TABLE 1.3 (*Continued*)**
**Sustainability in Construction Survey Results**

| **Part II Questions**<br>**Corporate-Level Sustainability** | **Yes** | **No** | **Do Not Know** |
|---|---|---|---|
| Participate in global reporting initiatives | 40% | 48% | 12% |
| The firm belongs to the Dow Jones Sustainability Group Index | 8% | 56% | 36% |
| | **Other Percentages** | **Other Percentages** | **Other Percentages** |
| Potential barriers to implementing industrial construction sustainability programs | Capital cost concerns: 25%<br>Competitiveness: 19%<br>Not required by Regulations: 6% | Not sure how to do it or measure it: 13%<br>Need a practical implementation plan: 10% | Not sure if it will be profitable: 9%<br>Need to show a positive rate of return: 18% |
| Drivers for the implementation of sustainable development in construction | Owners: 20%<br>Nongovernmental Agencies: 15%<br>Government: 18% | Public awareness of sustainability issues: 8%<br>Media: 15% | Competitive Differentiation: 4%<br>Profit: 14%<br>Other: 2% |
| Have implemented the ISO 14000 series of standards, or they are certified to them | Implemented ISO 14000: 23%<br>Not implemented ISO 14000: 12% | Certified to ISO 14000: 12%<br>Not certified to ISO 14000: 15% | Do not know: 20%<br>N/A: 12% |
| **Part III Questions**<br>**Project-Level Sustainability** | **Yes** | **No** | **Do Not Know** |
| Have benefited economically from implementing sustainability practices | 29% | 21% | 50% |
| Processes are used to sell, or reuse, material by-products generated during construction | 60% | 16% | 24% |
| Local social conditions are addressed during the construction of projects | 84% | 4% | 12% |
| Sustainable alternatives to standard materials are considered during design | 40% | 20% | 40% |
| Have standard techniques for measuring the benefits of using sustainable practices on construction projects | 32% | 60% | 8% |
| Using new techniques that improve resource efficiency, equipment efficiency, material resource efficiency, or training of laborers | 56% | 26% | 29% |

**TABLE 1.3 (*Continued*)**
**Sustainability in Construction Survey Results**

| **Part III Questions**<br>**Project-Level Sustainability** | **Yes** | **No** | **Do Not Know** |
|---|---|---|---|
| Innovative sustainable designs, construction components, or construction practices being integrated into projects | 39% | 19% | 42% |
| Prequalifying vendors and suppliers on sustainability practices or social responsibility | 12% | 64% | 24% |
| Renewable energy sources used during construction | 20% | 44% | 35% |
| Techniques or processes used to reduce the amount of waste generated during construction | 42% | 21% | 37% |
| More construction waste being recycled, or reused, than on projects before sustainability practices were implemented | 29% | 38% | 33% |
| Techniques used to reduce the amount of pollution generated during construction | 71% | 21% | 8% |
| Mobilization, or demobilization, processes used include sustainability practices | 25% | 37% | 38% |
| Sustainability is considered during constructability reviews | 38% | 33% | 29% |
| Project execution plans include a section on sustainability practices | 26% | 61% | 13% |
| Have a method for measuring metrics related to sustainability objectives | 21% | 52% | 17% |

*Source:* Adapted from Yates, J.K., *Sustainable Industrial Construction*, Construction Industry Institute, Austin, Texas, 2008.

## 1.9 ORGANIZATION OF THIS BOOK

This book is organized into chapters addressing sustainability in engineering design and construction operations. The first part of the book, Chapters 1 through 3, provides engineers and constructors with information that helps them understand sustainability and sustainable development and the organizations providing information related to these topics. Global reporting initiatives are discussed in the first part of the book since members of many firms are now required to produce these reports and it is important to understand what these reports include and how they are used in the E&C industry.

The second part of the book, Chapters 4 through 10, includes information about sustainable designs and design elements, passive survivability, selecting sustainable sites, designing for disassembly, environmental laws related to sustainability, life-cycle assessment models, and sustainable techniques, all of which influence how sustainable practices are implemented during the engineering design and construction operation phases of projects. The second part also summarizes corporate- and project-level sustainable practices, and it includes examples of global sustainability trends.

The last part of the book, Chapters 11 through 17, discusses sustainable construction materials, sustainable heavy construction equipment, traditional and alternative energy sources, the LEED Green Building Rating System, sustainability organizations, certification organizations, and sustainability implementation resources.

The chapters in this book cover the following topics:

- Corporate-level sustainable practices
- Current sustainability issues
- Environmental laws related to sustainability and their implications
- Global sustainability trends and implications
- Global environmental treaties
- LEED Green Building Rating System
- Life-cycle cost assessment models
- Project-level sustainable practices
- Sources of information on sustainability requirements
- Sustainable construction
- Sustainable design
- Sustainable heavy construction equipment
- Sustainability implementation resources
- Sustainability in engineering design
- Sustainability organizations and certifications systems
- Sustainable techniques used in the E&C industry
- Sustainable construction materials
- Traditional and alternative energy sources

## 1.10 SUMMARY

This chapter provided an introduction to the topics of sustainability and sustainable development as they pertain to engineering design and construction operations. Corporate social responsibility, socially responsible investments, the Dow Jones Sustainability Group Index, key performance indicators, and triple bottom line were discussed to demonstrate how sustainability and sustainable development fit into modern society. This chapter also introduced how sustainability influences engineering design and construction operations. The areas benefiting from sustainable practices were mentioned, and they are elaborated on in the rest of the book.

The USGBC and the LEED Green Building Rating System were introduced in this chapter, and they are discussed in detail in Chapter 14. The last part of this chapter provided definitions for a variety of different sustainability terms used throughout this book. A research project was introduced that collected data from

E&C industry executives. The results of the research investigation are included in Chapters 7 through 9.

## 1.11 KEY TERMS

Acidification
Carbon dioxide
Carcinogen
Corporate social responsibility
Corporate sustainability
Dioxin
Dow Jones Sustainability Group Index
Economic development
Embodied energy
Energy auditing
Environmental collaborations
Environmental conscious building
Environmental management
Environmental symbiosis building
Eutrophication
Industrial ecology
Industrial sustainability
Integrated chain management
Green building
Greenpeace
Key performance indicator
Leadership in Energy and Environmental Design
Pollution prevention
Social responsibility investment
Stakeholders
Supply chain management
Sustainability
Sustainable construction
Sustainable development
Triple bottom line
U.S. Green Building Council
Word Business Council on Sustainable Development

## 1.12 DISCUSSION QUESTIONS

1.1 What are key performance indicators, and how are they used by firms?
1.2 Explain sustainable construction and how it relates to sustainable development.
1.3 Explain the difference between eutrophication and acidification.
1.4 Discuss how buildings are responsible for some of the environmental pollution generated in the United States.

1.5 Discuss whether supply chain management is feasible in construction.
1.6 Discuss what is meant by green building.
1.7 Explain the triple bottom line and its relationship to sustainability.
1.8 Discuss corporate sustainability and how it affects the operations of a firm.
1.9 Discuss the seven principles of sustainable construction according to the Conceil International du Batiment.
1.10 What is the Dow Jones Sustainability Group Index, and how is it used to influence the use of sustainable practices?
1.11 How is environmental management different from sustainability?
1.12 Explain why corporate social responsibility influences the incorporation of sustainable practices into E&C projects.
1.13 Discuss how reputation management relates to sustainability.
1.14 Discuss how environmental collaborations are used to help promote sustainability.
1.15 Explain the difference between sustainability and sustainable development.
1.16 How are socially responsible investment strategies affecting the use of sustainable practices in the E&C industry?
1.17 Why is embodied energy important, and how is it used in E&C?

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# 2 Sources of Information on Sustainability Requirements

This chapter introduces the early adopters of *government sustainability objectives* and the environmental objectives of their governments. It also highlights some of the drivers and barriers to implementing sustainable practices mainly focusing on sustainability in the engineering and construction (E&C) industry. Information is also provided on pollution and waste management, both of which are discussed throughout this book. This chapter explains how to locate information on sustainability requirements, global environmental treaties, and resources in the United States and foreign countries that describe environmental regulations impacting E&C projects.

## 2.1 SUSTAINABILITY REQUIREMENTS

The topic of sustainability is an all-encompassing, broad topic, but there are areas specific to engineering design and construction operations. The focus areas directly pertaining to sustainable engineering design and construction are as follows:

1. Compliance with government regulations
2. Cradle-to-grave ecological costs of materials, including whether materials are reused or recycled, and reducing energy consumption during the manufacturing and transporting of materials
3. Deconstruction and recycling the by-products of deconstruction
4. Effects of not considering sustainability during construction
5. Environmental footprint of structures
6. Environmental impacts of production operations
7. Environmental impact statements
8. Generating less pollution or reducing the toxicity of pollution
9. International Organization for Standardization (ISO) 14000 environmental management standards
10. Producing less construction waste
11. Recycling more waste during construction
12. Reducing noise and spatial pollution
13. Resource efficiency including reducing energy consumption during construction
14. Social and community impacts of projects

15. Supplier and vendor environmental and social responsibility including responsible supply chains and procurement processes
16. Sustainable engineering designs
17. Using renewable energy sources

This chapter introduces sustainability requirements pertaining to these focus areas, and additional information directly related to each of these topics is discussed in detail throughout this book.

The next few sections, Sections 2.2 through 2.7, provide information about the early adopters of government sustainability objectives, drivers influencing the implementation of sustainable development practices on E&C projects throughout the world, barriers to implementing sustainable practices, sustainability in the building sector, sustainability in the construction sector, and pollution and waste management.

## 2.2 EARLY ADOPTERS OF GOVERNMENT SUSTAINABILITY OBJECTIVES

Some of the first and most far-reaching objectives related to sustainable development were adopted by the Swedish parliament (the Riksdag) in 1999, and they include (European Commission Enterprise—Industry Sectors: Construction: Finland 2001, p. 27):

- Balanced marine environment, sustainable coastal areas, and archipelagos
- Clean air
- Flourishing wetlands
- Good urban environment
- High-quality groundwater
- Limited influence on climate
- Natural acidification only
- No eutrophication
- Nontoxic environment
- Preserving mountain landscapes
- Protective ozone layer
- Safe radiation-free environment
- Sustainable forests
- Sustainable lakes and watercourses
- Varied agricultural landscape

During the early part of the twenty-first century, the Dutch developed five *environmental value standards* that address the following (European Commission Enterprise—Industry Sectors: Construction: Finland 2001, p. 1):

1. Raw materials
2. Emissions
3. Energy

4. Waste
5. Nuisance

In addition, at the same time the Dutch government recognized 13 types of environmental issues (European Commission Enterprise—Industry Sectors: Construction: Finland 2001, p. 1):

1. Acidification
2. Damage to the ozone layer
3. Depletion of fuel resources
4. Depletion of raw materials
5. Ecotoxicity in water (potential for biological, chemical, or physical stressors to affect ecosystems)
6. Eutrophication
7. Hazardous waste
8. Human toxicity
9. Radioactive waste
10. Summer smog
11. The greenhouse effect
12. Use of nonrenewable energy sources
13. Waste

In Holland, when members of firms assess the five Dutch environmental value standards the 13 types of environmental impacts are assessed and weighted to determine an overall value.

## 2.3 DRIVERS FOR IMPLEMENTING SUSTAINABLE DEVELOPMENT PRACTICES

There are many drivers influencing the implementation of sustainable development practices, including the following:

- Competitive differentiation
- Government legislation
- Media
- Nongovernmental organizations
- Owners
- Profit
- Public awareness of sustainability issues
- Quality of life for future generations

Other drivers include the following (Paramanathan et al. 2004, p. 526):

- Brand loyalty
- Employee loyalty

**TABLE 2.1**
**Calvert Social Index Companies versus Lipper Index and Standard and Poors Index**

| Funds or Benchmarks | 1 Year | 3 Years | 5 Years |
|---|---|---|---|
| Calvert Social Index | 11.93% | 8.05% | 5.25% |
| Calvert Fund Equity/no load | 11.06% | 7.23% | 4.43% |
| Calvert Fund Equity/load | 5.79% | 5.51% | 3.42% |
| Lipper Multiple Capital Core | 12.45% | 11.00% | 6.31% |
| Standard and Poors 500 Index | 14.51% | 10.31% | 6.83% |

*Source:* Calvert Investments. Various Years. *Calvert Social Index*. Bethesda. MD. Assessed on May 19, 2015. http://www.calvert.com/resources/calvert-social-index; Calvert Investments. Various Years. *Calvert Mutual Fund*. Bethesda. MD. Assessed on May 19, 2015. http://www.calvert.com/strategies/strategies-by-product/mutual-funds; McGraw Hill Financial. Various Years. *Standard and Poors Dow Jones Indices*. NY. Assessed May 19, 2015. http://us.spindices.com/indices/equity/sp-500; and Thompson Reuters Company. Various Years. *Lipper Fund Market Reports*. NY. Assessed on May 19, 2015. http://www.lipperweb.com/default.aspx

- Enhanced corporate reputation
- Financial gains
- Improved government relations
- Increased ease of recruitment
- Increased risk management skills
- Increased technology and innovation skills

One measure of the profitability of companies recognized as socially responsible is the *social responsibility index* developed and maintained by the Calvert Mutual Fund (CMF). Table 2.1 shows that Calvert Social Index companies do not perform as well as the benchmarked indices Lipper or Standard and Poors over a 3- to 5-year period. However, they do remain profitable.

According to Paramanathan et al. (2004, p. 527), companies may also implement sustainable development practices to “avert serious reputation damage, change the flow of the market demand, and avoid the risk of a boycott or being left behind in stiff competition.” In a survey of consumers conducted to collect data in four countries, the consumers were asked if they would switch brands if a firm was associated with a worthy cause. In the United Kingdom, 68% of those surveyed indicated they would switch, and in the three other countries the following percentages of respondents stated they would switch: Italy 75%, Australia 73%, and Belgium 65%.

## 2.4 BARRIERS TO IMPLEMENTING SUSTAINABLE PRACTICES AND LIABILITY ISSUES

Implementing sustainable development practices in the E&C industry is difficult because of the short duration of construction projects, the limited amount of time firms operate at construction jobsites, and the pressure to complete projects on time and within the budget. Having many different construction trades adds to the difficulty in effectively communicating how sustainable practices should be integrated and ensuring that they are properly implemented during projects.

According to research conducted at the Los Alamos National Laboratory (2002, p. 7), “There is ample evidence that the primary reasons engineers practice *green engineering* is because it is good for business. In one study, 54 companies who had professed to being *green companies* were asked about substituting nontoxic chemicals in the process. Two thirds of these companies said they would do so as long as the product cost did not increase by more than 0.1%. The other third of the companies would not entertain such a substitution if it increased the product cost.”

### 2.4.1 Liabilities Related to Designing and Constructing a LEED-Certified Building

Another barrier to implementing sustainable practices is the reluctance of members of construction firms to implement new, innovative methods and processes during construction projects because of liability issues (Lindley and McEvoy 2002). Many challenges arise when engineers and constructors design or construct buildings where the owner is seeking Leadership in Energy and Environmental Design (LEED) certification. Since the certification process is relatively new, there are a limited amount of precedent laws defining the legal ramifications of a structure not achieving LEED certification. Even without precedent laws, engineers and constructors need to be aware of their legal obligation when they are working on a building being evaluated for LEED certification.

A major issue that might arise when working on a building being evaluated for LEED certification is the structure not receiving the level of certification desired by the owner, such as a structure receiving silver certification rather than the desired gold certification. In this situation, the owner, engineer, and contractor usually work together to try and increase the LEED rating points to obtain the higher rating, but there might be situations where it is not possible to obtain the higher rating. Engineers and constructors should know what their liability will be under these circumstances and whether they would be liable for damages to the owner.

Another potential problem occurs when the energy savings for the structure are not up to the level expected, and for which the added costs were justified for the structure. There are some insurance companies offering liability insurance covering a few of the issues that could arise on LEED structures, but they may not insure against the building not achieving LEED certification.

In addition to taking on additional legal liability, engineers and constructors may also have to conduct additional research, obtain approvals, and face unique coordination challenges when they are working on a LEED building. Unless they have these added expenses built into their fee and schedule, they may end up underpaid and with a schedule impossible to maintain. Another situation may arise if the owner transfers responsibility for data reporting on energy and water use for five years to either the engineer or the contractor rather than doing it himself or herself and the building qualifies the first year but not in subsequent years.

Different types of issues have already occurred on LEED-certified projects; therefore, ConcensusDOCS 310 was developed with a green building addendum stipulating a green building facilitator for LEED projects (Cole 2011). Whoever is designated as the green building facilitator is responsible for all LEED interactions and reporting. This document also discusses risk allocation on projects, the sustainability or green building liability of contractors, and it defines the elected green status.

## 2.5 SUSTAINABILITY IN THE BUILDING SECTOR

In the building sector, there are numerous organizations providing publications and certification systems on sustainable development practices for buildings, and these organizations are discussed in Chapter 15. The following are some of the organizations:

- *Building for Environmental and Economic Sustainability* (BEES Stars) (National Institute of Standards and Technology [NIST])
- *BES 6001 and 6002*—Responsible Sourcing of Construction Products (British Standards Institute)
- *Building Research Establishment Environmental Assessment Method* (BREEAM) (Building Research Establishment Trust*)*
- *Civil Engineering Environmental Quality Assessment Award Scheme* (CEEQUAL) (Institute of Civil Engineers [ICE])
- Codes for Sustainable Homes (CSH) (Department for Communities and Local Government, United Kingdom)
- *Comprehensive Assessment System for Building Environmental Efficiency* (CASBEE) (Japan Sustainable Building Consortium)
- Council on Tall Buildings and Urban Habitat (CTBUH) (Illinois Institute of Technology)
- *The Energy and Environmental Guidelines for Construction*, Department of Engineering Building Technology Program (U.S. Department of Energy)
- *Design Quality Indicators* (DQI) (Construction Industry Council)
- Environmental Performance of Building Guidelines (Environmental Protection Agency)
- *Envision*—Sustainable Infrastructure Rating System (Institute for Sustainable Infrastructure)
- Forest Stewardship Council (National Office of Forest Stewardship Council International, Bonn, Germany)
- *Green Globes* (Building Owners and Managers Association [BOMA] in Canada and the Green Building Initiative [GBI] in the United States. Accredited by the American National Standards Institute [ANSI])
- *Green Guide to Specifications* (Building Research Establishment)
- *Greenroads* (U.S. Federal Highway Administration)
- *Green Star* (Green Building Council of Australia [GBCA])
- *International Green Construction Code* (International Code Council)

- *ISO 14000* series of environmental management standards (ISO)
- *Sustainability Design Guide* (Los Alamos National Laboratory)
- *NSI/ASHRAE/IES/USGBC Standard 189.1–2014, Standard for the Design of High Performance Green Buildings* (American Society of Heating, Refrigeration, and Air Conditioning Engineers [ASHRAE])
- *Sustainable Buildings and Construction Initiative of the United Nations* (United Nations Environmental Programme)
- *Sustainable Sites Initiative: Guidelines for Performance Benchmarks 2009 and the Case for Sustainable Landscapes* (American Institute of Landscape Architects)
- Sustainability and the Construction Industry in the United Kingdom (Chartered Institute of Building 2004)
- U.S. Department of Engineering Building Technology Program (U.S. Department of Energy)
- World Green Building Council (WGBC)

Members of the Los Alamos National Laboratory conduct research on the benefits of implementing sustainable development practices on building projects, and its website provides detailed information on sustainable building practices. The Los Alamos National Laboratory's *Sustainability Design Guide* provides an example of a *thermal test facility*, which is an open-plan laboratory building designed using a high-performance, whole-building approach. The building is a showcase for integrated energy efficiency features that considerably reduce energy costs. The additional cost of construction for implementing sustainable designs only increased the cost of construction by 4%. The energy costs for the thermal test facility were 63% less than those for other similar buildings built to the *Federal Energy Code* (10CFR435) (U.S. Department of Energy July 9, 2013). The energy cost savings include a 40% reduction in energy consumption and a 30% peak power reduction. Approximately 75% of the lighting needs were met by using daylight (Los Alamos National Laboratory 2002).

## 2.6 SUSTAINABILITY IN THE CONSTRUCTION SECTOR

The Department of Engineering Building Technology Program's *The Energy and Environmental Guidelines for Construction* indicates that to promote the use of sustainable practices at construction jobsites it is important to do the following (U.S. Department of Energy 2008):

- Analyze how runoff during construction is going to affect the site, using storm water management practices such as piping systems, retention ponds, or tanks used after the building is complete.
- Choose products and materials with minimal or no packaging.
- Develop plans for recycling that set goals for recycling or salvaging a minimum of 50% (by weight) of construction, demolition, and land clearing waste from construction sites, and aim for 75%.

- Ensure that the infrastructure for recycling construction and demolition materials is operating at the beginning of projects. Provide an on-site system for collecting and sorting waste for recycling, or for reuse, and monitor the system during all of the phases of the project.
- Incorporate methods for protecting vegetation when designing access roads and parking areas.
- Monitor the amount of waste produced during construction, and compare it with preexisting goals and guidelines.
- Purchase materials in the sizes required, instead of cutting materials to size at jobsites.
- Use methods for clearing and grading sites that lower the impact to the environment as much as possible.

*Sustainable industrial ecology* is another area being explored by members of the manufacturing, construction, and processing industries. Optimal resource consumption is being studied "through a framework that integrates different processes, economic and environmental constraints, and health and safety considerations" (Basu and Van Zyl 2006, p. 299).

Sustainable practices should be incorporated into construction projects during the planning stage, including the selection of more environmentally friendly materials and technologies and the use of construction processes using less toxic materials, consuming less energy, and producing less waste.

In the United States, some of the industries providing materials to the construction industry have implemented sustainable practices. The steel industry has already achieved high levels of sustainability by using over 90% recycled steel. Methods for improving the sustainability of concrete production are being investigated by some firms. The cement industry generates the most carbon dioxide ($CO_2$) per *primary energy input* of any of the industry segments because of the large quantities of limestone consumed during cement production (Amano and Ebihara 2005).

Cement is used in all types of construction, and the article by Basu and Van Zyl (2006) "Industrial Ecology Framework for Achieving Cleaner Production in the Mining and Minerals Industry" mentions numerous studies on how to improve the efficiency of cement production and how to minimize *toxic emissions* from the cement industry. One alternative helping to reduce the greenhouse gas emissions caused by cement production is to use *coal fly ash* or *granulated blast furnace slag* in concrete in place of some of the cement (Los Alamos National Laboratory 2002). The large kilns used to process all of the raw materials, to evaporate the water in the materials, and to *calcine* (heat to a high temperature to drive off water and produce a powder) the carbonate constituents (calcinations) consume 90% of the energy used to produce cement (Naik and Mariconi 2006).

Additional techniques and processes for improving the sustainability of materials used in the construction sector are covered in Chapter 11.

## 2.7 POLLUTION AND WASTE MANAGEMENT

The Chartered Institute of Building in the United Kingdom in their report on sustainability and construction indicates that the starting point for all members of the construction industry who wish to move toward sustainability as a business opportunity is to evaluate their operations in four key areas (Chartered Institute of Building 2004, p. 2):

1. *Energy*: Reduce energy consumption, be more energy efficient, and use renewable energy as well as "alternative technologies."
2. *Materials*: Choose, use, reuse, and recycle materials during design, manufacture, construction, and maintenance.
3. *Pollution*: Produce less toxic materials to reduce water and spatial pollution.
4. *Waste*: Produce as little waste as possible, and recycle more.

*The Energy and the Environmental Guidelines for Construction* written by the U.S. Department of Engineering Building Technology Program mentions that to promote sustainability at construction jobsites it is important to (U.S. Department of Energy 2008, p. 1)

- Document a site's existing natural, historical, and cultural features, and make specific plans to protect them.
- During the design phase, indicate locations for job trailers and equipment.
- Indicate the areas of the site that should be kept free of traffic, equipment, and storage.
- Prohibit clearing of vegetation beyond 40 ft. (4.27 m) from the building perimeter.

## 2.8 GLOBAL ENVIRONMENTAL TREATIES

The implementation of sustainable practices during E&C projects is affected by different drivers, including the requirements in various global treaties. Some of the environmental treaties driving the implementation of sustainable practices are the United Nations Framework Convention on Climate Change (UNFCC) and

- Kyoto Protocol
- Basel Convention
- Rio Declaration
- Stockholm Convention

These UNFCC environmental treaties are discussed in detail in Chapter 5 in Sections 5.2 through 5.7.

## 2.9 FOREIGN GOVERNMENT ENVIRONMENTAL REGULATIONS

Information related to the environmental regulations required in countries throughout the world is available from foreign government agencies and their websites. Examples of some of the government agencies and their environmental regulation websites are as follows:

- Australia: The Department of the Environment and Heritage, http://www.environment.sa.gov.au/
- China: State Environmental Protection Administration, http://english.sepa.gov.cn/
- Egypt: The Ministry of State for Environmental Affairs, http://www.eeaa.gov.eg/English/main/about.asp
- India: The Ministry of the Environment and Forests, http://envfor.nic.in
- Japan: The Ministry of the Environment, http://www/env/go.jp/en/
- Jordan: The Ministry of Municipal and Rural Affairs and the Environment, http://www.environment.gov.jo/main.hmtl
- Kenya: The Ministry of Tourism and Wildlife, http://www.tourism.go.ke/minitry.nsf
- Russia: The Federal Service for Hydrometeorology and Environmental Monitoring, http://www.meteorf.ru/en_default.aspx
- Saudi Arabia: The Meteorology and Environmental Protection Administration, http://www.pme.gov.sa/esoon.as
- United Kingdom: The Department for Environment, Food, and Rural Affairs, http://www.defra.gov.uk/
- United States: Federal and state Environmental Protection Agencies, http//www.epa.gov

In addition, there are numerous laws, guidelines, and documents published by foreign governments, organizations, and agencies pertaining to sustainable development practices, and examples of these are the following:

- Germany: The Waste Disposal Act of 1972, Waste Avoidance and the Waste Management Act of 1986, and Closed Substance Recycle and Waste Management Act of 1986.
- Spain: The Labor Relations and Social Affairs Committee developed a set of recommendations for corporate social responsibility.
- Brazil: The Environmental Crimes Law of 1995 allows executive officers of companies to be sued in criminal courts for not meeting environmental health and safety standards.
- Canada: The Canadian Project Green of 2005 pertains to oil and gas industry, thermal production, electrical generation, mining, and manufacturing.
- Chile: The Clean Production Agreements Environmental Legislation of 1993.
- China: The Division of Development and Construction and the National Committee on Environmental Planning and Coordination (NCEPC).
- France: The Law on Economic Regulations of 2001.

- United Nations: Global Compact.
- The World Business Council for Sustainable Development (WBCSD).
- United Kingdom: The Sustainable Development Policy of 2005.

## 2.10 DOMESTIC ENVIRONMENTAL REGULATIONS

In the United States, the main government agency influencing the implementation of sustainable practices is the Environmental Protection Agency. A majority of the EPA's laws focus on environmental issues, but some of the laws being passed in the twenty-first century directly pertain to sustainability. Chapter 5 includes information about environmental laws and some of the new and pending U.S. sustainability laws impacting the E&C industry.

## 2.11 SUMMARY

This chapter included a discussion of the first countries to incorporate sustainability concepts into their government regulations. It referred to the environmental objectives developed in these countries to incorporate sustainable practices. This chapter explained some of the current drivers changing the environment and making it easier for clients to request sustainable engineering designs and construction operations. To understand why members of some firms have been hesitant to incorporate sustainable practices, this chapter discussed some of the barriers to the implementation of sustainable practices. Both sustainability in the building and construction sectors were mentioned to provide a context for future discussions about these topics in this book.

This chapter also mentioned references to different sources of information on global sustainability requirements and environmental treaties affecting E&C projects, and domestic and foreign environmental regulations.

## 2.12 KEY TERMS

Calcine
Coal fly ash
Dutch environmental value standards
Environmental value standards
Government sustainability objectives
Granulated blast furnace slag
Green companies
Green engineering
Primary energy input
Social responsibility index
Sustainable industrial ecology
Thermal test facility
Toxic emissions
United Nations Framework Convention on Climate Change

## 2.13 DISCUSSION QUESTIONS

2.1 What four areas does the Chartered Institute of Building recommend construction industry members evaluate?

2.2 Discuss the results obtained from the Los Alamos National Laboratory thermal test facility and how the results might influence the use of sustainability in engineering design and construction.

2.3 What are the government agencies providing information on environmental regulations for Japan, the United Kingdom, China, Saudi Arabia, and Russia?

2.4 What are the two types of materials used in the construction industry that already have sustainable alternatives, and what are the alternatives?

2.5 Which agency is responsible for regulating environmental laws in the United States?

2.6 Discuss how if *the Energy and Environmental Guidelines for Construction* were followed they would help increase the sustainability of construction operations.

2.7 Of the drivers listed for implementing sustainable development practices, which ones have the most influence and why?

2.8 Discuss the major barriers to implementing sustainable practices.

2.9 Which country was one of the first to adopt sustainable development objectives, and what do their objectives focus on?

2.10 What are the four major global environmental treaties and conventions responsible for the initial emphasis on sustainability?

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# 3 Sustainability Issues in the Engineering and Construction Industry

In order to help foster an understanding of the importance of sustainability practices in the engineering and construction (E&C) industry, this chapter covers a variety of sustainability related issues. It reaffirms some of the obstacles to the implementation of sustainable practices mentioned in the previous chapters and introduces sustainability *global reporting initiatives*. In addition, the social and community impacts of E&C projects are examined along with responsible supply chains and procurement practices. Resource efficiency is also addressed by examining methods for reducing energy consumption during construction. The mining, metals, and mineral industry and the oil and gas industry are briefly discussed at the end of this chapter. This chapter only touches on renewable energy since this topic is covered in Chapter 13 in Sections 13.5 through 13.17.

## 3.1 OBSTACLES TO THE IMPLEMENTATION OF SUSTAINABLE DEVELOPMENT PRACTICES

In England, a study by Williams and Dair (2007) outlined 12 major obstacles to implementing sustainable practices, and they are listed in Table 3.1. These obstacles represent a common theme—the involvement of clients or stakeholders in the decision to implement sustainable development practices. Even though engineers and constructors design and build sustainable structures, it is the clients, or stakeholders, who request that sustainable alternatives be integrated into their structures. If clients do not understand the long-term benefits of sustainable alternatives, they are not willing to integrate them into their projects. Chapter 6 addresses the life-cycle cost assessment techniques available to help demonstrate to clients and stakeholders the monetary, social, and environmental benefits of integrating sustainable practices.

The 12 obstacles to implementing sustainable practices listed in Table 3.1 cover two categories: (1) those a client is able to influence and (2) those a client is not able to influence. To overcome the obstacles listed in Table 3.1, all of the parties working on a project should be involved during the design stage, owners should be knowledgeable about sustainable practices and be empowered to make decisions related to the use of sustainable practices.

One example, provided by Donald McFadden, on how the information in Table 3.1 is used to explain to clients why sustainable practices should be incorporated into engineering or construction projects is the following.

**TABLE 3.1**
**Obstacles to the Implementation of Sustainability Practices in England**

| | Barriers to Implementing Sustainability Practices | Incidence of Barriers |
|---|---|---|
| 1 | Sustainability measures were not considered by stakeholders | By far the most commonly recorded barrier |
| 2 | Sustainability measures were not required by clients (includes purchasers, tenants, and end users) | Commonly recorded |
| 3 | Stakeholders had no power to enforce or require sustainable measures (in some cases, it was the responsibility of clients or contractors) | Commonly recorded |
| 4 | One sustainability measure was forgone to achieve another (traded) | Commonly recorded |
| 5 | Sustainable measures were restricted, or not allowed, by regulators | Commonly recorded |
| 6 | Sustainability measures cost too much (in some cases, the investor would not fund them) | Commonly recorded |
| 7 | Site conditions mitigated against the use of sustainable measures | Commonly recorded |
| 8 | Inadequate, untested, or unreliable sustainable materials, products, or systems (including long-term management problems) | Commonly recorded |
| 9 | Sustainable measures were not available | Commonly recorded |
| 10 | An unsustainable measure was allowed by the regulator or statutory undertaker (so there is no impetus for a sustainable alternative to be used) | Infrequently recorded |
| 11 | Stakeholder was not included, or was included too late, in the development process to implement sustainability measures | Infrequently recorded |
| 12 | Stakeholders lacked information, were unaware, or lacked expertise to achieve sustainable measures | Infrequently recorded |

*Source:* Modified from Williams, K., and C. Dair, *J. of Sustainable Development*, 15(9), 135–147, 2007.

First address the three most common obstacles: (1) client did not know, (2) client did not require, or (3) client had no power to enforce (do not delegate to the architect, engineer, or contractor) the use of sustainable practices that the client is able to control. Next, engage the client—the project sponsor—at the inception of the project, and educate him or her about sustainability, the application of sustainable practices, the costs and benefits of integrating sustainable practices, and encourage him or her to perform an active role in the project.

Provide the client with a cost/benefit analysis explaining how sustainable design and construction techniques affect construction costs and the long-term savings realized by building sustainably in operations, maintenance, energy use, and tax credits (where available). Arrange a guided tour of a sustainable structure for the owner, architect, engineer, and contractor where they are able to view firsthand the advantages of sustainable construction. For instance, the advantage of a louvered window system allowing natural light into the structure, the use of solar voltaic arrays to help reduce energy costs, and a green roof used as an employee break area, all of which demonstrate to the client the benefits of a sustainable structure.

Explain to the client the marketing advantages of the social responsibility of sustainable design and construction. Use data from the Dow Jones Sustainability Group

Index (DJSGI) to indicate that there are societal trends toward sustainability and these trends are directly linked to corporate profitability.

Encourage the client to review the bidding process, and specify in the solicitation the inclusion of sustainable practices. For buildings, this would include a benchmark standard that the project needs to achieve such as Leadership in Energy and Environmental Design (LEED) gold certification. Encourage the inclusion of contract clauses to ensure LEED gold certification.

Explain the limitations, where applicable, and barriers outside the control of the client, such as what sustainable practices are not possible because of regulations or expense, or where technologies and materials are untested or unreliable.

## 3.2 SUSTAINABILITY GLOBAL REPORTING INITIATIVES

The most commonly recorded obstacle according to Williams and Dair (2007) to implementing sustainable practices is stakeholders; therefore, stakeholders could provide the impetus for firms to consider implementing sustainable practices. To address this issue global reporting initiatives were first introduced in 1997, and they include globally applicable guidelines on how to report sustainability achievements (Global Reporting Initiative 2000 2006; PriceWaterhouseCoopers 2004).

Sustainability reporting is performed using a voluntary process to summarize environmental performance on a diverse range of sustainability issues. Global reporting initiatives help members of companies to “quantify current impacts, formulate targets for development, and communicate with customers, communities, governments, financial markets, and other stakeholders about sustainability issues” (Andrews and Slater 2002, p. 87). Global reporting initiatives “are not a substitute for legally mandated reporting or disclosure requirements; they do not override legislative or regulatory requirements. The aim of global reporting initiative guidelines is to assist reporting organizations and their stakeholders in articulating and understanding the contributions these organizations make to sustainable development” (PriceWaterhouseCoopers 2004, p. 5). Global reporting initiatives are used to inform stakeholders about the environmental accomplishments of a company, and this allows stakeholders to make more informed decisions.

For example, in the energy utility industry some companies use their earlier experience with environmental reporting, which includes reporting harmful effects on the environment, to prepare sustainability reports. Many global reporting initiative reports are formulated based on the *Sustainability Reporting Guidelines* released in June 2000 (Global Reporting Initiative 2000 2006). Global reporting initiatives were developed by members of several international organizations such as the Coalition for Environmentally Responsible Economies (CERES), the United Nations Environment Programme (UNEP), private companies, government agencies, nongovernmental agencies (nongovernmental organizations [NGOs]), and members of academia (PriceWaterhouseCoopers 2004).

In the early 2000s, over 2000 companies throughout the world, including over one-third of the 250 largest companies listed in the global reporting initiative, issued numerous environmental reports (Andrews and Slater 2002). Table 3.2 provides the status of some of the firms included in the DJSGI and whether they have published

**TABLE 3.2**
**Dow Jones Sustainability Group Index and Sustainability Development Reports (as of March 2012)**

| Company Name | DJSGI | SDR |
|---|---|---|
| 3M | Y | Y |
| Abbrott | Y | Y |
| AES Corporation | N | N |
| Air Products and Chemicals, Inc. | N | Y |
| Alcoa | Y | Y |
| Amgen, Inc. | Y | N |
| Anheuser-Busch Companies, Inc. | N | N |
| Aramco Services Company | N | N |
| BHP Billiton | Y | Y |
| Biogen Idec, Inc. | N | N |
| BP America, Inc. | N | Y |
| Cargill, Inc. | N | Y |
| Chevron | N | Y |
| CITGO Petroleum Corporation | N | N |
| Codelco-Chile | N | Y |
| ConocoPhillips | Y | Y |
| Dow Chemical Company | Y | Y |
| DuPont | N | Y |
| Eastman Chemical Company | N | Y |
| Eli Lilly and Company | N | Y |
| ExxonMobil Corporation | N | Y |
| GM Corporation | N | Y |
| GlaxoSmithKline | Y | Y |
| Intel Corporation | Y | Y |
| International Paper | N | Y |
| Kaiser Permanente | N | N |
| Kraft Foods | Y | N |
| Marathon Oil Corporation | N | Y |
| NOVA Chemicals Corporation | N | Y |
| Ontario Power Generation | N | Y |
| Petroleo Brasileiro S/A–Petrobras | Y | Y |
| Praxair, Inc. | Y | Y |
| The Procter and Gamble Company | Y | Y |
| Progress Energy, Inc. | N | Y |
| Rohm and Haas Company | N | Y |
| Sasol Technology | N | Y |
| Shell Oil Company (Royal Dutch Shell) | Y | Y |
| Smithsonian Institute | N | N |
| Solutia, Inc. | N | Y |
| Southern Company | N | Y |

(*Continued*)

**TABLE 3.2 (*Continued*)**
**Dow Jones Sustainability Group Index and Sustainability Development Reports (as of March 2012)**

| Company Name | DJSGI | SDR |
|---|---|---|
| Sunoco, Inc. | N | Y |
| Tyson Foods, Inc. | N | Y |
| United States Steel | N | Y |

*Source:* Adapted from RobecoSAM, *Dow Jones Sustainability Indices—Group Index*, Zurich, Switzerland, Accessed on January 10, 2013, http://www.sustainability-indexes.com, 2012.

a *sustainability development report* (SDR). The DJSGI is a group of investment instruments including firms whose operations integrate sustainable practices.

The United Nations International Declaration on Cleaner Production was signed by members of over 1000 organizations, including government agencies, private firms, business associations, non-governmental organizations, academic institutions, professional societies, and international agencies (Basu and Van Zyl 2006). The most important elements of management involvement identified in this document are the following (Basu and Van Zyl 2006, p. 302):

- Corporate commitment
- Environmental cost accounting to identify and monitor total environmental costs in parallel with other costs facing the operation
- Integrating environmental management systems with general corporate management systems
- Selecting a core team with detailed knowledge covering all the business units, which could, in turn, involve the entire workforce
- Structured and proven methodology for implementing cleaner production, including assessment of environmental benefits and cost savings as well as communicating these assessments

The results of a survey conducted in 2007 by McKinsey and Company included responses from 391 chief executive officers (CEOs) from around the world who work for firms participating in the United Nations Global Compact, and the survey indicated the following (Sullivan 2008, p. 55):

- 95%: CEOs who said the society has greater sustainability expectations than it did 5 years ago
- 90%: CEOs who said they are doing more than they did 5 years ago to incorporate environmental, social, and governance issues into their core strategies
- 72%: CEOs who said companies should incorporate a stance on environmental, social, and governance issues in strategies and operations
- 50%: Executives who said their companies actually do incorporate such a stance

### 3.2.1 GLOBAL REPORTING PROFILES

When generating global sustainability reports, members of firms should include the following information (PriceWaterhouseCoopers 2001, p.1):

- Assurance policies and practices including management systems, processes, audits, and management reviews to ensure accuracy, reliability, and completeness
- Criteria/definitions used for accounting for, and measuring, sustainability costs and benefits
- Decisions on the application of global reporting initiative principles
- Means by which users could obtain additional information including country, region, or facility-specific information
- Policy and practice for independent assurance/verification of reports and actions contained therein (i.e., did they do what they said they did?)
- Significant changes in measurement methods

### 3.2.2 CORPORATE STRUCTURE GOVERNANCE

When a firm is planning to develop a global reporting initiative, its members should first identify the following (PriceWaterhouseCoopers 2001, p. 1):

- Linkages between executive compensation and achievement of sustainability objectives
- Major committees of the board that have responsibility for setting corporate strategy and that have oversight responsibilities, and the process used to determine their competencies to provide input on sustainability strategy
- Mechanisms for minority shareholders to provide opinions and input to management and the board
- Mission and value statements, guiding principles, core values, codes of conduct/ethics, policies relevant to sustainability performance, and status of implementation
- Organizational structure of the groups assigned primary responsibility for sustainability governance, and their alignment with strategy and policy, objectives, and identified risks
- The board-level processes for identification and management of enterprise-wide risks and opportunities
- The percentage of board members who are independent, nonexecutive directors

### 3.2.3 CONTENTS OF GLOBAL SUSTAINABILITY REPORTS

According to the Global Sustainability Reporting Guidelines in the global reporting initiative, the following should be included in sustainability reports (PriceWaterhouseCoopers 2001, p.1):

- Approach to managing indirect sustainability impacts resulting from its activities

- Decisions regarding opening or closing of new plants and expansions/contractions
- Externally developed, voluntary economic, environmental, and social charters, sets of principles, or other initiatives that the organization subscribes to or endorses
- Management systems, programs, and procedures, including planning, implementation, checking, and acting elements for continuous oversight and improvements in sustainability performance
- Memberships in industry associations and national/international advocacy groups
- Registration or certification of sustainability management systems, such as International Organization for Standardization (ISO) 14001; Occupational Health and Safety Advisory Services (OHSAS) 18,001; and Social Accountability International 8,000
- *Supply chain management*, as it pertains to outsourcing and supplier sustainability performance, and product and service stewardship initiatives
- The organization's approach to enterprise-wide risk management, including the application of the precautionary principle

Global sustainability reports usually provide information that is matched against company objectives, licensing requirements, or other relevant industry statistics (PriceWaterhouseCoopers 2004). Firms may also include performance evaluations for their subcontractors and vendors in global sustainability reports.

### 3.2.4 CORE SUSTAINABILITY INDICATORS

*Core sustainability indicators* are items used to measure sustainability achievements. The following are examples of core sustainability indicators (PriceWaterhouseCoopers 2001, p. 1):

- Dates, amounts, and reporting of significant spills of chemicals, oils, and fuels (total number and total volume)
- Direct and indirect energy use by primary source
- Greenhouse gas (GhG) emissions
- Impacts on biodiversity
- Incidents of and fines for noncompliance with international conventions, and national, regional, and local environmental legislation and regulations
- Location and size of land owned, leased, or managed in biodiversity-rich habitats
- Other significant air emissions (oxides of nitrogen, oxides of sulfur, and persistent organic pollutants)
- Percentage of materials used that are waste materials from sources external to the organization
- Percentage of products that are reclaimable and percentage reclaimed
- Significant discharges to water by type
- Significant environmental impacts of principal products and services

- Total amount of waste by type and destination
- Total material used other than water, by type
- Use and amount of emission of ozone-depleting substances (ODSs)
- Water use

### 3.2.5 SOCIAL PERFORMANCE INDICATORS

In global reporting initiatives, there are four areas identified as *key performance indicators* of social performance, and they are (PriceWaterhouseCoopers 2001, p. 1)

1. Human rights
2. Labor practices and decent work
3. Product responsibility
4. Society

One study, "Developing a Framework for Sustainable Development Indicators for the Mining and Minerals Industry," by Azapagic (2004) discusses the importance of having a sustainable mining and mineral industry where specific indicators for metallic construction and industrial minerals are developed that are suitable for some energy minerals. Economic, environmental, social, and integrated indicators are used to detect hot spots and report sustainability and stakeholder involvement. The indicators developed within the framework of having a sustainable mining, metals, and mineral industry are similar to the indicators proposed by the global reporting initiative that allows having identical corporate reports and cross comparisons (Azapagic 2004).

## 3.3 SOCIAL AND COMMUNITY IMPACTS OF CONSTRUCTION PROJECTS

During the construction of projects, there are *social and community impacts* negatively affecting the area surrounding construction project jobsites. According to Gilchrist and Allouche (2005, p. 91) in the article "Quantification of Social Costs Associated with Construction Projects: State-of-the-Art Review," the "types of adverse impacts associated with construction activities are grouped under four headings: traffic, economic activities, air and water pollution, and damage to the physical environment. Potential impacts as a result of unregulated construction activities include: traffic congestion and delays, disruption of economic activities, excessive generation of pollution and pollutants, damage to sensitive ecosystems, and damage to existing structures and infrastructure systems." Table 3.3 shows a breakdown of potential impacts and the *social cost indicators* associated with construction activities.

A social cost indicator is defined by Gilhchrist and Allouche (2005, p. 91) as a "measurable cost that could be quantified in monetary terms and is a result of

**TABLE 3.3**
**Impacts and Social Cost Indicators Related to Construction Projects in Urban Environments**

| Traffic | Economic Activities | Pollution | Ecological/Social Health |
|---|---|---|---|
| Prolonged closure of roads | Loss of income | Noise | Surface/subsurface disruption |
| Detours | Productivity reduction | Dust | Damage to recreational facilities |
| Utility cuts | Loss of tax revenue | Vibration | Treating compromised physical and/or mental health |
| Loss of parking spaces | Property damage | Air and water pollution | Reduced quality of life |
| Additional fuel consumption | Loss of income | Air pollution | Restoration cost |
| Travel delays | Loss of income | Air pollution | Reduced quality of life |
| Increased traffic accident rate | Injuries and loss of life | Runoff of toxic materials from damaged vehicles | Reduced quality of life |
| Accelerated deterioration of roads | Production reduction | Production of replacement materials | Restoration costs |
| Road rage | Production reduction | Air pollution | Reduced quality of life |

*Source:* Adapted from Gilchrist, A., and N. Allouche, *J. of Tunneling and Underground Space Technol.*, 20(2), 12–16, 89–104, 2005.

one or more construction-related adverse impacts on the environment surrounding a construction site. When applying *valuation method*(s) to quantify a given social cost indicator the contributions of all relevant adverse impacts should be considered. Social cost indicators could be classified into three main groups, namely: traffic, economic activities and ecological/social/health systems." The following are valuation methods for adverse impacts and social cost indicators (Gilchrist and Allouche 2005, pp. 89–103):

- Contingent valuation technique
- Hedonic pricing
- Human capital
- Lane closure cost
- Loss of productivity (LOP)
- Replacement cost
- User delay cost

### 3.3.1 CALCULATING THE LOSS OF PRODUCTIVITY DUE TO ADJACENT CONSTRUCTION PROJECTS

The area surrounding construction projects may be negatively impacted by construction activities, and some of the impacts include the following (Gilchrist and Allouche 2005, p. 93):

- Loss of income
- Productivity reduction
- Property damage
- Reduction in tax revenue

The LOP experienced by employers and employees in the surrounding community due to not being able to perform their assigned work function because of a construction project being built is estimated using Equation 3.1 (Gilchrist and Allouche 2005, p. 97):

$$\text{LOP} = (\text{number of employees affected}) \times (\text{average hourly output dollars per hour}) \times (\text{productivity reduction factor}) \times (\text{project duration in hours}) \tag{3.1}$$

An example of how this formula is used is the following. There are 10 employees working in an area affected by a construction project, and they have an average hourly output of $50.00/hour, the productivity reduction factor is .60 (the productivity of the 10 workers is reduced by 40% during construction), and the construction project lasts for 1 year. For these parameters, the LOP is calculated as follows using Equation 3.1:

$$\text{LOP} = (10 \text{ employees affected by construction}) \times (\text{average hourly output of } \$50.00/\text{hour}) \times (\text{productivity factor of } .60) \times (40 \text{ hour/week} \times 52 \text{ weeks}) = \$624{,}000$$

This indicates that the firm with 10 employees affected by the construction project will sustain a LOP of $624,000 for the year the project is under construction.

### 3.3.2 CALCULATING THE IMPACT ON PROJECT VALUES

The *impact to property values* during a construction project is estimated by including considerations such as "neighborhood accessibility and environmental variables instead of merely considering property market value" (Gilchrist and Allouche 2005, p. 98). Equation 3.2 is used to determine the impact to property values:

$$\text{Impact to property values} = (\text{property variables} + \text{neighborhood and accessibility variables} + \text{environmental variables}) \tag{3.2}$$

### 3.3.3 CALCULATING USER DELAY COSTS

*User delay costs* and *average traffic delay costs* due to construction activities are quantified using a method introduced by Gilchrist and Allouche (2005, p. 101): "User delay cost is a method used to evaluate the total amount of time for delays that the users experience due to reduced speed through construction areas or when traffic demand exceeds capacity due to congestion in the affected areas. A basic estimate of user delay cost utilizes a percentage of the average hourly wage, typically between 33% and 35%, and multiplies it by the average traffic delay (h) and the number of persons impacted. The value attributed to an hour of time depends on its various uses (i.e., work versus leisure)."

User delay costs are calculated using Equation 3.3 (Gilchrist and Allouche 2005, p. 99):

$$\text{Average user delay costs (\$)} = (\text{average number of passengers per car}) \times (\text{average delay per car}) \times (\text{average hourly wages of all persons in the car}) \times (\text{percentage of wage}) \tag{3.3}$$

### 3.3.4 Calculating Average Traffic Delay Costs

The average traffic delay cost is calculated using Equation 3.4 with the project duration, average annual daily traffic value, peak hour factor (*k*), number of passengers per car, and average hourly wage:

$$\text{Average traffic delay cost (\$)} = (\text{average annual daily traffic}) \times (k \text{ factor}) \times (\text{number of passengers per car}) \times (\text{lane closure duration}) \times (\text{average user delay cost in dollars}) \tag{3.4}$$

## 3.4 GLOBAL IMPACTS CAUSED BY CONSTRUCTION PROJECTS

One social concern related to construction projects is the loss of soil and agricultural lands. Land is lost:

1. Through the quarrying and mining of raw materials, since quarrying and mining adds 20% to the global land loss of about 1.5 million ha (4,053,565 acre ft) per year lost to urbanization
2. When creating energy for producing construction materials
3. When energy is consumed during construction projects
4. When forests are used for timber production, as one-third of the forests lost are used for wood for construction projects

Pollution is generated by construction activities when materials are produced for construction and by the construction processes that pollute water and the atmosphere. According to the article "Sustainable Development and the Construction Industry," additional environmental consequences of construction operations are (Spence and Mulligan 1995, p. 280)

- Accumulation of pollutants and GhGs in the atmosphere, leading to local hazards to soils, vegetation, and human health and the threat of global climate change
- Air pollution from the emission of dust fibers and toxic gases such as nitrogen and sulfur oxides during building material production

- Erosion of the global soil base, reducing the world's capacity for food production as populations increase
- Loss of forests and wild lands leading to loss of biodiversity, threat to indigenous cultures, and degradation of slopes and watersheds

In the European Union, the European Commission Enterprise identified three issue areas of concern related to the construction industry, and they are listed in Table 3.4.

One method for addressing sustainability issues during construction projects was introduced by the European Commission and Member States, and it suggests firms should "assess tenders on the basis of the *economically most advantageous tender* (EMAT) [bid estimate] balancing price, quality, and life cycle costs, for which the quality assessment criteria should include sustainability factors" (European Commission Enterprise—Industry Sectors: Construction 2001, p. 1). This approach is a viable approach that is becoming increasingly practical.

In some areas of material or unit specification, this is already practical because industry or trade indices exist that are used to evaluate the sustainable profile of a material or unit by including price, quality, life-cycle costs, quality assessment, and sustainability in a selection analysis. For example, the *seasonal energy efficiency ratio* (SEER) measure the operating efficiency of heating, ventilating, and air-conditioning equipment. The ratio is tied to the heating and cooling output in relationship to a unit of energy consumed. The higher the ratio, the more the output produced by a single unit of energy consumed. The SEER is applied in a cost/benefit analysis against unit purchase price, manufacturer quality (maintenance cost and useful unit life span), and applicable tax credits or rebates. In addition, the reputation of the sustainable production manufacturer might be measured against the corporate social responsibility index.

**TABLE 3.4**
**European Union Sustainability Issues Related to the Construction Industry**

| Issue | Brief Rationale |
|---|---|
| Environmentally friendly construction materials | Fifty percent of all of the materials extracted from the earth are incorporated into construction materials, and they constitute 40% of the energy used in construction and 50% of the waste generated during construction. |
| Energy efficiency in buildings | Forty percent of the energy is consumed during construction, operation, and demolition of facilities, and these processes generate similar amounts of GhG emissions. |
| Construction and demolition waste management | In the European Union, construction and demolition waste constitutes the largest waste stream by weight. |

*Source:* Adapted from European Commission Enterprise—Industry Sectors: Construction, *Proposals for a Response to the Challenge*, European Commission, Brussels, Belgium, 2001.

### 3.4.1 Noise and Particulate Pollution Impacts

One study conducted in Beirut, Lebanon, analyzed construction jobsite noise and particulate impacts on the local community. This study was performed at construction jobsites close to residential neighborhoods. Jobsites were selected where activities were disturbing local residents, especially during periodic construction activities sometimes lasting up to months or even years. In the Lebanese study, one type of disturbance caused by construction was additional traffic—heavy construction equipment—emitting *toxic particulates* into the atmosphere and also causing noise pollution. During the early construction phases, such as the excavation and erection phases, more particulates were released into the air than in the later construction stages (Lebanese Environment and Development Observatory 2007). Another disturbance was the high sound levels emitted by trucks, pile drivers, and the drilling and blasting of rocks. During some construction activities, the noise levels were up to 100 dBA (decibel A weighting) when measured 15 m (16.4 yd) away. Table 3.5 shows some of the average noise levels recorded during the Lebanese study for each construction phase.

### 3.4.2 Ecosystem Encroachment

Another source of community impacts discussed in the Lebanese study is *ecosystem encroachment*, which occurs when the boundaries of a construction project jobsite exceed the limits of the jobsite and damage local ecological systems. In some instances, construction projects are built on farmland, and this also disrupts the ecological systems that existed when the land was being used for agriculture (Lebanese Environment and Development Observatory 2007).

### 3.4.3 Use of Unauthorized Landfills

In some areas, demolition waste is created when an existing structure is removed to build new projects and then the waste is left along roadsides in *unauthorized landfills* that continue to be used during construction. The contents of the unauthorized landfills impact both members of the local community and construction workers if

**TABLE 3.5**
**Noise Levels for Five General Phases in Construction**

| Phase | Noise Level (dBA) at 15 m | Noise Level (dBA) at 30 m |
|---|---|---|
| Ground cleaning | 83 | 77 |
| Excavation | 85 | 79 |
| Foundation | 86 | 80 |
| Erection | 82 | 76 |
| Finishing | 83 | 77 |

*Source:* Adapted from Lebanese Environment and Development Observatory, *Lebanon State of the Environment Report*, Ministry of the Environment, Beirut, Lebanon, 2007.

any of the demolished materials contain toxic chemicals. Examples of toxic materials include *lead*, *chromium*, *asbestos*, and *petroleum products*.

### 3.4.4 ENVIRONMENTAL IMPACTS OF CONSTRUCTION OPERATIONS

Table 3.6 provides a description of some of the environmental impacts of construction during different phases from the report *The Environment in France*, which was written by the French Institute for the Environment (IFEN 1999). Table 3.6 represents industrial, residential, commercial, heavy highway, and building construction environmental impacts.

### 3.4.5 CONSTRUCTION WASTE GENERATION

Waste generated during construction and demolition activities, including the renovation of old buildings, accounts for approximately 32% of all of the waste generated in Western Europe. The generation of construction and demolition waste in Western Europe increased during the 1990s; Table 3.7 contains a breakdown of the main types of construction waste in Western Europe, and Table 3.8 shows the percentage of waste for each construction subcategory (Stenis 2005). In addition to construction waste, there are other areas where waste is generated, including solid, liquid, and airborne waste.

**TABLE 3.6**
**Environmental Impacts of Construction**

| Environmental Impacts | Description | Potential Impacts on Air | Potential Impacts on Water | Potential Impacts on Soil and Cover |
|---|---|---|---|---|
| Extracting raw material | Sand and gravel | Particulate emissions | Watercourses near quarries are altered | Landscape degradation |
| Manufacturing building materials | Material production | Particulate emissions $CO_2$, $SO_x$, and $NO_x$ | Water use to manufacture materials | Consuming new areas of land |
| Construction buildings | Transporting materials and building at sites | $NO_x$ and $CO_2$ emissions | Water pollution to surrounding area | Soil pollution to surrounding area |
| Using buildings | Energy and water consumption, and wear and tear of materials | $CO_2$ emissions and asbestos fibers and indoor radon emissions | Wastewater discharge containing detergents and organic matter | Hazardous materials contaminate the soil |
| Demolishing buildings | Removing materials and rehabilitating the site | Noise and particulate emissions | Runoff could contaminate the local water system | Demolition waste placed in landfills or reused for sea reclamation |

*Source:* Adapted from IFEN, *The Environment in France*, Paris, France: *L'environnement en FranceEdition 1999 (The Environment is France) p. 34,* 1999.

## TABLE 3.7
## Breakdown of Main Waste in Western Europe

| Type of Waste | Weight (t) | Breakdown (%) |
|---|---|---|
| Cast-in-place concrete | 14 | 13.3 |
| Combustible material | 34 | 32.4 |
| Pure gypsum | 12 | 11.4 |
| Scrap iron | 7 | 6.7 |
| Unpainted wood | 2 | 1.9 |
| General waste | 36 | 34.3 |
| Total | 105 | 100.0 |

*Source:* Adapted from Stenis, J., *J. of Waste Manage. Res.*, 23(2), 13–19, 2005.

## TABLE 3.8
## Combined Percentage of Construction Waste in Western Europe

| Subcomponent of Construction Waste | Breakdown (%) |
|---|---|
| Electrical subcontractor | 1 |
| Floor subcontractor | 1 |
| Formwork for cast-in-place concrete | 20 |
| Formwork steel reinforcement | 5 |
| Gypsum wallboard inner walls | 10 |
| Heating and plumbing subcontractor | 1 |
| Larch panel and Minerit [Swedish] material | 30 |
| Mineral wool, wet materials, and spillage | 15 |
| Miscellaneous | 10 |
| Painting subcontractor | 1 |
| Trabeation [gables including gypsum wallboard for facades] | 5 |
| Ventilation subcontractor | 1 |
| Total | 100 |

*Source:* Adapted from Stenis, J., *J. of Waste Manage. Res.*, 23(2), 13–19, 2005.

The origins of waste are as follows (Munier 2005, p. 49):

- Construction
- Hazardous
- Household
- Industry
- Institutional
- Municipal
- Nuclear
- Wastewater treatment plants

The options for dealing with these types of waste include recycling, removing to landfills, incineration, biological treatment, and second use. The least desirable of these processes is incineration. Incinerating waste requires high temperatures, and this consumes energy, converts waste into toxic gases, and might produce toxic fly ash. Other incineration by-products include *particulate matter*, *mercury*, lead, *dioxins*, and *furans*. "Dioxins and furans are a family of chemical polychlorinated compounds created when there is an incomplete combustion of hydrocarbons in the presence of chlorine and they remain in the environment for long periods of time" (Munier 2005, p. 60). Some studies indicate that incinerators also release carcinogenic chemicals from smoke stacks. Another complication of incineration is disposal of fly ash, which might contain heavy metals or be radioactive.

One alternative for disposing of excess inventory of construction materials is to sell them through resellers or websites specializing in the resale of construction materials. Some resellers are approved by the U.S. Green Building Council for up to four LEED points for using their service (Illia 2011).

Members of many countries in the world have adopted the four Rs: (1) reduce consumption, (2) reuse, (3) recover, and (4) recycle. Recommendations on how to implement the four Rs in the United States provided by E&C industry executives are included in Chapter 7.

### 3.4.6 Producing Lower Levels of Waste

In the European Union, a task group was formed that studied construction materials and methods for improving the life-cycle environmental performance of materials. One of their recommendations was to develop life-cycle-inventory-based environmental data schemes. The European Union Committee for Standardization (CEN) Construction Sector Environment Project Group worked with other CEN technical committees to develop guidelines on the life-cycle environmental performance of materials. One recommendation of the task group was to implement codes promoting the following (European Commission Enterprise—Industry Sectors: Construction 2001, p. 1):

- Avoidance of contamination
- No mixing of hazardous/nonhazardous waste, including separate storage and collection
- Selective demolition and/or waste segregation

According to Petkovic et al. (2004, p. 249), "The Norwegian Ministry of Local Government and Regional Development, the ministry responsible for building and housing, published a first generation action plan for 2001–2004." The plan identified low levels of recycling of construction materials; therefore, the government implemented a plan to increase the recycling of construction materials and promote using prefabricated and module-based production. The use of recycled materials was incorporated into Norwegian design codes and building practices. The materials included are as follows (Petkovic et al. 2004, p. 263):

- Asphalt
- Cellular glass

- Lightweight fill materials
- Recycled concrete aggregate
- Shredded tires

Petkovic et al. (2004, p. 264) also indicate "industrial waste consisting of coal combustion residues, steel, and iron slag has limited volume in Norway. Municipal solid waste incinerator ash is not included in the program due to potential labeling as hazardous waste in Norway." In the United States, at the Los Alamos National Laboratory in New Mexico waste minimization strategies were developed to help reduce the generation of construction waste, and they are listed in Table 3.9.

**TABLE 3.9**
**Waste Minimization Strategies**

| Potential Waste Materials | Segregation and Disposal | Reuse or Recycle | Waste Minimization |
|---|---|---|---|
| Asphalt | Stockpile in designated areas.<br>If contaminated, segregate, label, and store in a hazardous waste area.<br>Radioactive waste is stored at approved sites. | Use local recycling facilities.<br>Uncontaminated asphalt may be crushed and utilized as base course material. | Saw cut minimum perimeter of asphalt to be removed per construction drawings.<br>Remove and segregate contaminated asphalts from recyclable (uncontaminated) asphalt. |
| Concrete | Stockpile in designated area.<br>Segregate by hazardous and nonhazardous. | Use local recycling facilities.<br>Uncontaminated concrete may be crushed and used as base course material. | Remove only those areas indicated on the construction drawings.<br>Procure concrete in quantities consistent with the construction drawings and EPA affirmative procurement specifications. |
| Soil | Stockpile in segregated areas.<br>Dispose of in proper landfills—uncontaminated, contaminated, hazardous. | Use local recycling facilities. | Remove per elevations indicated by the construction drawings. |
| Electrical conduit/wire/equipment | Segregate by nonradioactive and radioactive. | Use appropriate recycling facilities. | Remove and segregate reusable conduit and wire from equipment. |
| Wood | Segregate pressure-treated wood from wood that is not pressure treated. | Use designated landfills for regular wood and for pressure-treated wood. | Avoid use of wooden pallets for storage of construction materials.<br>Minimize use of wooden framing and forming materials. |

(*Continued*)

## TABLE 3.9 (*Continued*)
## Waste Minimization Strategies

| Potential Waste Materials | Segregation and Disposal | Reuse or Recycle | Waste Minimization |
|---|---|---|---|
| Paper products | Stockpile | Recycle in local facilities. | Procure construction materials and equipment in bulk to minimize packaging.<br>Remove all possible packaging materials before entering controlled area to prevent generation of radiological waste. |
| Plastic | Stockpile | Recycle in local facilities. | Procure in bulk to minimize packaging.<br>Remove all possible packaging materials before entering controlled area to prevent generation of radiological waste. |
| Metal | Stockpile in designated area, and segregate by hazardous and nonhazardous. | Use a local metal recovery program.<br>Reuse pipe and valves at appropriate facilities. | Remove hazardous constituents from recyclable materials (e.g., lead-soldered wires from metal equipment). |
| Paints, stains, solvents, and sealants | Stockpile and segregate radioactive waste. | Contractor should check with waste management coordinators to see if excess materials may be used at other facilities. | Procure nonhazardous substitutes to traditional solvents, paints, stains, and sealants (green seal products at greenseal.org).<br>Procure only the materials that are needed (just-in-time purchasing).<br>Sequence work to minimize waste generation through material use on successive tasks. |
| Equipment | Stockpile and segregate by hazardous and nonhazardous. | Develop an equipment salvage program or locate a local program. | |

*Source:* Adapted from Los Alamos National Laboratory, *Los Alamos National Laboratory Sustainable Design Guide*, Los Alamos, New Mexico, Accessed January 29, 2015, http://www.lanl.gov/orgs/eng/engstandards/esm/architectural/Sustainable.pdf, 2002.

*Note:* EPA, Environmental Protection Agency.

In addition to minimizing waste, another concern is *soil contamination* caused by a variety of activities, including the following (Munier 2005, p. 126):

- Chemical residues from *herbicides* used on crops.
- Contamination at the bottom of heavily polluted rivers, where it forms a thick sludge.
- Contamination produced by dumping mainly organic waste.
- Deposition on soil of dust removed from filters in smokestacks or petrochemical operations.
- Manure or urine from farm animals.
- Oil or chemical spills.
- Phosphates, nitrogen, and potassium from fertilizers.
- Salt left by water extraction from an aquifer and evaporated by the sun.
- Serious contamination in car scrapyards: after vehicles are crushed and flattened, large amounts of fluids—such as gasoline, oils, grease, brake and transmission fluid, windshield washer fluid etc.—can end up in the soil without adequate safeguards.

## 3.5 RESPONSIBLE SUPPLY CHAINS AND PROCUREMENT PRACTICES

Some firms are requiring vendors and suppliers to sign a statement indicating they will follow the policies of the firm buying their products on "ethics, safety, the environment, and social responsibility or to demonstrate they have a similar company policy," and this is part of supply chain management (Ofori 2000, p. 196).

### 3.5.1 Supply Chain Management

The following are some of the features of implementing supply chain management (Ofori 2000, p. 198):

- Commitment of the supplier to pursue continuous improvement by monitoring technological trends
- Continuous development of the supplier by the customer
- Development of trust among partners, with suppliers taking full responsibility for the quality of their products, leading to the elimination of inspections of supplied products
- Exchange of information on business plans and operations, as well as best practices among the parties
- Inclusion of long-term contracts between parties
- Involvement of suppliers in the customer's product development and design processes
- Reducing the supplier base
- Willingness among the parties to learn more about each other's business operations

## 3.6 RESOURCE EFFICIENCY: REDUCING ENERGY CONSUMPTION DURING CONSTRUCTION

Producing construction materials consumes the highest level of energy of any construction activity. Producing asphalt requires 57% of the total energy, producing cement requires 25%, and the remaining processes consume 18%. Transporting materials requires 15%–30% of the energy used at jobsites (Moroueh et al. 2001). Several strategies are recommended in the article “Sustainable Development and the Construction Industry” (Spence and Mulligan 1995, p. 281) for reducing energy consumption during construction:

- Design for recycling, long life, and adaptability to varying requirements
- Design of low-rise buildings in place of high-rise buildings
- Improved energy efficiency in kiln processes
- Selection of low-energy materials and structural systems
- Selection where possible of waste or recycled materials
- Use of fewer materials
- Use of low-energy additives or extenders
- Use of recycled materials in production processes
- Using cheaper or non-premium fuels in kiln processes

Eight percent to 20% of the pollution emitted in the world is due to construction activities and producing building materials. Approximately 3% of the total emissions occur during the production of cement and lime. The following are some suggestions provided by Spence and Mulligan (1995, p. 283) for helping to reduce atmospheric pollution during construction:

- Improving site management efficiency
- Reducing avoidable transportation of materials
- Reducing the quantity of site waste produced
- Systematic separation of all unavoidable construction waste, to facilitate recycling

Some financial disincentives are being implemented to encourage reductions in pollution caused by construction activities such as the following (Spence and Mulligan 1995, p. 283):

- Carbon taxes
- Fines or charges for pollution
- Increased royalties for timber extraction from forests
- Landfill waste charges
- Mineral extraction taxes

In 2005, the *Strategic Forum for Construction* identified four areas where energy consumption might be reduced at construction jobsites (Strategic Forum 2005):

- Design [for energy reduction]
- More efficient use of heavy construction equipment
- Stockholding [ordering materials in larger quantities to reduce the number of material deliveries to jobsites]
- Transport [use locally sourced materials to reduce transportation distances]

During the design phase, the Strategic Forum (2005, p. 1) recommends

> design professionals need to be more aware of the part they play in ensuring good logistics, particularly at the scheme design stage. Logistics will be greatly helped if the design professionals draw up a Process Map at an early stage in the design. In addition as part of the Logistics Plan for a project, a Bill of Materials should be prepared. This should look at, for example, the flow of materials needed on a project and ways of minimizing stockholding. Which of the professional members of the supply chain should be responsible for this, needs to be discussed, but the quantity surveyors with their background in measurement and costing might have the appropriate skills for this; alternatively it could require the input of logistics specialists. Manufacturers, suppliers and distributors clearly need to make an input to this plan. (Strategic Forum 2005, p. 1)

The Strategic Forum also recommends that

- The Construction Industry Training Board (CITB) construction skills review the need for logistics skills in the industry and recommend what needs to be done to address this.
- Design professionals prepare a process map for each project as part of the scheme design.
- Key manufacturers', suppliers', and distributors' input into the bill of materials should be prepared as part of the logistics plan for each project.
- Main contractors prepare a logistics plan in consultation with the rest of the supply chain at the outset of each project. This plan should include the input to the project from the specialist contractors and the key manufacturers and suppliers.
- Manufacturers, suppliers, and distributors reflect the cost of distribution in their pricing policies.
- Professional institutions consider ways in which the role of their profession in project logistics could be incorporated in initial education and training.
- The professional institutions representing the design professions develop advice and offer briefings to members on the role they have to play in project logistics.
- The professional team needs to prepare a bill of materials as part of the logistics plan. (Strategic Forum 2005 p. 1).

The inadequacy of logistics was one of the areas investigated by the Strategic Forum, and they determined that (*lorries* are trucks) (Strategic Forum 2005, p. 1):

- A high proportion of lorries in the construction industry move around the road network either empty or with part-loads, whereas the retail sector and wider manufacturing industry are continually working to consolidate delivery loads to maximize vehicle fill, and reduce transport costs.

- Many lorries arriving at construction sites have to wait to gain access or be unloaded, whereas retail and other sectors designate time slots for supplier deliveries. Late or early deliveries could be turned away and suppliers charged a penalty.
- In construction, skilled craftsmen are often using their skills for less than 50% of their time on site. Among the unskilled tasks they are involved in are unloading lorries and moving products around the site. Other industrial and retail sectors use special equipment to unload lorries and designated trained teams to deal with material handling activities.
- Construction products are often stored on site for long periods of time and have to be moved to other parts of the site when they are eventually needed. Retailers and those in other industries are continually trying to reduce inventories and at least ensure they are held in the most appropriate location. Effort goes into delivering the right quantities at the right time.
- In construction, specialist contractors sometimes arrive on site when they are not expected or when the job is not ready for them. Good manufacturers would ensure they had the right information flows about work progress to ensure that this never happened.
- There continues to be much secondary working on site, whereas other industrial sectors make every effort to get it right the first time and avoid multiple handling.
- In construction, there would appear to be a much higher proportion of damaged and waste products removed from the site than in other sectors.
- There is little formal training in logistics and yet there are a large number of tasks that fall within a logistics umbrella. In many other sectors, training in logistics skills is given much greater priority and some employ those with degrees in the subject.

## 3.7 RENEWABLE ENERGY

One impediment to using renewable energy sources on construction projects is the short duration of projects. Another one is that the capital investment required to provide alternative renewable energy sources during construction prohibits firms from being awarded competitive bids. Renewable energy sources are used successfully in other industries, such as the wind turbines and solar panels used on oil production platforms in the North Sea, but these are stationary projects of a longer duration than typical construction projects.

Construction firms might purchase energy from renewable energy sources, but the cost of the energy created by renewable energy technology is normally higher than the cost of energy from traditional energy sources. Some construction firms incorporate renewable energy into projects, but whether they use it or not depends on the local pricing structure where a project is being built.

*Biofuel*, such as *ethanol*, is an alternative source of energy used for powering heavy construction equipment, but biofuel is only used where there are reliable sources for obtaining it. The *total carbon emissions* required to clear the land, grow corn for the ethanol, fertilize the crops, process the corn into ethanol, and transport the ethanol create twice the *carbon footprint* of gasoline (Begley 2008). Biofuel and other alternative sources of energy are discussed in detail in Chapter 13 in Sections 13.5 through 13.17. Another alternative energy option is achieved when using hybrid-electric construction equipment, and this topic is covered in Chapter 12 in Section 12.8.

## 3.8 MINING, METALS, AND MINERALS INDUSTRY

The impact of the construction sector on the environment occurs during all of the stages of construction from the mining of raw materials (quarry, operation, and cement production) to the construction of structures (noise, dust, and the generation of hazardous materials), as well as to the operation of facilities (the disposal of wastewater, energy consumption, and toxic emissions).

This section addresses the impact on the environment that occurs during mining operations. In the mining and minerals industry, sustainable development is divided into three levels:

1. Operational
2. Corporate/firm wide
3. Global/macroscale

To implement industrial ecology practices in the mining, metals, and minerals industry, members of firms become involved in the following (Basu and Van Zyl 2006, p. 301):

- Evaluating energy use and efficiency and renewable energy sources
- Examining material flows
- Measuring GhG emissions
- Performing a life-cycle analysis of products, including recycling and remanufacturing
- Performing earth systems engineering
- Reviewing the grand cycles of nitrogen, carbon, and other chemicals

For the mining, metals, and minerals industry to continue to operate in a sustainable manner, members of the industry have the option of adopting new strategies for the extraction and processing of minerals, especially the rare earth minerals used in various products in the United States. Some of the products requiring rare earth minerals are listed in Table 3.10.

Half the rare earth minerals are extracted from mining operations in China because the toxic nature of the extraction process results in strip-scarred and toxic reservoirs containing radioactive wastewater. Due to environmental regulations in the United States, many of the rare earth mines closed down in the 1970s. In 2010, one of the rare earth mines was reopened in the United States at a cost of $500 million to clean up the mine and additional costs were incurred to recycle the wastewater produced at the mine to generate *hydrochloric acid* and *sodium hydroxide*, which is required during the separation process for rare earth minerals. New processes have been developed for reducing water consumption at the mine to 10% of the amount

**TABLE 3.10**
**Products Requiring Rare Earth Minerals**

| Rare Earth Mineral | Smart phones | Wind Turbines | Hybrid Vehicles | Fiber Optics | Energy-Efficient Lightbulbs | Televisions |
|---|---|---|---|---|---|---|
| Dysprosium | × | × | × | | | |
| Neodymium | × | × | × | | | |
| Praseodymium | × | × | × | | | |
| Samarium | × | | | | | |
| Terbium | × | × | | × | × | × |
| Erbium | | | | × | | |
| Europium | | | | × | × | × |
| Yttrium | | | | × | × | |

of water required when the mine was operating in the 1970s. Additional rare earth mines might also be reopened in the future in the United States that use newer, more sustainable extraction processes.

## 3.9 OIL AND GAS INDUSTRY

One example of the type of issues examined for firms to provide sustainable alternatives to existing practices occurs in the oil and gas industry. All types of construction projects rely on oil products to conduct operations, and as part of sustainability assessments the environmental degradation caused by the extraction of oil and gas should be included in evaluations. The oil and gas industry has been developing new techniques for reducing the environmental consequences of their operations, and one successful technique is being applied during well-injection processes. The discharge of wastewater during the drilling process is a major area of concern to industry personnel because it creates waste that has to be cleaned before it is discharged into other bodies of water such as the sea. The types of water resulting from drilling processes are formation water, *brine* (salt water), injection water, and other technological waters.

When oil and gas are extracted, formation water and brine are also extracted. Each well requires hundreds of thousands of gallons of water to maintain adequate pressure in the system and for pushing the hydrocarbons up to the surface of the well. For each well, the drilling waste range is from 1 million $m^3$ to 15 million $m^3$ (1,307,000–1,962,000 $yd^3$). For each production platform, there may be dozens of wells and there may be hundreds for large drilling fields. The water used for these processes becomes polluted with oil, natural *low-molecular-weight hydrocarbons*, *inorganic salts*, and technological chemicals. Traditionally, separation units are used to remove oil from these waters. To remove drilling waste, a method is used that reinjects the slurry into geological formations and slim hole–drilling processes are also used to reduce discharges in environmentally sensitive areas (Patin 1997). Figure 3.1 is a photograph showing a small section of the

**FIGURE 3.1** Photograph of a small section of an oil refinery. (Courtesy of J. K. Yates.)

piping required for an oil refinery that processes oil extracted from beneath the surface of the Earth.

Additional information on petroleum products as an energy source is provided in Chapter 13 in Section 13.1.

## 3.10 SUMMARY

This chapter discussed the obstacles for implementing sustainable practices to highlight why it is still difficult to incorporate sustainable practices into engineering designs and construction operations. This chapter also explained how Global reporting initiatives are used worldwide to provide detailed information on the sustainable practices of firms, what is provided in global reporting profiles, corporate structure governance, core sustainability indicators, and the areas that are key performance indicators of social performance. This chapter also provided information on the Dow Jones Sustainability Group Index and included a list of some of the firms listed in this index.

The information provided in this chapter on the social and community impacts of construction projects included methods for calculating the LOP due to adjacent construction projects and user delay costs. Global impacts caused by construction projects were discussed in this chapter, including noise and particulate pollution impacts, ecosystem encroachment, use of unauthorized landfills, environmental impact of construction operations, construction waste generation, and information on producing lower levels of waste.

This chapter included information on responsible supply chains and procurement practices, resource efficiency, and reducing energy consumption during construction. It introduced renewable energy sources, which are discussed in more detail in Chapter 13.

The last part of the chapter explored the environmental impact of production operations for construction materials and included information on sustainability issues in the mining, metals, and mineral and oil and gas production industries.

## 3.11 KEY TERMS

Asbestos
Average traffic delay costs
Biofuels
Brine
Carbon footprint
Chromium
Coalition for Environmentally Responsible Economies
Core sustainability indicators
Dioxins
Ecological systems
Economically most advantageous tender
Ecosystem encroachment
Ethanol
Furans
Global reporting initiatives
Herbicides
Hydrochloric acid
Impact to property values
Inorganic salts
Key performance indicators
Lead
Lorries
Loss of productivity
Low-molecular-weight hydrocarbons
Mercury
Nitrogen
Particulate matter
Petroleum products
Phosphates
Potassium
Social and community impacts
Seasonal energy efficiency ratio
Social cost indicator
Sodium hydroxide
Soil contamination
Strategic Forum for Construction

Supply chain management
Sustainability development report
Sustainability Reporting Guidelines
Total carbon emissions
Toxic particulates
Unauthorized landfills
United Nations Environment Programme
User delay costs
Valuation method

## 3.12 DISCUSSION QUESTIONS

3.1 Discuss what types of information should be included in global sustainability reports.
3.2 Explain how a firm could be listed on the Dow Jones Sustainability Group Index and not have an sustainability development report.
3.3 Explain why incineration is one of the least desirable methods for waste disposal.
3.4 Discuss how industrial ecology practices are implemented in the mining, metals, and minerals industry.
3.5 Discuss the adverse impacts of unregulated construction operations.
3.6 Discuss the four ways land is lost due to construction projects.
3.7 What are the three issue areas of concern related to the construction industry according to the European Commission Enterprise?
3.8 Discuss whether the European Commission's and member states' suggestion on how to address sustainability issues during construction projects is viable, and explain why or why not.
3.9 Explain ecosystem encroachment and how it occurs during construction projects.
3.10 What is the main type of waste generated during construction projects in Western Europe?
3.11 Which types of waste are included in the Los Alamos National Laboratory Sustainable Design Guideline's waste minimization strategies?
3.12 When explaining to a client why sustainable practices should be incorporated into an E&C project, how could the information listed in Table 3.1—Obstacles to Implementing Sustainable Practices—be used in the explanation?
3.13 In addition to construction waste, what are the origins of other waste?
3.14 What are the four key performance indicators of social performance according to the global reporting inititive?
3.15 Explain the difference between core sustainability indicators and sustainable practices?
3.16 Discuss the issues of concern related to the extraction of oil and gas products from the earth.

3.17 Discuss the benefits of using supply chain management in the construction industry.
3.18 Discuss the strategies for reducing energy consumption during construction according to Spence and Mulligan.
3.19 What are global reporting initiatives?
3.20 Discuss the five social impacts of construction projects on surrounding communities.
3.21 What general methods are used throughout the world to encourage reductions in pollution caused by construction activities?
3.22 What are the four phases of life-cycle assessments?
3.23 Explain why it is difficult for construction projects to incorporate renewable energy sources into the energy used at construction jobsites.
3.24 Define social cost indicators and provide examples.
3.25 Discuss the dangers associated with using unauthorized landfills during construction projects.
3.26 Explain how to calculate average user delay costs and average traffic delay costs.
3.27 Discuss the different methods for the remediation of hazardous substances at potential construction sites.
3.28 Discuss why some firms use global reporting initiatves.
3.29 Explain why the extraction of rare earth minerals decreased in the United States.
3.30 Explain how to calculate LOP caused by construction operations.

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# 4 Sustainable Engineering Design

## 4.1 INTRODUCTION

According to the article "Environmental Process Engineering: Building Capacity for Sustainability" (Libra 2007, p. 312), 60%–80% "of the overall product costs, as well as a product's environmental impact are determined during the design phase"; therefore, this chapter introduces some of the design considerations affecting the sustainability of projects. This chapter includes information on the types of sustainable elements available for incorporation into designs. Designing for *passive survivability* is explained along with the similarity between passive survivability and sustainable designs. The criteria for sustainable site selection are discussed and so are the options of selecting green-, gray-, or brownfield sites. The requirements for *sustainable landscapes* are explained, and the processes required for designing *storm water management* systems are also introduced in this chapter. Methods for evaluating sustainable process alternatives are mentioned, as well as procedures for designing for the use of sustainable materials. One major element of design is ensuring that designs incorporate the principles and strategies of designing for *disassembly*, and suggestions are outlined in this chapter for this process. The *International Organization for Standardization* (ISO) 14000 series of standards for environmental management discussed to show how they interrelate with sustainable engineering designs and construction operations.

## 4.2 DESIGN ELEMENTS THAT ENHANCE SUSTAINABILITY

Several design elements are available for incorporation into structures during the design stage that enhance the sustainability of a project, such as (Kibert 2008):

- Electrical power systems including lighting systems and electric motors
- Energy optimization strategies including *radiant cooling* [temperature-controlled surface that cools indoor temperatures by removing the heat being sensed and where more than half of the heat transfer occurs through thermal radiation], *ground coupling* [underground heat exchanger that captures heat or dissipates heat to the ground], and *ground source heat pumps* [central heating and/or cooling system that transfers heat to or from the ground]
- Mechanical systems including chillers, air distribution systems, and energy recovery systems

- Plug load reduction [the devices plugged into electrical outlets]
- Renewable energy sources
- Replacing ozone-depleting chemicals such as *hydrochlorofluorocarbon* (HCFC) *refrigerants* [refrigerants used in air-conditioning systems] and *halon* replacement in fire protection systems
- Roof selection [thermal resistance and color]
- Ventilation air and carbon dioxide sensors
- Wall systems
- Water heating systems
- Windows [double pane, thermal pane, and *argon*, which is the third noble gas in period 8 used between window panes to help reduce frost on the bottom of windows and to increase soundproofing qualities]

Another area where designers are able to specify sustainable alternatives is plumbing fixtures. The Energy Policy Act of 1992 requires all plumbing fixtures to meet targets for reducing water consumption, and building codes mandate lower levels of water consumption. *Gray water* systems process the nonhuman part of wastewater, which is collected and reused for landscape irrigation.

### 4.2.1 SUSTAINABLE DESIGN ELEMENTS

Architects and engineers consider a variety of sustainable elements when they are designing structures, and some of the sustainability elements considered are the following (Langston and Ding 2001, p. 237):

- Alternatives for storm water runoff
- Carpeting versus other types of flooring
- Cogeneration power
- *Eco labeled products* [help identify products and services with a reduced environmental impact throughout their life cycle]
- Energy-efficient appliances
- Engineered lumber
- Natural ventilation, daylighting, *energy-efficient artificial light*, lighting controls, and lighting design
- Reduced energy use
- *Space conditioning* [provides heating or cooling within spaces and may use components such as chillers and compressors; fluid distribution systems including air ducts, water piping, and refrigerant piping; pumps and air handlers; cooling and heating coils; air- or water-cooled condensers; economizers; and associated controls]
- Sustainable fabrics
- Sustainable materials
- *Visual impact*
- Waste management

Archtieects and engineering designers should also be cognizant of the options related to *thermal comfort control* including insulation, passive solar heating, *thermal mass heating* (using the structure to provide passive heating), landscaping for energy efficiency, passive cooling, natural ventilation, and active heating and cooling systems such as centralized air and heat, and windows.

Three design elements helping to improve the sustainability of a structure are (1) renewable energy, (2) sustainable materials, and (3) cogeneration heating systems. Each of these items has an element of energy consumption as a component, and energy reduction is a major part of sustainable designs. Energy is required at the point of material extraction; for the production of materials; when transporting materials; and during construction, operations, maintenance, and disposal. In addition, in the United States reducing energy consumption was a key element of the 2010 *National Security Strategy*, and this is where embodied energy considerations play an important role (White House 2010).

One technique for reducing energy consumption is using natural lighting and louvered systems to deflect direct sunlight in the summer and allow direct sunlight into a structure during the winter. Fiber-optic cables are used to transmit natural light to areas of buildings requiring minimal lighting. Another energy reduction technique is using timers and sensors on lighting systems to turn on the lighting systems only when they are required and turn them off when there are no occupants in the structure or a room. Heating, ventilating, and air-conditioning (HVAC) systems should have the highest *seasonal energy efficiency ratio* (SEER) possible. Energy-efficient appliances should be specified based on their Energy Star rating. In some areas, using Energy Star appliances results in tax rebates and tax credits. Energy Star ratings are applicable to more than appliances as they also apply to HVAC systems, doors and windows, biomass stoves, insulation, hot water heaters, geothermal heat pumps, residential wind turbines, solar energy systems, and fuel cells.

Structured approaches for including sustainability considerations during design are listed in Chapter 7 in Section 7.10. Information on designs, construction components, and practices with sustainable components is provided in Section 7.11. Additional recommendations on incorporating sustainable design practices from engineering and construction (E&C) industry executives are summarized in Section 7.12.

The following are suggestions for reducing the energy consumed by buildings (Munier 2005, p. 204):

- Double glazed windows
- Employing central air-conditioning units operated with natural gas
- Extra insulation in ceilings
- Installing sensors in hallways that switch on lights when needed
- Purification plants in basements where wastewater is treated and reused for flushing toilets and for garden irrigation
- Tanks for storing storm water for later use
- Using high-efficiency appliances and boilers [water heaters]

- Using natural gas instead of oil or electricity in kitchen appliances
- Utilizing photovoltaic panels on the roof and in walls exposed to the sun's rays to generate electricity from the sun
- Ventilation systems with heat recovery

Additional suggestions for reducing energy consumption provided by E&C industry executives are listed in Chapter 7 in Section 7.14.

Cogeneration, defined as *combined heat and power*, is a single process for the generation of heat and power from the output of steam. Cogeneration systems process the energy normally lost (on average, 65% is lost) in the production of electricity through advanced technology into usable energy. This approach is 90% efficient as opposed to the 30%–40% efficiency obtained in conventional energy production. Additional details on combined heat and power systems are provided in Chapter 13 in Section 13.6.

### 4.2.2 Passive Survivability

Another sustainability design consideration is designing for passive survivability in buildings. The intent of passive survivability is to ensure a safe environment in the event of severe weather events, electrical power grid failures, or terrorist attacks. Passive survivability designs consider cooling load avoidance, capabilities for natural ventilation, high-efficiency *thermal envelopes* (physical separators between the conditioned and unconditioned environments of a building including the resistance to air, water, heat, light, and noise transfer), passive solar gain, and daylighting. Many of the elements designed into structures for passive survivability are similar to the elements recommended for green structures. Strategies for designing for survivability include the following (Kibert 2008, p. 349):

1. Configure heating equipment to operate on photovoltaic cell power.
2. Create a high-performance envelope.
3. Create storm-resilient structures.
4. Incorporate passive solar heating.
5. Install composting toilets and waterless urinals.
6. Limit building heights.
7. Minimize cooling loads.
8. Provide for food production in the site plan.
9. Provide for natural ventilation.
10. Provide natural daylighting.
11. Provide photovoltaic power.
12. Provide solar water heating.
13. Store water on site: consider using rainwater to maintain a cistern.
14. Where appropriate, consider wood heat.

Another area where designers are able to impact the sustainability of structures is in the selection of *sustainable sites*, and this is discussed in Section 4.3.

## 4.3 SELECTING SUSTAINABLE SITES

A major part of sustainable design is selecting a suitable site for construction projects. According to the *American Institute of Architects*, suitable sustainable sites would be (American Institute of Architects 2007, p. 1):

- *Brownfield* sites (a site documented as contaminated, or classified as a brownfield by a local, state, or federal government agency).
- *Grayfield* sites (a site where at least 30% of the site is already developed with an impervious surface).
- *Greenfield* sites are agricultural land as long as the building's purpose is related to the agricultural use of the land.
- Greenfield sites are designated parkland as long as the building's purpose is related to the use of the land as a park.
- Greenfield sites are either within 800 m [1/2 mi.] of a commuter rail, light rail, or subway station or within 400 m [1/4 mi.] of one or more stops for two or more bus lines.
- Greenfield sites are forestland as long as the building's purpose is related to the forestry use of the land.
- Greenfield sites are within 800 m [1/2 mi.] of at least 10 basic services and have pedestrian access between the building and the services.
- Greenfield sites are within 800 m [1/2 mi.] of residential land that is developed, or is under construction, at an average density of four units per hectare (10 units per acre) net.
- Within an existing building.

Prohibited sites would include the following (American Institute of Architects 2007, p. 1):

- Previously undeveloped land whose elevation is lower than 1.5 m [5 ft] above the elevation of the 100-year flood level
- Within 50 m [150 ft] of any wetland
- Within 90 m [300 ft] of any fish and wildlife habitat conservation area

Greenfield sites are undeveloped and natural, or agricultural. Brownfield sites are sites being recycled, such as previous industrial zones containing hazardous waste. Grayfield sites are blighted urban areas contaminated by hazardous waste.

In the Leadership in Energy and Environmental Design (LEED) rating system, there is a "brownfield redevelopment credit" used to reduce development occurring on undeveloped land and to redevelop sites listed as brownfields. When using a brownfield site, a risk assessment should be performed to determine whether the site requires *remediation*. Remediation is performed either on site or off site. On-site methods include pumping out hazardous substances and treating them or allowing natural processes to remediate the substances. Off-site remediation requires the removal of hazardous substances and then transporting them to appropriate government-approved hazardous waste dumpsites.

The U.S. Green Building Council (USGBC) LEED—NC 2.2 Green Building Rating System provides the *Intent, Requirements, Potential Technologies and Strategies*, and *Summary of Referenced Standards* for site assessment, and they are the following (Haselbach 2008, pp. 39–40):

Intent:

- Rehabilitate damaged sites where development is complicated by environmental contamination, reducing pressure on undeveloped land.

Requirements:

- Develop a site that is documented as contaminated (by means of an American Society for Testing and Materials (ASTM) E1903–97 phase II environmental site assessment or a local voluntary cleanup program) or on a site defined as a brownfield by a local, state, or federal government agency.

Potential technologies and strategies:

- During the site selection process, give preference to brownfield sites. Identify tax incentives and property cost savings. Coordinate site development plans with remediation activity, as appropriate.

Summary of referenced standards:

- ASTM E1903–97 Phase II Environmental Site Assessment (ASTM International) (http://www.astm.org/Standards/E1903.htm). This guide covers a framework for employing good commercial and customary practices in conducting phase II environmental site assessment of a parcel of commercial property. It covers the potential presence of a range of contaminants within the scope of the Comprehensive Environmental Response Compensation and Liability Act (CERLA), as well as petroleum products.

The Environmental Protection Agency's brownfield definition:

> The *Environmental Protection Agency* provides a *Sustainable Redevelopment of Brownfields Program* (www.epa.gov/brownfields). With certain legal exclusions and additions, the term "brownfield site" means real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or containment. (Public Law 107–118 HR 2869 2002)

## 4.4 SUSTAINABLE LANDSCAPES

In addition to selecting sustainable sites, designers should also design sustainable landscapes. Sustainable landscapes are landscapes having the following five characteristics (Kibert 2008, p. 142):

1. Incorporate technologies supporting sustainable landscaping goals, and treat technology as secondary and subservient, not primary and dominant.
2. Maintain local structure and function, and do not reduce the diversity or stability of surrounding ecosystems.

3. Maximize the recycling of resources, nutrients, and by-products, and produce minimum waste or conversion of materials to useable locations or forms.
4. Preserve and serve local human communities rather than changing or destroying them.
5. Use primarily renewable, horizontal energy at rates that could be regenerated without ecological disturbances.

## 4.5 STORM WATER MANAGEMENT

The object of storm water management is to protect ecosystems and preserve the character of landscapes. The following is a checklist for evaluating the success of storm water management systems (Kibert 2008, p. 148):

Reduce the amount of storm water created:

1. Do not install gutters unless rainwater is collected for use.
2. Install porous paving where appropriate.
3. Minimize directly connected impervious areas.
4. Minimize the impact area in a development.
5. Plant trees, shrubs, and ground cover to encourage filtration.
6. Reduce paved areas through cluster development and narrower streets.
7. Where possible, eliminate curbs along driveways and streets.

Keep pollutants out of storm water:

1. Control high-pollution commercial and industrial sites.
2. Design and lay out communities to reduce reliance on cars.
3. Design and lay out streets to facilitate easy cleaning.
4. Incorporate low-maintenance landscaping.
5. Label storm drains to discourage the dumping of hazardous waste into them.
6. Provide green spaces where people are able to exercise their pets.

Managing storm water runoff at construction sites:

1. Avoid soil compaction.
2. Construct temporary erosion barriers.
3. Minimize slope modifications.
4. Minimize the impact area during construction.
5. Stabilize disturbed areas as soon as possible.
6. Work only with reputable excavation contractors.

Permanent off-site facilities for storm water control and treatment:

1. Check dams for vegetated swales.
2. Construct wetlands.

3. Dry detention ponds.
4. Filtration systems.
5. Infiltration basins.
6. Retention ponds.
7. Rooftop water catchment systems.
8. Vegetated filter strips.
9. Vegetated swales for storm water conveyance.

## 4.6 EVALUATING SUSTAINABLE PROCESS ALTERNATIVES

Jensen et al. (2003, p. 209) in the article “An Integrated Computer-Aided System for Generation and Evaluation of Sustainable Process Alternatives” discusses

> an integrated system for the generation of sustainable process alternatives with respect to new process design as well as retrofit design. The generated process alternatives are evaluated through sustainability metrics, environmental impact factors, as well as inherent safety factors. The process alternatives for new process design as well as retrofit design are generated through a systematic method that is simple yet effective and is based on a recently developed path flow analysis approach (Jensen et al. 2003, p. 209).

According to this approach, a set of indicators are calculated to pinpoint unnecessary energy and material waste costs and to identify potential design (retrofit) targets that may improve the process design (in terms of operation and cost) simultaneously with sustainability metrics, environmental impact factors, and inherent safety factors. Only steady-state design data and a database with properties of compounds, including environmental impact factor–related data and safety factor–related data, are needed. The integrated computer-aided system generates the necessary data if actual plant or experimental data are not available.

## 4.7 DESIGNING FOR THE USE OF SUSTAINABLE MATERIALS

The specifications for sustainable materials should consider the cradle-to-grave (pre-building, building, and post-building phases) life span of materials. Including these considerations, it ensures minimum impact on the environment in terms of material extraction, loss of habitat, erosion, silting of waterways, carbon dioxide emissions, and sulfur dioxide production. During the construction phase, the selection of sustainable materials helps reduce the amount of waste and the waste generated could be recycled. In the disposal phase, the waste could be either recycled or disposed of in landfills. Additional recommendations for sustainable materials provided by E&C industry executives are included in Chapter 7 in Section 7.13. Chapter 11 provides detailed information on a variety of sustainable construction materials that could be specified during the design stage.

## 4.8 PRINCIPLES AND STRATEGIES OF DESIGNING FOR DISASSEMBLY

Designers also have to consider the deconstruction and disassembly of structures to increase their sustainability. "Deconstruction is the whole or partial disassembly of buildings to facilitate component reuse and material recycling" (Kibert 2008, p. 258). Philip Crowther of Queensland Technical University, Brisbane, Australia, has developed a list of 27 principles that apply to designing for deconstruction and disassembly of structures (Kibert 2008, p. 159):

1. Allow for parallel disassembly.
2. Avoid composite materials, and make inseparable products from the same material.
3. Avoid secondary finishes to materials.
4. Avoid toxic and hazardous materials.
5. Design components sized to suit handling at all stages.
6. Design for joints and connectors to withstand repeated assembly and disassembly.
7. Identify the point of disassembly permanently.
8. Minimize the number of different types of components.
9. Minimize the number of fasteners and connectors.
10. Minimize the number of types of materials.
11. Minimize the types of connectors.
12. Provide access to all building components.
13. Provide adequate tolerance to allow for disassembly.
14. Provide for handling components during assembly and disassembly.
15. Provide permanent identification for each component.
16. Provide spare parts and storage for them.
17. Provide standard and permanent identification of material types.
18. Retain information on the building and its assembly process.
19. Separate the structure from the cladding.
20. Use a standard structural grid.
21. Use an open building system with interchangeable parts.
22. Use assembly technologies compatible with standard building practices.
23. Use lightweight materials and components.
24. Use mechanical rather than chemical connections.
25. Use modular design.
26. Use prefabricated subassemblies.
27. Use recycled and recyclable materials.

The following are some other design strategies that assist in obtaining the goal of designing for disassembly (Calkins 2009, pp. 90–91):

1. Avoid finishes that could compromise the reuse or recyclability of the material.
2. Design connections that are accessible.

3. Design the site and structure for maximum flexibility, and plan for adaptation of the site over time.
4. Detail connections that facilitate disassembly.
5. Document materials and methods to facilitate deconstruction and disassemble after the useful life of the structure or site.
6. Specify materials and products with good reuse and recycling potential.
7. Specify materials that are durable, modular, and/or standardized to facilitate reuse many times.
8. Support the deconstruction or disassembly process in the design process.

## 4.9 ENVIRONMENTAL IMPACT OF PRODUCTION OPERATIONS FOR CONSTRUCTION MATERIALS

This section introduces information on the environmental impact of production operations in the area of construction materials. Detailed information on specific types of sustainable alternatives to construction materials is provided in Chapter 11.

To create sustainable structures, designers should incorporate green building materials into their designs. The term green building materials refers to not only the selection of sustainable materials but also the exclusion of materials that are not sustainable. According to the publication *Environmental Building News*, green building products can be divided into five major categories (Kibert 2008, p. 245):

1. Products made from environmentally attractive materials
    a. Certified wood products
    b. Minimally processed products
    c. Products made from agricultural waste material
    d. Products with post-consumer recycled content
    e. Products with postindustrial recycled content
    f. Rapidly renewable products
    g. Salvaged products
2. Products that are green because of what is not there
    a. Alternatives to conventional preservative-treated wood
    b. Alternatives to other components considered hazardous
    c. Alternatives to ozone-depleting substances
    d. Alternatives to products made from polyvinylchloride (PVC) and polycarbonate
    e. Products that reduce material use
3. Products that reduce environmental impacts during construction, renovation, or demolition
    a. Products that reduce the impact of demolition
    b. Products that reduce the impact of new construction
    c. Products that reduce the impact of renovation
4. Products that reduce the environmental impact of building operations
    a. Building products that reduce heating and cooling loads
    b. Equipment that conserves energy

    c. Fixtures and equipment that conserve water
    d. Products with exceptional durability or low maintenance requirements
    e. Products that prevent pollution or reduce waste
    f. Products that reduce or eliminate pesticide treatments
    g. Renewable energy and fuel cell equipment
5. Products that contribute to a safe and healthy indoor environment
    a. Products that block the introduction, development, or spread of indoor contaminants
    b. Products that do not release significant pollutants into the building
    c. Products that improve light quality
    d. Products that remove indoor pollutants
    e. Products that warn occupants of health hazards in the building

When construction materials are selected, they should be evaluated based on their life-cycle assessment (LCA) rather than merely on their initial cost. Some of the potential considerations for LCAs are the following (Kibert 2008, p. 249):

- Acidification and acid deposition (dry and wet)
- *Fossil fuel depletion*
- Global warming potential
- Ground-level ozone (smog) creation
- Nutrification and eutrophication of water bodies
- Other nonrenewable resource use
- *Stratospheric ozone depletion* [layer of the atmosphere closest to the earth, approximately 0–12 km above the surface of the earth]
- Toxic releases to air, water, and land
- Water use

In addition to these concerns, embodied energy should be considered when evaluating construction materials and the relative comparison of embodied energy per time of use should be considered rather than merely the embodied energy.

## 4.10 INTERNATIONAL ORGANIZATION FOR STANDARDIZATION 14000 ENVIRONMENTAL MANAGEMENT STANDARDS

Certification to the ISO 14000 environmental management series of standards is being pursued most frequently by firms in Japan, the United Kingdom, Sweden, Spain, Australia, and the United States. Firms in the United Kingdom account for 20% of the ISO 14000 certifications in Europe and 10% of the certifications throughout the world (ISO 2006).

The first environmental management standard to be developed by the *British Standard Institute* (BSI) in 1992 was *British Standard Number 7750* (BS 7750). It was followed by the European Union (EU) Eco-Management and Audit Scheme (EMAS) in 1993. During this same period, individual countries developed their own standards, such as IS 310 in Ireland, X30–200 in France, UNE77–801 in Spain, SABS–0251 in South Africa, and CSA 7750 in Canada (Elefsiniotis and Wareham 2005, p. 208). The ISO developed and issued the ISO 14000 series of environmental standards in 1996. ISO 14000 is a series of standards

> aimed at providing organizations with a structured framework to manage their environmental impacts and responsibilities; however, the emphasis is on the management process, which aims to be consistent and which, in turn, should generate products of consistent quality. Some of the ISO 14000 series of standards (the Organization Evaluation group) concentrate on an organization's management, environmental auditing, and environmental performance evaluation systems, whereas others (the Product Evaluation group) include things such as environmental labeling, LCA procedures, and product standards. In the latter case, there is an intuitive link to sustainable development because practices such as design for the environment can be included, which involve answering questions about the life cycle of the product and its production process. (Elefsiniotis and Wareham 2005, p. 208)

Organizations may seek ISO 14000 certification for one particular site, for multiple sites, or for processes. A firm might receive ISO 14000 certification and still not be in compliance with environmental legislation, since firms only have to show that they are committed to complying with legislation not compliance to legislation.

To evaluate the impact of using product LCA, techniques were developed to quantify the environmental effects during their use. Life-cycle assessment methods might assist in the following (International Organization for Standardization 14040 2006, p. 1):

- Identifying opportunities to improve the environmental performance of products at various points in their life cycle
- Informing decision makers in industry, government, or nongovernmental organizations (e.g., for the purpose of strategic planning, priority setting, product or process design, or redesign)
- Marketing (e.g., implementing an eco-labeling scheme, making an environmental claim, or producing an environmental product declaration)
- The selection of relevant indicators of environmental performance, including measurement techniques

ISO 14040 (International Organization for Standardization 14040 2006, p. 1) also states, "For practitioners of LCA ISO 14044 details the requirements for conducting an LCA. Life-cycle cost assessments address the environmental aspects and potential environmental impacts (e.g., use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e., cradle-to-grave)."

The following are the four phases in an LCA study (International Organization for Standardization 14040 2006, p. 1):

1. Goal and scope definition
2. Impact assessment
3. Interpretation
4. Inventory analysis

The ISO 14040 standard describes “the principles and framework for life cycle assessment (LCA)” including the following (International Organization for Standardization 14040 2006, p. 1):

- Conditions for use of value choices and optional elements
- Goal and scope definition of the LCA
- Life-cycle impact assessment (LCIA) phase
- Life-cycle interpretation phase
- Life-cycle inventory analysis (LCIA) phase
- Limitations of the LCA
- Relationship between the LCA phases
- Reporting and critical review of the LCA

The following are some of the key features of the LCA methodology (International Organization for Standardization 14040 2006, p. 1):

1. The depth of detail and time frame of an LCA may vary to a large extent, depending on the goal and scope definition.
2. LCA assesses, in a systematic way, the environmental aspects and impacts of product systems, from raw material acquisition to final disposal in accordance with the stated goal and scope.
3. LCA methodology is open to the inclusion of new scientific findings and improvements in the state-of-the-art of the technique.
4. Provisions are made, depending on the intended application of the LCA, to respect confidentiality and proprietary matters.
5. The relative nature of LCA is due to the functional unit feature of the methodology.
6. Specific requirements are applied to LCA that are intended to be used in comparative assertions intended to be disclosed to the public.

The areas considered when evaluating the processes based on the ISO 14040 guidelines include the following (International Organization for Standardization 14040 2006, p. 1):

- Acquisition of raw materials.
- Additional operations such as lighting and heating.
- Assessment of policies (models for recycling, etc.).
- Design briefs and life-cycle thinking.
- Disposal of process waste and products.
- Distribution/transportation.
- Environmental impact assessment (EIA).
- Environmental management accounting (EMA).
- Hazard and risk assessment of chemicals.
- Inputs and outputs in the main manufacturing/processing sequence.
- Life-cycle costing (LCC).
- Life-cycle management (LCM).

- Manufacture, maintenance, and decommissioning of capital equipment.
- Product stewardship and supply chain management.
- Production and use of fuels, electricity, and heat and the use and maintenance of products.
- Recovery of used products including reuse, recycling, and energy recovery and the manufacture of ancillary materials.
- Risk analysis and risk management of facilities and plants.
- Substance flow analysis (SFA) and material flow analysis (MFA).
- Sustainability assessment and economic and social aspects are not included in LCA, but the procedures and guidelines could be applied by appropriate competent parties.

The ISO 14000 series of standards do not set specific environmental targets. Instead, they provide firms with guidelines on how to set up environmental management systems and develop their own environmental improvement processes.

## 4.11 SUMMARY

This chapter discussed sustainable engineering designs and the types of sustainable elements available for integration into designs. It also covered passive survivability and the similarity between passive survivability and sustainable designs. One section covered sustainable site selection and the options for selecting sites. Storm water management plans were described along with an explanation of what constitutes sustainable landscapes. Methods for evaluating sustainable process alternatives were presented, along with procedures for designing for the use of sustainable materials. An important element of sustainable designs is ensuring the designs incorporate principles and strategies of designing for disassembly, and suggestions were provided for this process. The ISO 14000 series of standards for environmental management were explained to demonstrate how they interrelate with sustainable engineering designs and construction operations.

## 4.12 KEY TERMS

American Institute of Architects
Argon
British Standard Institute
British Standard Number 7750
Brownfield
Carbon dioxide sensors
Combined heat and power
Disassembly
Eco labeled products
Energy-efficient artificial light
Fossil fuel depletion
Grayfield
Gray water

Greenfield
Ground coupling
Ground source heat pumps
Halon
Hydrochlorofluorocarbon refrigerants
International Organization for Standardization
Passive survivability
Radiant cooling
Remediation
Seasonal energy efficiency ratio
Space conditioning
Storm water management
Stratospheric ozone depletion
Sustainable landscapes
Sustainable sites
Thermal comfort control
Thermal envelopes
Thermal mass heating
Visual impact

## 4.13 DISCUSSION QUESTIONS

4.1 Discuss what is meant by designing for disassembly.
4.2 Explain passive survivability in buildings and how its incorporation would benefit the occupants of buildings.
4.3 What percentages of overall product costs and environmental impacts are determined during the design phase?
4.4 Explain the difference between greenfield, brownfield, and grayfield sites.
4.5 Which of the design elements provided by Langston and Ding should be selected for incorporation into the design of a structure, and why?
4.6 Discuss the purpose of storm water management.
4.7 Which of the major areas incorporated into designs to help create sustainable structures provided by Kibert would have the most impact, and why?
4.8 What are the five major categories of green building products according to the *Environmental Building News*?
4.9 Discuss what is required to design a sustainable landscape.
4.10 Discuss the purpose of the ISO 14000 series of standards.

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# 5 Environmental Laws and Their Implications

While achieving success, both industrially and economically, members of different countries should be cognizant of the environmental effects of their actions and strive to help preserve the environment for future generations through sustainable development and limitation the number of facilities that are not eco-friendly. As the standard of living is improving in many parts of the world, air quality and water quality are being compromised and toxins are being released into the environment from gasoline and diesel vehicles, buildings, power generation facilities, industrial facilities, construction, and manufacturing plants. The *World Health Organization* indicates that air pollution endangers over 1 billion people in urban areas; 748 million do not have access to an improved water source; and 840,000 people die each year from unsafe drinking water (World Health Organization 2014).

Global environmental restrictions affect the engineering and construction (E&C) industry by regulating the amount of pollution the industry generates and by restricting the use of certain hazardous materials. Construction projects should include environmentally friendly materials, but at the same time they should be structurally safe materials. Construction materials are normally selected based on their structural integrity, including their strength, stiffness, and durability, but now there is increasing concern about the amount of energy required to produce construction materials and to transport them to construction jobsites. The construction materials requiring the highest levels of energy to produce are cement, steel, paint, glass, metals, and plastic (Garner 2000).

This chapter presents information on the issues related to sustainability affecting E&C professionals. It includes information on the *United Nations Framework Convention on Climate Control* (UNFCCC), the *Kyoto Protocol*, and other treaties the UNFCCC has implemented to help reduce the *greenhouse gases* (GhGs) released into the atmosphere and the generation of hazardous waste. A discussion is provided on how the Kyoto Protocol affects E&C projects throughout the world and how it is being implemented and monitored globally.

This chapter explains the evolution of environmental laws in the United States and focuses on the laws affecting engineering design and construction. Information on new and potential regulations fostering sustainable practices is mentioned to demonstrate the current status of sustainability at the U.S. government level.

## 5.1 UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

Environmental concerns related to global climate change led to the formation of the United Nations Framework Convention on Climate Change in 1992 and the development of the Kyoto Protocol Treaty, which introduced measures for attempting to control global climate changes caused by GhGs in industrialized and developing countries. According to the United Nations Framework Convention Committee (UNFCC), the Kyoto Protocol established baseline principles and commitments for each of the countries ratifying the convention that if followed would help reduce GhG emission levels (United Nations Framework Convention Committee 2005).

Scientists have postulated that GhGs contribute to the depletion of the *ozone layer* surrounding the earth. The ozone layer protects the surface of the earth from the damaging ultraviolet light rays of the sun, and if the ozone layer is compromised it could cause climate changes throughout the world such as increasing temperatures and melting of the polar ice caps. Greenhouse gases include *carbon monoxide* ($CO_2$), *nitrous oxide* ($N_2O$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and *sulfur hexafluoride* ($SF_6$) (United Nations Framework Convention Committee 2005). Table 5.1 provides a list of some of the major sources of GhGs, and Table 5.2 lists the percentages of carbon dioxide emissions for the top 20 industrialized countries for the year 2011.

Greenhouse gases also occur naturally in the atmosphere in various levels, and when these gases increase due to manmade causes the atmosphere becomes out of balance and it affects climates throughout the world. The types of GhGs occurring naturally in the atmosphere and the purposes they serve are the following (Langston and Ding 2001, p. 5):

- Nitrogen (79% of atmosphere): pressure builder, fire extinguisher, and an alternative to nitrate in the sea
- Oxygen (21% of atmosphere): energy reference gas

**TABLE 5.1**
**Sources of GhGs**

| Fuel Combustion | Industrial Processes | Rice Cultivation |
|---|---|---|
| Energy industries | Mineral products | Agricultural soils |
| Manufacturing industries | Chemical industry | Prescribed burning of savannas |
| Construction | Metal production | Manure management |
| Transportation | Other production | Solid waste disposal on land |
| Fugitive emissions from fuels | Solvents | Wastewater handling |
| | | Waste incineration |
| Solid fuels | Agriculture | Field burning of agricultural residues |
| Oil and natural gas | Enteric fermentation (methane emissions) | |

*Source:* Adapted from United Nations Framework Convention Committee, *Climate Change Information Sheet Number 22*, Information Unit or Conventions, Environment Program, New York, Accessed on January 12, 2015, http://unfccc.int/cop3/fccc/climate/fact22.htm, 2000.

## TABLE 5.2

## Energy Information Agency: Department of Energy Estimates of the Highest Carbon Dioxide Emissions by Country for 2011

| Rank | Country | Carbon Dioxide Emissions (Millions of Metric Tons) | Each Country's Share of Total Carbon Dioxide Emissions |
|---|---|---|---|
| 1 | China | 8715.31 | 27% |
| 2 | United States | 5490.63 | 17% |
| 3 | Russia | 1788.14 | 5% |
| 4 | India | 1725.76 | 5% |
| 5 | Japan | 1180.62 | 4% |
| 6 | Germany | 748.49 | 2% |
| 7 | Iran | 624.86 | 2% |
| 8 | South Korea | 610.95 | 2% |
| 9 | Canada | 552.56 | 2% |
| 10 | Saudi Arabia | 513.53 | 2% |
| 11 | United Kingdom | 496.80 | 2% |
| 12 | Brazil | 475.41 | 1% |
| 13 | Mexico | 462.29 | 1% |
| 14 | South Africa | 461.57 | 1% |
| 15 | Indonesia | 426.79 | 1% |
| 16 | Italy | 400.94 | 1% |
| 17 | Australia | 392.29 | 1% |
| 18 | France | 374.33 | 1% |
| 19 | Spain | 318.64 | 1% |
| 20 | Poland | 307.91 | 1% |
|  | Rest of the world |  | 20% |

*Source:* Adapted from Union of Concerned Scientists—Science for a Healthy Planet and Safer World, *Each Country's Share of $CO_2$ Emissions*, Cambridge, Massachusetts, Accessed on January 12, 2015, http://www.ucsusa.org/global_warming/science_and_impacts/science/each-countrys-share-of-co2.html#.VLQ-nCczETE, 2014.

- Carbon dioxide (0.03% of atmosphere): photosynthesis and climate control
- Methane (0.0004% of atmosphere): oxygen regulation and ventilation of the anaerobic zone
- Nitrous oxide (0.00001% of atmosphere): oxygen and ozone regulation
- Ammonia (0.000001% of atmosphere): pH control and climate control
- Sulfur gases (0.00000001% of atmosphere): transport gases of the sulfur cycle
- Methyl chloride (0.0000001% of atmosphere): ozone regulation

## 5.2 KYOTO PROTOCOL

The Kyoto Protocol Treaty is an amendment to the United Nations Framework Convention on Climate Change, and it was written to formalize the intentions of the UNFCCC, which is an international agreement on binding targets for industrialized countries for reducing GhG emissions by the year 2012. The Kyoto Protocol was developed to (United Nations Framework Convention Committee 2005)

- Change consumer patterns.
- Combat deforestation.
- Help manage waste.
- Promote sustainable human settlement development.
- Protect and promote safe human health conditions.
- Protect the environment, air, water, and ecosystems.

The Kyoto Protocol specified targets for reducing GhG emissions for each country ratifying the protocol that were supposed to be reached by the year 2012. The emission targets are a percentage reduction in the emissions levels of the GhGs recorded in 1990 ranging from 5% to 8% (Jeong 2001). Emission targets are different for each country or region. The European Union, Switzerland, and most Central and Eastern European states had a target of 8%; the United States had 7%; and Canada, Hungary, Japan, Poland, New Zealand, Russia, and Ukraine had 6%. Since Norway, Australia, and Iceland produce low levels of GhGs, they were allowed to increase their emissions by up to 1% in Norway, 8% in Australia, and 10% in Iceland (United Nations Framework Convention Committee 2005). The European Union was able to try and balance its emissions targets between countries by allowing countries with low emissions to increase their emissions as long as there was a reduction in emissions in countries with high levels of GhG emissions. Developed countries increased their GhG emissions from 1990 to 2000 by 8.3% except for Eastern Europe and the former Soviet Union, which had a reduction in GhG emissions during this period due to their declining economies (United Nations Framework Convention Committee 2005).

The target emissions in the Kyoto Protocol tried not to restrict growth in economies in transition, such as the former Soviet Union, Central and Eastern European nations, and developing countries. Economies in transition had the option of choosing a different baseline year rather than 1990, since they may not have had GhG emission measurements for 1990. Countries chose a baseline year of either 1990 or 1995 for the emissions of HFCs, PFCs, and sulfur hexafluoride ($SF_6$).

The effective date of the Kyoto Protocol was February 2005, as that was when 55 countries ratified the treaty. By March 2014, there were over 200 countries that had ratified the Kyoto Protocol, and they are listed in Appendix C (United Nations Framework Convention Committee 2005). The U.S. government signed the Kyoto Protocol, but it had not ratified it as of May of 2015. The United States produces the highest level of GhGs among any nation in the world, followed by China, Russia, India, Japan, Germany, Brazil, Canada, United Kingdom, Italy, Korea, Ukraine, France, and Mexico. A total of 15 countries produce 70% of the GhGs in the world.

**TABLE 5.3**
**Percentage of 1990 Greenhouse Gas Emissions Allowed by the Year 2012 (by Kyoto Protocol)**

| Country Name | Percentage of 1990 GhG Emissions | Country Name | Percentage of 1990 GhG Emissions |
|---|---|---|---|
| Australia | 108 | Liechtenstein | 92 |
| Austria | 92 | Lithuania[a] | 92 |
| Belgium | 92 | Luxembourg | 92 |
| Bulgaria[a] | 92 | Monaco | 92 |
| Canada | 94 | Netherlands | 92 |
| Croatia[a] | 95 | New Zealand | 100 |
| Czech Republic[a] | 92 | Norway | 101 |
| Denmark | 92 | Poland[a] | 94 |
| Estonia[a] | 92 | Portugal | 92 |
| European Community | 92 | Romania[a] | 92 |
| Finland | 92 | Russian Federation[a] | 100 |
| France | 92 | Slovakia[a] | 92 |
| Germany | 92 | Slovenia[a] | 92 |
| Greece | 92 | Spain | 92 |
| Hungary[a] | 94 | Sweden | 92 |
| Iceland | 110 | Switzerland | 92 |
| Ireland | 92 | Ukraine[a] | 100 |
| Italy | 92 | United Kingdom and Northern Ireland | 92 |
| Japan | 94 | United States of America | 93 |
| Latvia[a] | 92 | | |

*Source:* Adapted from United Nations Framework Convention on Climate Change, *Kyoto Protocol Reference Manual—On Accounting of Emissions and Assigned Amount*, New York, Accessed on January 12, 2015, http://unfccc.int/resource/docs/publications/08_unfccc_kp_ref_manual.pdf, 2008.

[a] Economies in Transition.

Table 5.3 provides a list of the target emission reductions, or target emission increases, for several countries for the year 2012 that are a percentage of 1990 emissions.

## 5.3 CLEAN DEVELOPMENT MECHANISM, JOINT IMPLEMENTATION PRACTICES, CARBON SINKS, AND EMISSION CREDITS

The *clean development mechanism* in the Kyoto Protocol allows industrialized countries to partially meet their emissions targets by using *emission credits* earned by sponsoring GhG-reducing projects in developing countries such as *carbon sinks* (Elliot 1998). The *joint implementation practices* process is a mechanism whereby developed countries are able to invest in clean technology to help reduce GhG emissions in other developing or developed countries and then both of the countries are awarded emission credits.

One example of a firm creating carbon credits is a U.S. steel company. This company is leasing land in Brazil where it grows eucalyptus trees, and then it burns the trees to produce the ash used in the steel production process. By growing the trees, the firm receives carbon credits for creating a carbon sink, plus a guaranteed supply of ash for its steel production. Burning the trees reduces carbon credits, but it still results in positive carbon credits at the end of the process (International Iron and Steel Institute 2005).

### 5.3.1 Emissions Trading

Some countries or companies are able to meet their emissions targets by *emissions trading*, a process where countries or companies sell their emission credits or debts to other countries. Countries may also bank their emissions credits for use in the future or sell them to other countries in subsequent years (World Bank 2005).

### 5.3.2 Carbon Sinks

Countries may counterbalance GhG emissions by removing GhGs from the atmosphere using carbon sinks, such as reforestation, which is the process of planting trees that absorb carbon monoxide and other pollutants from the air.

The methods used for estimating the level of GhG emissions from different sources, and the removal of emissions by carbon sinks, have to be approved by the *Intergovernmental Panel on Climate Change* and be accepted by the *Conference of the Parties*, which includes representatives of the governments of countries that have ratified the Kyoto Protocol. The Conference of the Parties is the organization that determines what the consequences are for a country not meeting its emissions targets.

## 5.4 BASEL CONVENTION

The UNFCC has developed and implemented another environmental convention called the *Basel Convention*, which stipulates the requirements for the transboundary movement of hazardous waste and the disposal of hazardous waste. The governments of 164 countries agreed to try to minimize the generation of hazardous waste, and the governments of 95 countries signed an agreement banning the exportation of hazardous waste materials from developed countries to developing countries, including toxic, poisonous, explosive, flammable, *ecotoxic* (toxic to the environment), and infectious waste of which many are the by-products of construction. Some countries require prior notification before any government, or firm, from another country may import a hazardous waste into their country. Prior approval has to also be obtained from nations where the hazardous waste will be in transit (United Nations Framework Convention Committee 2005).

## 5.5 RIO DECLARATION

The UNFCC facilitated the development and implementation of the *Rio Declaration*, which requires countries to enact environmental legislation facilitating the exchange of environmental information including *environmental impact statements* (EISs) or *environmental impact assessments* (EIAs), the results of internal legal decisions related to the environment, and the results of judicial and administrative proceedings between countries sharing natural resources (United Nations Framework Convention Committee 2005). International EIAs are reviewed during decision-making processes by members of governments or firms when they are evaluating the potential physical, biological, cultural, and socioeconomic effects of projects and their alternatives.

## 5.6 STOCKHOLM CONVENTION

The *Stockholm Convention* is another treaty developed and implemented by the UNFCC, and it is used to help reduce the global production, use, and release of 12 of the most harmful chemicals called *persistent organic pollutants* (POPs), which are listed in Table 5.4.

**TABLE 5.4**
**POPs**

| Pesticide | Industrial Chemical | By-Product |
|---|---|---|
| Aldrin[a] | Hexachlorobenzene | Hexachlorobenzene |
| Chlordane[a] | Mirex | Mirex |
| DDT[a] | Toxaphene | Toxaphene |
| Dieldrin[a] | Polychlorinated biphenyls | (PCBs) |
| Endrin[a] | Polychlorinated dibenzo-*p*-dioxins | Dioxins |
| Heptachlor[a] | Polychlorinated dibenzo-*p*-furans | Furans |
| Hexachlorobenzene[b] | | |
| Mirex[b] | | |
| Toxaphene[b] | | |
| PCBs[b] | | |
| Polychlorinated dibenzo-*p*-dioxins (dioxins)[b] | | |
| Polychlorinated dibenzofurans (furans)[b] | | |

*Source:* Adapted from Environmental Protection Agency, *Persistent Organic Pollutants: A Global Issue, a Global Response*, Washington, DC, Accessed on January 12, 2015, http://www2.epa.gov/international-cooperation/persistent-organic-pollutants-global-issue-global-response, 2009b.

*Note:* DDT, dicholorodiphenyl trichloroethane; PCB, polychlorinated biphenyl.

[a] Intentionally produced.

[b] Unintentionally produced (result from some industrial processes or combustion).

## 5.7 GLOBAL ENVIRONMENTAL COMPLIANCE

The UNFCC develops international compliance methods, and penalties for noncompliance, for the Kyoto Protocol. In the international arena, the enforcement of international treaties is difficult unless countries agree to voluntary compliance. When treaties are *international customary laws*, it means that they are laws defined by the *International Court of Justice* (general practices accepted as law) and governments enforce them because they are legally obligated to enforce them. Treaties and customs (such as the Kyoto Protocol) are called *hard laws*, and they are enforced through economic sanctions set by international legal systems. *Soft laws* are nonbinding laws based on international diplomacy and customs, and countries enforce them because they fear retribution by other countries if they do not enforce them (United Nations Framework Convention Committee 2005). There are various other types of environmental laws used globally, and they are treaties or conventions, declarations, international court decisions, or customary international law.

The International Network for Environmental Compliance and Enforcement (2015) is a network of governmental and nongovernmental practitioners from over 100 countries working to raise awareness on complying with environmental standards and regulations. They develop methods for the enforcement of standards and try to increase cooperation between nations to strengthen the capacity, implementation, and enforcement of environmental regulations.

## 5.8 GLOBAL ENVIRONMENTAL MANAGEMENT STANDARDS

The *International Organization for Standardization* (ISO) publishes 350 international environmental standards that are incorporated into the designs of projects. For more information on the specific standards available, see the ISO website. The ISO website also provides information on environmental management standards called the ISO 14000 series of standards. These standards address environmental management systems and describe the ISO 14000 certification process. The ISO 14000 series of standards are discussed in Chapter 4 in Section 4.10.

## 5.9 UNITED STATES ENVIRONMENTAL PROTECTION AGENCY LAWS

When engineers create designs and contractors build structures, they should be aware of the environmental laws that affect their work. In the United States, environmental laws did not significantly impact society until the 1950s when environmental legislation started moving to the forefront of societal concerns. The 1970s ushered in a period when the most extensive federal environmental legislation was passed and implemented by administrative agencies, and in the first decade of the twenty-first century there was a resurgence in concern for the environment.

This section introduces major U.S. federal environmental and sustainability legislation and explains how different environmental and sustainability laws affect the

E&C industry. This section also discusses environmental impact statements and how they are related to construction projects and the *Council on Environmental Quality* (CEQ) and its responsibilities.

The *Environmental Protection Agency* (EPA) strategic goals and its *Office of Research and Development Strategic Plan* list environmental priorities as being global climate change, loss of biodiversity, habitat destruction, and stratospheric ozone depletion (Environmental Protections Agency 2001). In addition, rising global temperatures, increasing exposure of humans to ultraviolet radiation, and diminishing availability of natural resources are also major concerns to environmentalists. Everyone involved in the E&C industry should be aware of the life cycle of resources and be able to establish life-cycle health and environmental considerations and integrate these considerations into material and product specifications.

The *Resource Conservation and Recovery Act* (RCRA) established the *Affirmative Procurement Program* (APP) to encourage the procurement of recycled products or products containing some recycled components (Environmental Protection Agency 2007). In addition, *Executive Order 13,101* requires federal government agencies to use recycled products and environmentally friendly products. Executive Order 13,423 replaced Executive Order 13,101 in January 2007, and it emphasizes energy and environmental issues (Environmental Protection Agency 2007).

The EPA also issued *Comprehensive Procurement Guidelines* (CPGs) specifying environmentally friendly products and the minimum recycled content for products. Federal government agencies are required to purchase these products. A total of 61 items are listed in the eight product categories in the CPG as compliant items, and new products are added to the list each year. The following are the product categories listed in the CPG (Environmental Protection Agency 2014a, p. 7):

- Construction products—including insulation, carpet, cement and concrete, latex paint, floor tiles, patio blocks, shower and restroom dividers, structural fiberboard, and laminated paperboard
- Landscaping products—including garden and soaker hoses, mulch, edging, and compost
- Miscellaneous products—including pallets, mats, awards, and plaques
- Non-paper office products—including binders, recycling and trash containers, plastic desktop accessories, plastic envelopes, trash bags, printer ribbons and toner cartridges, report covers, plastic file folders, and plastic clipboards
- Paper and paper products—including sanitary tissue, printing and writing paper, newsprint, paperboard and packaging, and paper office supplies (e.g., file folders and hanging files)
- Transportation products—including channelizers, delineators, parking stops, barricades, and cones

In March 2008, the EPA passed new ozone requirements reducing the allowable ozone emissions from 80 ppb to 75 ppb (Environmental Protection Agency 2009a). The original ozone standard was passed in 1997, and many counties in the United States had difficulties meeting the requirements of the original standard. The enforcement mechanism has penalties such as the withholding of federal transportation funding until counties are able to improve their air quality.

Sections 5.9.1 through 5.9.3 describe a few of the major U.S. environmental acts affecting engineering design and construction operations.

### 5.9.1 COUNCIL ON ENVIRONMENTAL QUALITY

In 1969, the *National Environmental Policy Act* (NEPA) was passed in the United States, and this act created the CEQ. This act also established the requirement for all federal projects, all federally funded projects, and every proposed legislative act affecting the environment to include an environmental impact statement. The CEQ was formed to advise and provide studies to the President of the United States on environmental matters and to produce the environmental quality report required each year, as per the NEPA (Ortolono 1997). The yearly CEQ environmental report provides the following (Public Law 91–190, Section 201, 42 U.S.C. 4341 1969):

1. A program for remedying the deficiencies of existing programs and activities, together with recommendations for legislation
2. A review of the programs and activities (including regulatory activities) of the federal government, state and local governments, and nongovernmental entities or individuals with particular reference to their effect on the environment and on the conservation, development, and utilization of natural resources
3. Adequacy of available natural resources for fulfilling human and economic requirements of the nation in light of expected population pressures
4. Current and foreseeable trends in the quality, management, and utilization of such environments and the effects of those trends on the social, economic, and other requirements of the nation
5. Status and condition of the major natural, manmade, or altered environmental classes of the nation, including, but not limited to, the air; the aquatic, including marine, estuarine, and freshwater; and the terrestrial environment, including, but not limited to, the forest, dryland, wetland, range, urban, suburban, and rural environment

Members of the CEQ also analyze and interpret environmental information for the President and his or her staff members and review the environmental programs and activities proposed by the federal government. Along with their advisory role, members of the CEQ develop policies to help improve environmental quality and document changes to the environment. Members of the CEQ also develop the guidelines used for preparing EISs.

### 5.9.2 ENVIRONMENTAL PROTECTION AGENCY

The EPA was created in September 1970 when President Richard Nixon presented to Congress proposed changes to the organization of U.S. government agencies. The programs transferred to the EPA were in the areas of water quality management, air quality and solid waste management, pesticides, *radiological health*, and water hygiene. The EPA is responsible for implementing environmental laws, "developing policies and regulations, conducting research and monitoring activities, imposing sanctions, and engaging in numerous other activities. The EPA influences legislation by proposing new programs to Congress and by informing Congress of methods for avoiding future environmental problems" (Ortolono 1997, p. 46). The U.S. Congress provides oversight for the EPA, and the Congress is able to monitor the EPA's implementation of environmental statutes by calling for reports on progress and requesting appraisals of performance from the General Accounting Office. Moreover, congressional committees and subcommittees frequently hold hearings that allow Congress to monitor the EPA's implementation of a statute or to amend a statute. These hearings give Congress a chance to hear from all interested parties, including those regulated by the laws (Ortolono 1997, p. 50).

Members of the E&C industry are required to follow EPA laws when designing and constructing structures, especially in the areas of air quality, water quality management, solid waste management, and hazardous waste mitigation.

### 5.9.3 Environmental Impact Statements

Environmental impact statements are required on all federal and federally funded projects, and state governments may also require more detailed versions of them. Congress, federal agencies, and the public use EISs when they are required to make decisions affecting the environment. They are used on federal and federally funded projects during licensing and permitting procedures and when projects are reviewed for funding (Ortolono 1997).

Environmental impact statements provide an analysis of the environmental costs and benefits of projects, and they explain the primary environmental consequences of proposed projects along with potential secondary consequences. Enviornmental impact statements provide a description of the potential environmental risks of all proposed alternative projects to allow decision makers to make more informed decisions. Members of engineering firms are hired to investigate the environmental consequences of projects and to write EISs.

## 5.10 FEDERAL LAWS OF CONCERN TO ENGINEERS AND CONSTRUCTORS

This section reviews some of the environmental laws pertinent to E&C professionals since these laws affect how professionals design and construct their projects. Additional information on these, and other U.S. environmental laws, is available in the *U.S. Federal Register* or in the book *Environmental Regulations and Impact Assessment* (Ortolono 1997).

### 5.10.1 Air Pollution Control Act of 1955

In 1953, U.S. Army General Dwight (Ike) D. Eisenhower became President of the United States. General Eisenhower had been a five-star general in the army, Supreme Commander of the Allied Forces in Europe during World War II, military governor of the American occupation zone in Germany in 1945, and Supreme Allied Commander in Europe from April 1951 to May 1952. While Eisenhower was directing military operations in Europe, he realized the importance of transportation systems in the success of military strategy and maneuvers. As a result of this experience, when Eisenhower became President he implemented plans for a nationwide interstate highway system in the United States. President Eisenhower envisioned a federal highway system providing both east/west and north/south major highways through every state in the union.

Although it took decades to complete his vision, one of the early effects of increased automobile travel because of the availability of highways was an increase in the level of air pollution. In 1955, the *Air Pollution Control Act* indicated for the first time that air pollution is a danger to public health, but it left the regulation of air pollution to the states. The act allowed the federal government to conduct research to investigate the effects of air pollution. The *Clean Air Act* of 1963 replaced the Air Pollution Control Act.

### 5.10.2 CLEAN AIR ACTS OF 1963, 1970, AND 1990

In 1963, the Clean Air Act was passed to help abate interstate air pollution. Prior to the passing of this act, individual states did not have any recourse when adjacent states had facilities polluting the local environment, including the environment across state boundaries. This act established the *U.S. Public Health Service* to conduct research into developing techniques for monitoring and controlling air pollution.

The Clean Air Act was amended in 1970 to establish *National Ambient Air Quality Standards* and again in 1990 to authorize a program for *acid deposition control*, to control 189 toxic pollutants, and to establish permit program requirements. The Clean Air Act and the *Air Quality Act* provide authority to the *U.S. Secretary of Health and Human Services* to establish air quality standards for different pollutants and combinations of pollutants. These acts also provide the EPA with the authority to require the abatement of pollutants. The Clean Air Act of 1970 set updated emissions standards for new vehicles and engines and authorized emissions testing of vehicles. Not all 50 states have adopted vehicle emissions testing, and some states, such as California and Colorado, require emissions standards that are more rigid than the emissions standards in other states.

### 5.10.3 MOTOR VEHICLE AIR POLLUTION CONTROL ACT OF 1965

The *Motor Vehicle Air Pollution Control Act* of 1965 established auto emissions standards and set the maximum emissions automobiles are allowed to eject through their exhaust systems.

### 5.10.4 AIR QUALITY ACT OF 1967

When the Air Quality Act was passed in 1967, it created a regional framework for the enforcement of federal and state air quality standards. The Air Quality Act also regulates a variety of toxic emissions. One situation illustrating how it regulates toxic emissions occurred in Florida in 2009. A major class action lawsuit was filed in March 2009 that involved toxic gases being emitted from drywall installed in homes in Florida, and this lawsuit is explained in Box 5.1.

### BOX 5.1 REGULATION OF TOXIC EMISSIONS

A group of Florida homeowners filed a class action lawsuit on Monday against a German drywall maker, its Chinese subsidiaries, and several U.S. homebuilders alleging they put toxic drywall in thousands of U.S. homes. The lawsuit alleges that defective Chinese drywall that emits sulfur gases was used during a building materials shortage at the height of the construction boom and installed in thousands of homes, where it is corroding wiring, wrecking air conditioners, and making residents sick. The lawsuit, which could represent the owners of up to 30,000 Florida homes, named three Chinese manufacturers of plasterboard and three homebuilding companies as defendants. At least 550 million pounds of Chinese drywall was brought into the United States from 2004 to 2006, the peak of the U.S. housing boom, and up to 60,000 homes could be affected. The only way to fix the problem is to move the homeowners out, gut the houses, and rebuild the interior, as well as replacing drapes, furniture, and other property that may have been contaminated by the gases (Engineering News Record 2010, pp. 10–11).

One of the first legal cases was settled in April 2011 in Louisiana, and the Chinese firm manufacturing the drywall was responsible for paying for the mitigation of the negative effects and damage caused to homes by the drywall. By April 2010, there were 3,082 cases in Florida, Louisiana, Mississippi, Alabama, Virginia, and other states for a total of 37 states where drywall was installed between 2005 and 2007. Mitigation requires the removal of all drywall from a home along with replacing electrical components and wiring, gas service piping, fire suppression sprinkler systems, smoke alarms, and carbon monoxide alarms. Other potential areas that might need replacing include heating, ventilating, and air-conditioning (HVAC) systems or leaking or corroded copper in the plumbing lines (Engineering News Record 2010, pp. 10–11).

### 5.10.5 NATIONAL ENVIRONMENTAL POLICY ACT OF 1969

The NEPA of 1969 (Public Law 91–190, 42 U.S.C. 4321–4347) provides requirements for the CEQ and includes Section 102 (42 U.S.C. 4332), which indicates

… every recommendation or report on proposals for legislation and other major federal actions significantly affecting the quality of the human environment requires a detailed statement by the responsible official on—

(i) The environmental impact of the proposed action
(ii) Any adverse environmental effects which cannot be avoided should the proposal be implemented
(iii) The relationships between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity
(iv) Any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented

All of these requirements are addressed in EISs.

### 5.10.6 National Environmental Policy Act of 1970

The NEPA established the EPA, and the agency is responsible for implementing the requirements included in the Clean Air Act of 1970. The EPA was established by executive order by President Nixon in 1970. It was charged with the enforcement of air pollution laws and with establishing criteria to help create a cleaner environment.

### 5.10.7 Noise Pollution Act of 1972

The *Noise Pollution Act* of 1972 provides the EPA with the legal right to control noise levels of products used for commerce, and it also regulates the noise levels of railroads and freight carriers. Noise pollution includes unwanted and disturbing sounds. Chronic exposure to high levels of noise sometimes leads to health-related illnesses such as “high blood pressure, speech interference, hearing loss, sleep disruption, and lost productivity” (Environmental Protection Agency 2009a, p. 3). The types of noise pollution that the EPA regulates include “low noise emission products, construction equipment, transport equipment, trucks, motorcycles, and the labeling of hearing protection devices” (Environmental Protection Agency 2009a, p. 2). Noise caused by airplanes is regulated by the *Federal Aviation Administration* (FAA).

In 1981, the responsibility for addressing noise issues, other than the ones cited previously, was transferred to state governments. Members of the federal EPA will still investigate noise issues, provide information on noise pollution, and evaluate existing regulations to determine whether there are any issues affecting public welfare (Environmental Protection Agency 2009a). In order to help reduce noise pollution many states regulate the hours in which construction activities may be conducted, such as not starting before 8 AM and not continuing after 6 PM.

The EPA regulates hearing protection devices (HPDs) through the *Labeling of Hearing Protection Devices Regulation* (40CFR, Part 211, Subpart B) (Occupational Health and Safety Administration 2007). The devices regulated by the EPA include earplugs, earmuffs, and communication headsets, all of which are used routinely at construction jobsites. Hearing protection devices are rated by the maximum decibel level they protect the user from and their effectiveness in reducing unwanted noise.

### 5.10.8 Federal Water Pollution Act of 1948, 1972, and 1977

The *Federal Water Pollution Act* of 1948 was amended in 1972, and it became known as the *Clean Water Act*. This act was amended again in 1977 to establish environmental standards for water and waterways and to create a system for the issuance of permits for discharging pollutants from point sources such as pipelines, drainage ditches, ships, floating facilities, and other point sources. The act also made it illegal to discharge pollutants from a point source into a navigable waterway without first obtaining a permit from the EPA through the *National Pollutant Discharge Elimination System* (NPDES).

Under the NPDES, the EPA also levies penalties for oil spills into waterways and requires firms to pay to remediate the surrounding areas after oil spills, as the case study in Box 5.2 illustrates.

A similar case demonstrating the mitigation of toxic spills is provided in Box 5.3.

Figure 5.1 shows a photograph of the offshore oil drilling platform *Deepwater Horizon* destroyed in the Gulf of Mexico that is discussed in Box 5.3.

Another landmark case involving water pollution was settled in 2009, and it is described in Box 5.4.

The EPA also has the authority to require equipment to be installed that helps prevent oil spills at oil handling facilities and when it is being transported by oil tankers. One example of an oil spill prevention technology is oil tankers with double hulls for containing the oil in situations where the exterior hull is compromised during transit.

### BOX 5.2 PENALTIES FOR POLLUTION DISCHARGE

One of the most environmentally damaging oil spills in the history of the United States occurred on March 23, 1989 when an oil tanker ran aground and 8 of its 11 cargo tanks were compromised, releasing 11 million gallons of oil into Prudhoe Bay in the Prince William Sound in Valdez, Alaska. For 3 days, the oil was not skimmed off the water surface and when a storm hit the area the oil spread onto the coastline. The oil company that owned the tanker was fined $1 billion in criminal and civil penalties and required to pay for cleaning up the oil and the adjacent environment (U.S. Government Accountability Office 1993).

### BOX 5.3 DEEPWATER HORIZON OIL SPILL

In March 2010, the *Deepwater Horizon* oil spill occurred in the Gulf of Mexico when an explosion blew up the offshore oil drilling platform. In addition to destroying the offshore oil drilling platform and killing 11 workers, the explosion caused the well head to break off and this precipitated the release of millions of gallons of oil into the Gulf of Mexico, polluting the local coastlines and destroying part of the regional economy. After several unsuccessful attempts, engineers were finally able to cap the well in August 2010 and drill an adjacent well intercepting the underwater pipeline damaged in the explosion. It was determined through court proceedings that several different companies were responsible, and they are providing billions of dollars to the cleanup effort, to local governments, to business, and to those whose economic livelihood was compromised by the oil spill in the region.

**FIGURE 5.1** Deepwater Horizon offshore oil drilling platform after explosion. (Open source photograph.)

### BOX 5.4 WATER POLLUTION REMEDIATION

Several major oil companies agreed to pay $423 million for the cleanup of wells and their surrounding areas owned by more than 153 water providers in 17 states and contaminated by the gasoline additive methyl tertiary butyl ether, known as MTBE. Under the terms of the settlement announced on May 7, 2008 pending approval by the U.S. District Court for the Southern District of New York, the oil companies will not only help pay for current remediation costs but will also pay 70% of future costs over the next 30 years. If approved, the settlement will be the largest of its kind to date (*Wall Street Journal* 2008).

### 5.10.9 FEDERAL INSECTICIDE, FUNGICIDE, AND RODENTICIDE ACTS OF 1972 AND 1996

The *Federal Insecticide*, *Fungicide*, *and Rodenticide Act* was passed in 1972 and amended in 1996. This act requires federal regulation of pesticide distribution, sale, and use. It also requires all pesticides to be registered (licensed) by the EPA. To obtain a license from the EPA, an applicant has to be able to demonstrate that the pesticides will not adversely affect the environment.

### 5.10.10 TOXIC SUBSTANCE CONTROL ACT OF 1976

The *Toxic Substance Control Act* (TSCA) of 1976 “provided the EPA with the authority to require reporting, recordkeeping and testing requirements, and restrictions relating to chemical substances and/or mixtures” and “addresses the production, importation, use, and disposal of specific chemicals including polychlorinated biphenyls (PCBs), radon, and lead based paint" (15 U.S.C. 2601 et seq. 1976). The EPA maintains a list of toxic chemicals containing thousands of chemicals considered to be toxic.

### 5.10.11 SOLID WASTE DISPOSAL ACT OF 1965, RESOURCE CONSERVATION AND RECOVERY ACT OF 1976, AND HAZARDOUS AND SOLID WASTE ACT OF 1984

The *Solid Waste Disposal Act of 1965* was amended in 1976, and it became the Resource Conservation and Recovery Act. Another amendment in 1984 changed the act into the *Hazardous and Solid Waste Act*. This act provides the federal government with the power to regulate hazardous waste. It also includes a provision for providing assistance to states in developing solid waste management plans and implementing new technology to reduce or abate hazardous waste.

The 1976 amendment provided the EPA with the legal authority to control hazardous waste from cradle to grave, including generation, transportation, treatment, storage, and disposal (42 U.S.C. 6901 et seq. 1976). The 1984 amendment requires federal facilities to pay fines and penalties for violating hazardous and solid waste requirements. In addition, it addresses problems resulting from underground petroleum storage tanks. Also included in this amendment are more stringent hazardous waste management standards and the phasing out of the disposing of hazardous waste in landfills. Permits are required for the treatment, storage, and disposal facilities for hazardous waste. Facilities allowed for the disposal of hazardous waste include "container storage areas, tanks, surface impoundments, waste piles, land treatment facilities, landfills, incinerators, containment buildings, and/or drip pads" (42 U.S.C. 6901 et seq. 1976).

One of the first incidences where the government implemented drastic measures to mitigate hazardous waste was at Love Canal in Niagara Falls, New York, in 1979. Box 5.5 provides a discussion of the issues and mitigation strategies implemented in this incident.

The RCRA also provides whistle-blower protection for employees in the United States who are fired or suffer other adverse actions because of their involvement in the enforcement of the RCRA. Employees have 30 days to file a complaint with the Occupational Safety and Health Administration. For additional information, contact the *National Whistleblower Center* (http://www.whistleblowers.org) or the *U.S. Department of Labor Whistleblower Program* (http://www.whistleblowers.gov/).

### 5.10.12 COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT OF 1980

The *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) of 1990 created the Superfund program, which documents the location of hazardous waste sites identified throughout the United States and tries to determine which organizations are responsible for the dumping of hazardous waste into the identified sites. As of February 27, 2014, there were 1,319 Superfund sites on the *Superfund National Priority List*. A total of 375 sites were removed from the list

### BOX 5.5 HAZARDOUS WASTE MITIGATION

An incident occurred during the 1970s that affected the manner in which the federal government dealt with hazardous waste sites. In Niagara Falls, New York, there was an incident where citizens in a neighborhood were falling ill with cancer and leukemia and there was a high level of miscarriages. The Federal Emergency Management Administration (FEMA) was called in to investigate why there were so many cases of cancer and miscarriages occurring in one neighborhood. Between 1974 and 1978, 56% of the children born to parents living close to a canal, called Love Canal, had birth defects.

After investigating the area, it was discovered that the local grade school had been built over a dumpsite used for decades and no one knew for sure what had been dumped in the area, but there were indications of different toxic chemicals being in the dumpsite.

The regional director of FEMA, Dr. Rita Meyninger, an environmental engineer, recommended to President Carter that the federal government purchase the homes in the surrounding area and move all of the residents out of the area.

This was the first time in the history of the United States that the federal government intervened in a situation involving hazardous waste and allocated funds to move residents out of an infected area. Since Love Canal, other incidences have been discovered where citizens were affected by toxic waste in dumpsites and the federal government has dealt with these incidences in a variety of ways (Meyninger 1994, Yates 2011).

after having been remediated, and 53 new sites were proposed to be added to the list. Figure 5.2 provides a map of the United States showing the Superfund sites as of January 1, 2009.

The *Superfund Amendments and Reauthorization Act* (SARA) of 1986 reauthorized the government under CERCLA to continue cleaning up hazardous waste sites in the United States. It also included Title III, which authorized the *Emergency Planning and Community Right-to-Know Act* (EPCRA).

CERCLA requires the organizations responsible for creating hazardous waste sites to pay for remediation costs, as the situation described in Box 5.6 illustrates.

The asbestos, that is referred to in Box 5.6, is a natural substance mined and used in the manufacture of insulation boards, sheetrock, wallboards, ceiling tiles, floor tiles, and other construction materials. As asbestos breaks down, or it is disturbed by drilling or other means of penetration, it releases a fine dust toxic to humans, but the effects of asbestos exposure may not be apparent for decades. One manifestation of asbestos poisoning is silicosis, which is sometimes a fatal lung disease; therefore, asbestos was banned in Great Britain in 1985 by the Health and Safety Code

**FIGURE 5.2** United States Superfund hazardous waste sites. (From Environmental Protection Agency, *Superfund Hazardous Waste Sites in the United States*, Washington, DC, Accessed on February 1, 2015, http://www.epa.gov/superfund/sites/query/queryhtm/nplmapsn.htm, 2014b.)

of Practice and in the United States in 1970 by the EPA. There are other countries throughout the world still using asbestos in the manufacture of wallboard (sheetrock) for construction. Construction workers in the United States should be aware of the possibility of being exposed to asbestos dust while installing, demolishing, or drilling into wallboard if it was originally installed prior to 1970 or if it was manufactured in a country where asbestos has not been banned by the government.

### 5.10.13 Occupational Safety and Health Communication Standard of 1988

The *Occupational Safety and Health Communication Standard* (Haz Com) was passed in 1988, and it requires all hazardous jobsite substances to be labeled and inventoried through the use of *Material Safety Data Sheets* (MSDSs). In addition, employers are required to train workers on the safe use of hazardous materials by performing the following (Clough et al. 2005, p. 426):

1. Prepare a hazard communication program that includes policies and procedures, a pertinent hazardous substance list, an employee training program, and MSDSs.
2. Conduct classroom or individual training concerning the employer's program and the exposure to hazards.
3. Establish a labeling system to ensure that all containers are properly identified.

### BOX 5.6 HAZARDOUS WASTE REMEDIATION

A firm based in Columbia, Maryland, agreed to pay $250 million, the highest sum in the history of the Superfund program, to help pay the cleanup costs of asbestos contamination in Libby, Montana, as the U.S. Justice Department and EPA announced on March 11. The settlement by the federal bankruptcy court overseeing the reorganization of the firm would settle the federal government's bankruptcy claim against the company. But the settlement does not resolve an ongoing federal criminal case alleging that senior company officials covered up the extent of the contamination in Libby.

The firm was a supplier of specialty chemicals and had owned and operated a vermiculite mine and vermiculite-processing facilities in Libby from 1963 to 1990. The vermiculite ore was contaminated with asbestos, and vermiculite and asbestos have been found in various locations in and around Libby since then. Hundreds of people in Libby have gotten sick or died from asbestos-related illnesses such as lung cancer and mesothelioma.

The EPA has been removing soil contaminated by asbestos and other materials in Libby since May 2000. The federal government filed suit against the firm on March 2001 to recover its cleanup costs through the Superfund program. The firm filed for bankruptcy the same year. Although the federal district court in Montana awarded the EPA more than $54 million for cleanup costs in 2003, that award has not been paid because of the firm's bankruptcy.

The March 11 settlement resolves the 2003 judgment and covers future cleanup costs that the firm might incur. The EPA will place the settlement funds into a special account within the Superfund program that will be used to pay for future cleanup work at the site.

On May 11, 2009, a jury in Libby acquitted the firm, and three of its former executives, of intentional exposure of mineworkers and Libby residents to asbestos (Hunter 2008; U.S. Asbestos Commission 2009).

### 5.10.14 ENERGY INDEPENDENCE AND SECURITY ACT OF 2007

The *U.S. Energy Independence and Security Act* of 2007 was passed to promote energy efficiency and the development of renewable energy sources. The four major provisions of the act are as follows (U.S. Congress 2007):

- Corporate Average Fuel Economy (CAFE): sets a requirement of 35 mpg as the combined fleet average for automobiles and light trucks to be achieved by the year 2020
- Renewable Fuels Standard (RFS): requires that 9 billion gallons of fuel be from renewable sources by the year 2008 and 36 billion gallons by the year 2022
- Energy efficiency equipment standards: sets new standards for lighting and residential and commercial appliances and equipment

- Repeal of oil and gas tax incentives: repeals two previously implemented tax subsidies to help fund the cost of the CAFE

Individual states are also passing environmental legislation relating to global warming, such as the Global Warning Solutions Act (AE 90) passed in the state of California.

### 5.10.15 AMERICA'S PROPOSED CLIMATE SECURITY ACT OF 2007

The *America's Climate Security Act* of 2007 (S. 2191) was introduced in October 2007, but in June 2008 it was not passed by the U.S. Senate. The proposed act was described as a "bill that sets a midterm goal of reducing emissions from the power, industrial, and transportation fuel sectors by 15% in 2020 and 70% by 2050, compared to 2005 emissions levels. These sectors account for about 75% of U.S. GhG emissions. By ratcheting down emissions by nearly 2% per year, the bill would have helped reduce total U.S. GhG emissions by approximately 51%–63% by 2050 from 2008 levels, taking an important step toward the 80% emissions reduction goal the international scientific community says is necessary to limit global warming" (Pew Charitable Trusts 2008, p. 1).

To meet the requirements of this act, methods were proposed for achieving emissions reductions or offsetting emissions with credits. A summary of the methods proposed is as follows (America's Climate Security Act of 2007 2007, p. 16):

- Act creates a *Carbon Market Efficiency Board* (CMEB) that is responsible for implementing cost relief measures if the cost of reducing emissions is higher than the original estimates.
- Act proposes to cut energy requirements of new buildings and homes by 50% by the year 2020 and to adopt new building codes to help meet this requirement.
- Act sets up a *cap and trade* system where there are mandatory limits on $CO_2$. Firms could borrow reductions from future years at 10%.
- After 8 years, the President is allowed to enact requirements that importers of products that create $CO_2$ emissions must submit emissions credits to sell their products in the United States.
- About 15% of allowances could be met by offsets that come from sources not covered by the bill, or they could be satisfied by international trading.
- Firms affected by the act include those that emit more than 10,000 carbon dioxide equivalents of GhGs per year.
- Firms will be required to disclose to the Securities and Exchange Commission their global warming–related financial risks to shareholders.
- Phantom reductions will be hard to verify.
- Pollution allowances will be auctioned off at a rate of 23% by the year 2012 and 73% by the year 2036. The proceeds from the auctions will be used to help workers and states transition to climate-friendly energy sources, help the poor with energy bills, and invest in clean technology.

### 5.10.16 CLIMATE CHANGE LEGISLATION DESIGN: U.S. GOVERNMENT WHITE PAPER OF 2007

The *U.S. Committee on Energy and Commerce and the Subcommittee on Energy and Air Quality* issued a White Paper on Climate Change Legislation Design—Scope of the Cap and Trade Program in 2007 (S. 3036 2008). The white paper discusses legislation that if enacted would require reductions in GhG emissions by 60%–80% by the year 2050. It seeks to stabilize atmospheric GhG concentrations of $CO_2$ equivalents to a level between 450 and 550 ppm. The gases covered include the following (S. 3036 2008):

- Carbon dioxide ($CO_2$)
- Methane ($CH_4$)
- Nitric oxide ($N_2O$)
- Fluorinated gases
- Hydrocarbons (HFCs)
- PFCs [perflourinated compounds]
- Sulfur hexafluoride ($SF_6$)

The toxic effects of some of these GhGs include the following:

> Nitrogen oxides, and sulfur oxides, can be grouped into pollutants, which cause acidification when mixed with water in the air. Acid rain is one effect of acidification, which leads to damage to agriculture, public health, buildings and materials. These pollutants together with suspended particulate matter cause detrimental effects to the human health or human toxicity. Moreover, NOx also causes eutrophication, a phenomenon that depletes the nutrients of the soil, thereby decreasing agricultural productivity. (Gerilla et al. 2007, p. 2782)

In 2012, 85% of all GhG emissions in the United States were caused by carbon dioxide. The percentages of emissions in 2012 for each of the pollutants were (Environmental Protection Agency 2013):

- Hydrocarbons, PFCs, and sulfur hexafluoride: 22%
- Nitric oxide: 5%
- Methane: 7.4%
- Carbon dioxide: 83.9%

The sources of GhG emissions in 2012 were from the following industries (Environmental Protection Agency 2013):

- Electrical generation: 38%
- Transportation: 32%
- Industry: 14%
- Commercial and residential: 6%
- Combustion: 6%

In the industrial sector and the electrical generation sector, GhG emissions were from the following areas (Environmental Protection Agency 2013):

- Petroleum refining: 3%
- Fossil fuel exploration and production: 3%

- Chemical manufacturing: 5%
- Other: 8%
- Coal: 27%
- Natural gas: 4%
- Petroleum: 2%
- Other: 1%

In the electrical power generation sector, power is generated by the following sources (Environmental Protection Agency 2013):

- Coal: 49.7%
- Petroleum: 3%
- Natural gas: 18.7%
- Hydroelectric: 6.5%
- Renewables: 2.3%
- Other gases: 0.4%

Any legislation resulting from the white papers will try to reduce GhG emissions by regulating the firms producing them.

## 5.11 FOREIGN GOVERNMENT ENVIRONMENTAL LAWS

For detailed information on the environmental laws of foreign governments, see the appropriate website for the government agency implementing and enforcing environmental laws. Examples of some of the foreign country environmental websites are the following (World Bank 2008; individual country government websites):

- Australia: Department of the Environment and Heritage, http://www.environment.sa.gov.au/
- China: State Environmental Protection Administration, http://english.sepa.gov.cn/
- Egypt: Ministry of State for Environmental Affairs, http://www.eeaa.gov.eg/English/main/about.asp
- India: Ministry of the Environment, Forests and Climate Change, http://envfor.nic.in/
- Japan: Ministry of the Environment, http://www.env.go.jp/en/
- Jordan: Ministry of Municipal and Rural Affairs and the Environment, http://www.environment.gov.jo/main.html
- Kenya: Ministry of Tourism and Wildlife, http://www.tourism.go.ke/ministry.nsf
- Russia: Federal Service for Hydrometeorology and Environmental Monitoring, https://www.mnr.gov.ru/english/
- Saudi Arabia: The Meteorology and Environmental Protection Administration, http://www.saudinf.com/main/c75.htm
- United Kingdom: Department for Environment, Food, and Rural Affairs, http://www.defra.gov.uk/

The International Network for Environmental Compliance and Enforcement (2015) provides a *Directory of Web Sites of Environmental Agencies of the World* on its website (http://www.inece.org/links_pages/onlineresourcesEnvironmentalagencies.html), and international environmental agencies are also listed in the book *World Directory of Environmental Organizations* (Trzyna and Didion 2001).

One example of how foreign governments are addressing sustainability issues is the Government Program for Ecologically Sustainable Construction enacted by the Finnish government. This program provides the construction and real estate sectors with targets and required actions implemented in 1998. It is the foundation for the *Land Use and Building Act*, which "promotes sustainable development, reduces environmental hazards, and conserves natural resources" (European Commission Enterprise 2001, p. 1). This Finnish legislation is one of the most stringent laws being used to minimize damage to the environment by monitoring the consumption of energy, raw materials, emissions, and waste.

## 5.12 SUMMARY

This chapter provided background information on environmental laws affecting engineering design and construction operations. There are numerous other laws enacted by both the United States and foreign governments, but the laws mentioned in this chapter are some of the ones directly affecting the work of engineers and constructors. The first part of the chapter included information on the global treaties affecting sustainability, such as the Kyoto Protocol, Basel Convention, Rio Declaration, and Stockholm Convention, and it discussed the mechanisms used for environmental compliance.

The second part of the chapter explained the EPA laws affecting the E&C industry, including laws on procurement; environmental quality; clear air; noise pollution; water pollution; insecticides, fungicides, and rodenticides; solid waste disposal and recovery; and the Superfund program.

The Occupational Safety and Health Communication Standard was also included in this chapter because it relates to the health effects addressed through sustainability. Two pending and passed government acts were mentioned that affect the use of energy and the creation of GhG emissions. Information was also provided on where to locate environmental laws in foreign countries.

## 5.13 KEY TERMS

Acid deposition control
Affirmative Procurement Program
Air Pollution Control Act
Air Quality Act
America's Climate Security Act
Asbestos
Basel Convention
Cap and trade
Carbon Market Efficiency Board

Carbon monoxide
Carbon sinks
Clean Air Act
Clean development mechanism
Clean Water Act
Comprehensive Environmental Response, Compensation, and Liability Act
Comprehensive procurement guidelines
Conference of the Parties
Council on Environmental Quality
Emergency Planning and Community Right-to-Know Act
Emission credits
Emissions trading
Environmental impact assessments
Environmental impact statements
Environmental Protection Agency
Executive Order 13,101
Ecotoxic
Federal Aviation Administration
Federal Emergency Management Administration
Federal Insecticide, Fungicide, and Rodenticide Act
Federal Service for Hydrometeorology and Environmental Monitoring
Federal Water Pollution Act
Government Program for Ecologically Sustainable Construction
Greenhouse gases
Hard laws
Hazardous and Solid Waste Act
Hydrofluorocarbons
Intergovernmental Panel on Climate Change
International Court of Justice
International customary laws
International Network for Environmental Compliance and Enforcement
International Organization for Standardization
Joint implementation practices
Kyoto Protocol
Labeling of Hearing Protection Devices Regulation
Land Use and Building Act
Material Safety Data Sheets
Motor Vehicle Air Pollution Control Act of 1965
National Ambient Air Quality Standards
National Environmental Policy Act
National Pollutant Discharge Elimination System
National Whistleblower Center
Nitrous oxide
Noise Pollution Act
Occupational Safety and Health Communication Standard
Office of Research and Development

Strategic Plan
Ozone layer
Perfluorocarbons
Persistent organic pollutants
Radiological health
Resource Conservation and Recovery Act of 1984
Rio Declaration
Soft laws
Solid Waste Disposal Act of 1965
State Environmental Protection Administration
Stockholm Convention
Sulfur hexafluoride
Superfund Amendments and Reauthorization Act
Superfund National Priority List
Toxic Substance Control Act
U.S. Energy Independence and Security Act
U.S. Committee on Energy and Commerce and the Subcommittee on Energy and Air Quality
U.S. Department of Labor Whistleblower Program
U.S. Public Health Service
U.S. Secretary of Health and Human Services
United Nations Framework Convention on Climate Control
World Health Organization

## 5.14 DISCUSSION QUESTIONS

5.1 Discuss why the incident at Love Canal related to the toxicity of hazardous waste is an important case in the history of U.S. environmental policies.
5.2 Discuss the responsibilities of the Council on Environmental Quality.
5.3 Which federal law impacts the generation of hazardous waste, and how does it impact it?
5.4 Which law helps protect the citizens of one state from air pollution generated in another state?
5.5 Which agency regulates (1) noise pollution and (2) the noise pollution generated by airplanes?
5.6 If a country does not meet its target emissions reductions, as set by the Kyoto Protocol, what sanctions are available to help enforce the target emissions?
5.7 Which law sets emissions standards for vehicles in the United States? Discuss whether states are allowed to enact more stringent requirements than federal standards and why they would require them.
5.8 Discuss how engineers are involved in environmental impact statements.
5.9 How is the Superfund program involved in the remediation of hazardous waste dumpsites included in it?
5.10 Discuss how pesticides are regulated in the United States and which law requires this form of regulation.

5.11 Discuss how the interstate highway system was established in the United States and why it led to the proliferation of air pollution problems.
5.12 What effect does the Kyoto Protocol have on the U.S. construction industry?
5.13 If the President of the United States, or a member of his or her staff, needed to obtain information about the potential hazards of a proposed project, which agency would assist him or her and how would the members of this agency provide assistance?
5.14 Discuss how the Environmental Protection Agency tries to regulate oil spills and what types of sanctions the agency has available when oil spills occur.
5.15 Discuss why it is necessary for engineers and constructors to know about sustainable practices and how they are affected by sustainability.
5.16 Explain emissions trading and carbon sinks and how they affect climate change.
5.17 Explain what vehicle emissions tests are and why they are required for vehicles in some of the states in the United States.
5.18 Which industries generate the highest level of greenhouse gas emissions?
5.19 How are environmental impact statements used by the U.S. federal government?
5.20 Explain how the National Environmental Policy Act of 1969 affects engineers when they are designing projects.

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# 6 Life-Cycle Cost Assessment Models

*Life-cycle environmental and cost analysis* includes evaluating how a structure is designed and constructed, how the materials used to build it are extracted and processed, how the transportation systems are used to supply the project with materials, what is required to operate and maintain the structure, and the effect the materials have on human health and environmental quality. Before materials are ordered they are evaluated to determine whether they are available locally, and if they are locally sourced it reduces the carbon dioxide emitted when materials are transported over long distances. Efficiently using materials, eliminating excessive waste, and reducing the requirement to bury leftover materials in landfills are goals incorporated into plans for site development and construction operations. Renewable materials should also be evaluated for use in construction projects.

The construction industry consumes 40% of the total energy used in the United States during the manufacture, construction, operation, and disposal of construction materials. This estimate was developed using *life-cycle assessment* techniques and by accounting for the extraction, processing, manufacturing, demolishing, and disposal of construction materials (Munier 2005).

To demonstrate the use of life-cycle cost assessment (LCCA) techniques, this chapter discusses economic considerations, computer software for sustainability assessment, life-cycle assessment processes, and a method for calculating the emissions caused by transporting materials.

## 6.1 ECONOMIC CONSIDERATIONS

There is a correlation between environmental and sustainability performance and shareholder value as measured by indices such as the Dow Jones Sustainability Group Index and the *FTSE4Good.* The FTSE4Good index series was developed to measure the performance of companies demonstrating strong environmental, social, and governance practices and meeting globally accepted corporate responsibility standards (Andrews and Slater 2002).

The article “A Facility Manager’s Approach to Sustainability” by Hodges (2005) states that designers should consider both *life-cycle cost* (LCC) and *total cost of ownership* in assessing green alternatives. The specification and installation of green materials is not the only criterion for assessing green structures, as the durability and the effects of materials on total cost of ownership should also be analyzed before they are selected for inclusion in structures (Hodges 2005).

One example provided by Donald McFadden on how, in addition to specifying and installing green materials, other criteria for assessing green structures are used for construction projects is the following.

In the preconstruction phase, the evaluation of the lighting zone, building orientation, and the use of sunlight as an energy source for renewable energy (electricity and heating water) and natural light for interior lighting are all areas to be examined to determine whether they meet sustainability criteria. The use of sunlight and natural light helps reduce energy demand and the operating costs of buildings. Submetering of tenants to monitor energy consumption and control lighting systems by floor or tenant encourages the use of lighting only when it is necessary. Automatic zone lighting controls on the building perimeter (with natural light) and motion sensors for interior areas with low natural light are also techniques for reducing energy consumption.

Having building occupants use public transportation minimizes requirements for parking areas. This also reduces the number of vehicles on the road and requirements for the production, installation, and maintenance of rigid and flexible pavement materials; requirements for storm water runoff management; and parking lot lighting systems and their associated costs. The parking occupant to parking spot ratio should be sized taking into consideration public transportation. Preferential parking could be used to encourage building occupants to drive green vehicles and to participate in automobile pools and vanpools.

Post-construction building-enhanced commissioning and post-occupancy commissioning programs are used to ensure that building systems are working as designed and in concert with one another with the greatest efficiency. Commissioning provides a quality assurance program to ensure that all building components work together to achieve environmental health, energy efficiency, and occupant safety, and to improve indoor air quality by ensuring that building systems are working correctly.

Water management systems could be installed to reduce operating costs. Storm water retention ponds are used for landscaping, and a gray water system is used for toilets and urinals. Lavatory faucets should have timers automatically turning them off when they are not being used by anyone. Other sustainable practices include installing low-flow faucets, drought-resistant and local and regional landscaping and associated irrigation systems, metering water use by building and tenant, and installing leak-monitoring systems.

In addition to evaluating the durability of materials, the service life of materials should also be evaluated because it provides a more efficient evaluation method for selecting among alternatives based on their LCCs (Hodges 2005). One example of how durability has a direct effect on the useful life of a structure and the LCCs associated with it is included in the following business case.

The business case for a company to construct an office building is for a structure with a 75-year useful life. Members of architectural and engineering firms design for and specify sustainable materials not considering that they only have a useful life span of 50 years. The alternative is materials that are not sustainable with a useful life of 100 years at twice the cost and twice the environmental impact.

The operations and maintenance cost for the structure using sustainable materials for years 51–75 may be greater in terms of cost and environmental impact than using materials that are not sustainable alternatives, but that have a longer life span. If the structure requires major renovation and replacement on a large scale, there would be duplicate costs and impacts for extraction, processing, manufacture, and installation of replacement materials. There might be additional costs associated with the demolition and disposal of failed materials to ensure that the structure continues to function safely as originally designed by the architect or engineer. Or, the structure might have to be replaced resulting in a new construction project.

According to Hodges (2005), green and sustainable do not necessarily mean lasting a long time since sustainable design processes do not always consider material durability. When incorporating sustainable practices, an evaluation of both the durability of materials and service life should be included in the overall strategy of an organization. Sustainable practices might lead to lower operating and maintenance costs, even if they are more expensive to install during construction.

Before firms switch to sustainable practices, three basic questions should be addressed (Ayres 1993, p. 190):

1. Is economic growth compatible with long-term ecological sustainability?
2. If so, is there a plausible mix of technologies and economic instruments that would be compatible with long-term sustainability?
3. What is the least-cost (and least-pain) political/institutional path to a sustainable world economy?

In the United Kingdom, in 2000 a conference was held on sustainable construction, and as a result of the conference, the following indicators were developed and they are being used for assessing LCCs in the construction industry (European Commission Enterprise—Industry Sectors: Construction: The United Kingdom 2001, p. 1):

- Biodiversity
- Embodied energy
- Operational energy
- Transport energy
- Waste
- Water

## 6.2 COMPUTER SOFTWARE FOR SUSTAINABILITY ASSESSMENT

In Europe, there are a vareity of computer software programs being used by members of government agencies to assess the environmental aspects of structures. Table 6.1 provides a list of some of the computer software programs being used in Europe, with the country of origin listed next to the name of the software program along with a brief description of the software program. (European Commission Enterprise—Industry Sectors: Construction: Finland 2001).

A new thematic network called E-CORE—*European Construction Research Network*—established a European research network defined in the *Communication of Commissioner Busquin* for the construction industry. Table 6.2 contains examples of thematic networks developed to address sustainability issues.

## TABLE 6.1
## Computer Software for Sustainability Assessment

| Software Name and Country | Brief Description of the Software Program |
|---|---|
| BEAT—Denmark | Software program for performing environmental assessments for products, building elements, and buildings.<br>Consists of databases containing data for energy sources, transportation methods, products, building elements, and buildings.<br>Contains a user interface that allows users to add, edit, and delete data in the databases.<br>Contains an inventory tool that permits users to perform calculations for products, building elements, and buildings.<br>http://www.dbur.dk |
| EcoEffect—Sweden | Calculates and assesses environmental loads caused by buildings during their lifetime.<br>Based on life-cycle analysis.<br>http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0CCYQFjAB&url=http%3A%2F%2Fwww.ecoeffect.se%2FIA05Hult416050215.doc&ei=XErRVPzBFcy4ggSL9IOICw&usg=AFQjCNHvN_qsWcFWhpI2672u2XJeo9Fn3g&bvm=bv.85076809,d.eXY |
| Eco-Install—Netherlands | Calculates the integral environmental effect of structures based on their civil construction.<br>Environmental analyses use life-cycle analysis, and the results are used for conceptual choices in the design stage.<br>http://res.illumina.com/documents/documentation/install_instructions/eco_v3.0_upgrade_instructions.pdf |
| EcoPro—Germany | A calculation tool used to help optimize material mass, energy flows, and the costs during early planning processes.<br>Uses element methods and life-cycle analysis.<br>http://www.ecodesign.at/methodik/software/index.en.html |
| EcoProP—Finland | Used for the settling of performance-based requirements for building construction projects.<br>The application is used during the project planning phase and to add targets and goals.<br>Based on generic and holistic building properties.<br>http://www.constructiondurable.com/docs/LogicielEcoProP_2301%20 2008.pdf |
| Eco-Quantum Greencalc—Netherlands | Quantifies the environmental performance of buildings, using life-cycle analysis methods.<br>In the design phase, the program clarifies the sustainability of buildings.<br>http://www.greencalc.com/ |
| EcoSoft—Switzerland, Austria, and Germany | Calculates the ecological performance during the erection of buildings.<br>Uses data from Switzerland, Austria, and Germany.<br>It results in classification factors such as greenhouse potential or primary energy consumption that is renewable and nonrenewable.<br>http://www.ibo.at/en/ecosoft.htm |

### TABLE 6.1 (*Continued*)
### Computer Software for Sustainability Assessment

| Software Name and Country | Brief Description of the Software Program |
|---|---|
| Ecotech—Germany and Austria | This software program calculates the physical, technical, ecological costs, and economics of buildings with an interface to CAD programs.<br>Life-cycle analysis data are integrated for the ecological assessment.<br>http://www.ecotech.cc |
| OI3-Index—Austria | Used for social housing subsidies in Austria that deal with nonrenewable primary energy, GWP, and the AP of building materials that interface to other programs used for building physics.<br>Part of the calculations is for heating energy consumption.<br>www.oebox.at |
| Envest2 and IMPACT—United Kingdom | Simplifies the process of designing environmentally friendly buildings.<br>Designers input their building design (height, number of stories, window area, etc.) and choices of elements are provided that have the most influence on the building's environmental impact.<br>The program demonstrates the effects of selecting different materials.<br>Also predicts the environmental impact of various strategies for heating, cooling, and operating a building.<br>http://www.bre.co.uk/page.jsp?id=2181 |
| Equer—France | Simulation tool that helps to predict the environmental consequences of design choices over the life cycle of buildings.<br>The life-cycle assessment methodology accounts for environmental impacts during different phases such as fabrication of materials, construction utilization, renovation, and demolition, and it is linked with a thermal simulation tool.<br>http://catalog.elra.info/product_info.php?products_id=996 |
| GEQ—France | Gebaude.Energie.Qualitat is designed for calculating energy building certifications.<br>Used to calculate classification factors, greenhouse potential, primary energy consumption that is renewable, and AP.<br>http://www.zet.at |
| LEGEP—Germany | Design tool within a CAD system, with integrated quantity surveying, energy calculations, and life-cycle analysis.<br>www.legep.de |
| OGIP—Switzerland | Instrument for realizing an architecturally and environmentally optimized project within given costs.<br>http://www.empa-ren.ch/ren/Projekte_Umwelt/Pdf%20Umwlt/ogip%20description.pdf |
| TEAM—International | Used for environmental evaluations of buildings based on life-cycle analysis.<br>http://www.ecobilan.com |

*Source:* Created by the authors from various sources.

*Note:* AP, acidification potential; CAD, computer-aided design; GWP, global warming potential.

**TABLE 6.2**
**Thematic Networks in the Construction Sector**

| Acronym | Activity |
|---|---|
| ETN Recy.net | Using recycled materials as aggregates in the construction industry |
| PRESCO | Practical recommendations for sustainable construction |
| DURANET | Network for supporting the development and application of performance-based durability design and assessment of concrete structures. |
| TENSINET | Upgrading the built environment in Europe through tensile structures |
| ENERBUILD | Energy in the built environment |
| CRISP | Construction- and city-related sustainability indicators |

*Source:* Adapted from E-CORE European Construction Research Network, *E-CORE Databases, Thematic Networks*, Brussels, Belgium, Accessed on January 12, 2015, http://www.ecore.org/index1.asp?nav=information, 2014.

## 6.3 LIFE-CYCLE ASSESSMENT PROCESSES

Figure 6.1 shows a sustainability life-cycle assessment process used in Holland to perform life-cycle assessments.

Life-cycle assessment processes contain three phases (European Commission Enterprise—Industry Sectors: Construction: The United Kingdom 2001, p. 1):

1. Production phase: the production of building products, from the extraction of raw materials, transportation to the factory, and production of products that are not finished to the finished product at the factory gate.
2. Construction phase: all the activities involved, starting with transportation of products to the building site, construction, maintenance, and replacement and ending with demolition. Each activity involves products (such as façade components), subsidiary activities (such as hoisting), accessories (such as props), equipment (such as hoists), and waste that requires disposal.
3. Disposal phase: from the transportation of demolition materials to final disposal (dumping, incineration, recycling, or reuse).

Figure 6.2 shows the total life-cycle assessment continuum for structural components. During the phases shown in Figure 6.2, the environmental performance of each component, along with the waste it generates, is assessed and the sum total of all of the phases provides an indication of the environmental performance of a structure.

In 2004, Andriantiatsaholiniaina et al. (2004, p. 150) developed a Sustainability Assessment by Fuzzy Evaluation (SAFE) model that "uses fuzzy logic reasoning and basic indicators of environmental integrity, economic efficiency, and social welfare, and derives measures of human (HUMS), ecological (ECOS), and overall sustainability (OSUS)." For additional information about this model, see the article (Andriantiatsaholiniaina et al. 2004), which explains how to evaluate sustainability using fuzzy evaluation.

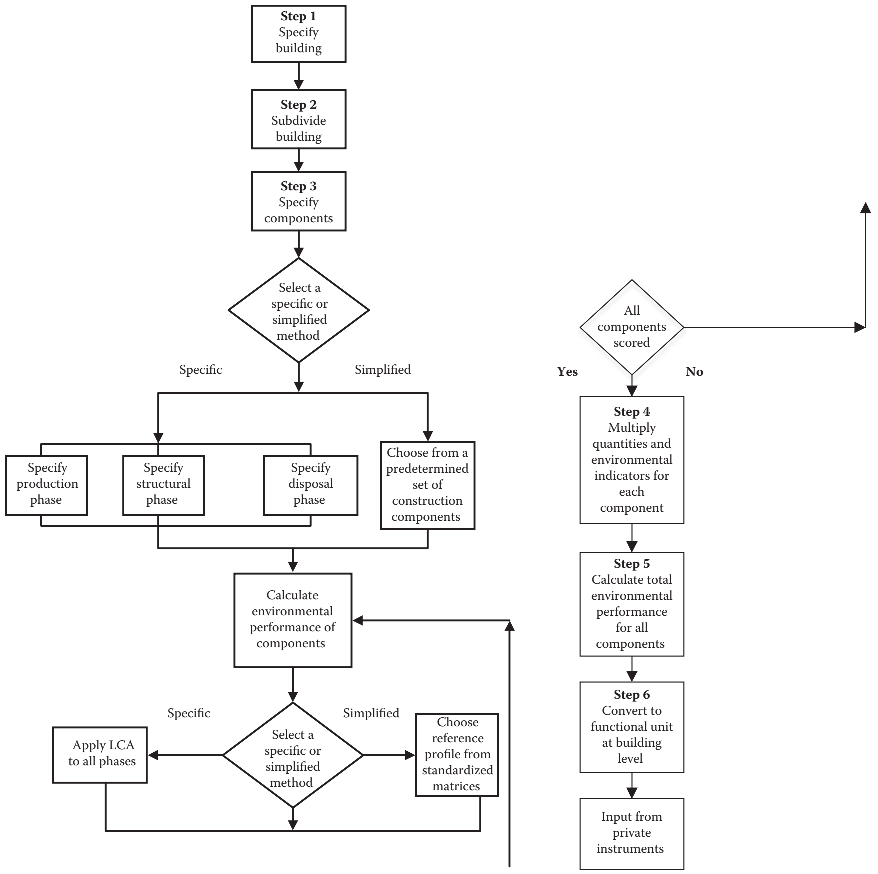

**FIGURE 6.1** Sustainability assessment process used in Holland. LCA, life-cycle assessment. (Adapted from European Commission Enterprise—Industry Sectors: Construction: The Netherlands, *Best Practices and Development*, European Commission, Brussels, Belgium, 2001.)

In the article "A Framework for Life Cycle Cost Assessment of Composites in Construction," The authors provide information on life-cycle costing. Life-cycle costing is defined as

> economic assessment of an item, area, system, or facility, considering all significant costs of ownership over its economic life, expressed in terms of equivalent dollars. In generic terms, LCC would include initial cost, maintenance costs, operating costs, replacement or refurbishment cost, retirement and disposal (decommissioning) cost, and other costs such as taxes, depreciation, and additional management costs. However, for infrastructure facilities, LCC may also include in addition to the ownership costs, the costs to the users of the structure as well as costs to others who are not direct users of the structure but are impacted by the infrastructure facility. (Hastak 2003 et al. p. 1409)

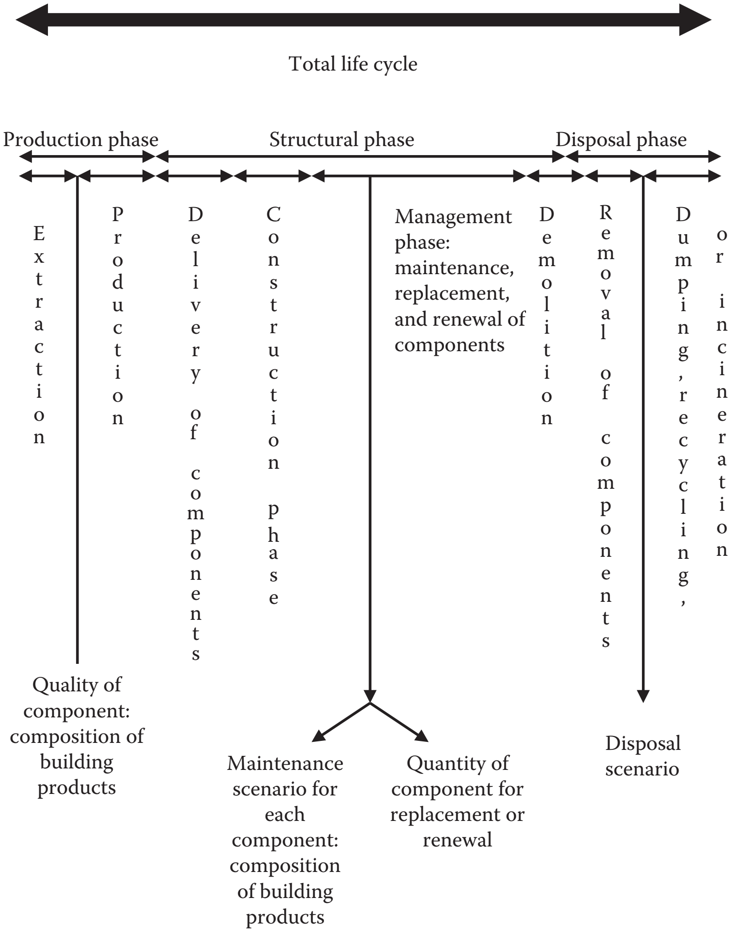

**FIGURE 6.2** Total life-cycle continuum used in Holland for structural components. (Adapted from European Commission Enterprise—Industry Sectors: Construction: The Netherlands, *Best Practices and Development*, European Commission, Brussels, Belgium, 2001.)

Engineers and constructors should consider evaluating projects using LCCAs because they are an important measure of the investment that an individual, a corporation, or a government agency has in a structure or an infrastructure from project initiation to disposal. Life-cycle cost assessments include initial, maintenance, operating, replacement, renovation, retirement, disposal, and decommissioning costs. In addition, they include direct costs, indirect costs, and depreciation.

When considering LCCAs, the effects of inflation or deflation should also be considered. For example, the cost and production of paving materials are projected to change over the next 50 years. The cost of concrete is projected to drop by 20% because of improvements in concrete mixes, reduced environmental impacts, production efficiencies, and performance improvements. The cost of flexible asphalt pavement materials is projected to increase by 95% due to the increasing demand for oil in emerging economies, political uncertainty in oil-producing regions of the world, and environmental cost. Engineers and constructors should be concerned because their business, and the needs of their customers, will be affected over time by the relative decrease in the cost of concrete and the increase in the cost of asphalt that will be drivers for initial, maintenance, operating, replacement, renovation, retirement, disposal, or decommissioning costs.

Additional sustainability considerations included in life-cycle assessments are listed in Chapter 7 in Section 7.2.

### 6.3.1 Emergy Accounting and Emdollars

Other methods for accounting for externalities are called *emergy* accounting and *emdollars*. Emergy is a term developed to encompass embodied energy, and it uses emdollars as the economic equivalent to emergy. These terms are used to measure the value of an activity not by using its market value but by using the amount of available energy required for its manufacture, production, marketing, and other activities (Munier 2005). Embodied energy is defined as "the energy consumed in all activities necessary to support a process, including upstream processes. Embodied energy is divided into two components, the direct energy requirement and the indirect energy requirement. Direct energy includes the inputs of energy purchased from producers used directly in a process (including in the case of a building the energy to construct it). Indirect energy includes the energy embodied in inputs of goods and services to a process, as well as the energy embodied in upstream inputs to those processes" (Treloar 1997, p. 375).

### 6.3.2 Social Cost/Benefit Analysis

In addition to the methods mentioned previously, there are standard methods for preparing a *social cost/benefit analysis*, and they include the following steps:

1. Define the scope of the project. Explain the rationale and the objectives, and identify who will be the beneficiaries of the project.
2. Identify the project constraints. These may pertain to administrative, environmental, financial, legal, physical, or other constraints.
3. Identify all of the potential alternatives including the "do nothing" alternative.
4. Determine the project useful life and the discount rate to be used for the analysis some firms use the minimum attractive rate of return. Public sector projects typically use a rate of 5%–10% per year.
5. Identify the costs and benefits. The costs and benefits are incremental and accrue to both the providing authority and all external parties. The use of a balance sheet is the preferred method as it eliminates the possibility of double counting.
6. Evaluate all of the costs and potential benefits, and convert them into monetary amounts if possible.

7. Calculate the net present value using time value of money analysis techniques. The costs and benefits should be in yearly cash flows and the net benefits (benefits minus cost) are calculated for each year and discounted back to year 0. The sum of the discounted values is the net present worth.
8. Analyze the risks associated with the project. Test the sensitivity of all of the alternatives to changes in variables or assumptions by using sensitivity analysis.
9. Determine the impact of the alternatives on different community or regional groups.
10. Explore all of the environmental issues related to the project.

## 6.4 EMISSIONS DURING THE TRANSPORTATION OF CONSTRUCTION MATERIALS

When calculating the emissions produced while transporting materials, it is important to remember that transporting materials over long distances by ship or rail could produce lower levels of emissions than using regional materials transported by diesel-powered trucks.

Life-cycle costing includes evaluating a facility from the purchase of raw materials, the transporting of the raw materials to where they are processed into building materials, the transporting of the building materials to the facility where they will be installed, and the resources required to salvage any products as waste. Equations 6.1 through 6.3 are used to estimate the total emissions generated while transporting materials (Gerilla et al. 2007, p. 2781):

$$\frac{\mathrm{EF_c} = (E_\mathrm{s} \times W_\mathrm{u} \times V_\mathrm{a} \times P_\mathrm{u})}{Y} \tag{6.1}$$

$$\frac{\mathrm{EF_m} = (E_\mathrm{s} \times W_\mathrm{u} \times V_\mathrm{a} \times P_\mathrm{u} \times K) \times [(Y_\mathrm{m} / Y) + 1]}{100} \tag{6.2}$$

$$\mathrm{EF_a} = (E_\mathrm{s} \times W_\mathrm{u} \times V_\mathrm{a} \times D_\mathrm{p}) \times [(1/Y) - K/(Y_\mathrm{m} \times 100)] \tag{6.3}$$

where

$\mathrm{EF_c}$ is the pollutant emission factor for construction (kg of pollutant/year in $\mathrm{m}^2$).
$\mathrm{EF_m}$ is the pollutant emission factor for maintenance (kg of pollutant/year in $\mathrm{m}^2$).
$\mathrm{EF_a}$ is the pollutant emission factor for disposal (kg of pollutant/year in $\mathrm{m}^2$).
$E_\mathrm{s}$ is the specific emission (kg of pollutant/1000 $\mathrm{m}^3$).
$W_\mathrm{u}$ is the unit weight ($\mathrm{kg/m}^3$).
$V_\mathrm{a}$ is the material volume per unit area ($\mathrm{m}^3/\mathrm{m}^2$).
$P_\mathrm{u}$ is the unit price of material ($ or other currency/kg).
$Y$ is the design life (years).
$Y_\mathrm{m}$ is the refurbishing/rebuilding cycle (years).
$K$ is the temporary repair rate for preventive maintenance (%/year).
$D_\mathrm{p}$ is the unit price of discarded material ($ or other currency/kg).

One example of how life-cycle assessment techniques are used to estimate the energy consumed by the transportation of materials in the construction industry, provided by Donald McFadden, is the following. This life-cycle assessment example includes energy consumed to transport raw materials to a processing plant, from the processing plant to a distributor, from the distributor to the construction site, and to a disposal site at the end of the useful life of the project.

When materials are sourced, the locality of the material is considered to mitigate the transportation energy consumed, the cost of transportation, and transportation emissions. The distance from the source is not necessarily a measure of efficiency in transportation. The method of transportation has a large impact on the transportation energy consumed and its cost. For example, how could aggregate needed in New Orleans and produced in St. Louis, Missouri (821 river mi. or 1,321.7 km), be cheaper than aggregate produced in Waco, Texas (560 road mi. or 901.2 km)? One answer is efficiency in the process, of which transportation energy and cost big considerations. Table 6.3 provides the energy consumed by major freight transportation methods and their efficiency in terms of British thermal units (BTUs) to move one ton of freight one mi. The answer is the aggregate from St. Louis, Missouri, should be moved by either barge or rail because the energy consumption per ton is 1/10 and 1/7 the energy required to move the same ton by truck from Waco, Texas.

Figures 6.3 through 6.7 show the different emissions for each life-cycle stage for a sample construction project for either wood and steel-reinforced concrete (SRC). According to Gerilla et al. (2007, p. 2782), for the comparison of wood versus steel-reinforced concrete "the carbon emissions from the construction stage were only

## TABLE 6.3
## Energy Consumed by Major Freight Transportation Methods

| Year | 1980 | 1990 | 2000 | 2006 | Percentage Change from 1980 to 2006 |
|---|---|---|---|---|---|
| Trucks BTU per vehicle-mile | 24,757 | 22,795 | 23,448 | 23,340 | –5.7% |
| Trucks BTU per ton-mile | 4,266 | 3,929 | 4,040 | 4,070 | –4.5% |
| Rail class I BTU per ton-mile | 18,741 | 16,610 | 14,917 | 14,900 | –20.0% |
| Rail class I BTU per ton-mile | 567 | 420 | 352 | 230 | –44.7% |
| Ships BTU per ton-mile | 358 | 387 | 475 | 571 | 59.8% |

*Source:* Adapted from Vehicle Technologies Office—Department of Energy's Office of Energy Efficiency and Renewable Energy, *Transportation Energy Data Book*, Center for Transportation Analysis, Energy and Transportation Science Division, Oak Ridge National Laboratories, Oak Ridge, Tennessee, Accessed on January12, 2015, http://cta.ornl.gov/data/tedb33/Edition33_Full_Doc.pdf, 2008.

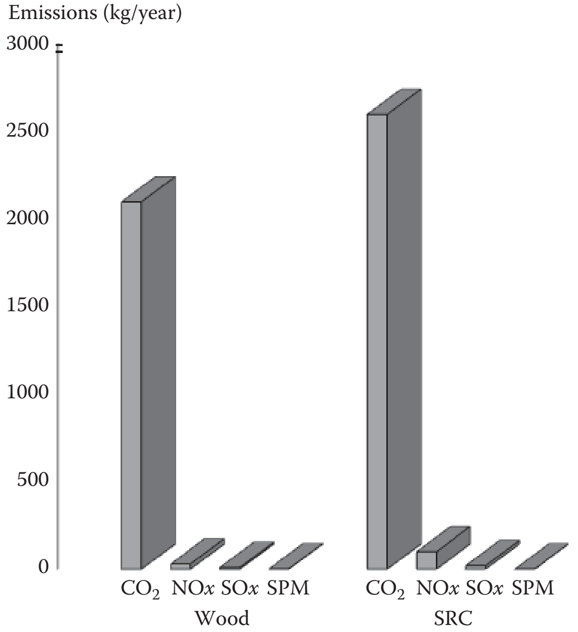

**FIGURE 6.3** Total life-cycle emissions for wood and steel-reinforced concrete construction. SPM, suspended particulate matter. (Adapted from Gerilla et al., *J. of Bldg. and Env.*, 42(7), 2778–2784, 2007.)

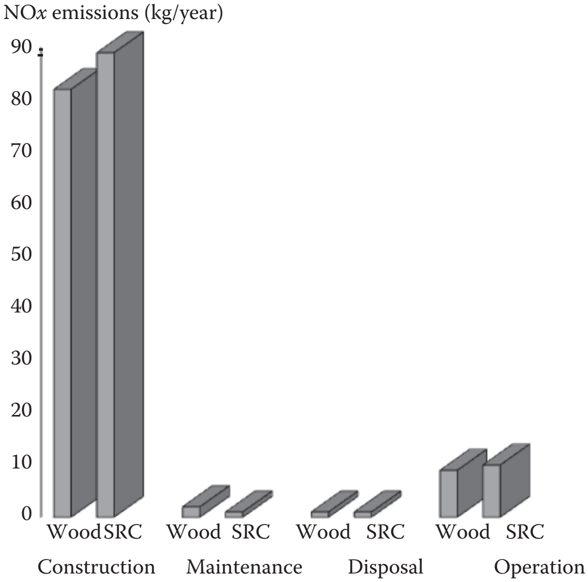

**FIGURE 6.4** Total life-cycle $NO_x$ emissions for each life-cycle stage for wood and steel-reinforced concrete. (Adapted from Gerilla et al., *J. of Bldg. and Env.*, 42(7), 2778–2784, 2007.)

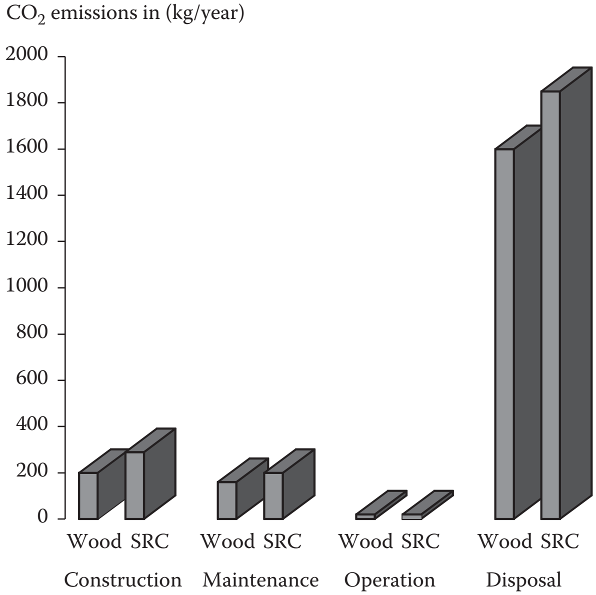

**FIGURE 6.5** Total life-cycle carbon emissions for each life-cycle stage for wood and steel-reinforced concrete. (Adapted from Gerilla et al., *J. of Bldg. and Env.*, 42(7), 2778–2784, 2007.)

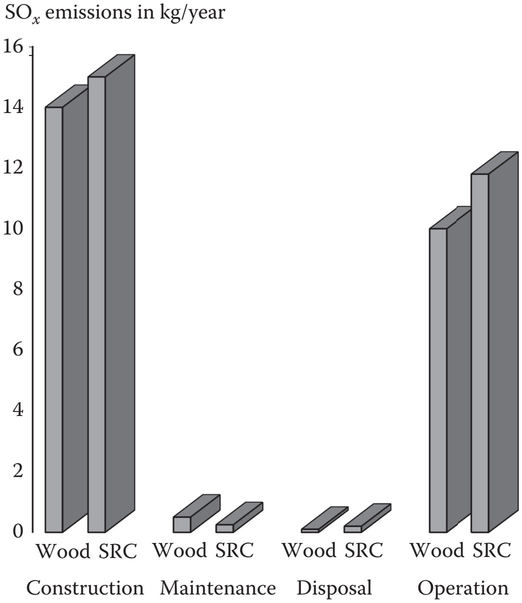

**FIGURE 6.6** Total life-cycle sulfur oxide ($SO_x$) emissions for each life-cycle stage for wood and steel-reinforced concrete. (Adapted from Gerilla et al., *J. of Bldg. and Env.*, 42(7), 2778–2784, 2007.)

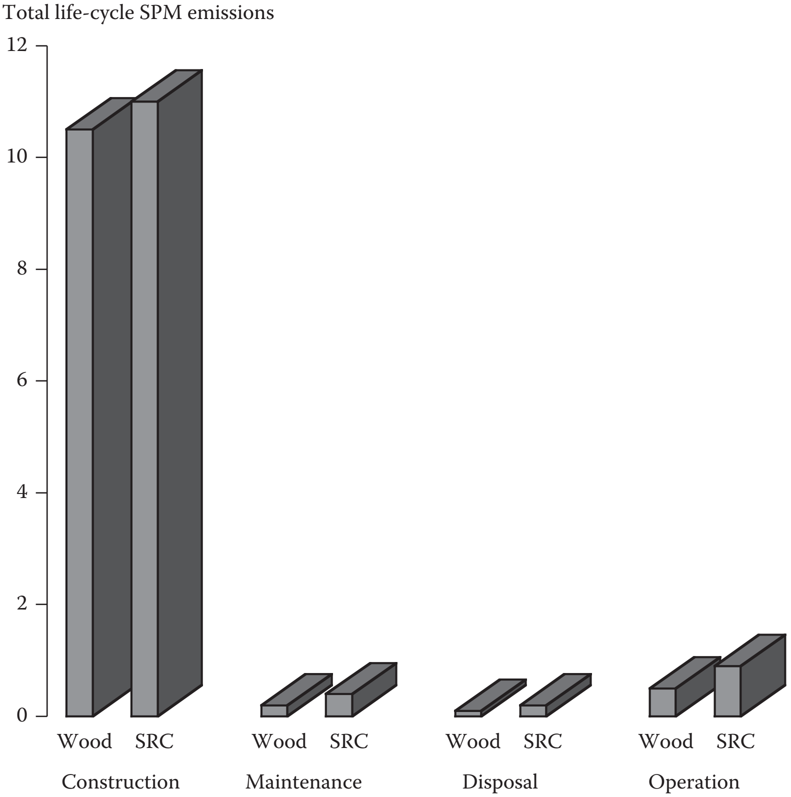

**FIGURE 6.7** Total life-cycle suspended particulate matter (SPM) emissions for each life-cycle stage for wood and steel-reinforced concrete. (Adapted from Gerilla et al., *J. of Bldg. and Env.*, 42(7), 2778–2784, 2007.)

about 12% of the total life cycle, whereas maintenance and disposal only had around 9% of the total carbon emissions. The biggest contributor to this pollutant was the construction stage with about 87% (wooden) and 86% (SRC) contributions to the total emissions. The construction stage was also the largest generator of sulfur oxide emissions, with about 58% of the total emissions, whereas the operation phase had about 40% of the total emissions. About 92% of the total SPM emissions are generated in the construction phase."

## 6.5 SUMMARY

This chapter explained life-cycle environmental cost analysis and discussed the economic considerations evaluated when making sustainability decisions. In addition, information was provided on a variety of different computer software programs used to assess the environmental aspects of structures. The life-cycle assessment process was illustrated using figures from the European Commission Enterprise, and formulas were provided for calculating emissions during the transportation of materials.

Several examples were provided to illustrate the concepts covered in this chapter. Embodied energy was mentioned in this chapter, and it is discussed in more detail in Chapter 1 in Section 1.7.12a.

## 6.6 KEY TERMS

Emdollars
Emergy
European Construction Research Network
FTSE4Good
Life-cycle assessment
Life-cycle cost
Life-cycle environmental and cost analysis
Pollutant emission factor
Social cost/benefit analysis
Total cost of ownership

## 6.7 DISCUSSION QUESTIONS

6.1 Discuss why the durability of materials should be considered when evaluating sustainable materials.
6.2 Discuss how life-cycle assessment techniques are used to estimate the energy consumed during the transportation of materials in the construction industry.
6.3 Explain the total life-cycle continuum used in Holland for structural components in Section 6.2 in Figure 6.1 in words.
6.4 Discuss the purpose of a social cost/benefit analysis.
6.5 Discuss why life-cycle cost assessments should be used by engineers and constructors.
6.6 In the BEAT Danish computer software program, what is included for assessing products, building elements, and buildings?
6.7 Summarize and analyze the data provided in Figures 6.3 through 6.7 in relation to using wood versus steel-reinforced concrete, and use them to explain which material should be selected for inclusion in a construction project.
6.8 Explain how the formula for estimating total emissions generated while transporting materials could be used in life-cycle cost analysis.
6.9 Discuss the indicators used for assessing life-cycle cost developed in the year 2000 in the United Kingdom.
6.10 Discuss the three phases of the life-cycle assessment process.
6.11 In addition to the specification and installation of green materials, what other criteria for assessing green structures should be used for construction projects?
6.12 Explain the difference between emergy and emdollars.
6.13 Discuss what is included in the transportation of materials in life-cycle cost analysis.

6.14 Discuss what is included in a life-cycle environmental and cost analysis.
6.15 Discuss how the Envest computer software program assists designers in designing environmentally friendly buildings.

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# 7 Sustainable Practices in the Engineering and Construction Industry

Engineering and construction (E&C) industry executives provided detailed information on the sustainable practices being used in their firms, and how sustainability is incorporated at the corporate and project levels. This chapter reviews the sustainable practices provided by E&C industry executives, Chapter 8 covers corporate-level sustainable practices, and Chapter 9 addresses project-level sustainable practices. In Chapter 1, Table 1.2 provided information on the types of firms providing data and Table 1.3 summarized their inputs. Appendix C contains a copy of the questionnaire used to solicit information from E&C industry executives. Each of the following sections presents specific topic areas and the recommendations from E&C industry executives for each area (Yates 2008).

## 7.1 PROCEDURES IMPLEMENTED RELATED TO SUSTAINABLE DEVELOPMENT

The following are some of the general procedures recommended by E&C industry executives related to sustainable development:

- Implementing waste diversion and zero waste to landfill initiatives
- Monitoring noise levels during construction and operations
- Participating in social development programs
- Procuring materials, supplies, and services through local businesses
- Providing craft training on sustainable practices and health and education awareness
- Recognizing government requirements for alternative fuels and renewable energy
- Requiring environmental impact assessments on projects
- Using a *health, safety, and environmental non-objection sustainability development scorecard*
- Using water containment measurements and sediment control to prevent temporary erosion
- Waste reduction schemes
- *World Bank* sustainability standards

Members of E&C firms are also integrating economic, social, and environmental concerns into business execution plans.

## 7.2 EXAMPLES OF SUSTAINABILITY CONSIDERATIONS INCLUDED IN LIFE-CYCLE ANALYSIS

A diverse array of sustainability considerations is already being integrated into life-cycle analysis for construction projects, including

- Construction and operation cost of facilities
- Cost of embodied energy
- Demolition and replacement costs
- Energy efficiency
- First cost and operating costs
- Hazardous and waste disposal fees
- Long-term energy utilization studies
- Maintenance and replacement cost
- Methods for recapturing energy
- Minimization or elimination of waste
- Overall resource use
- Minimization of pollution and emissions
- Process linkage with other enterprises
- Project expenditures for eliminating process waste streams
- Recycle streams
- Replacement cycles
- Reuse considerations
- Using waste as a resource
- Waste elimination strategies

## 7.3 WHEN SUSTAINABILITY SOCIAL ISSUES ARE EVALUATED AND HOW THEY ARE EVALUATED

*Sustainability social issues* are evaluated at different levels within a firm during all of the stages of a project. Evaluations are performed during the business development phase by in-house specialists or are subcontracted to consultants. They are also reviewed early in the planning phase, and during design and constructability reviews. In some firms, sustainability social issues are evaluated with community involvement at local meetings and by reviewing them in context to determine whether they support municipal growth plans. Sustainability social issues are identified and addressed during project development process considerations as projects advance through the approval process. Environmental reviews are conducted prior to the start of design, as required by the National Environmental Protection Agency (NEPA) or as required by clients. Sustainability social issues are evaluated when a firm is deciding whether to bid on a project; while they are completing the request for proposal; during contract discussions; and when they are awarded the engineering, procurement, and construction project scope from clients.

*Social impact studies* are used to determine the social issues affecting local citizens and businesses in the surrounding area. *Risk assessments* are performed to determine the effects on members of the community adjacent to or near the new facility being proposed for the community.

## 7.4 GOVERNMENT REGULATIONS RELATED TO SUSTAINABILITY BEING IMPLEMENTED ON CONSTRUCTION PROJECTS

One of the government regulations related to sustainability used on construction projects is Executive Order 13,423, which mandates improvements in energy efficiency, reductions in greenhouse gases, and incorporation of sustainability practice guidelines. Other government guidelines considered are the Department of Energy and Environmental Protection Agency Sustainability Practice Guidelines that support environmental management, the Building Research Establishment Environmental Assessment Method (BREEAM) in the United Kingdom, and the Resource Conservation and Recovery Act. Members of E&C firms also follow government requirements on pollution prevention, the environmental impact permitting process, water conservation, waste minimization, and energy conservation.

## 7.5 ECONOMIC BENEFITS OF IMPLEMENTING SUSTAINABLE PRACTICES

According to E&C industry executives, the economic benefits of implementing sustainable practices are

- Avoiding negative regulatory agency interactions
- Being awarded more projects
- Being known as a green firm with in-house expertise
- Increased consulting business in sustainable design, being known for sustainable construction expertise, and an enhanced reputation
- Obtaining financing for projects from development banking institutions
- Reduced costs due to the reuse of materials and equipment
- Using technologies providing significant paybacks

## 7.6 TECHNIQUES FOR MEASURING THE BENEFITS OF USING SUSTAINABLE PRACTICES

To measure the benefits of using sustainable practices, one technique is to track construction waste and whether it decreases when sustainable practices are implemented on projects. Another method is monitoring and calculating noise levels to determine the required levels of hearing protection or noise suppression. An additional measure is calculating storm water retention requirements during the design phase and then comparing the requirements to the actual data for storm water retention when a project is complete. The civil construction National Pollution Discharge Elimination System (NPDES) design system is used and then monitoring is done to determine whether it reduces pollution. Effluent discharge is monitored and analyzed to ensure that it meets the requirements of local permits.

## 7.7 METHODS FOR MEASURING SUSTAINABILITY METRICS

The methods for measuring sustainability metrics used at the corporate level are participating in sustainability certification programs such as the Leadership for Energy and Environmental Design (LEED) Green Rating, which is discussed in Chapter 14, and certification or other certification programs, such as the ones discussed in Chapter 15. Another metric used is providing health, safety, and environmental training and documenting successes and failures. Some firms use sustainability scorecards, and others use a website to track recycling.

## 7.8 SOCIAL, REPUTATION, OR ECONOMIC BENEFITS OF USING SUSTAINABLE PRACTICES

To achieve social, reputation, or economic benefits when using sustainable practices, a variety of processes are implemented in the E&C industry. The following are some of the processes pursued or incorporated into sustainability plans:

- Achieving professional recognition for environmental stewardship
- Being concerned with occupant comfort and facility efficiency
- Capturing market share through environmental stewardship
- Conducting business to promote economic growth
- Demonstrating concern for client satisfaction
- Determining *life-cycle paybacks* with minimal first cost when incorporating sustainable technologies
- Developing local vendor and supplier capabilities, and helping to improve the capabilities of the local business community
- Encouraging members of the company to become involved in the local community to foster acceptance for reliability and environmental stewardship
- Enhancing the marketability of projects for clients
- Fostering employee pride and satisfaction
- Fostering positive recognition by owners, members of the local community, and government organizations
- Implementing plans that avoid negative environmental impacts
- Improving value propositions
- Integrating sustainable development leads to greater value creation for society and sustainable growth for companies
- Meeting government requirements for sustainability
- Promoting goodwill in the community where a project is being built
- Providing health benefits to local workers
- Reducing the consumption of natural resources
- Working toward a good neighbor corporate reputation

## 7.9 SOCIAL CONDITIONS ADDRESSED DURING CONSTRUCTION PROJECTS

Social conditions should be explored as early as the planning stage to determine the impact of the project on the local community. Two major social conditions addressed include reducing the environmental footprint of a structure and being a good community citizen. In addition, it is beneficial to firms if members of the firm provide *sweat equity*—time dedicated to community projects by employees—to community organizations and explore methods for becoming engaged in the community. Members of firms should be concerned with the social impact of construction projects and final structures including noise levels, traffic disruption, safety, local aesthetics, and whether the project is compatible with the surrounding community. Two other social conditions that should be addressed are providing opportunities for minority- and women-owned businesses on projects with public funds and using local labor for non-specialized work. Employees should also be encouraged by their employers to become involved in community development projects. There could be economic impacts precipitated by projects on businesses, and the local community and firms should be cognizant of this and plan accordingly.

Promoting development of the workforce by supporting local educational institutions helps enhance the reputation of a firm within a community. By actively managing community relations, firms are able to prevent minor issues from escalating into community dissatisfaction. Employees should try to interact with members of the public in a positive manner whenever possible to increase the visibility of their firm. If firms are able to avoid negatively impacting the surrounding area during construction, it contributes to goodwill in the community. At remote construction jobsites, it benefits firms if they become involved in building schools and medical treatment facilities, along with training unskilled workers.

## 7.10 STRUCTURED APPROACHES USED TO INCLUDE SUSTAINABILITY CONSIDERATIONS DURING DESIGN

Recommendations on structured approaches for integrating sustainability considerations during the design phase include

- Analyze the toxicity of proposed materials
- Conduct a life-cycle cost analysis for all of the proposed sustainable alternatives
- Create designs that include Energy Star equipment and appliances
- Design for the integration of durable materials
- Design for waste elimination
- Determine the environmental life cycle of expectation costs
- Follow the National Environmental Policy Act procurement guidelines
- Incorporate local or regional materials
- Incorporate modular or prefabricated elements or structures
- Incorporate sustainable design criteria and specifications provided by owners
- Investigate the potential for using *closed-loop systems* to increase energy efficiency
- Plan for recycling structures
- Plan for vapor reclamation

- Provide designs for sustainable construction methods
- Use simple design processes to eliminate excess waste

## 7.11 DESIGNS, CONSTRUCTION COMPONENTS, OR PRACTICES THAT INCLUDE SUSTAINABLE COMPONENTS

The following were recommended to increase the use of sustainable components in designs or during construction operations. If possible, projects should be designed that exceed the requirements for reductions in water or energy use. Storm water should be incorporated as a resource by developing techniques for saving and reusing storm water at the jobsite for a variety of purposes such as dust control, fire protection, and irrigation. During the design stage, architects and engineers should explore the potential for prefabrication and *modularization*, both of which assist in achieving sustainable objectives by virtue of elimination of the waste created when components are fabricated at construction jobsites.

Another possible design strategy for the integration of sustainability is using natural grades rather than cutting and filling to achieve new grades. Earthmoving operations should minimize the removal of soil from the jobsite by incorporating excess cut into landscaping.

Designs should take advantage of *daytime lighting optimization*. *Wind orientation* and site characteristics should be used to reduce energy consumption. Sustainable practices helping to improve energy efficiency include proper site orientation, solar shades, increased *R*-value insulation, and using indirect lighting.

Another technique used during the design stage to help increase energy efficiency is to tie energy modeling and solar potential into *Building Information Modeling* (BIM) renderings during schematic designs. Some owners, architects, and engineers are requiring the use of BIM software on their projects, and E&C firms are being contractually required to use these three-dimensional (3D) modeling technologies.

In 2014, the current leaders in BIM technology were Autodesk with its REVIT suite of programs and Bentley System's Microstation, but other 3D software programs are also used for many different types of design. Both of the leading firms provide software that allows for the importation of different platforms and formats for design drawings. A 3D model is generated from two-dimensional (2D) drawings incorporating the contributions of all of the designers. Other aggregate model viewers and conflict resolution tool software systems are Autodesk's NavisWorks, Bentley's ProjectWise Navigator, VICO Contractor, ArchiCAD 12's Virtual Building Explorer, and Tekla Structures. Figure 7.1 is an example of a BIM rendering modeling construction sequencing, and Figures 7.2 and 7.3 provide examples of renderings of the exterior and interior, respectively, of a sustainable structure developed using Autodesk REVIT.

Building Information Modeling software also provides capabilities for creating four-dimensional (4D) schedules for generating the 3D models in predefined scheduling sequences. The *Quantity Takeoff* (QTO) program by Autodesk automatically generates a bill of materials used in bid estimates from 3D models.

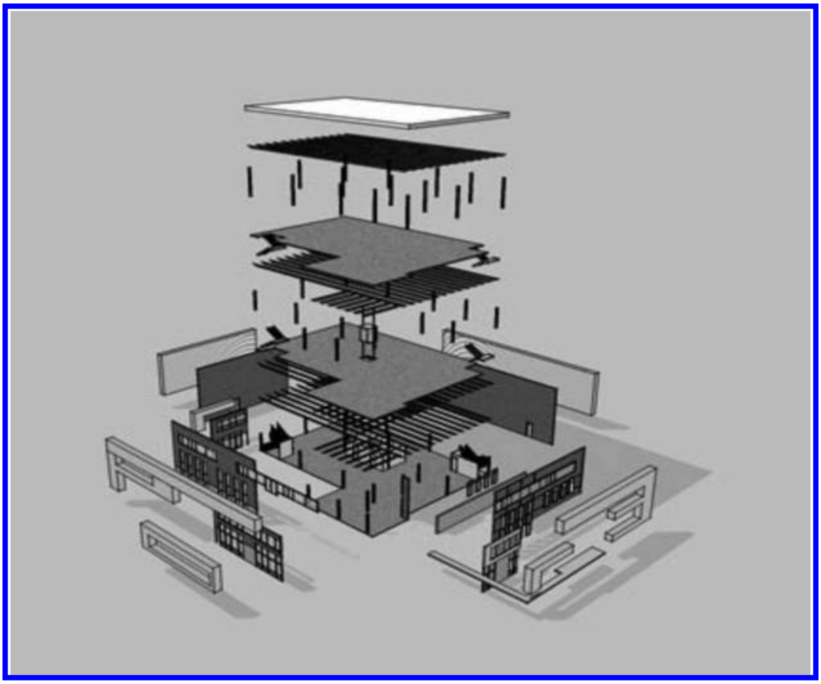

**FIGURE 7.1** Building Information Modeling rendering of construction sequencing. (Courtesy of Tim Bungert.)

Two of the features of BIM software directly benefitting contractors are clash detection—the highlighting of interferences between building elements—and generation of clash detection reports. Projects using the clash detection feature in BIM software experience a significant decline in change orders during construction since construction interferences are discovered during the design phase and construction methods and processes are modeled using the BIM software to determine their viability. With a reduction in the number of change orders issued during construction, the number of claims is also reduced, thus saving owners and contractors money. Even though the initial cost of BIM software seems prohibitive to small and medium-sized firms, the cost savings being realized through its use are leading to its adoption throughout the E&C industry.

## 7.12 ENGINEERING DESIGN PRACTICES THAT INCORPORATE SUSTAINABLE PRACTICES

The following are suggestions from E&C industry executives for incorporating sustainable practices into engineering designs:

- Create designs using standard length materials to reduce field effort and waste
- Include recycled content and rapidly renewable materials
- Incorporate water-saving plumbing
- Incorporate waste minimization as a value improvement practice

**FIGURE 7.2** Exterior of a sustainable structure designed using Building Information Modeling. (Courtesy of Tim Bungert.)

**FIGURE 7.3** Interior of a sustainable structure designed using Building Information Modeling. (Courtesy of Tim Bungert.)

- Integrate sustainable designs for heating, ventilating, and air-conditioning systems and lighting
- Monitor designs using a sustainability scorecard
- Reduce exposure to toxins, and focus on occupant health and safety
- Replace some of the cement in concrete with fly ash
- Simplify designs and use modularization and *prefabrication/preassembly* whenever possible
- Specify sustainable exterior building materials (walls, roofs, and glazing systems)
- Specify daylighting whenever possible in structures
- Use energy-efficient products
- Use low and no *volatile organic compound content paints*, sealants, adhesives, carpets, and furnishings
- Use *polyvinylchloride products* whenever possible

## 7.13 SUSTAINABLE MATERIALS CONSIDERED DURING THE DESIGN STAGE

Some of the sustainable materials and processes reviewed for inclusion in projects during the design stage are the following:

- Wood that is harvested and managed in a sustainable manner
- Fly ash substituted for some of the cement in concrete mixes
- Sustainable composite materials
- Materials with recycled content
- Lining corroded pipes to eliminate metal disposal and using more corrosion-resistant alloys to improve the length of life of metal products
- Recycling plastic, carpet, metal, and steel
- Reusing interior materials and remanufactured materials
- Low or no volatile organic compound paints
- Water-based paints for solvent-based paints
- Recycled steel
- Renewable materials
- Reusable concrete forms

## 7.14 TECHNOLOGIES FOR REDUCING ENERGY CONSUMPTION ON PROJECTS

The following technologies are used to help reduce energy consumption on construction projects:

- Design for energy efficiency for heating, ventilating, and air-conditioning and lighting systems
- Design for reduced power usage and water consumption
- Design systems for waste segregation, and recycle waste products
- Design a high-performance envelope

- Designate in the design proper equipment maintenance procedures to reduce environmental pollutants in engine emissions
- Encourage workers to carpool, join vanpools, or use buses
- Improve haul road designs
- Incorporate cool roofs energy modeling
- Maximize insulation
- Minimize the footprint of structures
- Provide a design incorporating thermal storage (a system for storing energy for use during peak energy use times)
- Provide for electrical and water demand management
- Purchase highly efficient vehicle fleets
- Select sites for buildings that maximize the use of passive solar opportunities
- Set policies on the amount of time that trucks and other equipment are allowed to idle their engines
- Use off the electric grid power during construction rather than large portable generators

## 7.15 TECHNIQUES FOR REDUCING POLLUTION DURING CONSTRUCTION

Some of the techniques used that help reduce pollution during construction are the following:

- Air pollution mitigation systems on heavy construction equipment
- Carpooling, vanpooling, and busing workers to jobsites
- Changing construction jobsite work hours to reduce traffic during normal peak periods
- Complying with permit stipulations
- Flushing out buildings prior to occupancy to remove volatile organic compounds
- Following an *indoor air quality (IAQ) management* plan during construction
- Implementing dust, erosion, and traffic control
- Implementing noise elimination schemes
- Installing *scrubbers* and *mufflers* on heavy construction equipment
- Isolating areas of construction to prevent contaminating newly installed ductwork
- Limiting certain activities causing noise to the daytime
- Preplanning traffic routes to reduce the distance traveled by vehicles and equipment
- Scheduling deliveries early in the day to avoid trucks traveling to and from the jobsite in the middle of the day during high-ozone days

- Scheduling delivery and installation of absorptive materials after dust-generating construction procedures are complete
- Treating effluent and non-potable water, and reusing it for dust suppression and landscape irrigation
- Using alternative fuel vehicles and construction equipment and hybrid-electric heavy construction equipment
- Water runoff protection and erosion protection

## 7.16 PROCESSES FOR RECYCLING WASTE AT THE END OF CONSTRUCTION

The following are some of the processes being used for recycling waste at the completion of construction:

- Advertising the availability of surplus materials throughout the company
- Developing a commercial waste management program
- Disposing of recycled materials by selling them to dealers
- Distributing materials to local manufacturers as feedstock for reuse
- Donating materials to local community organizations or businesses
- Establishing recycling pathways for excess or unused materials
- Handling all of the remaining construction materials as per the appropriate guidelines of the country where a project is being built
- Implementing processes for zero waste to landfill programs
- In developing countries, donating construction waste materials to local citizens
- Introducing global waste management standards
- Minimizing the generation of waste
- Offering unused materials to future projects
- Providing composting programs for organic waste
- Recycling concrete and asphalt
- Returning materials into corporate inventory for use on other projects
- Returning surplus materials to vendors
- Reusing asphalt in recycled paving
- Sorting construction waste materials and selling them to recyclers
- Stipulating requirements for recycling
- Trying to influence partners to implement similar recycling programs
- Using crushed concrete as aggregate in a new mix
- Using progressive waste service providers for waste diversion
- Using scrap metal dumpsters

Be aware that sometimes there are contamination issues preventing the recycling of materials.

## 7.17 PROCESSES FOR RESELLING OR REUSING MATERIAL BY-PRODUCTS

In addition to the methods for handling excess materials or material waste already mentioned, other methods for selling or reusing material by-products include

- Aggregate disposable waste materials to minimize the amount of energy expended in their final disposition
- Retain hydro test fluids for use on future projects
- Return ceiling tile and carpeting from surplus and demolition to manufacturers
- Return materials to corporate inventory or sell them to recyclers
- Salvage construction by-products in a formal manner
- Separate scrap metal or scrap cable and sell it to a recycler
- Share materials with other jobsites

## 7.18 LEVELS OF RECYCLING OR REUSING MATERIALS COMPARED TO PROJECTS BEFORE SUSTAINABILITY

Some of the methods used for recycling or reusing materials not used before implementing sustainable practices are

- Concrete being *rubblized* and used for the base course on roads
- Recycling or reusing structural members and finish materials (brick, stone, etc.)
- Reusing the wood in formwork
- Selling materials to recyclers rather than disposing of them in landfills
- Using site and demolition waste for foundation materials
- Using waste service providers with access to sorting facilities to divert waste

## 7.19 TECHNIQUES FOR IMPROVING RESOURCE EFFICIENCY

Techniques used during construction to improve resource efficiency include the following:

- Use BIM for designs
- Use BIM for energy modeling
- Buy or lease more efficient equipment
- Capture wastewater for other purposes
- Eliminate double handling of materials
- Evaluate overall project efficiency
- Ice roads in cold regions that melt in the summer leaving no trace of a road
- Incorporate land-balancing considerations during designs to minimize haul distances

- Incorporate the best control technologies for environmental monitoring and control systems
- Local sourcing to avoid pollution and the costs associated with long-distance shipping
- Minimize equipment usage
- Modularization and the manufacturing of modules off site
- Optimize jobsite layouts
- Reuse concrete forms
- Stockpile materials for reuse on site
- Train laborers on safety and sustainable techniques
- Train superintendents about the green advantage

## 7.20 CRITERIA FOR PREQUALIFYING VENDORS AND SUPPLIERS

The criteria used by industry experts to prequalify vendors and suppliers include the following:

- Avoid *green washing* (deceptively promoting a firm's products as being environmentally friendly)
- Energy and water conservation
- Local sourcing
- Pollution control methods; minimizing the production of waste, and recycling
- Recycled content in *feedstock*
- Recycled paper products
- Require sustainability consultants to participate on design/build teams
- Review vendor sustainability programs
- Specifications and contracts stipulating sustainable practices
- Specify sustainable products based on inherent characteristics
- Track record on previous green projects
- Using 100% certified renewable energy

## 7.21 RENEWABLE ENERGY SOURCES FOR CONSTRUCTION PROJECTS

The following are some of the renewable energy sources used during construction projects:

- Biodiesel fuel products used in generators
- Locally generated renewable energy
- Off-grid renewable power sources
- Photovoltaic (PV) cells
- Wind towers
- Wind turbines

## 7.22 TECHNIQUES FOR REDUCING WASTE DURING CONSTRUCTION

Some of the techniques for reducing the amount of waste generated during construction include

- Collecting wastewater for reuse
- Considering minimizing waste generation prior to material ordering and delivery
- Correctly sizing equipment, materials, and components
- Improving takeoff and material ordering control
- Incorporating durable and reusable materials and products
- Incorporating innovative methods for using off-specification concrete or the remnants of concrete to create items such as curbstones, barrier blocks, and pavers
- Minimizing waste when cutting objects from single sheets of *polycarbonate* materials
- Precutting drywall, pipes, conduit, and other materials
- Reusing concrete forms
- Setting waste diversion from landfill goals
- Simplifying designs
- Sizing windows to maximize the number of units of a similar size
- Using modular construction
- Using prefabrication, preassembly, and modularization

## 7.23 MOBILIZATION AND DEMOBILIZATION PROCESSES THAT INCLUDE SUSTAINABLE PRACTICES

The following are sustainable practices used during mobilization and demobilization:

- Considering site location, access, and safety considerations
- Designing temporary project access control to serve as the final security control building
- Developing salvage, auction, and reuse strategies
- Incorporating noise control
- Minimizing staging areas to limit areas of disturbance
- Providing temporary lighting guidelines
- Recycling or restocking surplus materials
- Recycling project components
- Salvaging or reusing temporary equipment
- Saving small tools and reusing or donating them to local vocational programs
- Using portions of temporary fencing for final perimeter security fencing
- Using runoff control to minimize downstream pollution

## 7.24 TOP FIVE SUSTAINABILITY CONSIDERATIONS

An example of five important sustainability considerations selected by Donald McFadden ranked in order of their impact on a project are

1. Construction and operation cost of the facility
2. Demolition and replacement cost
3. Embodied energy
4. Energy efficiency
5. Minimization or elimination of waste streams

These considerations are concerned with the monetary cost of constructing and operating facilities, reducing demolition and replacement costs, measuring the energy required to produce construction materials, reducing the amount of energy necessary to operate structures, and lowering the demand for using landfills.

Although it is related to demolition and replacement cost analysis, the cost of construction is a major consideration in the development process. Every design consideration has a cost/benefit component, an initial cost for the technology, or a design consideration balanced against the savings realized by the design feature or the use of sustainable technology over time.

Demolition and replacement cost analysis consider the entire structure and the costs and benefits of renovating a structure, as opposed to new construction. This should be a primary consideration because it reduces the amount of demolition waste being sent to landfills; negative effects on the environment by not disturbing a green field site; overall need for site work; sourcing, manufacture, distribution, and transportation requirements for materials; and vehicle traffic on existing surface roads. It also reduces the amount of noise generated during construction and demolition processes, the need for implementing storm water pollution protection plans, and the possibility of damaging waterways and aquatic plants and harming animals.

Embodied energy is listed second, and it is a measure of the amount of nonrenewable energy consumed during construction. It provides a guideline for selecting materials based on their embodied energy, and sustainability concerns during construction such as resource efficiency, the ecological cost of materials during the life cycle of the building, the deconstruction and recycling of materials, and an element of sustainable design. It is also a measure of the energy consumed during construction processes.

The main considerations related to energy efficiency are the incorporation of natural light as a primary light source to reduce electrical lighting; using passive solar energy as a heat source; using solar voltaic cells to provide off the grid electricity; and using sun shading during warm seasons to reduce heating, ventilating, and air-conditioning energy requirements.

To minimize or reduce the waste stream during construction, a waste recycling program should be implemented to allow for the segregation and reuse of construction materials during new construction and during the demolition required for renovation projects. The benefits are that it ensures the reuse of material waste generated by the project either in the present state of the material or as a basic material for recycled building products. The effect of not implementing this strategy is increased energy consumption to produce new materials and increased strain on existing landfills.

## 7.25 AN EXAMPLE OF SIX SUSTAINABLE DEVELOPMENT PROCEDURES

The following is another example by Donald McFadden illustrating the selection of six sustainable development procedures to be implemented on a project, why they should be implemented, how they would benefit the project, and what might potentially result if they are not used on a project. The six sustainable development procedures are

1. Requiring environmental impact statements
2. Measuring noise levels during construction
3. Procuring materials, supplies, and services through local businesses
4. Recognizing that there are government requirements for alternative fuels and renewable energy
5. Using water containment system measurements and sediment control to prevent temporary erosion
6. Implementing wastewater diversion and zero waste to landfill initiatives

Environmental impact statements provide a framework for reviewing the impact of a project on the environment, and on cultural, historical, and archeological resources. In addition, they examine the alternatives under consideration not only in terms of impact but also in terms of the cost of other alternatives. This includes the impact to air and water resources and endangered species, socioeconomic impacts, and any cost analysis attempting to balance the considerations of the triple bottom line. Environmental impact statements support sustainability in multiple ways. First, considering air and water resources ensures the sustainment of life. Considering impacts on endangered species ensures biodiversity, the health of the planet, and the preservation of plant material that may have undiscovered properties including medical uses. Considering historical and archeological impacts shows social responsibility when preserving archeological sites and the cultures they represent. Considering socioeconomic issues shows respect for human rights and economic justice as part of the project impact.

Measuring noise levels during construction should be implemented as a health and safety concern for project staff, the local community, and animals in the area. The noise levels produced on a construction jobsite could create unsafe conditions where project personnel lose situational awareness, and this might lead to industrial accidents. Not wearing hearing protection causes long-term hearing loss and increases the stress level of project personnel. The effects of a proper noise reduction program are reduced costs and loss of time due to industrial accidents and lower insurance rates for construction companies. The local community might be adversely affected in the same manner. Prolonged noise disrupts the migratory patterns of animals or displaces them from their natural habitat. Negatively affecting the community and/or animals might result in lawsuits and stop-work orders, increasing the cost and time of construction. An effective noise abatement program helps to build goodwill and support in the community, and it improves the reputation of the contractor responsible for construction.

If analyzed correctly, the procurement of local materials, supplies, and services helps to reduce the energy consumed during construction, and the amount of carbon dioxide produced as a result of construction by reducing material transportation requirements. In addition, local procurement results in a social development program if construction funds are spent in the local community and jobs are created when sourcing, manufacturing, and distributing materials. Not procuring materials locally might result in wasteful expenditures of energy.

The use of alternate fuels and renewable energy are critical to reducing reliance on fossil-based fuels and minimizing emissions from harmful chemicals into the environment from coal-fired electrical sources. The use of alternate energy sources, especially renewable energy, requires higher construction costs, but they should provide a payback over time in the form of reduced energy bills during the life cycle of the structure. Failure to integrate alternative energy or renewable energy sources into a project maintains reliance on fossil fuels requiring high levels of energy to produce electricity, and this increases pollution levels in the environment and the atmosphere.

The effective and efficient use of a storm water pollution prevention program (SWPPP) reduces and controls erosion. The implementation of SWPPP measures creates a safer construction jobsite by having a diversion and containment plan. This is especially important in those parts of the world where there are monsoon rains, such as Central America, the Pacific region, and Asia. Failure to contain water on site, or not implementing erosion control measures, results in the introduction of organic materials into waterways, resulting in silting and a reduction in the oxygen levels in water, which, in turn, kills aquatic plant and animal life.

The implementation of wastewater diversion and zero waste to landfill initiatives reuses gray water from sinks, showers, dishwashing, and laundry as a water source for irrigation or as a water source for urinals and toilets. The gray water is reused before it enters the wastewater management steam. The use of gray water reduces the operating cost of a building, but it does require more complex and expensive plumbing systems. A reduction in the volume of treated water reduces the strain on wastewater treatment facilities, the requirement for expanding wastewater treatment systems, the amount of energy required to operate them, and the possibility of the introduction of effluents into the natural water system.

Zero waste to landfill initiatives allow for the segregation and reuse of construction materials from new construction and from demolition in the case of renovation projects. The benefit to projects is that it ensures the reuse of the material waste generated by the project either in its present state or as a basic material for recycled or engineered building products. The effects of not implementing this strategy are the increased extraction of raw materials, higher embodied energy consumption, increased production of new materials, and an increase in the strain on existing landfills.

## 7.26 SUMMARY

This chapter included suggestions and recommendations provided by E&C industry executives on the sustainable processes they incorporate into their firms when they are designing or constructing projects. The topics covered in this chapter included procedures related to sustainable development, examples of sustainability considerations included in life-cycle analysis, when sustainability social issues are evaluated and how they are evaluated, government regulations related to sustainability practices being implemented on construction projects, economic benefits of using sustainable practices, techniques for measuring the benefits of using sustainable practices, and methods for measuring sustainability metrics.

Other topics addressed in this chapter were social, reputation, and economic benefits of using sustainable practices; social conditions during construction projects; structured approaches for including sustainability considerations in designs, construction components, or practices including sustainable components; engineering design practices incorporating sustainability practices; sustainable materials considered during the design stage; technologies used to reduce energy consumption on projects; techniques for reducing the amount of pollution during construction; processes for recycling waste at the end of construction; methods for selling or reusing material by-products; waste being recycled or reused compared to before implementing sustainable practices; techniques used during construction to improve resource efficiency; criteria for prequalifying vendors and suppliers; renewable energy sources available for construction projects; techniques for reducing the waste generated during construction; and mobilization or demobilization processes including sustainable practices. The last two sections of the chapter, Sections 7.24 and 7.25, provided an example of the top five sustainability considerations and an example of six sustainable development procedures.

## 7.27 KEY TERMS

Building Information Modeling
Cool roofs energy modeling
Daytime lighting optimization
Environmental life cycle of expectation costs
Feedstock
Health, safety, and environmental non-objection sustainability development scorecard
Indoor air quality (IAQ) management
Modularization
Mufflers
Off-grid renewable power sources
Polycarbonate
Polyvinylchloride products
Prefabrication/preassembly
Risk assessments

Rubblized
Scrubbers
Social development programs
Social impact studies
Sustainability social issues
Sweat equity
Vapor reclamation
Volatile organic compound content paints
Wind orientation
World Bank

## 7.28 DISCUSSION QUESTIONS

7.1 Explain why it is so difficult to incorporate renewable energy sources during construction projects.

7.2 Discuss the social conditions that should be addressed during construction projects.

7.3 Of the items listed in Section 7.13, which ones would be the most and least expensive to incorporate during construction if they were included in engineering designs?

7.4 Conduct research on Executive Order 13,423, and explain how it affects construction projects.

7.5 Divide the techniques used to reduce the amount of pollution during construction in Section 7.15 into the categories of equipment, labor, and materials.

7.6 Select five social, reputation, or economic benefits of using sustainable practices that are the most important reasons for implementing sustainable practices, and explain why they are the most important.

7.7 Discuss how using Building Information Modeling software helps in the incorporation of sustainable practices during the design stage.

7.8 Discuss which stages of a project would be the most appropriate for evaluating sustainability social issues, and explain why these stages would provide the most appropriate evaluation.

7.9 Discuss what would be the major difficulty in implementing the processes used to sell or reuse the material by-products mentioned in Section 7.17.

7.10 Select six sustainable development procedures for implementation on a construction project and explain why they were selected, how they would benefit the project, and what potentially might result if they were not used on the project.

7.11 Discuss whether the techniques for reducing the amount of waste being generated during construction mentioned in Section 7.22 would actually reduce the amount of waste created during construction.

7.12 Of the technologies for reducing energy consumption on projects listed in Section 7.14, which are actual technologies and which are design considerations?

7.13 Discuss which of the economic benefits of implementing sustainable practices in Section 7.5 would be the most beneficial to a firm, and explain why.

7.14 Discuss the techniques cited in this chapter for measuring the benefits of using sustainable practices, and provide three additional techniques based on the information provided in Chapters 1 through 6.

7.15 Discuss what criteria are used to prequalify vendors and suppliers on their sustainability, and explain why the criteria should be used on projects.

7.16 List four other processes that might be incorporated during mobilization or demobilization that would be sustainable that are not listed in Section 7.23.

7.17 For the sustainable materials considered during the design stage listed in Section 7.13, what is the reoccurring theme of many of the materials currently being used by members of firms in the E&C industry?

7.19 Discuss which of the processes used to recycle waste at the conclusion of construction projects mentioned in Section 7.16 would be the least expensive to implement during construction projects.

7.20 Of the techniques for improving resource efficiency mentioned in Section 7.19 during construction, which ones should be incorporated during the design stage?

## REFERENCE

Yates, J. 2008. *Sustainable Industrial Construction*. Research Report 250–11. Austin TX: Construction Industry Institute. Accessed on January 2015. https://www.construction-institute.org/scriptcontent/more/rr250_11_more.cfm.

# 8 Corporate-Level Sustainability Practices

This chapter summarizes the corporate-level sustainable practices cited by engineering and construction (E&C) industry executives as already being used in their firms (Yates 2008). Chapter 9 provides information on project-level sustainability initiatives; therefore, this chapter only covers corporate-level sustainable practices. Each of the sections in this chapter provides both statistics related to the specific sustainability concepts being discussed and a synopsis of the approaches being implemented by members of the E&C firms who provided the data.

The information provided in this chapter indicates that some of the largest firms in the E&C industry have already integrated sustainability concepts into their corporate objectives. One of the major driving forces for E&C firms for adopting sustainable practices is clients. Some of the major owner organizations are requiring the E&C firms they hire to demonstrate their commitment to sustainability. This does not merely mean incorporating sustainable practices into final products or structures, but it also means E&C firms are incorporating sustainable practices into their engineering designs and construction operations. Owners are also cognizant of whether members of the E&C firms they hire are also following sustainable practices in their corporate-level operations, as well as at the project level. Table 8.1 provides a summary of the types of corporate sustainability strategies being utilized by members of E&C firms and the percentages of the firms who provided the data who are using these strategies.

In addition to the areas listed in Table 8.1, a variety of sustainable initiatives are being integrated into firms. Some of the types of sustainable initiatives implemented at the corporate level are

- *Fleet green energy programs*
- Forming *green boards* to help set sustainability goals
- Green office practices
- Water and energy reduction plans

Members of firms also form stakeholder partnerships between industry members and communities, provide advice to their clients on sustainable practices, and include sustainable objectives in business activities. Other areas addressed at the corporate level are asset life cycles, strategic environmental and economic analysis, risk and sensitivity assessments, social and community impact modeling, advanced systems modeling, and logistic modeling treatments. At the corporate level, members of firms are also becoming more proactive in their legal compliance rather

## TABLE 8.1
## Sustainability in Engineering Design and Construction

| **Corporate-Level Sustainability** | **Yes** | **No** | **Do Not Know** |
|---|---|---|---|
| Environmental considerations in design documents | 96% | 0% | 4% |
| Sustainability issues are evaluated that could impact the completion of projects | 70% | 15% | 15% |
| Considerations due to regulatory compliance or other | Regulatory compliance: 48% | Beyond compliance: 52% | 0% |
| Environmental sustainability is considered when determining expected project life cycle | 63% | 18% | 19% |
| Evaluate sustainability social issues that impact completion of projects | 70% | 15% | 15% |
| Structured approach used when designing and specifying sustainable materials | 58% | 23% | 19% |
| Have a corporate strategy on sustainability | 84% | 8% | 8% |
| Firm participates in global reporting initiative | 40% | 48% | 12% |
| Firm belongs to Dow Jones Sustainability Group Index | 8% | 56% | 36% |
| | **Other Responses** | **Other Responses** | **Other Responses** |
| Firm implemented ISO 14000 series of standards or certified to them | Implemented ISO 14000: 23%<br>Not implemented ISO 14000: 12% | Certified to ISO 14000: 12%<br>Not certified to ISO 14000: 15% | Do not know: 20%<br>Not applicable: 12% |
| Potential barriers to implementing industrial construction sustainability programs | Capital cost concerns: 25%<br>Competitiveness: 19%<br>Not required by regulations: 6% | Not sure how to do it or measure it: 13%<br>Need a practical plan: 10% | Not sure if it will be profitable: 9%<br>Need to show a positive rate of return:18% |
| Drivers to the implementation of sustainable development practices in construction | Owners: 20%<br>Nongovernmental agencies: 15%<br>Government: 18% | Public awareness of sustainability issues: 8%<br>Media: 15% | Competitive differentiation: 4%<br>Profit: 14%<br>Other: 2% |

*Source:* Adapted from Yates, J.K., *Sustainable Industrial Construction*, Research Report 250–11, Construction Industry Institute, Austin, Texas, 2008.

than reactive. They are supporting the *Global Responsible Care Charter* and the *United Nations Global Compact* and becoming certified to the *Responsible Care Program*. The following sections, Sections 8.1 through 8.12, discuss the sustainable practices being incorporated into corporate-level operations.

## 8.1 SUSTAINABILITY CONSIDERATIONS RELATED TO DESIGN

Ninety-seven percent of the E&C industry executives providing data indicated that their firms include environmental considerations in their design documents and include sustainability considerations in constructability reviews 44% of the time. A total of 86% indicated that their firms have a corporate strategy on sustainability, and 62% indicated that a structured approach is used when considering project design and material alternatives including sustainability considerations.

Among the respondents, there were a variety of sustainability considerations evaluated for inclusion in projects during constructability reviews, including the United Nations Global Compact, the Responsible Care Program, the Department of State Overseas Building Operations, the Federal Leadership in High-Performance Buildings, fleet green energy programs, and sustainability goals set by a green board. In addition, some firms also review *Executive Order 13,423*, along with the *Global Chemical Industries Performance Initiative*. They incorporate carbon capture and storage techniques, processes for integrating clean coal, methods for carbon credits and emissions trading, and perform advanced systems modeling. Some of the sustainable materials considered during design include recycled steel, certified wood products, environmentally preferable products, composite materials, low volatile organic compound paints, and recycled plastic and metals.

When the results to questions related to corporate-level sustainable practices were compared to questions about project-level sustainable practices, it demonstrated that corporate-level sustainability considerations do not always translate into the actual use of sustainable practices. Only 46% of the firms providing data use sustainable alternatives to standard materials in their designs. A total of 42% said that they integrate sustainable components into their projects. Thirty-five percent indicated that a section on sustainable practices is included in their project execution plans (construction management plans), which is where sustainable practices are integrated into projects. Only 22% include sustainable practices in mobilization, or demobilization, processes, but 45% did not know whether their firm uses sustainable initiatives during mobilization and demobilization.

Some of the structured approaches to incorporating sustainable initiatives include the following:

- Analyzing the durability of materials
- Calculating the environmental life cycle of expectation costs
- Conducting *material use impact studies*
- Evaluating the *toxicity* of materials
- Following design criteria and specifications from owners
- Incorporating local or regional materials
- Performing life-cycle cost analysis

- Selecting products based on the Energy Star rating system
- Using closed-loop energy systems
- Using *vapor reclamation* and recycling

Additional procedures implemented related to sustainable development include emphasizing quality, health, safety, and a nontoxic environment; indoor air quality management; low volatile organic compound commissioning; World Bank standards; and sustainability standards specified by owners.

## 8.2 CONSIDERATIONS DUE TO REGULATORY COMPLIANCE OR BEYOND COMPLIANCE

Government regulations are not the only driver influencing the implementation of sustainable practices. A total of 57% of the respondents indicated that measures beyond compliance influence their using sustainable practices. A large portion of those contributing data—45%—did not know whether their firm was following government regulations on construction projects, and 22% indicated that government regulations were not being followed at all. The firms implementing government regulations were following Executive Order 13,423; Department of Energy and Environmental Protection Agency guidelines; the Resource Conservation and Recovery Act; and the Building Research Establishment Environmental Assessment Method (BREEAM). The Resource Conservation and Recovery Act is discussed in Chapter 5 in Section 5.10.11, and the Department of Energy, Environmental Protection Agency, and BREEAM guidelines are discussed in Chapter 15 in Section 15.3.

## 8.3 SUSTAINABILITY ISSUES CONSIDERED IN PROJECT EXPECTED LIFE CYCLE

According to industry executives, sustainable practices are considered 60% of the time, but only 22% of the firms have a method for measuring metrics (quantifying the achievement of sustainable development). The types of items considered related to the expected life cycle of the project include the following:

- Maintenance and repair costs
- Demolition reclamation costs
- Embodied energy
- Emissions elimination
- Energy efficiency
- Environmental impacts of discharge quality
- Minimization or elimination of waste
- Overall resource use
- Reuse considerations process linkage with other owner enterprises
- Waste elimination

## 8.4 SUSTAINABILITY SOCIAL ISSUES EVALUATED IMPACTING THE COMPLETION OF PROJECTS

Social issues related to sustainability were evaluated by 74% of the firms, and a variety of different social projects were described in detail. In addition to evaluating social issues, 82% of the firms also implement initiatives to address social conditions during the construction of projects. Social issues are evaluated at different stages ranging from the risk evaluation stage, during design and constructability reviews, as a part of environmental reviews prior to design, during project planning, in the project development stage, and when deciding whether to bid on a project. The types of social issues addressed during construction include the following:

- Actively managing community relations
- Being cognizant of the impact of the workforce on local communities
- Building schools and medical facilities (when working on projects in developing countries)
- Community development projects
- Economic impact of projects on local businesses and communities
- Eliminating high traffic conditions
- Evaluating public health impacts
- Having members of firms provide sweat equity to local organizations
- Informal interactions with the public
- Minority-owned business outreach
- Providing days off on cultural holidays
- Reducing social impacts caused by noise, traffic, safety, and aesthetics
- Using local labor

Some of the social, reputation, or economic benefits of implementing sustainable practices are that they provide a good neighbor corporate reputation, help capture market share, provide a competitive advantage, enhance the marketability of clients' projects, provide client satisfaction and positive press, generate goodwill in communities, and there is recognition by owners and members of the local community. The social issues directly affecting construction personnel are poverty, quality of life, health, and education.

Contractors use outreach programs to target and hire local minority subcontractors. On federal projects, this means the extension of *Davis–Bacon prevailing wages* and benefits to woman, small, and minority-owned subcontractors who typically are not union shop or pay lower hourly rates than larger, well-established subcontractors.

Contractors use local suppliers to ensure that the construction funds they spend on materials stay in the community. These funds typically have fourth and fifth orders of effect impacting other community businesses, as they filter through the community for the purchase of vehicles, groceries, medical services, and homes and generate more employment. The expenditure of these funds also raises the tax base to provide for schools and other community services.

In developing countries, contractors may choose to participate in the renovation or construction of medical facilities or schools in the community. These initiatives raise the standard of living for the community, protect the health of community members, provide an improved future for youth in the community, and enhance the reputation of a contractor. Each of these initiatives helps improve the community and leaves behind goodwill after a project is complete.

## 8.5 STRUCTURED APPROACHES TO EVALUATING SUSTAINABLE DESIGN AND MATERIAL ALTERNATIVES

This section discusses some of the structured approaches used to evaluate sustainable design and material alternatives.

Many firms use the Leadership in Energy and Environmental Design (LEED) Green Building Rating System guidelines for selecting sites, determining energy and water requirements, evaluating indoor environments, and reviewing material alternatives. Life-cycle cost analysis techniques are used to evaluate sustainable alternatives. Closed-loop systems are selected if it is feasible to incorporate them into a design. Designs are reviewed for process simplification and waste elimination to determine whether there are any methods for eliminating pollution. Materials are evaluated based on their durability in addition to their sustainability. Sustainable design criteria are considered when they are mandated by owners. Local and regional materials are evaluated to determine whether they meet specification requirements. Energy Star options are investigated to determine their viability. The Environmental Protection Agency Procurement guidelines are reviewed and implemented if they are feasible. Designs are evaluated to determine whether modular or prefabricated components might be used to replace other design options.

## 8.6 POTENTIAL BARRIERS TO IMPLEMENTING CONSTRUCTION SUSTAINABILITY PROGRAMS

The most prevalent barriers to the implementation of sustainability programs during construction were capital cost concerns (24%), potential barriers to competitiveness (19%), and needing to show a positive rate of return (18%). If the responses to “not sure if it will be profitable” were added to “needing to show a positive rate of return,” that would be the most frequent response at 27%. Two of the other categories, “need a practical implementation plan” and “not sure how to do it or measure it” were also a concern, with a total percentage of 20%.

## 8.7 DRIVERS TO THE IMPLEMENTATION OF SUSTAINABLE DEVELOPMENT PRACTICES

The drivers to implementing sustainable development in the E&C industry include owners at 21%, public awareness of sustainability issues at 16%, government at 15%, competitive differentiation at 15%, and quality of life for future generations at 14%. Although owners only received 21%, it is becoming an increasing driver for the incorporation of sustainable practices into engineering designs and construction operations.

## 8.8 FIRMS FOLLOWING SUSTAINABILITY GUIDELINES PROVIDED BY OWNERS

Fifty-seven percent of the owners provide sustainability guidelines that are followed during design and construction, which might indicate that owners as a driver are higher than 21%.

## 8.9 FIRMS PARTICIPATING IN CORPORATE GLOBAL REPORTING INITIATIVES

Fifty percent of the firms participate in global reporting initiatives. This indicates that members of firms prefer to have a formal evaluation process for validating their implementation of sustainable practices reviewed by stakeholders.

## 8.10 FIRMS BELONGING TO THE DOW JONES SUSTAINABILITY GROUP INDEX

Fifty-seven percent of the firms belong to the Dow Jones Sustainability Group Index, which evaluates firms based on their sustainable development practices. This indicates that there is a need for more involvement by firms in the evaluation process determining their sustainability, but it is not necessarily an indication that they are not implementing sustainable practices.

## 8.11 FIRMS THAT ARE ISO 14000 CERTIFIED

Thirty percent of the firms either had not implemented ISO 14000 procedures or were not certified to the ISO 14000 series of standards. Thirty percent have implemented ISO 14000 and are certified to it, and for 39% either they did not know if their firm was certified to ISO 14000 or the question was not applicable to their firm. Since ISO 14000 certification requires a lengthy registration process, it might be years before more firms are certified to the ISO 14000 series of standards. Most of the firms certified to ISO 14000 were in the petrochemical or power sectors.

## 8.12 SOCIAL, REPUTATION, AND ECONOMIC BENEFITS TO CONTRACTORS OF USING SUSTAINABLE PRACTICES

Contractors incorporate various sustainable practices during construction processes to contribute positively to the local community, prevent the creation of pollution, and protect the community during construction. The suggestions provided to help create social, reputation, and economic benefits to contractors include the following:

- Ensuring air quality is considered during construction
- Establishing worker training programs to develop vocational skills in the community
- Hiring local subcontractors and workers

- Implementing noise and erosion control measures to protect and enhance the quality of life for members of the community
- Protecting communities from the negative effects of construction
- Protecting cultural, historical, and archeological resources
- Sourcing and purchasing materials locally
- Using the information in environmental impact statements to help protect the environment

When contractors implement these types of practices, they earn goodwill and trust from community members. Contractors receive the added benefits of having a satisfied customer and a model project, which improves their corporate reputation, and they receive positive media and industry recognition. The activities creating these types of benefits are used for marketing purposes to provide contractors with a competitive advantage over rivals who are not sustainably conscious. This helps contractors capture a larger share of the market and may further increase the implementation of sustainable practices. In addition, the expansion of business should improve profits and increase business diversification. Business diversification might encourage contractors to perform sustainability consulting or to enter the Small Business Administration Mentor–Protégé Program to assist small contractors and influence their adoption of sustainable construction and development practices.

## 8.13 SUMMARY

This chapter presented information obtained from E&C industry executives about corporate-level sustainable practices. The areas covered in this chapter were sustainability considerations related to designs; considerations due to regulatory compliance or beyond compliance; sustainability issues considered during the expected life cycle of a project; sustainability social issues evaluated impacting the completion of projects; structured approaches to evaluating sustainable designs and material alternatives; potential barriers to implementing construction sustainability programs; drivers to the implementation of sustainable development practices; firms following sustainability guidelines provided by owners; participation in corporate global reporting initiatives; involvement of firms in the Dow Jones Sustainability Group Index; ISO 14000 certification; and the social, reputation, and economic benefits to contractors of using sustainable practices.

## 8.14 KEY TERMS

Davis–Bacon prevailing wages
Executive Order 13,423
Green boards
Fleet green energy programs
Material use impact studies
Toxicity
Vapor reclamation

## 8.15 DISCUSSION QUESTIONS

8.1 Discuss which of the drivers to the implementation of sustainable development practices are increasing in influence.

8.2 Discuss why it is important to have a structured approach for evaluating sustainable design and material alternatives.

8.3 Discuss which of the social, reputation, or economic benefits of using sustainable practices are the most important to a contractor and why they are the most important.

8.4 What percentage of the firms participating in the study were using sustainable alternatives to standard materials, and what percentage were integrating sustainable components into their projects?

8.5 Discuss the three methods mentioned in this chapter being used by firms at the corporate level to become more proactive in their legal compliance rather than reactive.

8.6 Discuss why it would help to incorporate sustainable practices into project execution plans.

8.7 Discuss the sustainable materials considered during the design stage and why these materials are the main materials considered at this stage.

8.8 Discuss why there are so many different sustainability considerations evaluated for inclusion in projects during constructability reviews.

8.9 Discuss the government regulations that some of the industry experts were following.

8.10 Discuss which of the social issues addressed during construction directly affect personnel working on construction projects, and explain why they directly affect construction personnel.

8.11 Discuss the different stages where social issues related to sustainability are evaluated by members of firms.

## REFERENCE

Yates, J. 2008. *Sustainable Industrial Construction*. Research Report 250–11. Austin, TX: Construction Industry Institute. Accessed on January 2015. https://www.construction-institute.org/scriptcontent/more/rr250_11_more.cfm.

# 9 Project-Level Sustainability Initiatives

This chapter reviews project-level sustainability initiatives and includes information on what types of sustainable strategies are being implemented on projects. At the project level, it is the responsibility of project team members to provide a working environment that fosters sustainable practices. The following are some of the primary responsibilities related to sustainable implementation strategies of project team members (Kibert 2008, p. 309):

- Ensuring stringent *erosion control and sedimentation control* measures are instituted on projects
- Improving handling and storage of materials to reduce construction waste
- Making provisions for installing products and materials to reduce the potential for indoor air quality problems
- Minimizing the impact of construction operations, such as compaction and the unnecessary destruction of trees, on the site
- Paying attention to moisture control in all aspects of construction to prevent future mold problems
- Recycling site materials such as topsoil, *lime rock*, asphalt, and concrete into new building projects

Table 9.1 includes summaries of the percentages of firms experiencing the items indicated in the left-hand column that were provided by E&C industry executives. To augment the information shown in Table 9.1, this chapter discusses recommendations from E&C industry executives on the economic benefits from project-level sustainable practices, addressing project-level waste reduction, sustainable alternatives to materials, measuring the benefits of using sustainable practices, sustainable design and construction components, sustainable resource efficiency, supply chain management, project-level renewable energy, project-level pollution reduction, sustainable mobilization and demobilization practices, sustainable *project execution plans*, sustainable practices incorporated into *constructability reviews*, and project-level sustainability metrics. Other sustainable practices incorporated at the project level are requirements set at the corporate level, and these are discussed in Chapter 8.

## TABLE 9.1
## Project-Level Sustainability Information

| Project-Level Sustainability | Yes Responses | No Responses | Do Not Know Responses |
|---|---|---|---|
| Firm has benefited economically from implementing sustainability practices | 28% | 20% | 52% |
| Processes are used to sell, or reuse, material by-products generated during construction | 61% | 19% | 21% |
| Local social conditions are addressed during the construction of projects | 82% | 4% | 14% |
| Sustainable alternatives to standard materials are considered during the design phase | 46% | 18% | 36% |
| Firm has standard techniques for measuring the benefits of using sustainable practices on construction projects | 36% | 53% | 11% |
| Firm is using new techniques that improve resource efficiency, equipment efficiency, material resource efficiency, or training of laborers | 61% | 14% | 25% |
| Innovative sustainable designs, construction components, or construction practices are integrated into projects | 42% | 17% | 41% |
| Firm is prequalifying vendors and suppliers on sustainability practices or social responsibility | 18% | 61% | 21% |
| Renewable energy sources are used during construction | 21% | 43% | 36% |
| Techniques or processes are used to reduce the amount of waste generated during construction | 44% | 19% | 37% |
| More construction waste is recycled, or reused, than on projects before sustainability practices were implemented | 37% | 33% | 30% |
| Techniques are used to reduce the amount of pollution generated during construction | 74% | 19% | 7% |
| Mobilization, or demobilization, processes used include sustainable practices | 22% | 33% | 45% |
| Sustainability is considered during constructability reviews | 44% | 03% | 26% |
| Project execution plans include a section on sustainable practices | 35% | 54% | 11% |
| Firm has a method for measuring metrics related to sustainability objectives | 22% | 59% | 19% |

*Source:* Adapted from Yates, J., *Sustainable Industrial Construction*, Research Report 250–11, Construction Industry Institute, Austin, Texas, Accessed on January 2015, https://www.construction-institute.org/scriptcontent/more/rr250_11_more.cfm, 2008.

## 9.1 ECONOMIC BENEFITS FROM PROJECT-LEVEL SUSTAINABLE PRACTICES

Only 28% of the members of E&C firms indicated that their firm has benefited economically from implementing sustainable practices. But 52% did not know if their firm had benefited economically or not. This could mean that either there is a lack of knowledge about the benefits of implementing sustainable practices at the project level or firms do not have a technique for quantifying the economic benefits. Only 36% have a standard technique for measuring the benefits achieved by using sustainable practices on construction projects.

Some of the economic benefits provided were reduced costs due to reusing materials and equipment, avoiding negative regulatory agency interactions, being awarded more projects, enhanced reputation, increased consulting opportunities, and being able to obtain financing from development banking institutions.

## 9.2 ADDRESSING PROJECT-LEVEL WASTE

Sixty-one percent of firms sell or reuse material by-products generated during construction, 44% use processes to reduce the amount of waste being generated during construction, and 37% recycle or reuse materials for other purposes more often than they did prior to the implementation of sustainable practices on projects. Fifty percent either did not know or said they were not using processes to reduce the amount of waste being generated during construction.

There may be local initiatives implemented by workers or construction management personnel that the executives of the companies were not aware of that help reduce waste. The industry executives said waste management is one area benefiting from having standard techniques that firms are able to use either to reduce the amount of waste created at jobsites or for using waste by-products for other purposes.

The following are some of the processes mentioned to sell or reuse material by-products generated during construction:

- *Aggregating* (separating different types of waste) *disposable waste* to minimize the amount of energy expended in its final disposition
- Recycling by-products
- Refurbishing transformers and meters
- Returning materials back into corporate inventory to be sold to recyclers
- Selling unused materials to marketers who resell them for their originally intended purpose
- Separating scrap metal and reselling it
- Sharing leftover materials with other jobsites

A variety of processes are used to reduce, recycle, or eliminate waste materials including

- Advertising surplus materials throughout organizations
- Donating materials to local community organizations

- Establishing recycling pathways for excess materials
- Hiring appropriate firms to deal with contamination issues
- Returning materials to corporate inventory
- Returning materials to vendors
- Selling materials to dealers
- Selling waste to commercial waste contractors
- Using scrap metal dumpsters
- Using waste materials as feedstock for reuse
- Reducing the amount of waste sent to landfills (zero waste to landfills initiative)

To reduce the amount of waste generated at jobsites, it was suggested that improvements might result from correctly sizing materials and components and precutting drywall, pipe, and conduit. Additional reductions in waste are achieved through the following:

- Increased modularization
- Increased takeoff and material ordering control
- Making durable and reusable material and product choices
- Using *off-specification concrete* or remnants of concrete to fabricate other items such as curbstones and barrier blocks
- Using reusable concrete forms

A total of 37% were recycling or reusing more construction waste than before sustainable practices were implemented on projects.

## 9.3 SUSTAINABLE RESOURCE EFFICIENCY

Sixty-one percent were using sustainable techniques during construction that improve resource efficiency. Resource efficiency addresses items such as labor efficiency, equipment efficiency, material resource efficiency, or the training of laborers. Some of the techniques being used are

- Implementing productivity improvement programs to improve labor efficiency
- Increasing use of modularization
- Land balancing to minimize haul distances
- *Local sourcing* of materials to reduce transportation-related pollution
- Minimizing the handling of materials numerous times
- Optimizing jobsite layouts
- Reusing materials on site

## 9.4 INNOVATIVE SUSTAINABLE DESIGN AND CONSTRUCTION COMPONENTS OR CONSTRUCTION PRACTICES INTEGRATED INTO PROJECTS

Forty-two percent were integrating innovative designs and construction components, or implementing construction practices that include sustainable components into projects. As the incidence of owners requesting sustainable practices increases, this percentage will continue to increase in the E&C industry.

## 9.5 SUPPLY CHAIN MANAGEMENT

In the area of supply chain management, there were not many firms prequalifying vendors or suppliers on their sustainable or social responsibility practices, as only 18% of the firms follow this practice. The criteria used to prequalify vendors and suppliers include the following:

- Avoid green washing
- Contracts and specifications include requirements for implementing sustainable practices
- Evaluate energy and water conservation
- Include recycled content in feedstock
- Local sourcing of materials
- Specify sustainable products based on inherent characteristics
- Use 100% certified renewable energy

## 9.6 USING SUSTAINABLE GOVERNMENT REGULATIONS

Thirty-three percent of the firms were following government regulations on sustainable practices during construction. Following government regulations is not mandatory, but it is recommended in situations where they would help a project increase its sustainability.

## 9.7 PROJECT-LEVEL RENEWABLE ENERGY

Only 21% were using renewable energy during construction projects. Thirty-six percent did not know if renewable energy was being used or not, which could indicate that the decision on whether to use renewable energy is determined by site personnel or it is dependent on local pricing schemes. The renewable energy techniques mentioned were photovoltaic cells, wind turbines, biodiesel for generators, and wind towers.

## 9.8 PROJECT-LEVEL POLLUTION REDUCTION

Seventy-four percent incorporate techniques for reducing the amount of pollution generated during construction, and some of the techniques mentioned were the following:

- Installing scrubbers and mufflers on heavy construction equipment
- Limiting certain activities causing excessive noise to the daytime
- Minimizing the idling of heavy construction equipment engines
- Reducing or eliminating excessive noise
- Planning water runoff and *erosion protection schemes*

- Preplanning traffic routes to reduce fuel consumption
- Scheduling deliveries early in the day to avoid truck deliveries during the hottest hours on *high-ozone days*
- Treating effluent and *non-potable water*, and reusing it for dust suppression and landscape irrigation

## 9.9 MOBILIZATION AND DEMOBILIZATION, SUSTAINABLE PROJECT EXECUTION PLANS, AND SUSTAINABLE PRACTICES IN CONSTRUCTABILITY REVIEWS

In the area of mobilization and demobilization, only 22% of the firms were using sustainable processes and practices. A higher percentage of firms were investigating sustainability considerations during constructability reviews (44%), but only 35% were involved with project execution plans with a section on sustainable practices.

## 9.10 PROJECT-LEVEL SUSTAINABILITY METRICS

It would be useful if firms were able to quantify the achievement of sustainable development, but only 22% of the firms have a method for measuring metrics relating to sustainable objectives for construction projects.

## 9.11 SITE PROTECTION PLANNING

Project team members are responsible for *site protection planning*. The Leadership in Energy and Environmental Design (LEED) and Green Globes certification systems, as well as several other sustainability certification systems, include site protection planning in their rating systems. The following is an example of what should be included in a site protection plan, which was developed for the Department of Design and Construction of the City of New York (Kibert 2008, p. 310):

- Protection plan for vegetation and trees.
- *Tree rescue plan* for those trees and plantings that must be removed (ideally to be given to a park, community garden, nursery, or some other appropriate entity).
- Site access plan, including designated staging or *lay down area* designed to minimize damage to the environment. This plan should indicate storage areas for salvaged materials, including day-to-day construction waste (packaging, bottles, etc.). It must also designate site sensitive areas where staging, stockpiling, and soil compaction are prohibited.
- Wastewater runoff and erosion control measures.
- Measures to salvage existing clean topsoil on site for reuse.
- Plans to mitigate dust, smoke, odors, and other impacts.
- Noise control measures, including schedules for particularly disruptive, high-decibel operations, and procedures for compliance with state and local noise regulations.

## 9.12 AIR QUALITY DURING CONSTRUCTION

Construction project team members are also responsible for maintaining indoor air quality during construction, and this requires the development of an indoor air quality plan. *Health and safety plans* are not specifically a part of the LEED and Green Globes certification processes, or other sustainability certification systems, but there are elements of health and safety plans in most of them. Health and safety plans should account for the air quality design of a building and provide for the following (Kibert 2008, p. 311):

- Adequate separation and protection of occupied areas from construction areas for building additions.
- Protection of ducts and airways from dust, moisture, particulates, volatile organic compounds (VOCs), and microbes resulting from construction/demolition activities.
- Increased ventilation/exhaust air at the construction site.
- Scheduling of construction procedures to minimize the exposure of absorbent building materials to VOC emissions. For example, *wet construction procedures* such as painting and sealing should occur before storing or installing *dry absorbent materials* such as carpets and ceiling tiles. These porous components act as a sink, retaining contaminants and releasing them during building occupancy.
- A *flush-out period*, beginning as soon as systems are operable and before or during the furniture, fittings, and equipment installation phase. The process involves flushing the building with 100% outside air for a period not less than 20 days.
- Appropriate steps to control vermin.
- Prevention of pest infestation once the building or renovated portion is occupied, using integrated pest management.

## 9.13 SUMMARY

This chapter discussed project-level sustainable practices. The topics covered were the economic benefits from implementing project-level sustainable practices, addressing project-level waste reduction, sustainable alternatives to materials, measuring the benefits of using sustainable practices, sustainable design or construction components, resource efficiency, supply chain management, project-level renewable energy, project-level pollution reduction, sustainable mobilization and demobilization practices, sustainable project execution plans, sustainable practices incorporated into constructability reviews, project-level sustainability metrics, site protection planning, and air quality during construction.

## 9.14 KEY TERMS

Aggregating disposable waste
Constructability reviews
Dry absorbent materials
Erosion control and sedimentation control

Erosion protection schemes
Flush-out period
Health and safety plans
High-ozone days
Lay down area
Lime rock
Local sourcing
Non-potable water
Off-specification concrete
Project execution plans
Recycling pathways
Site protection plan
Tree rescue plan
Wet construction procedures

## 9.15 DISCUSSION QUESTIONS

9.1 Discuss why health and safety plans should be part of sustainable practices.
9.2 Discuss how resource efficiency is related to sustainable techniques.
9.3 Discuss why only a limited number of firms were following government regulations on sustainable practices during construction.
9.4 Explain why such a small percentage of industry experts indicated that they have benefited economically from implementing sustainable practices.
9.5 Discuss why the percentage of firms using techniques to reduce the amount of pollution generated during construction is higher than any of the other responses obtained to sustainability questions.
9.6 Discuss why it is the responsibility of project team members to provide a working environment that fosters sustainability.
9.7 Discuss which of the processes for selling or reusing material by-products might be implemented without any additional cost to a firm.
9.8 Discuss whether members of firms would use more sustainable practices if there was a better method for quantifying the achievement of sustainable development.
9.9 Explain what site protection plans are, and describe some of the required elements of site protection plans.
9.10 Discuss how to increase the use of sustainable practices during the mobilization and demobilization phases of construction projects.

## REFERENCES

Kibert, C. 2008. *Sustainable Construction: Green Building Design and Delivery*. Hoboken, NJ: John Wiley and Sons.

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# 10 Global Sustainability Trends and Implications

In the United States, the International Affairs Program, which is managed by the Office of International Affairs (OIA) and is part of the Environmental Protection Agency (EPA), provides information on international environmental issues (Office of International Affairs–Environmental Protection Agency 2005). In the European Union (EU), the European Commission Environment Directorate (2014) provides environmental information. The United Nations Environment Programme Sustainable Buildings and Construction Initiative (2007) focuses on improving energy efficiency in buildings throughout the world. In other countries, such as France, Italy, South Korea, Portugal, Chile, Guinea, and Eastern European countries, the Ministry of the Environment controls environmental issues. In other regions of the world, there are a variety of different agencies regulating the environment and examples are included in Chapter 2 in Section 2.11.

In the early 2000s, the minimum standards for energy efficiency were updated in Austria, France, Japan, New Zealand, and the United Kingdom for roofs and walls to limit heat loss and to set minimum levels of *thermal efficiency* for furnaces and water heaters. The guidelines such as these for minimum standards for each country should be reviewed before undertaking projects in these countries by contacting the appropriate government agencies responsible for developing and enforcing environmental regulations.

Construction and demolition wastes constitute a large percentage of the total hazardous waste produced in most countries. In the United States, 50% of the hazardous waste is generated during construction and 40 million tons of the types of hazardous waste regulated by the Resource Conservation and Recovery Act are generated each year (Environmental Protection Agency 2012a). The nonhazardous solid waste (municipal solid waste) produced in the United States in 2012 was 251 million tons (Environmental Protection Agency 2012b).

In Australia, the construction industry produces 38% of the total hazardous waste. Construction waste includes concrete, tiles, brick, soil, mortar, plaster, insulation, carpets, and paper. Demolition waste includes wood, plastic, steel, metal, wire, concrete, cardboard, brick, insulation, asphalt, tar, paving stones, gravel, *ballast* (small crushed stones), soil, rock, and buried materials (Office of International Affairs–Environmental Protection Agency 2012). The following list indicates the percentages of each type of construction and building waste in the United States (Environmental Protection Agency 2012c, p. 1):

- Concrete and mixed rubble: 40%–50%
- Wood: 20%–30%
- Drywall: 5%–15%

- Asphalt roofing: 1%–10%
- Metals: 1%–5%
- Bricks: 1%–5%
- Plastics: 1%–5%

To reduce the amount of heat absorbed into structures during the hot summer months, green roofs are being used throughout the world. Green roofs are covered with plants that are able to survive with the water they receive during rain events or with minimal watering. Even though green roofs are not mandatory in the United States, as they are in Germany, some designers are incorporating green roofs or skins into buildings. Figure 10.1 shows the completed Portland, Oregon, Government Services Building—the Edith Green-Wendell Wyatt Modernization Project—and Figure 10.2 is a Building Information Modeling rendering of the building, illustrating the south side of the building after the plants have grown up that side.

This chapter provides information on some of the sustainability issues occurring in different parts of the world. The first part of the chapter addresses country-specific sustainability issues including environmental challenges in the People's Republic of China, India, Germany, South Korea (Republic of Korea), Great Britain, and the United States. The second part of the chapter includes examples of mitigation strategies and quantification methods for evaluating sustainability during construction. Sections 10.2 through 10.6 provide information on sustainability issues and some of

**FIGURE 10.1** Green building skin on the Portland federal building. (Government Services Administration, *Edith Green–Wendell Wyatt Modernization Project—Portland, Oregon Federal Building*, Portland, Oregon, Accessed on February 5, 2015, http://gsa.gov/portal/content/252613, 2014.)

**FIGURE 10.2** Building Information Modeling rendering of the Portland federal building. (Government Services Administration, *Edith Green–Wendell Wyatt Modernization Project—Portland, Oregon Federal Building*, Portland, Oregon, Accessed on February 5, 2015, http://gsa.gov/portal/content/252613, 2014.)

the techniques being implemented in different countries for reducing pollution and toxic waste. Examples are included of the types of sustainability issues affecting different countries. Some environmental issues are unique to each country, and the issues vary depending on the level of industrialization in each country.

## 10.1 SUSTAINABILITY ISSUES IN THE PEOPLE'S REPUBLIC OF CHINA

This section describes some of the environmental issues that citizens of the People's Republic of China are addressing due to the rapid industrialization occurring in their country.

### 10.1.1 Air Quality

In the People's Republic of China, air pollution is a major problem because there are high levels of *trisodium phosphate* (TSP), which is a chemical released into the atmosphere in the by-products of paint and washing detergents. Trosodium phosphates pollute lakes, rivers, and streams and contaminate the drinking water extracted from them. In addition, according to the Chinese State Environmental Control Network

85% of the major cities in northern China have exceeded the allowable levels of *sulfur dioxide* by 30% (Dwivedi and Jabbra 1998). Other negative health effects of high concentrations of sulfur dioxide in the air include acid rain and an increased risk of people developing lung cancer.

Many of the major metropolitan areas in China are experiencing concentration levels of pollutants 400–600 times the allowable levels, which is contributing to major health issues being experienced by many of their citizens. The two primary sources of air pollution in major cities are carbon dioxide emissions from gasoline- and diesel-powered vehicles and coal-fired power plants (Facts and Details 2013).

### 10.1.2 WATER QUALITY

In northern China, there is a severe shortage of safe drinking water due to the toxic levels of chemicals in the water. It was estimated in 2013 that 45% of the water in northern China is not fit for human consumption, but fortunately this rate is only 10% in southern China. Only 20% of the rivers in northern China are fit for human consumption. In 2013, 40% of river water and 80% of the subsurface water in major cities was polluted by improper disposal of waste leaching into water systems, and these percentages have increased exponentially with the rapid industrialization of the country. Over 600 million people in China drink water contaminated with animal or human waste, and 20 million people only have access to water contaminated by high levels of radiation. There are also high levels of arsenic, fluorine, and sulfates in the water in China, leading to elevated levels of liver, stomach, and esophageal cancer (Facts and Details 2013).

### 10.1.3 ENVIRONMENTAL POLICIES

Laws with provisions for protecting the environment in the People's Republic of China were enacted in 1989, and they established a legal foundation for environmental management (Solange et al. 2003). In the People's Republic of China, construction projects now require the following (Dwivedi and Jabbra 1998):

- An environmental responsibility system
- Central pollution control
- Discharge permits
- Environmental impact assessments (EIAs)
- Pollution discharge fees
- Required assessments of urban environmental quality

Members of the construction industry are required to follow the environmental policies set by the government, but the enforcement of policies is sporadic in the People's Republic of China. For example, in the year 2000 the Shanghai Division of Development and Construction Administration had only eight officials supervising 500–600 construction projects per year, whereas in other regions one official normally supervises 40–70 projects per year. Engineers and constructors are now being required to follow the environmental legislation and procedures set forth by the government of the People's Republic of China and to conform to the environmental policies of the country (Jeong 2001).

## 10.2 SUSTAINABILITY ISSUES IN INDIA

Some of the most prevalent environmental problems in India are air pollution, water pollution from industrial and domestic effluents, soil erosion, *deforestation* (the removal of trees to a level where the forest no longer regenerates), degradation of land due to increases in salinity and alkalinity in the soil, soil and water pollution caused by the excessive use of pesticides and fertilizers, and improper agricultural practices. Natural resource extraction activities such as mining and metallurgy, aggregate production, and other manufacturing industries generating products for the construction industry create hazardous waste (Dwivedi and Jabbra 1998).

### 10.2.1 Air Quality

Air pollution is prevalent in India in both urban and rural environments. In urban areas air pollution is caused by carbon dioxide emissions, and in rural areas it results from the burning of wood, charcoal, and dung for fuel. Industrial air pollution is affecting structures by the pitting of their exteriors from airborne acids.

### 10.2.2 Water Quality

In India, there has long been a problem with the dumping of chemical and industrial waste into water systems. In addition, fertilizers and pesticides run off the land and end up in water systems. As a result, in India 70% of the surface water has been polluted by groundwater runoff and chemicals. With the help of water treatment systems, 95% of urban and 79% of rural citizens have access to safe drinking water (Encylopedia of the Nations 2015).

### 10.2.3 Government Reforms

Government Reforms and Policies of India established the Indian National Committee on Environmental Planning and Coordination (NCEPC) in 1972 and the Department of Environment (DOE) in 1980, and these agencies developed national standards for the abatement of pollution, which are implemented by the central and state pollution control boards. Environmental audits are required to monitor and evaluate effluents and emission control (Dwivedi and Jabbra 1998).

The government of India passed the Indian Prevention and Control of Pollution Act for Water, and it sets penalties for noncompliance such as jail terms for up to 3 months or a fine of up to Rs. 5000, or both. This fine is approximately US$81.13 if the exchange rate is Rs. 61.63 per dollar. Under the Indian Prevention and Control of Pollution Act for Air, jail terms might be for 3 months and fines could be imposed for up to Rs. 10,000 ($162.26). Under the Environmental Protection Act of 1986, jail terms could be for up to 5 months or there could be fines of Rs. 100,000 (Dwivedi and Jabbra 1998; X-Rates 2015).

## 10.3 SUSTAINABILITY ISSUES IN GERMANY

Germany is known as a country where sustainability is a high priority for both government agencies and citizens, but even with all its efforts to implement sustainable practices it still encounters issues with air pollution.

### 10.3.1 Air Quality

Even though Germany has been a leader in promoting sustainability, it is still struggling with trying to limit pollution caused by industrial plants. In 2008, the government implemented environmental zones in locations where industrial pollutants were the highest. Every car entering an environmental zone must have a sticker identifying the level of exhaust pollution emitted by the vehicle. The stickers are green, yellow, or red, and vehicles with the highest level of exhaust pollution are prohibited from entering environmental zones. Throughout Germany, there are 54 environmental zones; 42% of the measuring stations in these zones have measured excessive levels of particulate pollutants and 57% have measured excessive amounts of nitrogen dioxide. “Excessive levels mean more than 35 days a year of particulate matter exceeding 50 micrograms per cubic meter or 30 micrograms for nitrogen dioxide” (Deutsche Welle 2012, p. 2).

### 10.3.2 Government Acts

In Germany, there are a variety of environmental laws and three of them directly affect construction: the (1) Waste Disposal Act of 1972, (2) Waste Avoidance and Waste Management Act of 1986, and (3) Closed Substance Recycle and Waste Management Act of 1986. The combination of these acts has created a situation where there is minimal disposal of waste, because all waste must be redirected to other locations and used as secondary raw materials. Germany has a 3R principle—reduce, reuse, and recycle (Euring and Ashworth 2003).

Some European countries are using labeling systems for construction materials indicating the amount of energy required to produce materials, and in Germany this process is called the *Blue Angels*. Conventional construction materials such as concrete, wood, and brick require low energy levels to produce compared to other construction materials. A steel I-beam with the same strength as a wood beam requires six times more energy to produce than a wood beam (Euring and Ashworth 2003).

### 10.3.3 Construction Waste Reduction Procedures

The construction industry in Germany was producing 63% of the total waste in the country during the 1990s. To comply with government guidelines, members of the industry volunteered to reduce the generation of waste by half by the year 2005 and their efforts resulted in the construction industry recovering 70% of their waste per year by 2005. German laws also mandate that buildings have green roofs, and companies are taxed if they do not install impermeable drainage systems in new structures (Euring and Ashworth 2003).

## 10.4 SUSTAINABILITY ISSUES IN SOUTH KOREA (REPUBLIC OF KOREA)

South Korea (Republic of Korea) is experiencing environmental issues due to sewer discharge, industrial emissions, drift net fishing, and packaging of consumer goods. Environmental issues in South Korea are influenced by activities within the country and also by trans-boundary migration of pollutants.

### 10.4.1 Air Quality

South Korea (Republic of Korea) has environmental pollution caused by carbon dioxide exhaust from vehicles, but some of its worse pollution comes across the sea from China. During the winter, South Korea experiences a haze called *mise meonji*, which contains excessive levels of heavy metals including arsenic and lead according to the National Institute of Environmental Research. Residents attempt to combat the haze and heavy metals with dust masks and special detergents for cleaning the pollutants, and they install dustproof windshield wipers and air filters on their vehicles (U.S. Embassy in Seoul 2011).

During the spring, *yellow dust* from industrial pollution in China comes across the sea and it affects citizens with respiratory illnesses, children, and the elderly. Advisory warnings are issued by the Korea Meteorological Administration to stay inside if the yellow dust particles exceed 400 $\mu g/m^3$ and to avoid outdoor activities if the levels exceed 800 $\mu g/m^3$ (U.S. Embassy in Seoul 2011).

### 10.4.2 Water Quality

In South Korea (Republic of Korea) in 2011, only 3 of the 26 lakes classified as class 1 lakes were able to meet the pollution standards set in 2007. This indicates that 23 lakes are polluted and experience eutrophication. Two out of all of the graded lakes (49) are *hypertrophic* (highly fertile and saturated with phosphorus and nitrogen), 11 are *mesotrophic* (medium levels of nutrients), and 3 are *oligotrophic* (little to sustain life and low in nutrients) (Tunza Eco Generation 2012).

### 10.4.3 Construction Waste Disposal

In South Korea (Republic of Korea), construction waste constitutes 49% of the total waste disposed of in landfills. Ninety percent of the construction waste in South Korea is from concrete, asphalt, and soil as concrete and asphalt are the primary components of their structures. The waste problem in South Korea (Republic of Korea) is being addressed by a process involving a sliding scale of rates charged for the disposal of materials in landfills. Mixed waste costs US$160 per ton (160,000 Korean won per ton) for disposal, but if the mixed waste is separated into different types of materials then the disposal of concrete only costs US$16 per ton (Ministry of the Environment 2004).

## 10.5 SUSTAINABILITY ISSUES IN GREAT BRITAIN

Great Britain struggles with environmental issues in terms of air quality, construction waste, and hazardous waste. Sections 10.5.1 through 10.5.3 discuss some of the environmental issues being addressed in Great Britain.

### 10.5.1 Air Quality

> The UK Supreme Court has already declared that air pollution limits are regularly exceeded in 16 zones across the UK. The areas affected are Greater London, the West Midlands, Greater Manchester, West Yorkshire, Teesside, the Potteries, Hull, Southampton, Glasgow, the East, the South East, the East Midlands, Merseyside, Yorkshire and Humberside, the West Midlands, and the North East. The Court also noted that air quality improvement plans estimate that for London compliance with EU standards will only be achieved by 2025, fifteen years after the original deadline, and in 2020 for the other 15 zones. (European Commission 2014, p. 2)

### 10.5.2 Construction Waste

Ninety percent of the nonenergy materials extracted in Great Britain are used in the construction industry (Department of the Environment, Transport, and the Regions 2000). When materials are quarried for use in the construction industry, it impacts the environment in many different ways including the following (Lindley and McEvoy 2002, p. 163):

- *Amenity issues*: associated with noise
- Depletion of nonrenewable resources and the environment
- Ecological impacts: landform alteration and the disruption of ecosystems
- Health-related issues: associated with dust
- Hydrological problems: caused by modifications and pollution
- Transport-related issues: caused by congestion and air pollutant emissions

According to Lindley and McEvoy (2002, p. 167), “Changes to the hydrological regime could have more ecological significance than the quarrying activity itself. Habitat destruction and unfavorable changes in the chemistry of soils and surface waters could occur due to the physical disturbance caused by quarrying. It is therefore important to take account of all flows rather than just those converted within the economy, including ‘hidden’ flows such as those associated with overburden, spoil heaps, etc.”

To achieve sustainability goals in Great Britain, the following would have to be implemented (Lindley and McEvoy 2002, p. 165):

- Closing material loops (moving from a linear to a circular metabolism)
- Increasing self-sufficiency (reducing the export of environmental damage, and incorporating the important caveat of proximity)
- Minimizing environmental impacts (focusing on the reduction of carbon-based energy, in particular the reduction of fossil fuel freight transport)

- Promoting integrated materials management, which enables the measures listed previously including new technology; materials management; design specifications; economic levies and new markets; institutional and policy changes; skills development; and, not the least, coordination of information and data systems to support these
- Promoting whole-life responsibility (engage suppliers and consumers in finding beneficial uses at each stage of the material chain)
- Reducing resource inputs (reducing the amount of primary extracted material entering regional systems)

### 10.5.3 Hazardous Waste

In Great Britain, a large proportion of the structures built before 1985 are coated with paints containing *lead* and the water pipes installed before 1985 also contain lead. Lead is used for roof and pipe flashing, leaded lights, paints, and lining pipelines. Lead becomes toxic when it is exposed to soft water. Almost half of the water pipes in Great Britain contain some lead, approximately one-fifth of the allowable amount of lead. In Scotland, over 50% of the households have water exceeding the allowable lead concentrations per liter based on the maximum permitted upper limit set by the European Council Directives (Euring and Ashworth 2003). Lead solder used in pipe joints and lead-based paints, varnishes, and wood stains are also hazardous to the environment. Lead is especially harmful to children if it is ingested in paint chips or when they are exposed to the lead paint on drinking containers (Euring and Ashworth 2003).

Four million of the 4.5 million *council homes* (low income housing) in Britain built before 1985 have *asbestos* in their roofs and walls. Also, 80% of the metropolitan schools and colleges and 77% of the school service buildings built before 1985 also contain asbestos. *Vermiculite* was used for roofing and boiler insulation before 1985 in the United Kingdom, and it also contains asbestos (Euring and Ashworth 1993).

Asbestos is a natural substance removed from mines and used in the manufacture of sheetrock (drywall and wallboard), insulation, and other construction materials. Asbestos breaks down when it is disturbed by drilling or other means of penetration, and it releases a fine dust toxic to humans, but the effects of asbestos exposure are not apparent for decades. One of the manifestations of asbestos poisoning is *silicosis*, which might be a fatal lung disease; therefore, asbestos was banned in Great Britain in 1985 by the British Health and Safety Code of Practice and in the United States by the U.S. EPA in the 1970s. There are other countries throughout the world still using asbestos in the manufacture of wallboard for construction; therefore, construction workers need to be aware that they could be exposed to asbestos dust while installing, drilling into, or demolishing wallboard (sheetrock) and they should take precautions to prevent inhalation of the fine asbestos dust particles.

## 10.6 SUSTAINABILITY ISSUES IN THE UNITED STATES

Many of the major environmental issues in the United States are covered throughout this book; therefore, this section only describes issues related to hazardous waste and pressure-treated lumber.

### 10.6.1 Hazardous Waste

In the United States, the construction industry generates over 50% of the hazardous waste in the country and before the 1970s hazardous waste was disposed of in landfills, or unmarked sites. The EPA has identified over 500 Superfund hazardous waste sites, and the EPA Superfund program is attempting to mitigate the materials in these sites. A map showing Superfund sites is provided in Chapter 5 in Figure 5.2. Hazardous waste should be disposed of by dumping it into protected dumpsites clearly marked as containing hazardous waste, but using these sites substantially increases the cost of disposal. The materials in hazardous waste sites have been linked to health issues such as cancer, leukemia, autism, and miscarriages in people living above, or close to, former dumpsites. Being exposed to more than one hazardous toxin at the same time increases the associated risk of contracting cancer or other diseases (Meyninger 1994).

### 10.6.2 Pressure-Treated Lumber

Pressure-treated lumber is regular lumber that has been treated with chromated copper arsenate, and it is being studied by the EPA in the United States to determine its toxicity. Its use has been phased out for some residential applications in the United States and for playground equipment. There are some studies indicating that construction workers might contract serious illnesses or develop neurological problems such as *bells palsy* (paralysis or weakness of the muscles on one side of the face) if they are exposed to sawdust while sawing or working around pressure-treated wood, especially in enclosed environments (Nowak 2006). Additional information on pressure-treated lumber is provided in Chapter 11 in Section 11.7.1.

## 10.7 SAMPLES OF ENVIRONMENTAL DEGRADATION MITIGATION STRATEGIES

Throughout the world, mitigation strategies are being implemented to reduce pollution or the use of energy. The following are examples of some of these mitigation strategies:

- Austria: provides grants for building passive houses that expend only minimal energy, and in Sweden fluid-filled pipes use the heat in the earth to heat homes.
- Austria, Germany, Belgium, Switzerland, Japan, and Slovenia: promote transportation of materials by ship or rail to reduce pollutants.
- Belgium, Germany, Hungary, and Switzerland: *green tariffs*, which means that the energy generated by renewable sources is purchased by the government at a higher price.
- Denmark: stabilized its greenhouse gas (GhG) emissions by switching from coal to renewable natural gas.
- Europe: government agencies issue grants and tax breaks to firms incorporating energy-efficient techniques into structures.

- EU Directive: requires housebuilders, landlords, and home sellers to have energy efficiency certificates for their structures listing the energy efficiency rating of each structure.
- EU: uses energy labeling for household appliances.
- Japan: energy requirements have been reduced through the redesign of digital videodiscs (50% reduction), refrigerators (30% reduction), and computers (83% reduction).
- Norway and Switzerland: charge landfill tariffs if a facility is not sealed to prevent methane gas from escaping from landfills.
- The Netherlands: rebates are provided for energy-efficient appliances.

### 10.7.1 GREEN PURCHASING POLICIES

One city in the United Kingdom, named Sheffield, has adopted a *green purchasing* policy that includes the following (Ofori 2000, p. 201):

- Conserving the ecological processes that sustain life
- Conserving *biodiversity* (degree of variation of life)
- Using renewable resources
- Minimizing the depletion of *nonrenewable resources*

In the United States, city managers follow the aforementioned purchasing policy when they consider purchasing materials. If the managers are able to locate materials and products meeting the policy guidelines they are purchased, and if they are not able to locate them they may approach suppliers to determine whether the suppliers would be able to produce products meeting the green policy guidelines. Table 10.1 lists some of the strategies used for environmental purchasing (Ofori 2000, p. 201).

**TABLE 10.1**
**Strategies in Environmental Purchasing**

| Category | Activity |
|---|---|
| Product standards | Purchase products possessing environmentally friendly attributes such as recycled materials, nontoxic materials, and materials containing disclosures of environmental attributes (having eco labels). |
| Behavior standards | Suppliers disclosing information about their environmental practices and pollution discharge procedures, who audit their environmental performance and implement and maintain environmental management systems such as ISO 14000. |
| | Audit suppliers to evaluate their environmental performance. |

(*Continued*)

**TABLE 10.1 (*Continued*)**
**Strategies in Environmental Purchasing**

| Category | Activity |
|---|---|
| Collaboration | Help suppliers reduce the environmental impact of their operations through changes in their product designs and material use.<br>Implement a product stewardship program during all of the stages of the life cycle of products. |
| Development | Institute training programs for suppliers to increase their knowledge of the environmental implications of the activities of the company.<br>Stay informed about supplier technological developments relating to their operations. |

*Source:* Adapted from Ofori, G., *European J. of Purchasing and Supply Manage.*, 6(3/4), 195–206, 2000.

*Note:* ISO, International Organization for Standardization.

## 10.8 QUANTIFICATION OF SUSTAINABLE VALUE IN CONSTRUCTION

Members of construction firms are adapting assessment models to fit the industrial construction environment and using procedures to assess the impact of their construction operations. Table 10.2 contains one assessment model for industrial buildings developed by Jose et al. (2007) and explained in their article “Approach to the Quantification of the Sustainable Value in Industrial Buildings.” Sustainable industrial building aspects considered today mainly refer to the production processes performed inside industrial buildings.

To assess the use of alternative or sustainable materials in projects throughout the world during construction, there are several questions that should be answered before decisions are made about which raw materials to incorporate into structures (Jose et al. 2007, p. 3920):

- How will materials be transported to the jobsite?
- How will the materials be stored at the jobsite?
- How will the raw materials be obtained and from where?
- What are the methods used to extract the raw materials, and was the land restored to its natural state (if required)?
- What materials are required for the project?
- What techniques were used to process the raw materials?
- Whether, and how, renewable raw materials are regenerated.

In the Netherlands, the minister of Housing, Spatial Planning, and the Environment has adopted new regulations on performance standards for materials

**TABLE 10.2**
**Assessment Model for Industrial Buildings**

| Study Scope | Study Stages |
|---|---|
| Location | *Design* |
| | Integrating industrial buildings into the natural built-up environment. |
| Construction materials | *Construction* |
| | Investigate the environmental impacts of materials to be used and the alterations caused by construction. |
| | Manage waste during construction. |
| Energy and water consumption | *Building operation* |
| | Monitor building consumption during its operation. |
| | Manage the waste generated during operation. |
| Influence on the construction and reintegration phase | *Reintegration* |
| | Monitor the alterations caused by the reintegration process. |
| | Manage the waste generated during demolition. |

*Source:* Adapted from Jose et al., *J. of Bldg. and the Env*., 42(11), 3916–3923, 2007.

used for constructing houses and similar legislation may follow for other areas of the construction industry. The method used to assess the performance of materials in the Netherlands is the Material-Based Environmental Profile for Buildings (MEFB). The MEFB assesses the environmental impact of the materials used for construction projects throughout their entire life cycle. It creates environmental profiles for "both licensable and non-licensable structural components, installation of materials, and structural and other fixtures" (European Comission Enterprise 2001, p. 1). The MEPB is used in conjunction with the standards developed by the Dutch Institute for Standardisation (NEN).

## 10.9 SUMMARY

This chapter provided examples illustrating the sustainability issues faced in countries throughout the world that are being addressed to either maintain their status or continue developing as industrialized nations. A few of the agencies regulating the environment in specific countries were mentioned in this chapter along with some of the major sustainability issues related to construction occurring in these countries. This chapter provided country-specific environmental issues for the People's Republic of China, India, Germany, South Korea (Republic of Korea), Great Britain, and the United States. The last part of the chapter provided examples of environmental degradation mitigation strategies used in some countries and quantification methods for sustainable value in construction.

## 10.10 KEY TERMS

Amenity issues
Asbestos
Ballast
Bells palsy
Biodiversity
Blue Angels
Council homes
Deforestation
Fluorine
Green purchasing
Green tariffs
Hypertrophic
Mesotrophic
Mise meonji
Nonrenewable resources
Oligotrophic
Silicosis
Sulfates
Sulfur dioxide
Thermal efficiency
Trisodium phosphate

## 10.11 DISCUSSION QUESTIONS

10.1 Discuss why having lead in existing structures and piping systems is dangerous to construction workers and to other people exposed to it.
10.2 Why is asbestos dangerous to construction workers, and why is it not banned everywhere in the world?
10.3 Discuss why it is taking decades to clean up hazardous waste sites in the United States designated as Superfund sites.
10.4 Discuss how the Material-Based Environmental Profile for Buildings method is being used in the Netherlands.
10.5 How could construction waste such as concrete be recycled and used to meet the 3Rs required in Germany?
10.6 Discuss why it is important to know who to contact about environmental requirements when working in a foreign country.
10.7 Discuss what constitutes the largest percentage of the total hazardous waste produced in most countries, and explain why.
10.8 Discuss what is unusual compared to other countries about the penalties for noncompliance of the Indian Prevention and Control of Pollution Act for Water and Air.
10.9 Discuss whether a program similar to the one implemented in Germany that reduced construction waste by 70% would be successful in the United States, and why or why not.

10.10 Discuss why it is so difficult for the government to enforce environmental policies in the People's Republic of China.

10.11 Discuss why air pollution is a major problem in the People's Republic of China and whether there are any techniques for reducing air pollution in this country.

10.12 Discuss why the South Korea (Republic of Korea) technique of separating waste before disposal is so successful.

10.13 Discuss the most prevalent environmental problems occurring in India.

10.14 Explain how hazardous waste should be properly disposed of in the United States.

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# 11 Sustainable Construction Materials

This chapter discusses sustainable construction materials and some of the processes required to produce them to demonstrate the cradle-to-grave consequences of construction materials. The sustainable construction materials reviewed in this chapter are paints; sealants; steel; cement and concrete; fly ash concrete; *concrete canvas*; *porous concrete*; *Hardie board*; asphalt; masonry products; *fiber-reinforced polymer* (FRP) *composite materials*; wood products; and *polyvinyl chloride* (PVC), *thermoplastic*, and metal products.

Sustainable construction materials "minimize resource use, have low ecological impacts, pose no or low human and environmental health risks, and assist with sustainable site strategies" (Calkins 2009, p. 3). In addition to incorporating sustainable materials, structures would be more sustainable if they incorporated fewer materials or were reduced in size. Reusing existing structures or structural elements from existing structures also leads to more sustainable structures. Sustainable structures include materials that will last for the life of a structure and the materials used in the structures should be reclaimed and reused in future structures (Calkins 2009). Another method for reducing the environmental impact of construction materials is to use materials *sustainably harvested* or mined in such a manner as to minimize air, water, or soil pollution.

Recommendations on how to reduce the amount of resources consumed during the construction of a structure through the selection of materials and products include the following (Calkins 2009, pp. 3–5):

- Reclaim and reuse materials or products in whole forms.
- Reduce material use.
- Reprocess existing structures and materials for use on site.
- Reuse existing structures in place.
- Specify materials and products made from renewable resources.
- Specify materials and products with reuse potential, and design for disassembly.
- Specify materials or products from manufacturers with product take-back programs.
- Specify recycled-content materials and products.
- Use durable materials.
- Use materials and products with recycling potential.
- Use reclaimed materials from other sources.
- Use reprocessed materials from other sites.

Sometimes the choice of materials or products helps to minimize environmental impacts, and suggestions on materials and products accomplishing this are the following (Calkins 2009, pp. 6–7):

- Local materials
- Low embodied energy materials
- Low water consumption and low water polluting materials
- Low polluting materials
- Materials or products without toxic chemicals or by-products
- Materials produced with energy from renewable sources
- Minimally processed materials

Some of the types of materials or products blending with or contributing to sustainable site design strategies are ones that perform the following (Calkins 2009, p. 8):

- Promote a site's hydrologic health.
- Reduce energy consumption of site operations.
- Reduce the urban *heat island* effect.
- Reduce water consumption of site operations.
- Sequester carbon.

According to the *Los Alamos National Laboratory Sustainable Design Guide*, certain characteristics are preferable in construction materials, and they are listed in Table 11.1. This guide also includes a table of design evaluations for materials and resources, and it is provided in Table 11.2.

**TABLE 11.1**
**Sample Characteristics of Environmentally Preferable Materials**

| Category | Characteristic |
|---|---|
| Life-cycle cost impact | Relative impact of life-cycle cost of building operations (not to be confused with environmental life-cycle assessment, which measures environmental burdens, not financial impact). |
| Energy efficiency | Construction materials directly influencing building energy use. |
| Water efficiency | Construction materials directly influencing building water use. |
| Locally manufactured | Construction materials manufactured within a defined radius [500 mi. for the LEED rating system]. |
| Material reduction | Products or materials serving a defined function using less material than is typically used. |
| Locally derived raw material | Construction materials locally manufactured using raw materials obtained within the defined radius [500 mi.]. |
| Nontoxic | Construction materials releasing relatively low levels of emissions of odorous, irritating, toxic, or hazardous substances.<br>VOCs, formaldehydes, particulates, and fibers are examples of substances emitted from construction materials adversely impacting human health (allergens, carcinogens, and irritants). |

(*Continued*)

**TABLE 11.1 (*Continued*)**
**Sample Characteristics of Environmentally Preferable Materials**

| Category | Characteristic |
|---|---|
| Recycled content | Amount of reprocessed material contained within a construction product originating from postconsumer use and/or postindustrial use.<br>Including the reuse of existing building structures, equipment, and furnishings. |
| Salvages | Construction materials that are reused as is (or with minor refurbishing) without having undergone any type of reprocessing to change the intended use. Reusing existing building structures, equipment, and furnishings |
| Rapidly renewable | Construction materials that replenish themselves faster (within 10 years) than traditional extraction methods and do not result in adverse environmental impacts. |
| Certified wood | Construction materials manufactured completely or in part from wood certified to the standards of the Forest Stewardship Council, as originating from a well-managed forest. |

*Source:* Modified from Los Alamos National Laboratory, *Los Alamos National Laboratory Sustainable Design Guide*, Los Alamos, New Mexico, Accessed on January 15, 2015, http://www.lanl.gov/orgs/eng/engstandards/esm/architectural/Sustainable.pdf, 2002.

## 11.1 PAINTING PRODUCTS

Latex paints with some or almost all (99%) of their content from recycled materials are now available. One environmental concern regarding traditional paints is the amount of *volatile organic compound* (VOC) emissions resulting from their use. Volatile organic compounds are compounds containing carbon that readily evaporate at room temperature and are found in many housekeeping, maintenance, and building products made with organic (carbon-based) chemicals. Paint, glues, paint strippers, solvents, wood preservatives, aerosol sprays, cleansers disinfectants, air fresheners, stored fuels, automotive products, and even dry cleaned clothing and perfume are all sources of VOC. There are six major classes of VOCs: aldehydes (formaldehyde), alcohols (ethanol, methanol), aliphatic hydrocarbons (propane, butane, hexane), aromatic hydrocarbons (benzene, toluene, xylene), ketone (acetone), and halogenated hydrocarbons (methyl chloroform, methylene chloride) (Kibert 2008, p. 284).

Formaldehyde is the most common VOC by-product in construction, and it is used in “paints, wood products, floor finishes, glues, binders, particleboard, interior grade plywood, wallboard, some paper products, fertilizers, chemicals, glass, and packaging materials” (Kibert 2008, p. 294). Formaldehyde irritates the eyes, the upper respiratory tract, and other body surfaces.

The independent nonprofit organization *Green Seal* (GS) certifies paint products meeting ISO 14024 environmental label standards and its GS-11 standard for paints and coatings. The GS-11 standard was developed to restrict VOC emissions and the use of toxic chemicals in paints (Los Alamos National Laboratory 2002). Table 11.3 provides the emissions limits for paints according to the *Los Alamos National Laboratory Sustainable Design Guide*. Green Seal also has a standard for

## TABLE 11.2
## Sustainable Design Evaluations for Materials and Resources

| Material | Material Cost | Life-Cycle Cost Impact | Energy Eff. | Water Efficiency | Material Reduction | Locally Manufactured | Locally Derived Raw Material | Nontoxic | Recycled Content | Rapidly Renewable | Certified Wood |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ceiling tiles | = + | – | | | | | | | × | | |
| Carpet | = | = | | | × | | | × | × | | |
| Fabrics | = + | = – | | | | | | × | × | | |
| Resilient flooring | = + | = – | | | | | | × | × | × | |
| Interior/exterior paints | = | = | | | | | | × | × | | |
| Sealants and adhesives | = | = | | | | | | × | | | |
| Steel | = | = | | | × | | | | × | | |
| Cement concrete | = | = | × | | × | × | × | | × | | |
| Insulation | = | – | × | | | × | o | × | × | | |
| Bathroom cubicles | = | = | | | | | | | × | | |
| Wood products | = + | = | | | × | | | × | | × | × |
| Gypsum wall board | = | = | | | | × | × | | × | | |
| Furniture | = + | = | | | | | | | × | × | × |
| Brick CMU | = | = | | | | × | × | | | | |
| Roofing | = | = | × | | | | | | × | | |
| Windows | + | – | × | | | | | | × | | |
| Doors | = + | – | × | | | | | | × | | |
| Ceramic tile | = | = | | | | | | × | | × | × |
| Insulating concrete forms | + | – | × | | | | | | × | | |
| Structural insulated panels | + | – | × | | | | | | × | | |
| Aerated autodave concrete | + | – | | | | | | | × | | |
| Exterior finishes | | | | | | × | o | | | | |
| Permeable paving | = | – | | × | | | | | × | | |

*Source:* Adapted from Los Alamos National Laboratory, *Los Alamos National Laboratory Sustainable Design Guide*, Los Alamos, New Mexico, Accessed on January 15, 2015, http://www.lanl.gov/orgs/eng/engstandards/esm/architectural/Sustainable.pdf, 2002.

*Note:* o, potentially applicable material and resource issue, research ongoing; ×, applicable material and resource issue; =, equivalent; –, generally less expensive; +, generally more expensive.

### TABLE 11.3
### Volatile Organic Compounds Emissions Limits for Paints

| Paint Applications | Type | VOC Content Limit[a] (Grams of VOC/Liter) |
|---|---|---|
| Interior coatings (GA-11) | Flat | <150 |
| | Non-flat | <50 |
| Exterior coatings (GS-11) | Flat | <200 |
| | Non-flat | <100 |
| Anticorrosive (GS-03) | Gloss | <250 |
| | Semigloss | <250 |
| | Flat | <250 |

*Source:* Data from Los Alamos National Laboratory, *Los Alamos National Laboratory Sustainable Design Guide*, Los Alamos, New Mexico, Accessed on January 15, 2015, http://www.lanl.gov*/orgs/eng/engstandards/esm/architectural/Sustainable.pdf, 2002.*

[a] Excluding water and tinting added at the point of sale.

### TABLE 11.4
### Volatile Organic Compounds Emission Limits for Sealants

| Sealant Applications | VOC Content Limit[a] (Grams of VOC/Liter) |
|---|---|
| Architectural | 250 |
| Roadways | 250 |
| Single-ply roof material installation/repair | 450 |
| Non-membrane roof installation/repair | 300 |
| Other | 420 |
| **Sealant Primer Applications** | **VOC Content Limit[a] (Grams of VOC/Liter)** |
| Architectural—nonporous | 250 |
| Architectural—porous | 775 |
| Other | 750 |

*Source:* Data from Los Alamos National Laboratory, *Los Alamos National Laboratory Sustainable Design Guide*, Los Alamos, New Mexico, Accessed on January 15, 2015, http://www.lanl.gov/orgs/eng/engstandards/esm/architectural/Sustainable.pdf, 2002.

[a] Water, acetone, parachlorobenzotrifluoride (PCBTF), cyclic, branched, or linear, fully methylated silozones (VMSs), and difluoroethene (HCF-152a) are not considered part of this product.

the emissions of VOC from sealants and adhesives, GS-46, and Tables 11.4 and 11.5 show the allowable emissions limits for these products.

## 11.2 STEEL PRODUCTION

In the United States, the steel industry produces approximately 7% of the *anthropogenic* (human-caused) emissions of carbon dioxide ($CO_2$). If the mining and transportation of iron ore are included in calculations, the emissions increase to

## TABLE 11.5
## Allowable VOC Emissions for Adhesives

| Adhesive Applications Architectural | VOC Content Limit[a] (Grams of VOC/Liter) | Adhesive Applications Specialty | VOC Content Limit[a] (Grams of VOC/Liter) |
|---|---|---|---|
| Indoor carpet | 50 | PVC welding | 285 |
| Carpet pad | 50 | CPVC welding | 270 |
| Outdoor carpet | 150 | ABS welding | 400 |
| Wood flooring | 100 | Plastic cement welding | 250 |
| Rubber flooring | 60 | Adhesive primer for plastic | 250 |
| Subfloor | 50 | Contact adhesive | 80 |
| Ceramic tile | 65 | Special-purpose contact adhesive | 250 |
| VCT (vinyl composition) and asphalt tile | 50 | Adhesive for traffic marking tape | 150 |
| Drywall and panel | 50 | Structural wood member adhesive | 140 |
| Cove base | 50 | Sheet-applied rubber lining | 850 |
| Multipurpose construction | 70 | Substrate-Specific | |
| Structural glazing | 100 | Metal to metal | 30 |
| Single-ply roof membrane | 250 | Plastic foams | 50 |
| | | Porous material (except wood) | 50 |
| | | Wood | 30 |
| | | Fiberglass | 80 |

*Source:* Data from Los Alamos National Laboratory, *Los Alamos National Laboratory Sustainable Design Guide*, Los Alamos, New Mexico, Accessed on January 15, 2015, http://www.lanl.gov/orgs/eng/engstandards/esm/architectural/Sustainable.pdf, 2002.

*Note:* ABS, acrylonitrile butadiene styrene. PVC, polyvinylchloride. CPVC, chlorinated polyvinylchloride.

[a] Water, acetone, parachlorobenzotrifluoride (PCBTF), cyclic branched or linear, fully methylated silozones (VMSs), and difluoroethene (HCF-152a) are not considered part of this product.

approximately 10%. Large portions of the emissions are generated during the burning of coke and coal when they are processed to produce iron. Emissions also come from the electric power used for melting scrap steel and the natural gas used for producing iron. Energy costs constitute approximately 15%–20% of the overall cost of steel production (World Steel Association 2008).

In 2011, China, Japan, the United States, India, Russia, and South Korea (Republic of Korea) produced 77.3% of the steel in the world. To produce one ton of steel, 19 GJ of energy (equivalent to three barrels of crude oil) are required during the production process. The U.S. steel industry has reached a 95% material efficiency rating, which indicates that only 5% of the by-products of the steel production process are sent to landfills or for incineration; therefore, the steel industry is reaching its maximum capacity for efficiency in reducing waste (World Steel Association 2008). Table 11.6 provides the list of major steel-producing countries in the world in 2013, along with their rank and level of production.

Producing on ton of metal products requires *megajoules* of embodied energy and kilograms of *embodied carbon*. The following amounts of energy and carbon are required to produce various metals (Calkins 2009, p. 340):

- Aluminum, cast products—167,500 and 9,210
- Aluminum, extruded—153,500 and 8,490
- Aluminum, rolled—150,200 and 8,450
- Brass—44,000 and 3,710
- Copper—47,500 and 3,780
- Lead—25,000 and 1,290
- Stainless steel—51,500 and 6,150
- Steel, bar and rod—19,700 and 1,720

## TABLE 11.6
## Major Steel-Producing Countries in 2013

| | Rank of Production in Millions of Metric Tons | | | Rank of Production in Millions of Metric Tons | |
|---|---|---|---|---|---|
| China | 1 | 779.0 | Austria | 19 | 8.0 |
| Japan | 2 | 110.6 | Poland | 20 | 8.0 |
| United States | 3 | 86.9 | South Africa | 21 | 7.2 |
| India | 4 | 81.2 | Belgium | 22 | 7.1 |
| Russia | 5 | 68.7 | Egypt | 23 | 6.8 |
| South Korea (Republic of Korea) | 6 | 66.1 | Netherlands | 24 | 6.7 |
| Germany | 7 | 42.6 | Malaysia | 25 | 5.9 |
| Turkey | 8 | 34.7 | Vietnam | 26 | 5.6 |
| Brazil | 9 | 34.2 | Saudi Arabia | 27 | 5.5 |
| Ukraine | 10 | 32.8 | Argentina | 28 | 5.2 |
| Italy | 11 | 24.1 | Czech Republic | 29 | 5.2 |
| Taiwan (Republic of China) China | 12 | 22.3 | Australia | 30 | 4.7 |
| Mexico | 13 | 18.2 | Slovak Republic | 31 | 4.5 |
| France | 14 | 15.7 | Sweden | 32 | 4.4 |
| Iran | 15 | 15.4 | Finland | 33 | 3.5 |
| Spain | 16 | 13.8 | Thailand | 34 | 3.5 |
| Canada | 17 | 12.4 | Kazakhstan | 35 | 3.3 |
| United Kingdom | 18 | 13.1 | Romania | 36 | 3.0 |

*Source:* Adapted from World Steel Association, *World Steel in Figures 2014*, Brussels, Belgium, 2014b.

- Steel, galvanized sheet—35,800 and 2,820
- Steel, pipe—23,000 and 1,800
- Steel, section—22,700 and 1,790
- Steel, sheet—20,900 and 1,640
- Steel, wire—36,000 and 2,830
- Titanium—298,000 and unknown
- Zinc—61,900 and 3,200

Steel production not only requires large amounts of energy but also releases toxins into the environment. In 2003, the steel industry was faced with disposing of, or treating and releasing 636 million pounds (288.48 million kilograms) of toxins. "Sixty-two percent of these were managed (usually recycled) and 38%, 242 million pounds [109.77 million kg], were disposed of or released into the environment. Of this approximately 4.8 million pounds [2.18 million kg] were released into the air, 4.8 million pounds [2.18 million kg] were released into water, and the remainder was released on land" (Calkins 2009, p. 335).

In 2005, "fossil fuel combustion accounted for 94% of $CO_2$ emissions, with the remainder from sources such as chemical conversions (e.g., cement, iron, and steel production), forestry, and land clearing for development" (Calkins 2009, p. 15). Table 11.7 lists the $CO_2$ emissions by industrial sector in teragrams (Tg) of $CO_2$ equivalent in the United States for 2012. Industrial processes accounted for 5.1% of the total U.S. greenhouse gas (GhG) emissions in 2012. Carbon dioxide emissions from all of the different industrial processes listed by the Environmental Protection

**TABLE 11.7**
**Carbon Dioxide Emissions in the United States in 2012 by Industrial Sector**

| Industry (Production) | $CO_2$ Equivalent (Tg) |
|---|---|
| Iron and steel | 54.3 |
| Cement | 35.1 |
| Lime | 13.3 |
| Ammonia | 9.4 |
| Petrochemical | 3.5 |
| Aluminum | 3.4 |
| Titanium dioxide | 1.7 |
| Zinc | 1.4 |
| Glass | 1.2 |
| Lead | 0.5 |
| Clinker | 41.3 |

*Source:* Adapted from Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990–2012*, Washington, DC, Accessed on January 8, 2015, http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Chapter-4-Industrial-Processes.pdf, 2012.

Agency (EPA) in 2012 were 144.6 Tg of $CO_2$ equivalents. This represents 2.7% of the total $CO_2$ emissions in the United States in 2012. Table 11.8 lists $CO_2$ emissions for the different steel-manufacturing processes, including *basic oxygen furnaces* (BOFs), *electric arc furnaces* (EAFs), and *directly reduced iron basic electric arc furnaces* for 2005. The steel industry produced 6.7% of the total $CO_2$ emissions in the world in 2010. For most steel production techniques, 1.8 tons of $CO_2$ are created for every ton of steel produced by the steel industry (World Steel Association 2014a).

During the previous two decades, the U.S. steel-manufacturing industry has reduced its $CO_2$ emissions. Table 11.9 shows the $CO_2$ emissions for several industries from 1990 to 2010. As Table 11.9 indicates, the U.S. steel industry has reduced its $CO_2$ emissions to below 1990 levels.

A major consumer of energy related to using steel products in the construction industry is transportation. Transporting materials by sea requires 0.2 MJ/km/t and produces an emissions factor of 0.0269 million tons (0.0244 million metric tons) of $CO_2$ per billion ton-miles. Transporting ore, coal, and steel products creates 105 million tons (95.26 million metric tons) of $CO_2$ per year or 0.14 tons of $CO_2$ per ton of steel (Braathen 2003).

### 11.2.1 STEEL PRODUCTION PROCESSES AND EFFICIENCIES

German steel mills reached theoretical maximum efficiency because in their steel mills all of the iron ore is used to produce steel and no waste ore is generated during the steel-manufacturing process. One major Chinese steel firm has implemented a zero waste program recycling *high-zinc electrogalvanizing sludge* by reusing it for zinc smelting or mixing it with power plant *coal fly ash* and selling it to cement companies.

**TABLE 11.8**
**Emissions in Tons of $CO_2$ per Ton of Steel Produced in 2005**

| Type of Energy | Basic Oxygen Furnace | Standard Electric Arc Furnace | Directly Reduced Iron Basic Electric Arc Furnace | Total |
|---|---|---|---|---|
| Coal | 1115 | 9 | 2 | 1126 |
| Hydropower | 18 | 59 | 16 | 94 |
| Natural gas | 12 | 0 | 21 | 33 |
| Rolling and Finishing | | | | |
| Fuel oil | 16 | 0 | 0 | 16 |
| Hydropower | 44 | 17 | 3 | 64 |
| Fossil fuels | 87 | 35 | 7 | 129 |
| Total | 1292 | 120 | 50 | 1462 |
| Carbon dioxide per ton of steel | 2.5 | 0.6 | 1.2 | 1.9 |

*Source:* Modified from International Iron and Steel Institute, *Sustainability Report of the World Steel Industry—Steel: The Foundation of a Sustainable Future*, Brussels, Belgium, 2005.

**TABLE 11.9**
**Carbon Dioxide Emissions by Industry from 1990 to 2010**

| Carbon Dioxide Source | 1990[a] | 2005[a] | 2010[a] |
|---|---|---|---|
| Cement manufacture | 33.3 | 45.2 | 30.5 |
| Lime production | 11.5 | 14.4 | 13.2 |
| Aluminum production | 6.8 | 4.1 | 3.0 |
| Iron and steel production | 97.1 | 64.0 | 52.5 |
| Ammonia | 13.0 | 9.2 | 8.7 |
| Ferroalloy production | 1.2 | 1.4 | 1.7 |
| Petrochemical production | 3.3 | 4.2 | 3.5 |
| Total | 4988.5 | 5305.9 | 5840.0 |

*Source:* Data from Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2011*, Washington, DC, Accessed on January 8, 2015, http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Chapter-4-Industrial-Processes.pdf, 2012.

[a] MMtpy, million metric tons per year of carbon dioxide equivalent.

In the United States, the rates for recycling steel exceeded 90% during the first decade of the twenty-first centry since almost all of the steel manufactured contained recycled steel (World Steel Association 2008). The amount of recycled steel incorporated into steel-manufacturing processes is determined by the type of processes used to manufacture the steel. When a basic oxygen furnace is used, the recycled steel content is 30%. If an EAF is used, it processes almost 100% recycled steel. Electric arc furnaces produce structural shapes, and basic oxygen furnaces produce plates, sheets, and tubing components (Los Alamos National Laboratory 2002).

One South African steel firm has developed a *zero effluent plant* using a *closed cooling system* and *reverse osmosis* (using a semipermeable membrane to remove large particles) technology and pretreatment facilities to *desalinate* (remove salt from) the water used in their plants. At a plant along the Berg River, north of Cape Town in the Western Province of South Africa, they were allotted 12,000 $m^3$ (15,695.4 $yd^3$) of water per day, but with the closed cooling system they are only using 8,000 $m^3$ (10,463.6 $yd^3$) of water per day (World Steel Association 2008).

Steel companies are exploring alternative methods for producing and casting steel and reducing the amount of energy required to produce steel elements. One process for casting and rolling carbon steel reduces carbon emissions by 60% by using *natural gas–fired reheat furnaces* (Nucor Steel 2015a). Another innovative process is used to manufacture *molten pig iron* using waste iron ore and coal. This process also reduces carbon emissions during the production of pig iron (Nucor Steel 2007). Figures 11.1 through 11.3 provide a technological comparison between integrated conventional slab casting, mini-mill thin-slab casting, and the new casting process; the $CO_2$ emissions for these three methods; and the energy consumption for these three methods for hot and cold band steel.

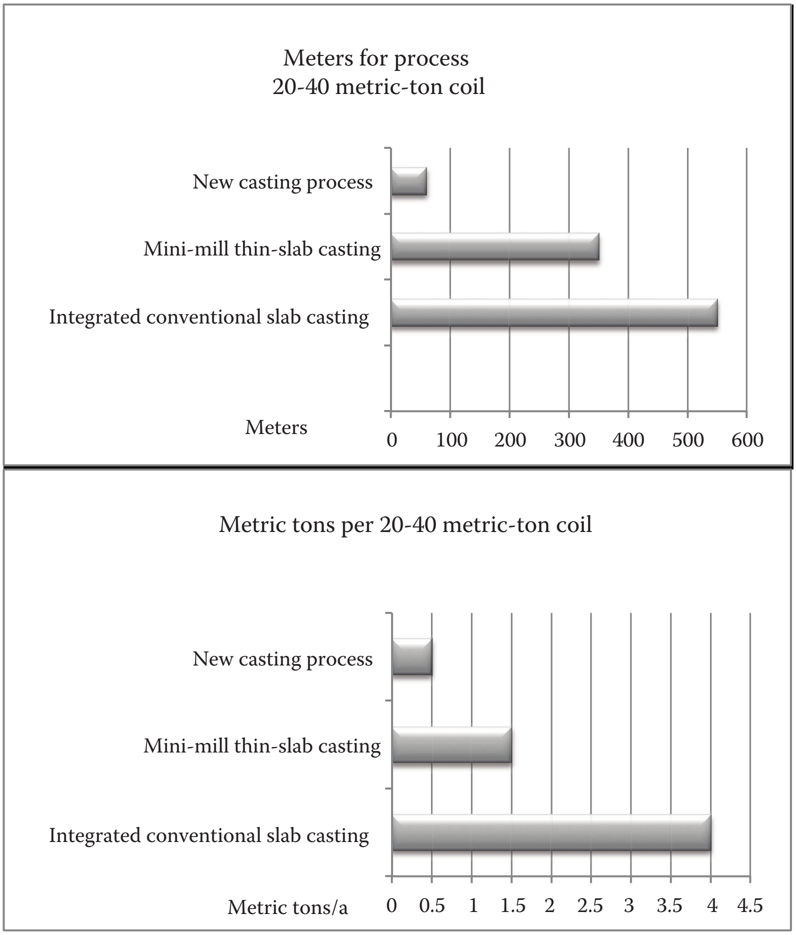

**FIGURE 11.1** Comparison between conventional slab casting, mini-mill thin-slab casting, and the new casting process. (Adapted from Nucor Steel, *Our Story—Chapter 3 Technical Leadership*, Accessed on February 6, 2015, http://www.nucor.com/story/chapter3, 2015a.)

In Finland, a product called *Bi-Steel*™ is being manufactured, and it is "a high performance composite system, comprised of two steel faceplates, permanently connected by a series of friction-welded bars, to leave a void between the plates. Panel voids are filled with structural concrete, in-situ, to form a super-strong composite wall construction. No formwork or reinforcement is required" (International Iron and Steel Institute 2005, p. 38).

One of the major advantages of Bi-Steel is prefabrication of the modules being used in *Corefast*™, which is

> an off-site construction system for lift [elevators] and stairway cores on multi-story buildings. Using the company's patented Bi-Steel panels, the Corefast™ system is prefabricated into modules and delivered to a site, ready to lift into position. This reduces

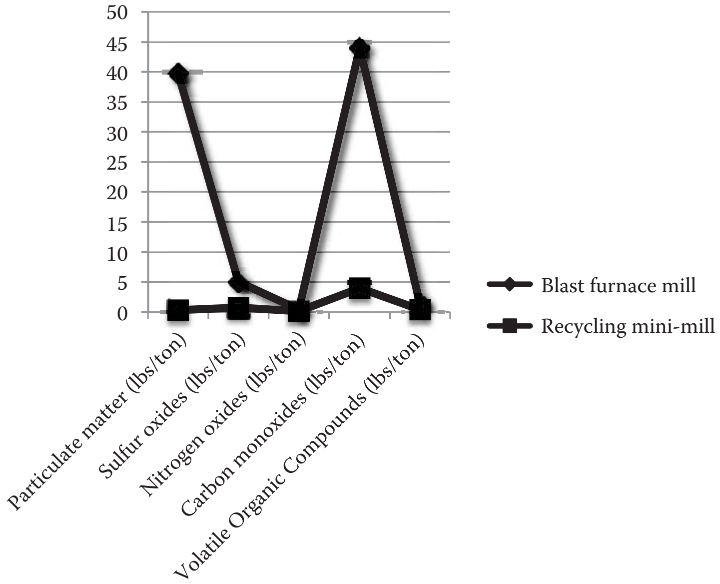

**FIGURE 11.2** Reduction in emissions for the new casting process (*Castrip*™). (Adapted from Nucor Steel, *Investor Relations—Mini-Mills: Consuming Fewer Resources, Releasing Fewer Emissions*, Accessed on February 6, 2015, http://www.nucor.com/responsibility/environment/leadership/fewer/, 2015b.)

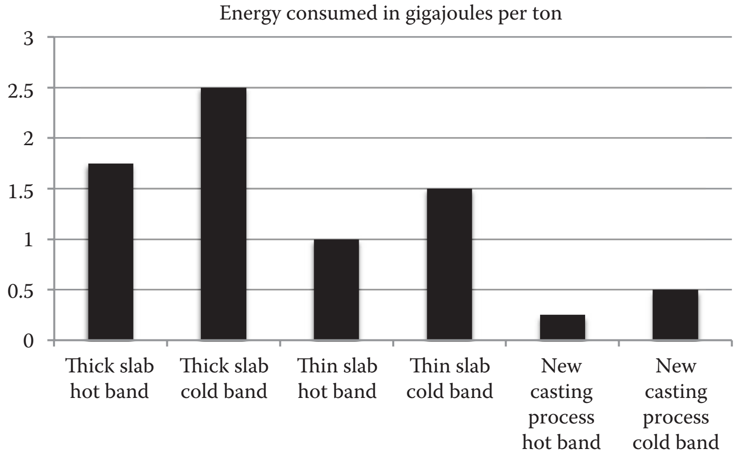

**FIGURE 11.3** Energy consumption comparison for hot and cold band steel. (Adapted from Nucor Steel, *Our Story—Chapter 3 Technical Leadership*, Accessed on February 6, 2015, http://www.nucor.com/story/chapter3, 2015a.)

the time, labor, and plant needed to build the elevator core. The system also provides a stronger, stiffer, and more accurate structure than a traditional concrete core, as well as reducing environmental impacts and exposure to work at height. (International Iron and Steel Institute 2005, p. 38).

Figure 11.4 provides an example of the steel arrangement used in Bi-Steel prior to it being filled with concrete, and Figure 11.5 shows completed Bi-Steel structural elements.

In South Korea (Republic of Korea), there is another innovative process for manufacturing steel called FINEX™. This process uses iron ore fines and non-metallurgical coal, which eliminates the requirement for *sintering* (creating a solid from powder) and *coking* (distillation of low-ash, low-sulfur bituminous coal to remove impurities). In addition to reducing the cost of steel production, the FINEX process reduces sodium dioxide emissions by 92%, nitric oxide emissions by 96%, and dust emissions by 79% compared to using conventional blast furnaces to produce steel. Energy requirements are also reduced using the FINEX process along with initial capital costs (International Iron and Steel Institute 2005). Figure 11.6 shows the reductions in $SO_x$, $NO_x$, and dust emissions from using the FINEX process versus traditional blast furnaces.

In Europe, a consortium of steel companies refurbished a Florence, France steel plant to reduce carbon emissions. They used a technique for reducing carbon dioxide emissions by 55%. The World Steel Association's $CO_2$ Breakthrough Program coordinated the project. At the French steel plant, the waste $CO_2$ is stored in the ground and the waste carbon monoxide is captured and reinjected into the blast furnace along with pure oxygen. This method is called *top-gas recycling*, and it helps to reduce carbon dioxide emissions (Halper 2011).

One prospective technique for improving steel production includes feeding "common sand-size bits of iron ore called fines straight into a blast furnace, eliminating the energy-intensive process of first sintering the fines into bigger chunks" (Halper 2011, p. 4). Another method is to use coal instead of converting it to coke, which is an energy-intensive process. Other techniques include using hydrogen and *electrolysis* (an electrical current is passed through a substance to cause chemical changes to the substance) to replace carbon fuels. The steel industry continues to seek methods for improving the processing of steel. Between 1960 and 2007, the steel industry was able to reduce carbon emissions by 45% by using natural gas instead of coke and stronger iron ores.

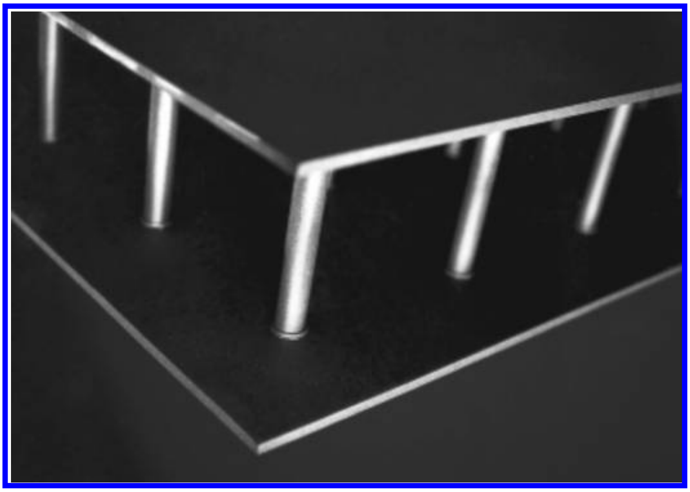

**FIGURE 11.4** Example of Bi-Steel without the concrete interior. (Open source photograph.)

**FIGURE 11.5** Example of Bi-Steel structural elements. (Open source photograph.)

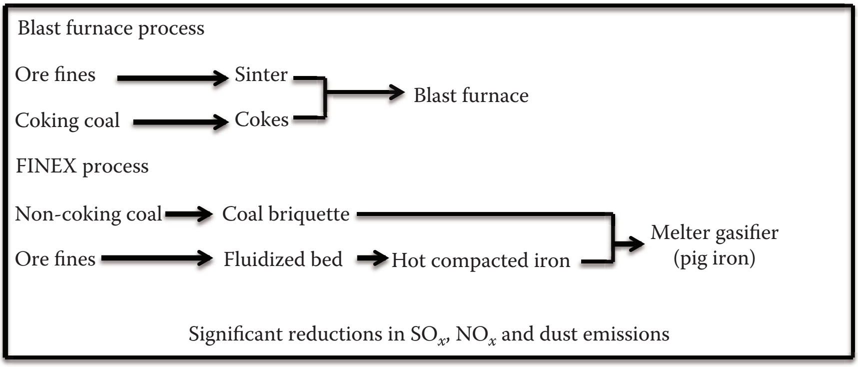

**FIGURE 11.6** Comparison between the FINEX process and traditional blast furnaces. (Authors.)

Some of the steel firms in the United States that moved their operations to other countries during the 1990s and 2000s started returning to the United States in 2013. The reason for this reversal is the availability of natural gas, which was discovered in shale formations, and petroleum firms are now able to access the natural gas using hydraulic fracturing techniques. Steel mill furnaces used to be powered by coal, which when burned releases pollutants into the atmosphere. The availability of natural gas, which burns much cleaner than coal and is less expensive, is contributing to the return of the steel to the United States. Starting in 2013, five natural gas–powered steel mills, at a cost of close to a billion dollars each, were being built in the United States.

The steel industry has also developed stronger, lighter weight steel, and when this steel is used in vehicles it helps reduce energy consumption. Even with these improvements, the steel industry still generates 8% of the global GhG emissions. Part of the problem in reducing GhG emissions further is that emerging countries do not have much steel to recycle, as is the case in industrialized nations where recycled steel is mostly used in steel production processes. Using recycled steel requires less energy and produces less GhG emissions (Halper 2011).

To evaluate whether to use steel versus wood products, members of firms need to review all of the steps in the process of producing either material along with all of the other life-cycle environmental costs. Figure 11.7 provides a comparison of the processes required to produce steel versus a *glulam* (wood created by gluing together layers of wood) beam. Figure 11.7 shows that even though the production processes are similar there are differences in the energy requirements during production and in the ability to recycle the demolition products.

### 11.2.2 Steel Portal Building Systems

A steel building system is being used in commercial building structures that is “an innovative portal frame system incorporating sandwich panels as roof and wall claddings and steel rectangular hollow sections as purloins and girt at wider spacing” (Gurung and Mehendran 2002, p. 37). When this building system was being developed, a three-dimensional computer model was used to categorize “columns, rafters, purloins, and girt as beam elements and roof and wall claddings as equivalent truss (tension) members” (Gurung and Mehendran 2002, p. 37). This type of a *composite* has two steel faces. “The steel faces are commonly made of 0.42–9.69 mm G300 or G550 steel whereas the foam is of SL grade and *sandwich panels* have a lightweight *polystyrene* foam core sandwiched between 50–200 mm thick steel. The composition and geometry of the panels enable them to possess both insulation and structural capacities” (Gurung and Mehendran 2002, p. 37). Conventional sheeting systems are normally used in panels only 1.5 m (1.64 ft) long, and the new panels may be used to span up to 3 m (9.84 ft) even in windy conditions.

The initial cost of using sandwich panels instead of conventional materials for the test panels was 20% higher. The benefits of using sandwich panels are realized in cost savings due to consuming less energy when heating and cooling structures and reducing toxic emissions. The savings are realized when total life-cycle cost calculations are performed for structures rather than only considering initial construction costs.

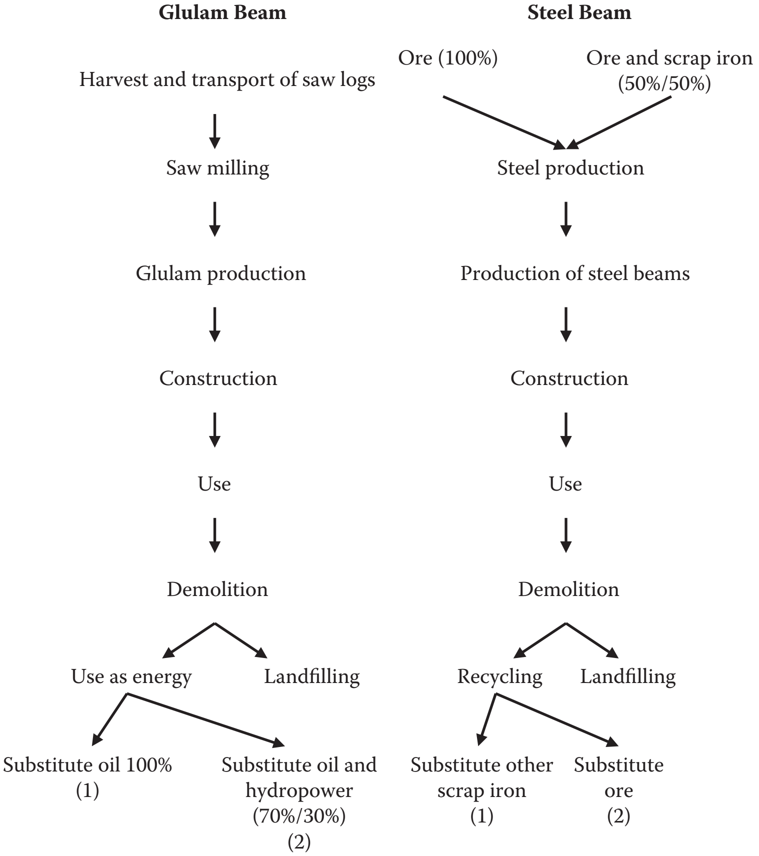

**FIGURE 11.7** Production processes for glulam beams versus steel beams. (Modified from International Iron and Steel Institute, *World Steel 2006 in Figures*, Brussels, Belgium, 2006.)

### 11.2.3 LIFE-CYCLE COST EXAMPLE FOR STEEL BRIDGES

To estimate the life-cycle costs for steel bridges, Equation 11.1 was proposed by Kwang-Min Lee and Cho Choi (2004, p. 1590):

$$E[C_T(X)] = C_I(X) + E[C^L{}_M(X)] + \Sigma^K{}_K = {}_1E[C^L{}_{FSk}(X)] \qquad (11.1)$$

where

$E[C_T]$ = total expected life-cycle cost, which is a function of design variable $X$

$C_I$ = initial cost

$E[C^L{}_M]$ = discounted life-cycle maintenance cost

$E[C^{L}_{FSk}]$ = expected rehabilitation cost over the life span for considered limit state k

## 11.3 CEMENT AND CONCRETE

This section discusses cement production and how cement is used in the construction industry when producing concrete. Cement production is an energy-intensive manufacturing process creating high levels of air pollution.

Amano and Ebihara (2005) evaluated 16 industrial categories using data from numerous sources—such as the national physical distribution census, national and regional input/output tables, and comprehensive energy statistics for Japan for the year 1995—to determine the environmental intensity in local regions and industrial sectors. The following categories were used for evaluation:

- Agriculture
- Cement
- Chemical
- Coal and petrol
- Commercial aspects
- Construction
- Energy supply
- Fiber
- Food
- Metal
- Mining
- Nonferrous metals
- Pulp
- Service
- Steel
- Transport

The objective environmental load items included carbon dioxide ($CO_2$), nitric oxide, sulfur oxide, and suspended particulate matter (PM) emissions for 47 Japanese regions. The study determined that the cement industry in Japan generates the highest level of $CO_2$ per primary energy input of any of the other industry segments. One method for measuring industrial eco-intensity is the ratio of environmental load to energy flow. Figures 11.8 and 11.9 summarize the carbon dioxide and nitric oxide emissions for various industries examined in the Japanese study. The cement industry produced the highest level of emissions because of the energy required to process the large quantities of limestone necessary for cement production (Amano and Ebihara 2005).

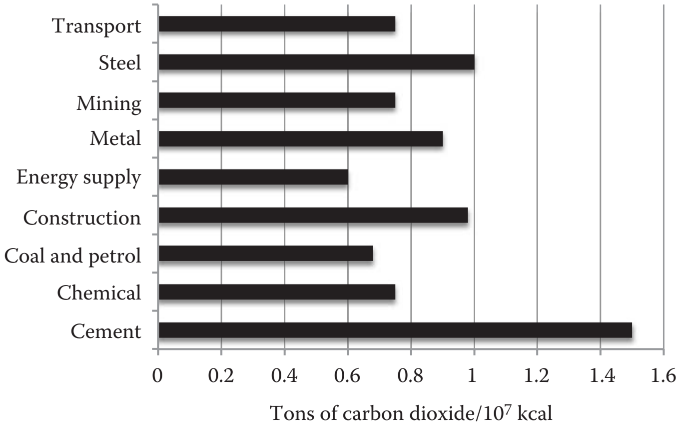

**FIGURE 11.8** Carbon dioxide emissions versus primary energy inputs for industry sectors (tons of carbon dioxide per $10^7$ kcal). (Data from Amano, K., and M. Ebihara, *Intl. J. of Manage. of Env. Quality*, 16(2), 160–166, 2005.)

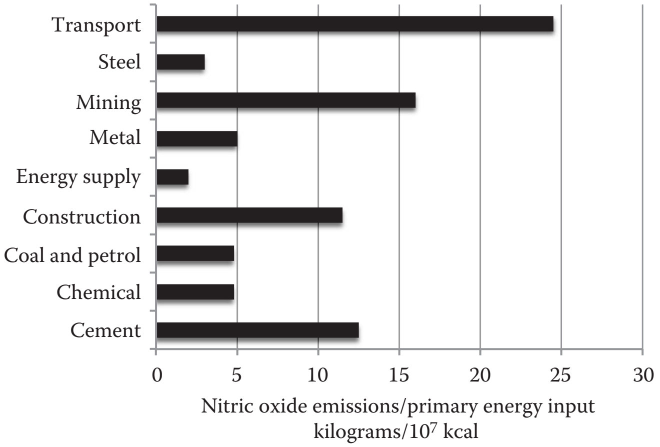

**FIGURE 11.9** Nitric oxide emissions versus primary energy inputs for different industry sectors (kilograms of nitric oxide per $10^7$ kcal). (Data from Amano, K., and M. Ebihara, *Intl. J. of Manage. of Env. Quality*, 16(2), 160–166, 2005.)

### 11.3.1 FLY ASH CONCRETE AND OTHER CEMENT SUBSTITUTES

One alternative helping to reduce the level of GhG emissions caused by cement production is replacing some of the cement in concrete with coal fly ash (a residual produced during the burning of coal) or *granulated blast furnace slag* (waste matter separated from metals during the smelting or refining of iron ore). Fly ash is sometimes used to replace 15%–30% of the cement, and large structures such as girders, road bases, major walls, and dams sometimes consist of up to 70% fly ash. Many state departments of transportation have built concrete road systems using 30% fly ash. Although fly ash is a viable alternative to cement, it contains natural

**FIGURE 11.10** Sunshine Skyway Bridge in Tampa with 30% fly ash in the concrete mix. (Authors.)

**FIGURE 11.11** Toxic reference to using fly ash in structures. (Open source photograph.)

*radioisotopes* (isotopes with an unstable nucleus, which casues them to be radioactive); therefore, *radio analytic* laboratories should monitor the use of fly ash to determine if there is any *residual radioactivity* (Los Alamos National Laboratory 2002). Another product being developed is *ashcrete*, which is created by using almost 100% fly ash. Figure 11.10 shows a photograph of the Sunshine Skyway Bridge in Tampa, Florida, containing 30% fly ash. Figure 11.11 is one interpretation of what results when using fly ash in a building.

Other materials substituted for Portland cement *clinker* (fused stony matter from a furnace) in concrete production are rice-husk ash, wood ash, natural *pozzolans* (silica-based materials reacting with the calcium hydroxide generated by hydrating cement), and silica fume (by-product of producing silicon metal or ferrosilicon alloys) (Naik and Mariconi 2006). Manufacturing clinker is the most energy-intensive part of producing cement. The large kilns used to process the raw materials, to evaporate the water in the materials, and to *calcine* (heat to a high temperature to drive off waste and produce a powder) the *carbonate constituents* (calcinations) consume 90% of the energy required to produce cement (Naik and Mariconi 2006).

Naik and Mariconi (2006, p. 7) also indicate that crushed glass "is highly reactive with cement (alkali silica reaction). But Class F fly ash was used as a replacement for cement by mass of 45% or more, which helped in controlling alkali-silica reaction. However, ground waste glass was used as aggregate for mortars and no reaction was detected with particle size up to 100 meters."

According to Naik and Mariconi (2006, p. 13), "Wood fly ash has substantial potential for use as a *pozzolanic mineral admixture* and as an activator in cement based materials. Wood ash has been used in the making of structural grade concrete; bricks, blocks, and paving stones; flowing slurry; and blended cements. Air entrained concrete is achieved by using wood fly ash up to 35%. Structural grade concrete is made using wood fly ash and its blends with Class C fly ash to achieve a compressive strength of 50 MPa or higher."

An alternative aggregate to crushed rocks is using *glass-reinforced plastic scrap*, which is ground into a fine powder and mixed with cement. Additional substitutes for natural aggregates in concrete include reclaimed concrete aggregate, air-cooled blast furnace slag, expanded blast furnace slag, *palletized blast furnace slag*, tires or crumb rubber pellets, plastic products, and crushed bricks (Calkins 2009). In Sweden, there is concern that the by-products of slag produced by the blast furnace process and *bottom ash* from municipal waste incineration plants could leach toxic substances; therefore, the government in Sweden restricts the use of these by-products in concrete production (Roth and Eklund 2003).

Worldwide, the concrete production industry consumes trillion liters (0.22702 trillion gallons) of water and 8 billion tons (7.2576 billion metric tons) of sand and gravel per year, but "recycled-aggregate fractions up to 15 mm (.5905 in), although containing masonry rubble up to 25–30 percent, proved to be suitable for manufacturing structural concrete even if employed as a total substitution of the fine and coarse natural aggregate fractions" (Naik and Mariconi 2006, p. 14).

At Louisiana State University, an expert system was developed to "assess industrial residuals and their potential road construction applications. The system uses EPA regulations to classify the residuals as hazardous or nonhazardous" (Fonseca et al. 2005, p. 3). The system produces one or more of eight possible general application areas within the following American Association of State Highway and Transportation Officials (AASHTO) standards (Fonseca et al. 2005, p. 3):

1. Admixture in Portland cement concrete class C (AASHTO M 295–86)
2. Admixture in Portland cement concrete class F (AASHTO M 295–86)
3. Filler for bituminous paving mixtures (AASHTO M17–83)
4. Blended cement (AASHTO M 240–85)

5. Drainage filler material (AASHTO M 17–88)
6. Granular material for control of pumping beneath pavements (AASHTO M 155–87)
7. Microsilica for concrete (AASHTO M 307–91)
8. No possible application in highway construction

According to the article "A Knowledge-Based System for the Recycling of Nonhazardous Industrial Residuals in Civil Engineering Applications" by Fonseca et al. (2005, p. 4), "The final set of heuristics performs detailed analysis on material properties, and leads to specific (individual) application areas. These were developed according to standard specifications of the AASHTO." The system follows heuristics to generate one or more of the following six specific application areas (Fonseca et al. 2005, p. 5):

1. Coarse aggregate for Portland cement concrete (AASHTO M80–87)
2. Fine aggregate for bituminous paving mixtures (AASHTO M29–83)
3. Fine aggregate for Portland cement concrete (AASHTO M6–93)
4. Material for embankment and subgrade (AASHTO M145–91)
5. Material for embankment and subgrade with special consideration (AASHTO M145–91)
6. No possible application in highway construction

According to Fonseca et al. (2005, p. 6), "The system evaluates the waste's potentially hazardous properties against ignitability, corrosivity, reactivity and toxicity levels established by EPA regulations. The system then uses the material's chemical and physical properties to evaluate whether a match exists between the waste's characteristics and an application in road construction. This comparison is performed through AASHTO test methods."

During the process of making cement, as limestone (calcium carbonate) is broken down it releases carbon. One firm, in the United Kingdom, has developed a new process that "replaces limestone with a family of carbon free materials called magnesium silicates. The raw material emits no carbon, cooks at just 700°C [1292°F], and emits 85% less carbon than cement does" (Time September 20, 2010 p. 31). So far, the new process is only able to create a product with half the strength of limestone-based cement, but the firm is working on developing stronger products.

### 11.3.2 POROUS CONCRETE

In some situations, it is beneficial to install porous concrete, which allows surface storm water to permeate the concrete and settle into the ground layer below. Porous concrete is "concrete with uniformly graded coarse aggregate, usually No. 89 with no fines. The uniformly sized aggregate creates pore spaces between 11% and 21% of the mix for water to flow through the pavement. The typical porous pavement is six inches [15.24 cm] thick with a minimum sub base of four inches [10.16 cm] of open graded aggregate. This can support a 2,000 pounds per square inch (psi) [140.65 kg/cm$^2$] load. Thickening the slab and sub base may support heavier loads. A thickened sub base will also accommodate soft subgrade and/or provide greater storm water storage for slower percolating soils" (Calkins 2009, p. 133).

### 11.3.3 CONCRETE FORMWORK

Concrete formwork is an expensive element of concrete production, but if the formwork is reusable this substantially reduces its cost and improves its sustainability. The main types of formwork are wood, steel, aluminum, plastic, earth, and fabric. Wood forms may be used multiple times if adequate amounts of form release agents (form oil) are properly applied before the concrete is placed in the formwork. Plant oil is one type of form release agent that does not damage wood. Steel and plastic forms are also reusable, and earth forms are sometimes used for footing forms.

### 11.3.4 CONCRETE CANVAS

One innovative use for cement is concrete canvas—an application developed by two students at the London Royal College of Art. Concrete canvas is "made of cement-impregnated fabric folded into a plastic sack. After the fabric is saturated with water, the structure is inflated, and dries to form an impermeable shell. The shelters could be sterilized (for use as operating theaters), secured with a locking door, insulated with earth or sandbags, or ventilated with windows cut out of the skin. They come

**FIGURE 11.12** Concrete canvas as delivered to the site. (From London Royal College of Art, *Concrete Canvas*, London, United Kingdom, Accessed on February 6, 2015, http://www.rca.ac.uk/research-innovation/innovation/innovationrca-start-up-and-fellowship-projects/concrete-canvas/, 2015.)

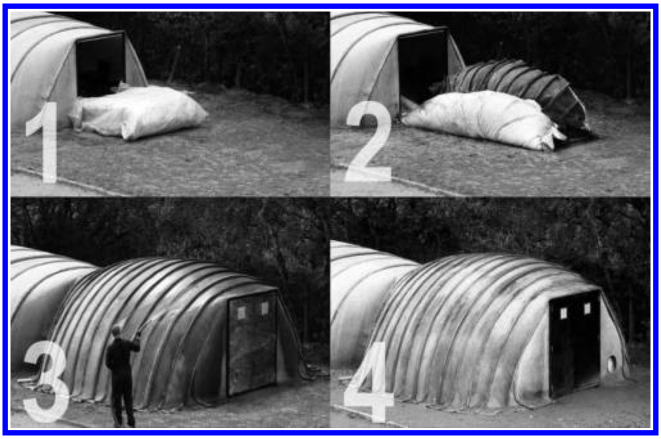

**FIGURE 11.13** Concrete canvas after inflating and saturating with water. (From London Royal College of Art, *Concrete Canvas*, London, United Kingdom, Accessed on February 6, 2015, http://www.rca.ac.uk/research-innovation/innovation/innovationrca-start-up-and-fellowship-projects/concrete-canvas/, 2015.)

**FIGURE 11.14** Concrete canvas structure in cold climate. (From London Royal College of Art, *Concrete Canvas*, London, United Kingdom, Accessed on February 6, 2015, http://www.rca.ac.uk/research-innovation/innovation/innovationrca-start-up-and-fellowship-projects/concrete-canvas/, 2015.)

in sizes ranging from 53 to 177 feet$^2$ [4.924 to 16.44 m$^2$] of floor space, and could be joined to form larger structures" (Yabroff 2008, p. 72). Figures 11.12 through 11.14 provide photographs of concrete canvas when it is still in the canvas bag and after it has been saturated with water and inflated.

## 11.4 MASONRY PRODUCTS

Traditional clay bricks consist of clay and shale. Clay contains feldspar, quartz, and other impurities, including iron oxide. Shale is a *sedimentary rock* that includes clay, mud, and silt. A large percentage of the waste produced during the manufacturing of bricks is ground into *grog*, also known as fire sand or chamotte clay, which is mostly silica and alumina produced by firing clay and grinding it into specific particle sizes and added to the mix. Waste products not reused in this manner are sold for landscaping or aggregate base.

In addition to clay, some brick manufacturers now use bottom ash from coal-fired power plants and soils contaminated by petroleum because the firing process for bricks burns off any excess *hydrocarbons* (HCs). Other elements used for brick production include "fly ash, sewage sludge, waste treatment incinerator ash, recycled iron oxides, metallurgical wastes, papermaking sludge, rice husks, slag, and recycled glass" (Calkins 2009, p. 181).

The most expensive elements of brick production are the mining of materials used in the bricks and the cost of energy for firing the bricks at temperatures of 100°F–400°F (37.78°C–204.4°C) for 15–50 hours. The most common fuels used for firing bricks are natural gas, coal, and sawdust. Manufacturing bricks creates several types of pollution including "sulfur dioxide, sulfur trioxide, nitrogen oxide, carbon monoxide, carbon dioxide, metals, methane, ethane, hydrochloric acid, and fluoride compounds" (Calkins 2009, p. 183).

If manufactured properly, bricks are durable materials for residential and commercial construction. The most important aspect of masonry construction is the mortar and joints. If water is unable to penetrate into the joints, then the bricks will retain their structural integrity. Because bricks expand and contract, expansion joints need to be added every 20–35 ft (6.1–10.67 m) and at "points of stress or weakness such as level changes, openings, and between panels and columns" (Calkins 2009, p. 191). If brick walls are constructed correctly, they do not need to be sealed or coated in any manner because they are already water resistant.

Brick pavements are not as durable as other types of pavement, especially in conditions subject to freezing and thawing, because the bricks will shift. The shrinking and swelling of soil causes the bricks to become offset from their original positions, and frequent repairs are required to realign the bricks.

Rock is another durable construction material if it is constructed using the proper type of mortar mix and if the gaps between rocks are properly filled with mortar. The benefit associated with the durability of rock as a construction material is offset by the initial cost of the material and construction costs. Marble and granite are also initially expensive to purchase and install, but their longevity is demonstrated by all of the marble and granite structures from previous centuries still standing.

The following is the embodied energy in megajoules per metric ton required for producing masonry products (Calkins 2009, p. 239):

- Aggregate: 150
- Granular base (50/50 fine and coarse aggregate): 90
- Stone/gravel chippings: 300
- Local granite: 5,900
- Imported granite: 13,900
- Limestone: 240
- Sand: 100

## 11.5 ASPHALT PAVEMENT

Asphalt production creates pollution and consumes large amounts of energy during processing of the feedstock and mixing of the asphalt. Extracting the raw materials used in asphalt also pollutes the environment. In addition, the darkness of asphalt pavements creates *heat islands* by absorbing solar radiation and releasing it back into the environment as heat.

Asphalt production requires crude oil, which is mined by drilling into the surface of the earth. The oil extraction process requires large amounts of water, which is contaminated during extraction with oil, *sulfides* (inorganic anion of sulfur), ammonia, *phenols*, heavy metals, and suspended and dissolved solids (Calkins 2009). Heating asphalt binders releases emissions that may cause workers to experience health problems. Asphalt is composed of approximately 85% coarse and fine aggregates by volume and 94% by weight. The aggregate production process requires mining and crushing, both of which consume large amounts of fuel and also cause pollution.

Methods for reducing the environmental impact of traditional hot mix asphalt include lowering the production and placement temperatures of asphalt mixes. Lowering these temperatures results in the following benefits (Calkins 2009, p. 205):

- Decreased fumes
- Decreased wear on equipment
- Energy savings
- Reduced aging of the asphalt binder
- Reduced drain down of asphalt
- Reduced emissions

To lower the temperature for warm mix asphalt by 50°F–100°F (10°C–37.78°C), emulsions, foam processes, or additives are included in the mixes to improve the workability of the asphalt. Hot mix asphalt requires paving temperatures between 275°F and 325°F (135°C and 162.8°C), warm mix requires temperatures between 275°F and 300°F (135°C and 148.89°C), and cold mix requires temperatures of approximately 60°F (15.56°C) (Calkins 2009).

One method for improving the sustainability of asphalt is to use recycled aggregate. The recycled materials used for aggregates include recycled asphalt, tires, roofing shingles, glass, slag, and concrete. According to the Asphalt Recycling and Reclaiming Association, in 2001 approximately 80% of asphalt was recycled into new asphalt (Calkins 2009).

In the LEED Green Building Rating System, credits are provided for asphalt not absorbing ultraviolet rays and returning the rays into the environment as heat. The ability of a material to reflect, rather than absorb, heat is called solar reflectance, or *albedo*:

> An albedo of 0.0 indicates total absorption of solar radiation and a 1.0 value represents total reflectivity. Generally, albedo is associated with color, and lighter colors being more reflective.
>
> The *solar reflective index* (SRI) combines albedo and emittance into a single value expressed as a fraction (0.0 to 1.0) or percentage. A source for SRI data on basic paving is SS credit 7.1 of the U.S. Green Building Council's LEED for New Construction Version 2.2 (2008). The reference guide states that new asphalt has an SRI of 0, meaning that all solar radiation is absorbed, while new white Portland cement concrete has an SRI of .86. Other pavement types generally range between these values with a .35 SRI for new gray concrete. The LEED credit requires an SRI of at least .29 for 50% of the paving. (Calkins 2009, p. 213)

## 11.6 FIBER-REINFORCED POLYMER COMPOSITE MATERIALS

Fiber-reinforced polymer composite materials are used in the following industries: heavy construction, highway construction, oil and gas, chemical, petrochemical, power, mining, and process. Carbon-fiber composites are used for repairing and rehabilitating systems because they are "ten times as strong as steel, at less than a quarter the density, and they are corrosion resistant. Application of composite repairs involves layers of carbon fiber impregnated with epoxy resin being built up to the specified requirements in terms of thickness, overlap onto good metal, fiber orientation, gradient at the ends or edges of the repair and so on, in line with the repair design specifications. The repairs could be designed for the lifetime required—from just a couple of years, to permanent (25 years plus)" (Engineer Live 2007, p. 1). According to Hastak et al. (2003, p. 1409), "Composites offer several advantages over conventional materials such as superior strength/weight and stiffness/weight ratios, a higher degree of chemical inertness, and design flexibility. Some of the potential downstream benefits include lower life cycle costs, lighter members, high corrosion and fatigue resistance, and higher live load capacity."

Architectural and structural elements manufactured from highly durable FRP composite materials are increasingly being specified in highway bridge decks, bridge superstructures, commercial building architectural façades, beams, columns, and marine structures (Federal Highway Administration 2011; Market Development Alliance 2004). When evaluating the sustainability of FRP composite materials used on construction projects, the extraction and processing of raw materials and the manufacturing processes should be considered, along with the service life, which often far exceeds a comparable component, element, or structure constructed using mild steel or traditional reinforced concrete. When analyzing the energy requirements for the manufacturing and disposal of FRP materials, each of the individual constituent materials should be evaluated separately.

Fiber-reinforced polymer composite materials contain two main constituent materials, fibers and matrix material, both of which require different manufacturing processes. Many types of fibers, fiber architecture, and matrix materials are available; therefore, their life-cycle performance and mechanical properties may be designed for specific applications. The two fibers that are the most frequently incorporated into construction material composites are glass and carbon. Glass fibers are manufactured from melted silica (sand) and carbon typically derived from precursor materials such as polyacrylonitrile (PAN) fibers, rayon fibers, or pitch. Other fibers are produced from renewable or recyclable materials such as hemp, flax, and mild and stainless steel (Burgueno et al. 2004; Fu et al. 2008). A process called *sizing* is used to coat the fibers with a chemical compound to allow greater adhesion to the matrix material.

Matrix materials should be analyzed as part of the life cycle of composites because they are a major element of FRP composites. Fiber-reinforced polymer matrix materials typically used in construction include thermoplastic resins, which may be reshaped on heating, and the more common thermoset resins, whose cross-linking (curing) process does not allow reshaping. Typical thermoset resins include polyester resins, which are produced by condensation polymerization of dicarboxylic acids and difunctional alcohols (glycols). Unsaturated polyester resins use an unsaturated material, such as maleic anhydride or fumaric acid, and styrene to produce a low-viscosity liquid. Other thermoset resins are corrosion-resistant vinylesters; epoxies; high temperature–resistant, low-smoke phenolic resins; and polyurethanes (Market Development Alliance 2005).

Fibers and resins are combined in a wide range of manufacturing processes, including hand layup, bag molding, autoclave curing, compression molding, resin transfer molding, pultrusion, filament winding, and vacuum infusion (Yuhazri et al. 2008). Volatiles such as styrene are released in differing amounts during FRP component manufacturing and processing and vary depending on resin selection. Emissions should be monitored and controlled during the individual processes (vacuum infusion, bag molding, and compression molding) or by compliant heating, ventilating, and air-conditioning systems used to collect and process emissions from processes such as hand layup and filament winding.

Fiber-reinforced polymer composite materials often possess a superior service life and require less maintenance compared with traditional building materials such as steel or conventionally reinforced concrete or masonry. However, specifications for FRP composite materials used in construction should consider various fibers, resins, and manufacturing processes to minimize environmental impacts. Designers and constructors should consult with local authorities about the proper disposal of FRP materials because they may not be biodegradable.

## 11.7 WOOD PRODUCTS

Forest products are becoming scarce as forests throughout the world are being harvested to produce construction materials such as dimension lumber, plywood, and beams. To continually regenerate forests, some forest product companies are planting their own trees. Even though only 5% of the total forest cover in the world is planted forests, these forests contribute 35% of the commercial wood in the world (International Paper 2006).

According to Nogueron and Laestadius (2007, p. 1), "Forests and paper products are used and reused by society over long periods of time, which represents an expanding reservoir of carbon removed from the atmosphere. On average, one ton of paper contains about 1.33 metric tons of carbon equivalent ($CO_2$). Forests contribute to net carbon emissions when they are logged, converted, or burned at a faster rate than they grow back. An estimated 24% of global carbon dioxide emissions are attributable to land use change and forestry."

Wood procurement is monitored and certified by third parties such as the Bureau Veritas Quality International (BVQI), Sustainable Forestry Initiative (SFI), American Tree Farm System, Canadian Standards Association, and Forest Stewardship Council. Wood certified through the SFI program has to come from legal sources, be harvested using techniques protecting water quality in the surrounding area, and adhere to the principles of responsible forest management, as stated by the SFI (International Paper 2006). The Forest Stewardship Council also monitors wood products by issuing chain of custody certificate numbers (Los Alamos National Laboratory 2002).

The standards followed for sustainable development in the forest products industry were developed as a result of the 1992 United Nations Conference on the Environment and Development (UNCED) Rio Convention. These standards were further refined at the Helsinki and Montreal meetings. The sustainable forestry criteria provide guidelines on the following (United Nations Framework Convention on Climate Change 2005, p. 1):

- Biodiversity
- Economic viability
- Habitat provision
- Legality
- Social and economic issues
- Sustained yield harvests
- Water quality
- Wildlife protection

According to Calkins (2009, p. 6), "Environmentally responsible forest management includes practices that protect the functional integrity and diversity of tree stands, minimize clear cutting, protect old growth forests, and minimize wasteful harvesting and milling techniques" as prescribed by the Forest Stewardship Council. When forests are eliminated, "they no longer provide ecological services such as carbon sequestration, habitat, erosion control, and regulation of the *hydrologic cycle*. Forests play a vital role in stabilizing the climate by sequestering atmospheric carbon. The *Food and Agriculture Organization of the United Nations* (FAO) estimates that between 1990 and 2005, the carbon storage capacity of forests declined by more than 5%" (Calkins 2009, p. 19).

Sustainably developing forest products requires using every part of a tree. After raw wood is processed into dimension lumber, plywood, and beams, the leftover bark, sawdust, shavings, and resin might be used to create additional products such as fiberboard, *plystrand* (created by fusing wood chips together and encasing them in veneer to resemble plywood), and fireplace logs. Wood shavings are not considered to be recycled materials when they are disposed of in landfills. Wood shavings and bark can be used for *biorenewable fuel* in industrial boilers and heavy machinery (International Paper 2006).

The bonding resins used in making wood products might emit toxic substances such as formaldehyde (Los Alamos National Laboratory 2002). Natural resins from trees include sterols, and these are used to make perfume, fabric, toothpaste, tires, and pharmaceuticals. Another by-product is a cholesterol-lowering ingredient used in drinks, milk, yogurt, and other foods.

Unfortunately, the trees providing the most sustainable, decay-resistant wood are becoming scarce. Decay-resistant trees include the following:

- Redwood (California)
- Western red cedar (Washington, Oregon, Idaho, and Montana)
- White cedar (Eastern United States)
- Incense cedar (California, Nevada, and Oregon),

- Bald cypress (Southern states)
- Black locust (Tennessee, Kentucky, West Virginia, and Virginia)
- Ipe (Latin America)
- Jarrah (Australia)
- Teak (Southeast Asia)
- American mahogany (Southern Mexico to Bolivia)
- African mahogany (Western Central Africa)

### 11.7.1 CHROMATED COPPER ARSENATE–TREATED WOOD

To compensate for the declining availability of decay-resistant wood, wood products are being treated with wood preservatives to increase their durability and resistance to decay, insects, and weathering. Since the 1930s, a variety of chemicals have been used to preserve wood products, many of which are hazardous to both humans and the environment. The utility, railroad, and agricultural industries were the first industries to widely use chemically treated wood.

Petroleum-based creosote was replaced by a water-based wood treatment called *chromated copper arsenate* (CCA), commonly known as *pressure-treated wood*, during the twentieth century. Chromated copper arsenate treatment is applied to wood building materials, and it provides wood with a combination of fungicide, pesticide, herbicide, and insecticide protection. The use of CCA prolongs the service life of wood exposed to water, soil, fungi, mold, or insects. In some cases, treating wood with CCA extends its useful life from 5 years to 30 or 40 years. Chromated copper arsenate contains materials known to be carcinogenic.

Hundreds of thousands of tons of *arsenic* and *chromium* are used every year to preserve wood. At the end of its useful life, preserved wood is buried in unlined and unmonitored landfills throughout the United States. Even though the government requires customer information sheets (CISs) and warning labels to be attached to CCA construction materials, the labels may no longer be attached by the disposal stage (Environmental Protection Agency 2002). The toxic chemicals in CCA leach out of wood when they are exposed to water or soil and migrate from landfills into water supplies (Khan et al. 2006). Waste from construction sites is typically buried directly under and on top of unprotected soil in landfills (Environmental Protection Agency 2003).

Over the past 40 years, the Occupational Safety and Health Administration (OSHA) has implemented new, more protective standards for occupational exposure to arsenic and chromium (U.S. Department of Labor 2006). To comply with the OSHA policy of limiting employee exposure to carcinogens to the lowest feasible level, many new laws are in effect to protect employees in the wood treatment industry.

Whereas arsenic and chromium are carefully regulated as individual chemicals because of their toxicity, the regulation of CCA has historically been much less restrictive for all occupations using CCA once the treatment has been applied to wood. Currently, there are precautions and suggested *personal protective equipment* (PPE) for CCA use supplied by registrants of CCA, but neither the EPA nor the OSHA requires occupational protection beyond the treatment phase.

Arsenic and chromium are human carcinogens used in the manufacture of industrial products. Arsenic occurs naturally in soil or rocks, and traces of it are found in water, food, trees, and plants. Arsenic and chromium are elemental heavy metals, and they exist in varying valence states and containment matrices. Natural events, such as volcanic eruptions, erosion of rocks, and even forest fires, release arsenic into the environment. Arsenic discharge is also a direct result of activities such as smelting, mining, combustion engines, burning fossil fuels, incinerating waste, producing pulp and paper, treating wood, and manufacturing cement.

When arsenic is manufactured for industrial use, it is primarily produced as a byproduct in the smelting of nonferrous metal ores such as gold, silver, lead, nickel, and cobalt (Bleiwas 2000). Due to the toxic nature of arsenic and the expenses associated with containing the production emissions, arsenic production in the United States was essentially eliminated with the implementation of the Clean Air Act Extension of 1970.

The recovery of arsenic from the smelting of nonferrous metals takes place in 17 countries throughout the world, with the bulk of the imported arsenic used in the United States coming from China (Bleiwas 2000). The prevalent past agricultural use of arsenic was to kill weeds, fungi, and other pests. Arsenic is still found in common products including wood preservatives, rat poison, paints, dyes, pharmaceuticals, fungicides, pesticides, semiconductors, and some medicinal tonics. The inorganic forms of arsenic are much more toxic to humans than the organic types found in food (World Health Organization 2004).

According to the California Environmental Protection Agency (2006), arsenic is one of the highest ranked chemicals of the 164 developmental and reproductive toxicants. The International Agency for Research on Cancer (IARC) and the EPA classify arsenic as a group one carcinogen. The Committee on Medical and Biological Effects of Environmental Pollutants (1977, p. 176) wrote, “Evidence of significant systematic concentrations of arsenic has been found in several studies of the incidence of lung cancer in populations exposed to arsenic dust.” In addition, direct contact between arsenic-laden dust and the mucus membranes of the nose could cause a perforation of the nasal septum after only a few weeks of exposure.

The chemicals contained in CCA migrate to water supplies and drinking water. According to the California Environmental Protection Agency (2004, p. 55), “At relatively low acute intake levels, arsenic provokes mild gastrointestinal effects. The Feinglass 1973 Report showed the acute gastrointestinal effects … (nausea or vomiting, dryness or burning of the mouth and throat, abdominal pain, and diarrhea). One of the most common long-term indicators of acute arsenic exposure is Mees’ lines, which are ridges appearing on the fingernails six to eight weeks after the exposure.”

Exposure to continuous doses of chromium in drinking water or through accidents or occupations also occurs. According to the U.S. Department of Labor (2006, p. 9), “Human data would place hexavalent chromium compounds into Group 1, meaning there is decisive evidence of the carcinogen properties of those compounds in humans.” The Environmental Protection Agency (2007, p. 2) indicates that “skin exposures to hexavalent chromium for children contacting treated wood surfaces exceed the OSHA level of concern for skin sensitization.”

The EPA and the OSHA regulate arsenic and occupational exposure hazards. In 1978, the U.S. Department of Labor (1978) produced new rules for permanent exposure to inorganic arsenic and reduced the *permissible exposure limits* (PELs). A directive published by the OSHA in 1978 states that PELs "include arsenic, all arsenic-containing, inorganic compounds and arsine among the substances in the 'High Hazard Health' category. … Respiratory protection is required against any of the substances included or specified in the list that follows: (i) arsenic trichloride, (ii) arsenic trifluoride, (iii) arsenic pentafluoride, (iv) arsenic tribromide, (v) arsenic triiodide, (vi) arsenic monophosphide" (U.S. Department of Labor 1978, p. 2).

*Material safety data sheets* (MSDSs) inform interested parties about products and possible hazards associated with the handling, use, and storage of products, and they provide safety and emergency information. Material safety data sheets became federally mandated in the mid-1980s in their present form; they have to accompany all products with hazardous constituents and employers should have them available for workers at jobsites and manufacturing facilities. The MSDS for CCA has changed its content many times since the 1970s as new discoveries were made about the hazards of arsenic and chromium.

Because exposure to CCA wood products is toxic to humans, research has been conducted to determine whether there are any viable alternatives to using CCA. Lebow (2004) presents some alternative wood treatments including the following:

- Acid copper chromate (ACC)
- Alkaline copper quaternary (ACQ)
- Copper azole (CBA–A and CA–B)
- Copper citrate (CC)
- Copper dimethyldithiocarbamate (CDDC)
- Copper HDO (CX–A) [*Bis*-(*N*-cyclohexyldiazeniumdioxy)-copper affects sulfhydryl groups of essential amino acids of fungi and causes protein denaturation]

Lebow (2004) indicates that the retention rate for the chemicals in the alternatives is equivalent to CCA products, but because they are typically copper based and the other components have not been identified as mammalian carcinogens these alternatives may be used as replacements for CCA in residential applications.

Wood treatment industry workers are exposed to concentrated levels of arsenic and chromium in CCA when they apply the treatment to lumber products. When construction personnel work with these products, they are being exposed to known carcinogens, and this exposure may cause illness and other negative health effects such as bells palsy (Johnloz 2005).

The cutting, nailing, and placement of treated wood by construction workers releases heavy metals, which are absorbed through the skin, eyes, mouth, nose, and lungs. Demolition workers face many of the same hazards as construction workers, but they may be less aware of the proper handling procedures due to their inability to identify products treated with CCA. Carpenters, electricians, plumbers, masons, and landscape professionals are exposed to carcinogens from CCA during the installation and maintenance of wood structures, and utility workers are exposed to CCA-treated poles and pilings. Road and bridge construction crews work with CCA, as do agricultural and railroad workers. Electricians and plumbers are exposed to CCA during material installations when holes and channels are cut in wood for wire and pipe installations. Rain runoff after CCA roof installations dislodges small particles containing chemicals from the shingles. After construction, smaller debris is washed into surrounding landscape areas and into storm drains.

### 11.7.2 HARDIE BOARD

One alternative to using traditional wood products is Hardie board. Hardie boards are sometimes substituted for wood siding because Hardie board offers sustainable benefits. It is constructed of concrete and stamped with an artificial wood grain to give it the appearance of wood siding. Hardie board is available in various thicknesses and lengths and may be cut to desired lengths. The benefits of using Hardie board instead of wood or aluminum siding are that it is durable and lasts for decades, it only has to be painted approximately every 20 years, it is an excellent insulator, it is termite resistant, and it has an appearance resembling real wood. Figure 11.15 shows a home with Hardie board siding. A precursor to Hardie board was *masonite*, which is also manufactured to resemble wood but is actually made of steam-cooked and pressure-molded wood fibers that are distintegrated by saturating them with 100 psi steam, then increasing the steam or air pressure to 400 psi and suddenly releasing them through a small opening to atmospheric pressure and then pressing and heating them to form a finished board.

### 11.7.3 INDUSTRIAL STRENGTH FUNGUS

*Mycelium*, the white rootlike fibers of fungi, is used as a biological alternative to several different types of products including insulation and building materials. If grown under

**FIGURE 11.15** Hardie board home siding. (Courtesy of J. K. Yates.)

proper conditions, according to one firm growing mycelium products, it could be developed into a variety of products including green alternatives to styrofoam and home insulation, and if it is densely packed it could be used as a wooden beam (Fisher 2010).

## 11.8 POLYVINYL CHLORIDE AND THERMOPLASTIC PRODUCTS

Sections 11.8.1 and 11.8.2 discuss PVC and thermoplastic construction materials.

### 11.8.1 Polyvinyl Chloride Products

New techniques are being developed to recycle polyvinyl chloride plastic waste to reduce the consumption of the biomass used to produce PVC products. The recycling process breaks PVC down into synthetic gas and hydrogen chloride (HCl), which are then available for use in the production of new PVC products.

Denmark has enacted a tax on some PVC products to pay for their incineration to prevent them from being disposed of in landfills. Barriers to recycling PVC include the high cost of recycling relative to producing new PVC products from raw materials. The European Plastic Pipes and Fittings Association (TEPPFA) and the European PVC Window Profile and Related Building Products Association (EPPA) have set up collection and recycling task forces around Europe to ensure that over 50% of recovered pipes and windows are recycled (Leadbitter 2002). One of the problems associated with the use of PVC is the toxic chemicals that are the byproducts of processing PVC, such as organochlorines, furans, and dioxins.

### 11.8.2 Thermoplastic Products

Innovative materials are becoming more prevalent in the oil and gas industry because of the rising cost of traditional piping materials such as wood, clay, concrete, and metal. Even though thermoplastic products have been in widespread use for a long time in “residential drain/waste/vent, gas transmission, acid waste drainage, water lines, underground irrigation, swimming pools, and water theme parks,” they are gaining acceptance for industrial uses (Thermoplastic Industrial Piping Systems 2007, p. 1). In the oil and gas industry,

> plastic pipe, itself a derivative of oil and natural gas, has successfully been applied in handling most crudes, saltwater, and natural gases. Most natural gas distribution today uses millions of feet of plastic pipe. Polyethylene piping, colored beige or orange, is the preferred material for this application. In the mining industry, the most popular use of thermoplastics is in ore leaching, in which the ore is treated with dilute sulfuric acid or sulfides and then with ferric sulfate solutions. Polyvinylchloride, ABS [acrylonitrile butadiene styrene], and polyethylene piping are used in many of the leaching process stages. Plastics also are used for the movement of ore slurries and other piping applications in under and above ground mining. (Thermoplastic Industrial Piping Systems 2007, p.1)

In addition to piping, many products are produced from plastics such as polyethylene terephthalate, high-density polyethylene, PVC, polypropylene, polystyrene, and other resins and the products produced from these including (Munier 2005, p. 184):

- Credit cards, clear plastic containers, and pharmaceutical bottles
- Hard plastic for compact disc and digital video cases, television and computer frames, food carryout containers, and packing foam
- Milk cartons, snack bags, and microwaveable containers
- Nontransparent bottles
- Plastic fibers for upholstery and luggage
- Transparent bottles

In the United States, over 113 billion pounds (51.26 billion kilograms) of plastic resin was produced in 2006. Of this amount, 14.9 billion pounds (6.76 billion kilograms) was PVC, of which approximately 75% was used in construction, and 38.6 billion pounds (17.51 billion kilograms) was used in polyethylene production. In 2006, 29% of polyethylene was used for packaging products, and 19% was used in the construction industry. Approximately 11.5 billion pounds (5.22 billion kilograms) of PVC was used in the construction industry in “piping, siding, flooring, windows, electrical wire, cable and other products” (Calkins 2009, p. 374).

Plastics are derived from petroleum or natural gas, and approximately 10% of the products produced by the petroleum and gas industry are used for plastic products. The same toxins are released during the extraction of petroleum products as during oil and gas production. Chlorine is used to manufacture PVC, and it requires less embodied energy to produce than other plastic products.

Plastics are also being used to make single-resin plastic lumber, commingled plastic lumber, composite lumber, *biocomposite lumber*, and fiberglass-reinforced lumber incorporating at least 50% plastic content measured by weight, as well as other materials such as fiberglass. Plastics are also used to produce recycled rubber for sidewalk paving units. *Bioplastics* are being introduced to replace petroleum-based plastics and incorporate plant materials, such as “cornstarch, soy, polylactides, or cellulosic [made from cellulose] materials” (Calkins 2009, p. 404).

## 11.9 MINING, MINERAL, AND METAL PRODUCTS

The mining, metals, and mineral (MMM) industry produces over 80 types of materials. The countries supplying a large proportion of the mining, metals, and mineral products worldwide are the United States, Canada, Australia, Russia, Brazil, South Africa, China, and countries in the European Union. The mining, metals, and mineral industry employs over 30 million workers in large operations and 13 million in small-scale operations, which are approximately 1% of the worldwide workforce. Table 11.10 summarizes the sustainability issues affecting the MM industry (Azapagic 2004).

One major concern of the mining, metals, and minerals industry is acid drainage, which could lead to the long-term contamination of waterways. Some discharge also contains large quantities of *cyanides* (consisting of a carbon atom triple-bonded to a nitrogen atom and heavy metals, which is highly toxic). The mining process

### TABLE 11.10
### Sustainability Issues in the Mining, Metals, and Minerals Industry

| Economic Issues | Environmental Issues | Social Issues |
|---|---|---|
| *Contribution to the gross domestic product and wealth creation:* | *Biodiversity:* | *Contribution to social issues:* |
| Costs, sales, and profits | Emissions to air | Bribery and corruption |
| Distribution of revenues and wealth | Energy consumption | Creation of employment |
| Investments (capital, employees, communities, pollution prevention, and time closure) | Global warming and other environmental impacts | Employee education and skills development |
| Shareholder value | Land use, management, and rehabilitation | Equal opportunities and non-discrimination |
| Value added | Nuisance | Health and safety |
| | Product toxicity | Human rights and business ethics |
| | Resource consumption and availability | Labor and management |
| | Generation of solid waste | Social relationships |
| | Water use, effluents, and leachates, including acid mine drainage | Stakeholder involvement |
| | | Wealth distribution |

*Source:* Adapted from Azapagic, A., *J. of Cleaner Prod.*, 12(6), 639–662, 2004.

### TABLE 11.11
### Categories of Environmental Indicators Used in the Mining, Metals, and Minerals Industry

| Indicator Category | Provides Information on Measures |
|---|---|
| Mineral resources | Availability, resource efficiency, and rate of depletion of mineral resources. |
| Land use | Land requirements for activities related to minerals. |
| Materials | Use of chemicals, packaging, and other materials, and the recycling rate. |
| Water | Water consumption and efficiency. |
| Energy | Energy consumption and efficiency, use of fossil fuels, and renewable energy. |
| Closure and rehabilitation | Pace of restoration and the level of commitment to rehabilitation. |
| biodiversity | Extent to which the extractive activities affect habitats and species. |
| Air emissions and liquid effluents | Contribution to air, water, and land pollution and related impacts. |
| Nuisance | Level of nuisance for neighboring communities. |
| Compliance and voluntary activities | Sustainable responsibility demonstrated through compliance and voluntary activities. |
| Transport and logistics | Minimizing transport distances for products and employees. |
| Suppliers and contractors | Sustainable performance of suppliers and contractors. |
| Products | Life-cycle environmental impacts of products. |

*Source:* Adapted from Azapagic, A., *J. of Cleaner Prod.*, 12(6), 639–662, 2004.

itself may also dangerously affect the workers who mine materials, especially if they are being exposed to materials such as asbestos, lead, or *uranium*. Mining companies are now including decommissioning and rehabilitation plans in their proposals for new mining operations. It is noted that 88% of the firms surveyed by PriceWaterhouseCoopers (2004) indicated that they have environmental post-closure plans, but only 45% have socioeconomic plans. Table 11.11 lists the categories of environmental indicators used by the mining, metals, and minerals industry.

Metal ore is extracted from the earth through a variety of techniques including strip mining, open-pit mining, mountaintop removal, and dredging. Processing mined materials requires "milling, crushing, consolidation, washing, leaching, flotation, separation, and thermal processes" (Calkins 2009, p. 329). The raw materials required to manufacture iron or steel are iron ore, coal, and limestone; however, additional additives such as chromium, nickel, zinc, manganese, and cadmium are used for alloys and coatings. The main elements of raw materials for steel production are extracted using strip mining. The process for mining copper is one of the least efficient, requiring 400 tons (362.88 metric tons) of waste and by-products to create 1 ton (0.9072 metric tons) of copper. In addition to creating overburden waste, copper mining also results in contaminated water runoff that is toxic to fish (Calkins 2009).

The metal recycling effort in the United States has resulted in various percentages of metals being recycled, and the amounts and percentages of metals recycled in 2005 are listed in Table 11.12.

Those who select metals for use in construction projects should ask several questions when they are trying to determine which metals are the most sustainable (Calkins 2009, p. 368):

- Are corrosion-protective coatings required?
- Are the metal structures reusable or recyclable?

**TABLE 11.12**

**Metal Recycling in 2005 in the United States Listed by Metric Ton and Percentage Being Recycled**

| Type of Metal | Amount Recycled in Metric Tons | Percentage of Metal Recycled |
|---|---|---|
| Aluminum | 2,990,000 | 36.0% |
| Chromium | 124,000 | 24.0% |
| Copper | 951,000 | 30.0% |
| Iron and steel | 65,400,000 | 54.0% |
| Lead | 1,140,000 | 74.5% |
| Magnesium | 72,800 | 44.0% |
| Tin | 14,000 | 30.0% |
| Titanium | 25,700 | 50.0% |
| Zinc | 345,000 | 29.5% |

*Source:* Data from Calkins, M., *Materials for Sustainable Sites*, John Wiley, Hoboken, New Jersey, 2009.

- Do they off-gas VOCs; pose health risks to workers or users; or contribute to air, water, or soil pollution?
- Does the coating limit the recyclability of the metal member?
- How much metal may enter the environment from corrosion carried by runoff? Is the corrosion hazardous?
- Is there a risk of coating loss to the environment attributable to wear or spalling [cracking, flaking, chipping, or edge breakage]?
- What are the maintenance requirements of the metal structure?
- What are the potential air, water, and soil pollution impacts of the metal in extraction, production, manufacture, and fabrication?
- Will hazardous cleaners or new protective coating applications be required to maintain the structure?
- Will the metal structure last for the expected duration of the landscape?

## 11.10 UNCONVENTIONAL BUILDING PRODUCTS

In addition to the conventional building products mentioned in the previous sections, Sections 11.2 through 11.8, many types of unconventional building products are being designed and manufactured each year. BuildingGreen cited the following materials and processes in its list of the top 10 innovative products in 2007 (adapted from BuildingGreen 2006, p. 1):

- Electronically tintable glazing: The tinting of the glass is changed using an electrochromic control [changes with the amount of sunlight].
- Evaporative cooler: Indirect evaporative cooler.
- Interior molding: Molding profiles made with at least 90% recycled polystyrene.
- Interior panels: Panels for workstations, trim, or toilet partitions made with 40% pre-consumer-recycled copolymers.
- Irrigation system controls: Irrigation control based on local weather data.
- Polished concrete: Polish old and new concrete slabs into attractive, durable, and finished floors.
- System for salvaging timber: Harvest trees submerged in reservoirs created by hydroelectric dams.
- Water-efficient showerhead: A showerhead using only 1.6 gallons [6.1 L or 1.33 imperial gallons] of water per minute.
- Water-resistant composite: Solid composite material made from postconsumer paper.

## 11.11 SUMMARY

This chapter introduced sustainable construction materials and presented information from the Los Alamos National Laboratory on the types of sustainable materials to be considered for incorporation into buildings and structures. Individual construction materials were reviewed, and information was provided on the processes required for manufacturing some of the major types of construction materials. In addition to traditional construction materials, sustainable and nontraditional construction materials were discussed so that they may be included in reviews during the material selection process for construction projects. The materials reviewed in this chapter included paints, sealants, steel, cement, concrete, fly ash concrete, concrete canvas, porous concrete, asphalt, masonry, carbon-fiber composites, wood products, PVC products, thermoplastic products, and petrochemical products.

## 11.12 KEY TERMS

Albedo
Anthropogenic
Arsenic
Ashcrete
Basic oxygen furnace
Bi-Steel
Biocomposite lumber
Bioplastics
Biorenewable fuel
Bottom ash
Calcine
Carbonate constituents
Castrip
Chromated copper arsenate
Chromium
Clinker
Closed cooling system
Coal fly ash
Composite
Concrete canvas
Corefast
Cyanide
Desalinate
Directly reduced iron basic electric arc furnaces
Electric arc furnace
Electrolysis
Embodied carbon
Fiber-reinforced polymeric composite material
Glass-reinforced plastic scrap
Glulam
Granulated blast furnace slag
Green Seal
Grog
Hardie board

Heat island
High-zinc electrogalvanizing sludge
Hydrocarbons
Hydrologic cycle
Masonite
Material safety data sheets
Megajoules
Molten pig iron
Natural gas–fired reheat furnaces
Palletized blast furnace slag
Permissible exposure limits
Personal protective equipment
Phenols
Plystrand
Polystyrene
Polyvinyl chloride
Porous concrete
Pozzolanic mineral admixture
Pozzolans
Pressure-treated wood
Radio analytic
Radioisotopes
Residual radioactivity
Reverse osmosis
Sandwich panels
Sedimentary rock
Sintering
Sizing
Solar reflective index
Spalling
Sulfides
Sustainably harvested
Thermoplastic
Top gas recycling
Uranium
Volatile organic compound
Zero effluent plant

## 11.13 DISCUSSION QUESTIONS

11.1 What makes construction materials sustainable?
11.2 According to the Los Alamos National Laboratory sample characteristics of environmentally preferable materials, what are considered to be locally manufactured materials?

11.3 According to the Los Alamos National Laboratory sample characteristics of environmentally preferable materials, what are considered to be locally derived raw materials?
11.4 Explain what volatile organic compounds are and why they should be avoided in paint products.
11.5 Explain how using recycled steel helps the U.S. steel-manufacturing industry.
11.6 How does using the FINEX process for steel manufacturing benefit the steel industry and the environment?
11.7 Explain the purpose of GreenSeal.
11.8 Explain which stages of the steel-manufacturing process produce toxic emissions.
11.9 Of the three traditional types of steel-manufacturing processes, which one produces the highest level of carbon dioxide emissions?
11.10 Explain why the steel industry is a major energy consumer of transportation energy.
11.11 Explain how the new casting process and the rolling carbon steel process are benefiting the steel industry.
11.12 Discuss the potential harm caused by the use of chormated copper arsenate as a preservative in pressure-treated wood.
11.13 Discuss what is a major concern when using fly ash as a cement substitute in concrete.
11.14 Discuss why composite sandwich panels would be used in construction operations.
11.15 Explain why the cement industry produces the highest level of carbon dioxide emissions per primary energy input.
11.16 Describe some of the uses for plastic resin.
11.17 Which of the metal production processes require the largest quantity of megajoules of embodied energy and kilograms of embodied carbon, and which processes require the least?
11.18 Discuss the different types of pollution generated during the manufacture of bricks.
11.19 Discuss what process could be used to make concrete formwork more sustainable.
11.20 Explain how the steel industry disposes of, treats, or releases environmental toxins.
11.21 Which industrial process released the highest amount of greenhouse gas emissions in 2012, and which one released the least?
11.22 Explain why a percentage of fly ash would be substituted for cement in concrete production.
11.23 How does ashcrete differ from fly ash concrete?
11.24 Discuss what would be the purpose of using porous concrete rather than standard concrete in construction.
11.25 Discuss the techniques for reducing the environmental impact of traditional hot mix asphalt production.

11.26 According to the Sustainable Forest Initiative, what are the requirements for wood procured through the Sustainable Forest Initiative program?

11.27 Discuss what Bi-Steel is and what the benefits are of using Bi-Steel in the construction industry.

11.28 In addition to being in some paint products, where else is formaldehyde found in construction products?

11.29 According to the sustainable design evaluations for materials and resources listed in the *Los Alamos National Laboratory Sustainable Design Guide*, which material receives the highest rating and why does it receive this rating?

11.30 Explain the purpose of concrete canvas, and suggest three potential uses for it.

11.31 Discuss some of the methods used by the steel industry to improve the processing of steel between 1960 and 2007.

11.32 Which industry emitted the highest level of carbon dioxide between the years 1990 and 2010?

11.33 Which masonry product requires the highest level of embodied energy to be produced, and which requires the lowest level?

11.34 Discuss what types of water contamination occur during the oil extraction process.

11.35 Discuss fiber-reinforced polymer composite materials and where they could be used in the construction industry.

11.36 What were the top five steel-producing countries in 2013?

11.37 Describe arsenic, and explain where it comes from.

11.38 Describe the environmental issues related to the mining, metals, and minerals industry according to Azapagic.

11.39 Describe the four techniques for extracting metal ore from the earth.

11.40 Explain what heat islands are and why they are detrimental to the environment.

11.41 Explain how the German steel industry reached theoretical maximum efficiency in their steel mills.

11.42 Explain how industrial strength fungus could be used for construction materials.

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# 12 Sustainable Heavy Construction Equipment

This chapter discusses some of the sustainable technologies available for consideration when selecting heavy construction equipment. Sustainable technologies include tires, *engine repowering*, engine upgrades, *cooled exhaust gas recirculation* (CEGR), *selective catalytic reduction* (SCR), remanufacturing and rebuilding engines, and hybrid-electric heavy construction equipment. This chapter also introduces the Environmental Protection Agency *Tier Four Final Standards* for heavy construction equipment.

## 12.1 HEAVY CONSTRUCTION EQUIPMENT TIRES

Sustainable technologies are incorporated into some of the manufacturing processes for producing components of heavy construction equipment. For instance, manufacturers of truck tires have developed a technology for retreading old tires. A retreaded tire sometimes lasts for up to 80% of the mileage of a new tire (Michelin 2014). New tires contain 20%–30% natural rubber; therefore, retreading tires saves natural resources and decreases the number of tires that are disposed of after being used one time.

In 1992, one tire manufacturer launched a third generation of energy-saving tires called *Energy Saver Green tires*. The tread technology in these tires improves traction and makes the tires self-cleaning. The ability of the tire to expel the soil that collects between the tread blocks helps to improve their gripping potential and reduces rolling resistance and fuel consumption. The use of these tires reduces fuel consumption by up to 3%, which is equivalent to one gallon per 62.14 mi. (1 L per 100 km) of fuel consumption compared with traditional tires used on three-axle trailers. In addition, lower rolling resistance translates into a reduction in $CO_2$ emissions (Michelin 2014).

## 12.2 HEAVY CONSTRUCTION EQUIPMENT EMISSIONS

Reducing heavy construction equipment emissions is one method for increasing the sustainability of the construction industry. For example, diesel engines emit lower levels of hydrocarbons (HCs), carbon monoxide (CO), and other toxic air pollutants than gasoline engines. Using diesel engines on heavy construction equipment also increases fuel economy; however, diesel engines have the disadvantage of emitting significant amounts of particulate matter (PM) and nitrogen oxide ($NO_x$).

The transportation sector is one of the largest sectors contributing to greenhouse gases (GhGs) in the United States, and it contributed 27% of the total GhGs in 2011. A report released by the Environmental Protection Agency (EPA) in September 2013 summarized energy consumption and GhG emissions data pertaining to the operation of off-road heavy construction equipment. The report indicated in 2011 that heavy construction equipment consumed 0.6 billion gallons (0.499604 billion imperial gallons or 2.27125 billion liters) of gasoline and emitted 68.7 Tg of $CO_2$ (Environmental Protection Agency 2013b). The EPA has estimated that 47% of mobile source diesel particulate matter emissions and 25% of mobile source $NO_x$ come from off-road diesel engines (Environmental Protection Agency 2007, 2013b).

In May 2004, the EPA introduced a diesel engine pollution control measure called the *Clean Air Non-Road Diesel Rule* to help reduce the pollution caused by diesel-powered equipment used in the agriculture, construction, and mining industries. This off-road diesel program was implemented in 2008 and resulted in a reduction in annual PM emissions of 129,000 tons (117,028.8 metric tons) and a reduction in nitrogen oxide ($NO_x$) emissions of 738,000 tons (669,513.6 metric tons) (Environmental Protection Agency 2009a).

### 12.2.1 DIESEL-RETROFIT TECHNOLOGY

To help reduce emissions, engine manufacturers have developed new engines with advanced emission control technologies, such as diesel-retrofit systems. *Diesel-retrofit technology* (DRT) includes devices attached to the engines of heavy construction equipment to help remove pollutants, such as PM and $NO_x$ emissions, from the engine exhaust system. Retrofit equipment is being installed in school buses, long-haul trucks, heavy construction equipment, and mining equipment.

The two most common DRTs are *diesel oxidation catalysts* (DOCs) and *diesel particulate filters* (DPFs). Both of these help reduce PM, CO, and HC emissions. Diesel oxidation catalyst devices employ chemicals that react with exhaust stream gases to convert them into inert or less harmful products. A DOC might reduce the concentration of PM by 20%, CO by 40%, and HC by 50% in a diesel engine exhaust system. Diesel oxidation catalysts are also called *catalytic converters* and they are used not only with conventional diesel fuel but also with biodiesel and other alternative diesel fuels (Wescott 2005).

Diesel particulate devices use filters to reduce PM in exhaust systems. They could be used on their own, but it is more efficient to use them in conjunction with an *ultra-low-sulfur diesel* (ULSD) *fuel* because of the damage caused by sulfur in off-road diesel vehicles. Ultra-low-sulfur diesel fuel is an environmentally friendly fuel containing less than 15% sulfur. The use of DPFs and ULSD could reduce PM, HC, and CO emissions by 60%–90%.

Ainslie et al. (1999) wrote a report for the Society of Automotive Engineers (SAE) about a testing program conducted to study the emissions and duty cycles from five heavy-duty construction vehicles. The authors confirmed that retrofitting exhaust emission control technologies used on off-road heavy construction equipment leads to reduced emissions. For instance, a Caterpillar wheel loader equipped with a catalyzed DPF reduced PM emissions by 97%. A backhoe equipped with an active DPF had PM reductions of 81%. According to the EPA, reductions in $NO_x$ and PM emissions from off-road diesel engines provide public health benefits (Environmental Protection Agency 2009b). The EPA estimated that by 2030 controlling these emissions could annually prevent 12,000 premature deaths; 8,900 hospitalizations; and 1 million lost workdays (Environmental Protection Agency 2009b).

## 12.3 BIODIESEL FUEL

Biodiesel fuel (biofuel) is a renewable plant- or animal-based diesel fuel substitute composed of mono-alkyl esters of long-chain fatty acids derived from vegetable oils or animal fats (National Biodiesel Board 2014). Biofuels are usually blended with gasoline or diesel fuel at low levels, such as 20% (B20) or less, but in some instances they are also used at 100% (B100).

The American Society for Testing and Materials specification for B100 diesel fuel covers biodiesel fuel blend stock in grades S15 and S500 for use as a blend component with middle distillate fuels (American Society for Testing and Materials 2011). This specification describes the required properties of biodiesel fuels. The use of biodiesel fuel in a conventional diesel engine results in a substantial reduction in unburned HC, CO, and PM; decreases the solid carbon fraction of PM; and helps to eliminate sulfur, while the HC fraction remains the same or increases. According to the EPA, B20 biodiesel fuel decreases PM by approximately 10% but increases $NO_x$ by approximately 2% (Environmental Protection Agency 2013a). According to a manufacturer of emissions-controlled devices, retrofitted DOCs and DPFs operate effectively on vehicles using a biodiesel-blended fuel up to B20. The exhaust gas recirculation (EGR) engines manufactured by John Deere operate efficiently with traditional low-sulfur-diesel (LSD) fuels, as well as with B5 to B20 (15%–20%) biodiesel fuel blends.

In *A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions*, the Environmental Protection Agency (2002) concluded that even though the use of biodiesel fuels reduces the emissions of PM, HC, and CO it also increases the emission of $NO_x$. Specific $NO_x$ increases depend on the fuel blend used, equipment type, and operating patterns of the equipment or vehicle. Using B20 fuel results in a $NO_x$ emissions increase of approximately 2%, and with B100 in heavy-duty highway engines the increase was approximately 10% (Environmental Protection Agency 2002).

The cost of corn and other biofuel feedstock influences the price of biofuels, and when the price increases the price of the foods derived from these farm products also increases proportionally. The European Commission has written a report on indirect land use change (ILUC) indicating that carbon emissions are increasing as croplands are converted for ethanol or biodiesel fuel production in response to the increased global demand for biofuels (European Commission Joint Research Centre 2013).

In response to the U.S. EPA Interim Tier Four (IT4)/Stage III B emissions regulations for diesel engines of 174 hp and above, the equipment manufacturer Caterpillar indicated that its C18 Advanced Combustion Emissions Reduction Technology (ACERT) industrial engines are designed to use B20 biofuel (Caterpillar 2013). The ACERT industrial engines are compliant with the U.S. EPA Tier Three emissions regulations governing off-road machines, which took effect on January 1, 2005, for engines of 300–750 hp. The fuel system allows for multiple injections during each combustion cycle. Small amounts of fuel are injected at precise times to achieve the combined goals of fuel economy and lower emissions. An advanced air system provides more cool air in the combustion chamber. A waste-gate turbocharger provides an effective low-end response. In addition, cross-flow cylinder heads provide a direct path of air to the engine (Caterpillar 2013). The Caterpillar 349E hydraulic excavator has an Interim IT4, 396-net-hp C13 ACERT engine. This excavator is able to operate on either ULSD or B20 fuel or a combination of diesel fuel and 20% biodiesel fuel (Caterpillar 2013).

## 12.4 ENVIRONMENTAL PROTECTION AGENCY TIER FOUR FINAL STANDARDS

In 2014, the EPA fully implemented its Tier Four Final Standards, which were part of the phase in of the multi-tiered emissions reduction process that started in 1996 to reduce PM and $NO_x$ emissions by 90%. As of result of the Tier Four requirements, manufacturers have created CEGR and SCR systems for heavy construction equipment. Selective catalytic reduction systems use higher combustion temperatures and urea-based diesel exhaust fluid (DEF) after treatment. Cooled exhaust gas recirculation systems mix the exhaust gases with fresh air before recirculating it. A DPF is still required to filter soot. Meeting Tier Four requirements adds an additional 25% to the cost of the equipment. In addition, the engines are more sensitive to water, dust, and extreme temperatures. They may require low-ash engine oil, ULSD fuel, and an extra fuel filtration system (*Engineering News Record* 2014a).

In addition to emission reductions, these technologies also reduce fuel consumption. For instance, according to the heavy construction equipment manufacturer John Deere (2011), extensive testing of its products featuring CEGR platform engines for $NO_x$ control—including the 350D excavator, 700J crawler dozer, and 772G motor grader—showed a 10% or more increase in material moved per unit of fuel used compared with the equipment manufactured by their competitors.

Specific pieces of equipment have been designed to meet Tier Four standards, such as the Kelly Tractor Company IMT Tier 4 A150 hydraulic drill rig. It is powered by a Caterpillar C7.1 ACERT engine delivering 118,000 ft/lb (53,523.62 m/kg) of rotary torque using 217 hp (*Engineering News Record* 2014b). The Manitowoc lattice-boom crawler crane is available with either a Tier 3 or Tier 4 Cummins engine.

## 12.5 ENGINE REPOWERING AND ENGINE UPGRADES

Another method for reducing emissions in heavy construction equipment is engine repowering, and it involves replacing an existing engine with a new engine that meets lower emission standards than the original engine. Engine repowering involves the use of on-road engines to replace existing off-road engines. Depending on the type and year of manufacture of the on-road engine, the replacement engine could reduce PM emissions by 90% and $NO_x$ emissions by 70% compared with the off-road engine. Repowering could lead to credits in retrofit requirements in environmental regulations (Caterpillar 2010).

*Engine upgrading* occurs when emissions-reducing parts are added to an existing engine during an engine rebuild. This involves installing an upgrade kit to bring the old heavy construction equipment up to current codes. According to the EPA, upgrading an engine during a rebuild allows companies to modernize equipment at a lower marginal cost (Environmental Protection Agency 2007).

The emission upgrade design manufactured by Caterpillar (model 3306 diesel engines with mechanical direct fuel injection for off-road applications, compatible with model years 1988–1995) has been verified by the EPA to reduce PM emissions by 22%, $NO_x$ by 37%, HC by 71%, and CO by 13%. According to the EPA report *Cleaner Diesel: Low Cost Ways to Reduce Emissions from Construction Equipment*, the cost-effectiveness of repowering a piece of equipment depends on the make and model of the machine and the availability of funds to defray the costs (Environmental Protection Agency 2007). For Sukut Equipment, Inc., the repowering of single-engine scrapers costs up to $120,000 (Sacramento Metropolitan Air Quality Management District 2011). Therefore, the cost of repowering should be compared with the cost of buying new equipment before a decision is made to repower.

## 12.6 REMANUFACTURING AND REBUILDING HEAVY CONSTRUCTION EQUIPMENT

Caterpillar (2011) offers a *CAT Remanufacturing Service*, a one-for-one exchange in which end-of-life products are returned for remanufactured products. This service reduces waste and minimizes the need for raw materials to produce brand-new heavy construction equipment. Caterpillar defines remanufacturing as the process of using a manufacturing and quality-control system to refurbish worn-out equipment. The equipment is rebuilt to operate in the same manner as a new machine at a fraction of the cost of a new product. The core is completely disassembled into its constituent parts, down to the level of individual nuts and bolts. The parts are cleaned using environmentally friendly processes and then inspected to determine whether they are eligible for being remanufactured using detailed Caterpillar remanufacturing criteria. Fewer resources are consumed to remanufacture a component than to build a completely new one.

Remanufacturing is more environmentally friendly than recycling because remanufacturing dramatically lowers the use of new resources (Caterpillar 2011). According to Caterpillar,

> the cost of a remanufactured engine is 60% of the price of a new one, [and] remanufactured parts are sold at the price of 40% of new ones, both with the same guarantees as new ones. The economics of remanufacturing depend directly on the number of parts of each engine that can be remanufactured. Today, 40% of the components in a remanufactured engine are new; ideally, this could be reduced to about 25%. Possible strategies to reduce this percentage are a better availability of remanufactured components, a better quality control and less scrapping of parts that could be remanufactured. The financial benefit for increased remanufactured content is considerable. The minimum rate of 25% is due to the fact that some components will always need to be replaced, due to the materials used (gaskets, filters, etc.) or their specificity (bearings). (Caterpillar 2015, p. 1)

In its 2008 sustainability report *The Big Picture*, Caterpillar (2008) indicated that it processes nearly 3 billion pounds (1.36 billion kilograms) of remanufactured products per year and uses close to 70% recycled materials in the manufacture of its engines, transmissions, hydraulic locomotives, and railcars.

## 12.7 OTHER TECHNOLOGICAL ADVANCES IN HEAVY CONSTRUCTION EQUIPMENT

Advancements in technology have made it possible to optimize construction processes for efficiency. One example is *intelligent compaction* (IC), a technology used to measure, monitor, and evaluate the stiffness of the layers of soil, aggregate bases, and asphalt materials during road construction. The IC system employs modern vibratory rollers equipped with an in situ measurement system and feedback control. Often, global positioning system (GPS)-based mapping is included, along with software that automates the documentation of results. The ability to continuously measure stiffness, both during the compaction process to aid in optimum compaction and as an acceptance or design tool that is used on the in situ material, improves highway engineering. The possible benefits are immediate identification of weak areas needing to be recompacted and the avoidance of harmful overcompaction, both of which save time and money and reduce exhaust emissions.

Another new technology enhancing the sustainability of a process in the construction heavy equipment sector is the Caterpillar AccuGrade grade-control system. The AccuGrade system increases productivity by up to 40%, which sustantially reduces exhaust emissions. It is factory integrated and sensor independent, and features a suite of products, including cross-slope, sonic, laser, and GPS technology (Caterpillar 2011). By combining digital design data, in-cab operator guidance features, and automatic blade controls, the AccuGrade grade-control system enhances grading accuracy and helps eliminate the need for survey stakes.

## 12.8 HYBRID-ELECTRIC HEAVY CONSTRUCTION EQUIPMENT

Using hybrid-electric heavy construction equipment helps reduce gasoline consumption but may not always be a sustainable alternative. If hybrid vehicles use electricity to recharge, and the electricity in the recharging system is generated by burning coal, then the GhG emissions from burning the coal might be comparable to the emissions from using gasoline or diesel fuel. If the electricity comes from a mix of renewable and traditional energy sources and the electricity from burning coal constitutes only half of the resources, then hybrid-electric vehicles would reduce GhG emissions by 50% (Begley 2008).

The EPA emissions reduction requirements and the need for incorporting fuel-efficient engines have resulted in heavy construction equipment manufacturers developing hybrid-electric vehicles. A hybrid-electric vehicle is any type of vehicle using more than one power source. Hybrid-electric systems for heavy construction equipment reduce fuel consumption and $CO_2$ emissions when the electric motor turning the upper structure of the hybrid hydraulic excavator converts kinematic energy—regenerated when the turning of the upper structure slows down—into electric energy. This electric energy is then stored in a capacitor and reused for the next turning of the upper structure. The power-generating motor also reuses the energy produced as extra energy to accelerate the engine revolution speed.

Sections 12.8.1 through 12.8.6 discuss a few specific types of hybrid-electric heavy construction equipment.

### 12.8.1 Volvo Hybrid-Electric Wheel Loader

Volvo Construction Equipment (Volvo CE) created the L220F hybrid-electric wheel loader, which offers more power and a 10% reduction in fuel consumption (Volvo Construction Equipment 2011). The Volvo hybrid system includes an *integrated starter generator* (ISG), mounted between the engine and the transmission, coupled to an advanced battery. An ISG is an electronically controlled electrical unit used in place of a conventional starter motor and the generator in internal combustion engines. It is used as a starter, a booster electric motor, a generator, and an electric propulsion unit. When a wheel loader is being used, it idles for up to 40% of the time. The ISG allows the diesel engine to shut off when the machine is stationary and to restart almost instantly by rapidly spinning the engine to an optimum working speed using a highly powered battery. The ISG also mitigates the problem of low torque at low engine speeds by automatically offering an electric torque boost. The 50 kW electric motor offers a torque up to 516 lb/ft (700 Nm) from standstill (Van Hampton et al. 2008).

### 12.8.2 Caterpillar D7E Hybrid-Electric Bulldozer

In 2008, Caterpillar released a D7E electric bulldozer. According to the *Engineering News Record* (2008, p. 1),

> A 9L ACERT diesel drives a generator, whose wiring harness has effectively replaced the driveshaft. It runs a power inverter wired to two WC *liquid-cooled electric motors* mated to an axle containing two *double-reduction gear sets*. A third plenary set in between, powered hydraulically, controls differential steering. Transmission is continuously variable, eliminating the need for extra valving and gearing. The engines are beltless, and the entire machine weighs about 3,000 lb [1,360.77 kg] less than the current D7R. By taking out 60% of the moving parts and lightening the load, Cat is able to cut down on parasitic energy losses to get a 20% fuel economy improvement.

Figure 12.1 shows the Caterpillar D7E dozer. In 2013, Caterpillar released another hybrid construction vehicle, the 336H excavator, which operates under similar principles as the D7E bulldozer.

### 12.8.3 Komatsu PC200LC Hybrid-Electric Excavator

In 2008, Komatsu, the second largest producer of heavy construction equipment in the world, released its PC200LC-8 and HB215LC1–hybrid-electric excavators (Komatsu 2008). The HB215LC-1 excavator has three main components in its hybrid drive system. Its design incorporates an electric swing motor, an ultracapacitor, and a generator. Electricity is stored in the ultracapacitor, which sends energy to the electric swing motor or to the generator/motor to power the engine. One key feature is the electric swing motor generates and stores electricity during swing braking that is then reused by the capacitor. Figure 12.2 shows the Komatsu PC200LC-8 hybrid excavator.

Regenerating its own energy is what allows a hybrid-electric excavator to be more efficient and increase fuel savings. The 20-ton (18.144-metric-ton) hybrid-electric excavator also reduces emissions, and the average fuel savings are 25% compared

**FIGURE 12.1** Caterpillar D7E hybrid-electric dozer. (From U.S. Federal Highway Administration, *Part G—Construction Equipment*, Washington, DC, Accessed on December 19, 2014, https://fhwaapps.fhwa.dot.gov/nhswt/reader?agency=Delaware&fn=Part+G_Construction+Equipment.pdf&type=manual, 2012.)

**FIGURE 12.2** Komatsu PC200LC-8 hybrid excavator. (From U.S. Federal Highway Administration, *Part G—Construction Equipment*, Washington, DC, Accessed on December 19, 2014, https://fhwaapps.fhwa.dot.gov/nhswt/reader?agency=Delaware&fn=Part+G_Construction+Equipment.pdf&type=manual, 2012.)

with the same-size traditional heavy construction equipment. The emissions reduction is equivalent to using 14 hybrid vehicles. In an average work year, the HB215LC-1 hybrid-electric excavator reduces fuel consumption by approximately 1,500 gallons (1,248.9 imperial gallons or 5,681.25 L) of diesel fuel or 6,300 gallons (5,245.38 imperial gallons or 23,861.25 L) of crude oil and will produce 25% less $CO_2$ than a standard excavator without hybrid technology (Komatsu 2008).

Komatsu is marketing the 22-ton (19.96-metric-ton) PC200LC-8 hybrid-electric excavator in Asia and the United States. The excavator is 25%–40% more fuel efficient than the diesel-powered version and emits 22 lb (9.98 kg) less $CO_2$ per hour of operation. Unfortunately, in 2013 the new Komatsu hybrid-electric excavator cost 50% more than the diesel version of the same model.

The Komatsu hybrid-electric excavator uses a "diesel engine, an electric-swing motor, a generator, a capacitor and pumps. As the swinging superstructure slows down, kinetic energy converts to electricity, which is sent through in inverter and then is captured by a capacitor … . The generator/motor is located behind the engine and the hydraulic pumps. It can charge the capacitor during periods of downtime, and it can receive power from the capacitor for engine assist, determined by the power controller" (*Engineering News Record* 2010, pp. 12–13). The hybrid-electric excavator is rated at 138 hp and has a four-cylinder, 4.5 L engine. The traditional version of the excavator is rated at 148 hp and has a six-cylinder, 6.7 L Komatsu turbo-diesel engine.

### 12.8.4 John Deere Diesel-Electric 644K and 944K Hybrid Wheel Loaders

John Deere manufactures a diesel-electric 644K hybrid-electric wheel loader and a more efficient 944K hybrid-electric loader. This John Deere technology uses internal combustion engines with electric motors. Some of the existing loaders used for quarrying operations consume up to $200,000 per year in fuel if they are operated for two or three shifts a day. The 644K saves between 15% and 20% per year and the 944K saves 25%–30% per year in fuel costs. The 644K uses existing technology, and the 944K uses an all new technology. According to John Deere (2011, pp. 26–27),

> Deere's 944K hybrid starts with a 13.5L diesel engine that produces about 500 hp. It connects to two generators, each of which powers two motors, one at each wheel. Sandwiched between the engine and generators is a pump drive, a simple gearbox that grabs power from the engine's flywheel to drive the hydraulic pumps for the bucket and steering. The pumps run 20% faster than engine speed; the generators run at three times engine speed.
>
> The generators send AC power to an inverter assembly, which converts the power to DC current to run accessories, then switches it back to AC to run the four outboard electric wheel motors. Overall the system runs at 700 volts. A computer can sense when the wheels are slipping and adjust the power to boost traction.
>
> Though it has no traditional energy storage, the 944K captures some regenerative braking when the machine is slowing down by sending power back to the generators to drive the hydraulics. Unused energy is "cooked off" in brake resistors.

Figure 12.3 shows the John Deere 644K hybrid diesel-electric wheel loader.

**FIGURE 12.3** John Deere 644K diesel-electric hybrid wheel loader. (From U.S. Federal Highway Administration, *Part G—Construction Equipment*, Washington, DC, Accessed on December 19, 2014, https://fhwaapps.fhwa.dot.gov/nhswt/reader?agency=Delaware&fn=Part+G_Construction+Equipment.pdf&type=manual, 2012.)

### 12.8.5 PETERBUILT HYDRAULIC-HYBRID TRUCK

A hydraulic-hybrid truck was developed by the EPA in conjunction with the Cleveland-based *Eaton Hybrid Power Systems*, *Parker Hannifin*, and *Peterbuilt*. For this hydraulic-hybrid truck (Dumaine 2010, p. 14),

> the energy from deceleration is stored in a pressurized tank called an accumulator, which is full of hydraulic fluid and nitrogen. When the truck starts moving pressure released from the tank drives the wheels, saving the diesel engine from having to kick in. The system is great for stop and go driving. Annual fuel savings should reach 1,000 gallons [832.6 imperial gallons or 3,787.5 liters] of diesel per truck per year, about a 30% improvement over traditional haulers. Greenhouse gas emissions are reduced 20% or more.

Figure 12.4 shows the Peterbuilt Model 320 hydraulic-hybrid class 8 refuse truck.

### 12.8.6 RESEARCH COMPARING TRADITIONAL DIESEL TO HYBRID-ELECTRIC HEAVY CONSTRUCTION EQUIPMENT

A two-year study of hybrid-electric construction equipment was conducted at the University of California–Riverside and completed in 2013. According to the results of the research, hybrid-electric construction equipment does save fuel, with the results varying by the type of construction equipment. For the Caterpillar D7E bulldozer, the average fuel savings was 14% and $CO_2$ emissions were reduced by 14%. The Komatsu HB215LC-1 hybrid-electric excavator reduced both fuel and $CO_2$ emissions by 16%. Unfortunately, the research also indicated that for the Caterpillar D7E

**FIGURE 12.4** Peterbuilt model 320 Hybrid Class 8 refuse truck. (From U.S. Federal Highway Administration, *Part G—Construction Equipment*, Washington, DC, Accessed on December 19, 2014, https://fhwaapps.fhwa.dot.gov/nhswt/reader?agency=Delaware&fn=Part+G_Construction+Equipment.pdf&type=manual, 2012.)

bulldozer $NO_x$ emissions increased by 13% for the hybrid-electric machine and for the Komatsu HB215LC-1 hybrid-electric excavator they increased by 1% compared with the emissions of a Caterpillar D6T and Komatsu PC200, respectively. Even though the $NO_x$ emissions were higher for both types of hybrid-electric construction equipment, they did not exceed federal limits. Additional research will be conducted as new models of hybrid-electric construction equipment become available in the industry (*Engineering News Record* 2013).

## 12.9 SUMMARY

This chapter presented information on the use of tires to help increase the sustainability of construction equipment and the use of biodiesel fuel products to reduce GhG emissions from heavy construction equipment exhaust systems. The EPA Tier Four Final Standards were introduced along with information on cooled exhaust gas recirculating and selective catalytic reduction systems. Engine repowering, engine upgrading, and diesel retrofit technology were also covered in this chapter to demonstrate alternatives to purchasing hybrid-electric heavy construction equipment.

This chapter also discussed sustainable alternatives for heavy construction equipment and hybrid-electric heavy construction equipment such as the Caterpillar electric dozer, Komatsu hybrid-electric excavator, John Deere diesel-electric hybrid wheel excavator, and Peterbuilt hydraulic-hybrid truck.

## 12.10 KEY TERMS

CAT Remanufacturing Service
Cooled exhaust gas recirculation
Diesel oxidation catalysts
Diesel particulate filters
Diesel-retrofit technologies
Double-reduction gear sets
Eaton Hybrid Power Systems
Energy Saver Green tires
Engine repowering
Engine upgrading
Integrated starter generator
Intelligent compaction
Liquid-cooled electric motors
Parker Hannifin
Peterbuilt
Selective catalytic reduction
Tier Four Final Standards
Ultra-low-sulfur diesel fuel

## 12.11 DISCUSSION QUESTIONS

12.1 Describe how using Energy Saver Green tires is sustainable.
12.2 Explain whether the efficiency achieved by using hybrid-electric heavy construction equipment justifies the increase in its purchase price over traditional diesel engine heavy construction equipment.
12.3 Explain engine repowering and why it is used in heavy construction equipment.
12.4 What is diesel retrofit technology, and how does it benefit the environment?
12.5 Describe how hybrid-electric heavy construction equipment is different from traditional diesel-powered equipment.
12.6 Explain why it is important to reduce the toxic emissions from heavy construction equipment.
12.7 What is a major disadvantage to using biodiesel fuel in heavy construction equipment?
12.8 Discuss the different types of emissions generated when using diesel engines.
12.9 Explain what diesel retrofit technologies are used to accomplish when installed on heavy construction equipment.
12.10 Explain why using biodiesel fuel is advantageous compared to using conventional diesel fuel.
12.11 Discuss why the John Deere diesel-electric hybrid wheel loaders could be viable alternatives to traditional diesel wheel loaders.

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# 13 Traditional and Alternative Energy Sources

This chapter discusses traditional energy production, including petrochemical products, hydrocarbon separation processing, hydraulic fracturing (hydrofracking), *liquefied natural gas* (LNG) production, nuclear power, coal-fired power, and hydropower. It also presents information on alternative energy sources such as *combined heat and power* (CHP) *technology*; solar power and *photovoltaic* (PV) cells; fuel cells; and osmotic, wind, biomass, geothermal, tidal, and wave energy. In addition, this chapter explains energy efficiency standards and energy auditing.

Electrical power generation irrespective of the source is measured in *watts*, *kilowatts* (kW or 1000 W), *megawatts* (MW MWe, or 1 million watts), or *gigawatts* (GWe or 1 billion watts). The consumption of energy is measured in *kilowatt-hours* (kWh). "A kilowatt-hour means one kilowatt (1,000 watts) of electricity produced or consumed for one hour. One fifty watt light bulb left on for 20 hours consumes one-kilowatt-hour of electricity (50 watts × 20 hours = 1,000 watt-hours = 1 kilowatt hour)" (Gavorkin 2006, p. 112).

The construction industry is a major consumer of energy-intensive materials and products, and if the energy requirements for producing construction materials are reduced it would contribute to a decline in overall energy consumption. Table 13.1 provides the energy consumed in 2006 and 2009 for some of the manufacturing sectors supporting the construction industry.

In 2013, the following were the percentages of energy generated by each type of energy source in the United States (U.S. Energy Information Administration 2013, p. 1):

- Coal: 39%
- Natural gas: 27%
- Nuclear: 19%
- Hydropower: 7%
- Other renewables: 6%
- Biomass: 1.48%
- Geothermal: 0.41%
- Solar: 0.23%
- Wind: 4.13%
- Petroleum: 1%
- Other gases: <1%

**TABLE 13.1**
**Energy Consumption of Manufacturing Sectors in the United States in 2006 and 2009**

| Manufacturing Sector | 2006 Total Energy Consumption (Trillion Btu) | 2009 Total Energy Consumption (Trillion Btu) |
|---|---|---|
| Chemical manufacturing: solvents, cleaners, adhesives, paints, stains, dyes, and other compounds used in construction products | 3195 | 3200 |
| Petroleum refining: fuel for transporting materials and polymer production | 3396 | 3490 |
| Iron and steel production | 1455 | 1503 |
| Cement: Portland, natural, masonry, pozzolanic, and other hydraulic cements | 409 | 458 |
| Primary metals | 1744 | 1200 |
| All other metals | 3782 | |
| Alumina and aluminum | 351 | 378 |
| Paper | 2354 | 2400 |
| Food | 1186 | 1200 |

*Source:* Adapted from U.S. Energy Information Administration—Independent Statistics and Analysis, *Total Energy, Annual Energy Review Energy Trends in Selected Manufacturing Sectors*, Washington, DC, Accessed on January 13, 2015, http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0202, 2012; *and* Battles, S., *Energy Consumption in the Manufacturing Sector, a Brief Analysis,* Energy for Manufacturing Roundtable–International Trade Administration, Department of Commerce, Washington, DC, Accessed on January 13, 2015, http://www.ita.doc.gov/td/energy/EIA_Energy%20Consumption%20in%20the%20Manufacturing%20Sector.pdf, 2009.

*Note:* Btu, British thermal unit.

Sections 13.1 through 13.4 discuss traditional types of energy sources that are used in the construction industry.

## 13.1 PETROCHEMICAL PRODUCTS

The types of petroleum products used in the United States include transportation fuels; fuel oil for heating and electricity generation; asphalt and road oil; and the feedstock used to make chemicals, plastics, and synthetic materials. About 74% of the 6.89 billion barrels of petroleum used in the United States in 2013 were gasoline, heating oil/diesel fuel, and jet fuel. The petroleum products and their relative share of the total U.S. petroleum consumption in 2013 were (U.S. Energy Information Administration 2014, p. 1)

- Gasoline: 46%
- Heating oil/diesel fuel: 20%
- Jet fuel (kerosene): 8%
- Propane/propylene: 7%
- NGL and LRG*: 6%
- Still gas: 4%
- Petrochemical feedstocks: 2%
- Petroleum coke: 2%
- Residual/heavy fuel oil: 2%
- Asphalt and road oil: 2%
- Lubricants: 1%
- Miscellaneous products/special naphthas: 0.4%
- Other liquids: 1%
- Aviation gasoline: 0.1%
- Waxes: 0.04%
- Kerosene: 0.02%

*Note: natural gas liquids and liquefied refinery gases.

"The amount of fuel used to generate electricity depends on the efficiency or heat rate of the generator (or power plant) and the heat content of the fuel. Power plant efficiencies (heat rates) vary by type of generator, power plant emission controls, and other factors. Fuel heat contents also vary" (U.S. Energy Information Administration 2014a, p. 1). Two formulas for calculating the amount of fuel used to generate 1 kWh of electricity are shown in Equations 13.1 and 13.2:

$$\text{Amount of fuel used per kilowatt-hour} = \text{heat rate (in Btu/kWh)/fuel heat content (in Btu/physical unit)} \tag{13.1}$$

$$\text{Kilowatt-hours generated per unit of fuel used} = \text{fuel heat content (in Btu/physical unit)/heat rate (in Btu/kWh)} \tag{13.2}$$

Examples using these two formulas are shown in Box 13.1, along with the assumptions used in the examples.

Sections 13.1.1 through 13.1.4 discuss some of the energy source options generated by the petrochemical industry.

### 13.1.1 TAR SANDS OIL PRODUCTION

One financially intensive method for obtaining oil is extracting it from tar sands. The removal of oil from tar sands is being pursued in Canada in some of the coldest regions of the country. In addition to the tar sands in Alberta, Canada, there are tar sand deposits being mined in Venezuela, Russia, eastern Utah, a few countries in Africa, and the Middle East.

Producing oil from tar sands requires extracting the sand permeated with tar from the ground using heavy construction equipment. After the tar sand is excavated, it

## BOX 13.1

## EXAMPLES OF THE AMOUNT OF FUEL USED TO GENERATE ELECTRICITY

Amount of fuel used to generate one kilowatt-hour (kWh) of electricity:

Coal = 0.00054 short tons (1.09 lb or 0.4944 kg)

Natural gas = 0.00786 Mcf (1000 ft$^3$ or 28.317 m$^3$)

Petroleum = 0.00188 barrels (0.08 gallons or 0.0302833 L)

Kilowatt-hour generated per unit of fuel used:

1,842 kWh per ton of coal (0.9 kWh per pound or 0.4082 kg of coal)
127 h per Mcf (1000 ft$^3$ or 28.317 m$^3$) of natural gas
127,533 kWh per barrel of petroleum (12.7 kWh per gallon or 48.04 L)

Assumptions:

Power plant heat rate:

Coal = 10,498 Btu/kWh

Natural gas = 8039 Btu/kWh

Petroleum = 10,991 Btu/kWh

Fuel heat contents:

Coal = 19,336,000 Btu per short ton (2,000 lb or 907.19 kg)

(Note: The heat content of coal varies by type of coal)

Natural gas = 1,023,000 Btu per 1,000 ft$^3$ (Mcf)

Petroleum = 5,861,814 Btu per barrel (42 gallons)

(Note: The heat content varies by type of petroleum product)

*Source:* U.S. Energy Information Administration, *How Much Coal, Natural Gas, or Petroleum is Used to Generate a Kilowatt Hour of Electricity?*, Washington, DC, Accessed on February 12, 2015, http://www.eia.gov/tools/faqs/faq.cfm?id=667&t=6, 2014a.

is transported by trucks to refineries, where the oil is extracted from the tar through a separation process. The tar sands are a combination of clay, sand, water, and *bitumen;* a heavy black viscous oil. “Tar sands are mined and processed to extract the oil-rich bitumen, which is then refined into oil. The bitumen in tar sands cannot be pumped from the ground in its natural state; instead tar sand deposits are mined, usually using strip mining or open pit techniques, or the oil is extracted by underground heating” (U.S. Department of the Interior, Bureau of Land Management 2012, p. 1).

To generate oil similar to the type of oil that is found in conventional oil wells, the tar sands are processed through extraction and separation systems that remove clay, sand, and water from the bitumen. Since the bitumen is so viscous (thick), it is diluted with light hydrocarbons to create a liquid that can be transported through pipelines. For the refining process, the

> tar sands are transported to an extraction plant, where a hot water process separates the bitumen from sand, water, and minerals. The separation takes place in separation cells. Hot water is added to the sand, and the resulting slurry is piped to the extraction plant where it is agitated. The combination of hot water and agitation releases bitumen from the oil sand, and causes tiny air bubbles to attach to the bitumen droplets, that float to the top of the separation vessel, where the bitumen can be skimmed off. Further processing removes residual water and solids. The bitumen is then transported and eventually upgraded into synthetic crude oil. (U.S. Department of the Interior, Bureau of Land Management 2012, p. 1)

If the bitumen deposits are too deep for open-pit mining, then in situ production methods are used to recover the bitumen. Some of the in situ techniques include steam injection, solvent injection, and firefloods (oxygen is injected, and part of the resource is burned to produce heat). These methods require large quantities of water and energy (for heating and pumping). To produce one barrel of oil several barrels of water are required for well injection procedures, but some of the water could be recycled (U.S. Department of the Interior, Bureau of Land Management 2012).

Figure 13.1 shows one of the Canadian tar sand pits during the tar sand removal process.

### 13.1.2 HYDROCARBON SEPARATION PROCESSING

The hydrocarbon separation processing technique of oil extraction is discussed in Chapter 3 in Section 3.9.

In New Mexico, the Sandia National Laboratory conducted a research project on the hydrocarbon separation process with the following objectives (Nenoff 2001, p. 33):

1. Designing a commercially scalable and economically and technically feasible pilot plant module using uniquely optimized, microporous membrane elements to separate hydrocarbon molecules from a typical mixed stream
2. Developing novel membrane materials tailored to separate hydrocarbon mixtures
3. Formulating a material and process development program that could be applied to other commercial separation opportunities in the chemical and petroleum refining industries

**FIGURE 13.1** Canadian tar sands removal project. (From NASA Earth Observatory, *Athabasca Oil Sands*, Greenbelt, Maryland, Accessed on December 19, 2014, http://earthobservatory.nasa.gov/Features/WorldOfChange/athabasca.php, 2009.)

According to Nenoff in the article "Advanced Materials for Reducing Energy Consumption and Manufacturing Costs in the Chemical and Petroleum Refining Industries,"

> This key separation area is currently conducted primarily by cryogenic distillation [low temperature liquefaction process used to separate gases from air]; extremely low temperatures (–90°C [104°F]) and corresponding high refrigeration costs and high compressor utility charges characterize this process. Energy-efficient separation processes involving novel microporous inorganic thin film materials could lead to significant energy savings compared to conventional adsorption or cryogenic processes. (Nenoff 2001, p. 34)

### 13.1.3 HYDRAULIC FRACTURING (HYDROFRACKING)

*Hydraulic fracturing*, referred to as *hydrofracking* or *fracking*, is a process whereby millions of gallons of water are mixed with sand and chemicals and blasted into the ground into shale deposits to create fissures in the rocks that precipitate the release of natural gas from the rocks. Each drilled well requires more than 3 million gallons of water to create the fractures that allow the gas to be released from the ground. There are known shale gas deposits in the United States in most states, and new discoveries of shale gas deposits keep occurring; therefore, deposits might be found in every state.

The hydrofracking process may contaminate drinking water supplies in areas surrounding the hydrofracking fields; therefore, the Environmental Protection Agency (EPA) is studying hydrofracking processes to determine if they are harmful to public health. Investigations are being conducted to determine methods for recycling the water used during hydrofracking, once it returns to the surface after the natural gas is released from the earth. In some parts of the United States, the water released is treated and reinjected back into new wells. If the local geology does not permit the reinjection of water, it is treated and transported to storage sites and some of the water is released back into local rivers and streams.

Alternative drilling techniques are being evaluated to combine the current hydrofracking techniques with traditional drilling methods using high-pressure cutting heads rather than the cutting heads currently used for hydrofracking. If these methods prove to be a viable method, then they would lower the amount of water required for drilling each well and also help reduce energy requirements.

The difficulties in treating the *flow back water* resulting from the hydrofracking process are related to its high salt content. Typical industrial wastewater treatment plants are not able to effectively process water with a high salt content. Special water treatment facilities are being built to treat the flow back water requiring additional chemical processes and adjustments to the pH levels.

### 13.1.4 LIQUEFIED NATURAL GAS

During the beginning of the twenty-first century, the facilities required for liquefying natural gas from shale gas were once again being built in the United States. In the past, most LNG was processed overseas; however, now there are *regasification facilities* in the United States in Freeport, Texas, and additional regasification facilities are being built in other states. Liquefying natural gas is a process where the gas released from underground deposits is sent through exchangers where it is cooled to temperatures at which the gas becomes a liquid (–250°F/160°C), and it is condensed to 1/600th of its normal volume. Once it is cooled, it is transported through pipelines or by special LNG tankers to other locations or countries and then reprocessed in regasification facilities back into a vaporous state. Figure 13.2 shows an LNG plant exchanger under construction.

**FIGURE 13.2** Liquefied natural gas plant exchanger under construction in Bontang Bay, Borneo, Indonesia. (Courtesy of J. K. Yates.)

Liquefied natural gas liquefaction plants in China are able to process hydrocarbon gas, which is a by-product of industrial coke ovens, and convert it into LNG after it is cleaned. In the past, the hydrocarbon emissions from industrial coke ovens were vented into the air.

## 13.2 NUCLEAR POWER

This section discusses nuclear energy created by nuclear *fission*, and nuclear fusion is only briefly mentioned since it is not yet a viable source of energy.

### 13.2.1 NUCLEAR FISSION

The creation of nuclear power involves nuclear fission, where *uranium-238* atoms are split to create energy. Nuclear power plants contain a reactor core where the nuclear reaction occurs and a containment structure to protect the environment from the radioactive material. The reactor core also includes a mechanism for stopping the nuclear reaction in case it becomes critical, which occurs when the radioactive elements reach a level at which a nuclear chain reaction might occur and result in a nuclear explosion. The nuclear reaction is used to heat water, and the heated water, in turn, drives turbines, creating energy that is harnessed to produce electricity. In the United States, the nuclear reactors originally built were *boiling water reactors* (BWRs), where the water is heated directly and results in steam driving the turbines, and *pressurized water reactors* (PWRs), where the water is piped through a system surrounding the nuclear reactor and after it is heated the steam it generates is moved through turbines to create energy and electricity. Since the water in the pipes is heated, it is referred to as pressurized water.

Boiling water reactors and PWRs are used in France, Japan, Russia, China, and most other countries, but there are several other types of nuclear reactors. Pressurized heavy water reactors are used in Canada and India; advanced gas reactors are used in the United Kingdom; light water graphite reactors are used in Russia; and fast breeder reactors are used in Japan, France, and Russia. In 2012, there were 265 pressurized water, 90 boiling water, 44 pressurized heavy water, 18 gas cooled, 16 light water graphite, and two fast breeder reactors in use throughout the world (Peres 2012).

Members of the nuclear power industry are seeking methods for incorporating sustainable development practices into the construction of nuclear power plants. One initial step toward sustainable practices is to divide the components of nuclear power plants into nuclear and nonnuclear structures. For PWRs, the structures are divided in the following manner (Lapp and Golay 1997, p. 334):

- Nuclear buildings:
    - Control building (CB)
    - Fuel-handling building (FHB)
    - Reactor auxiliary building (RAB)
    - Reactor containment building (RCB)
    - Waste process building (WPB)

- Nonnuclear buildings:
    - Intake structures
    - Other warehouse buildings
    - Turbine building
    - Water treatment buildings

Buildings containing systems directly related to the reactor, which are safety related and radioactive, are segregated for construction purposes.

Nuclear power plants were traditionally built as either PWRs or BWRs, and both of these types of reactors are still in operation throughout the world. In the United States, there were 100 nuclear reactors in 2014, although some of the reactors were going through decommissioning due to their age (U.S. Energy Information Administration 2015b). Twenty-three of the U.S. nuclear power plants are BWRs, which was the type of reactor damaged by the 9.0-magnitude earthquake and tsunami in Fukushima, Japan, on March 11, 2011 (*Engineering News Record* 2011). As a result of the nuclear incident in Japan, some countries are either restricting or eliminating the construction of new nuclear reactors.

In 2007, Greenpeace founder Patrick Moore endorsed nuclear power "as the only large-scale electricity source with no emissions of global warming gases. But one major concern is there is still 'no long-term storage for radioactive waste' " (Lavelle 2007, p. 32). In addition, the initial cost of constructing nuclear power plants is 65% higher than the cost of building a *coal-fired power plant* and six times the cost of building facilities to process natural gas into electricity.

It is difficult to obtain information pertaining to the sustainable practices being implemented in the nuclear power industry due to confidentiality requirements imposed by the firms constructing nuclear power plants.

### 13.2.2 Nuclear Batteries

Nuclear batteries are being developed by several firms including one firm that was, originally part of the Los Alamos National Laboratory. Portable nuclear batteries are the size of a refrigerator and even the smallest one could provide enough power (5 MWe) to provide electricity to a city with 20,000 citizens. They will range in size from 5 to 1,600 Megawatts (MWe). The estimated construction cost of nuclear batteries is $100 million in contrast to the $4–$6 billion or more required for constructing conventional nuclear power plants. Currently, nuclear batteries are not licensed by the Nuclear Regulatory Agency, and it is anticipated that they will be licensed by 2016 for commercial operation in the United States; therefore, nuclear batteries may be built and tested in countries other than the United States before they are built in the United States (World Nuclear Association 2015).

Another revolutionary nuclear reactor was developed using NuScale technology. NuScale reactors are 1/20th the size of large nuclear reactors, and the reactor core has only 5% of the fuel of a large nuclear reactor; they are small enough to fit on the back of a tractor trailer and are capable of producing 10 MWe of electricity per unit. The units can be connected in series to produce higher levels of electricity. NuScale reactors are able to withstand earthquakes, floods, tornados, hurricane force winds, and aircraft impact. The reactors are housed inside high-strength steel containment vessels and submerged in 4 million gallons of water below the ground inside reactor buildings. Another prospective nuclear battery is being developed by B&N mPower (World Nuclear Association 2015).

### 13.2.3 NUCLEAR FUEL ROD DISPOSAL

One of the main concerns related to nuclear power generation is the disposal of the radioactive *nuclear fuel rods* at the end of their useful life after they are used in nuclear power plants. Fuel rods are tubes filled with uranium pellets and located at the core of nuclear reactors. The uranium is part of the nuclear fission process generating the heat used to boil water and create the steam powering the turbines and generating electricity. The fuel rods are used for approximately 18 months, and then the spent rods are submerged in circulating water in cooling ponds to help cool the rods. It takes approximately ten years for the rods to cool down, although the fuel rods continue to be radioactive for approximately 10,000 years. If the fuel rods are no longer surrounded by circulating water, their temperature climbs to thousands of degrees and there is the possibility of the rods melting and releasing high levels of radiation. In 2011, there were over 71,000 tons of nuclear fuel rods in containment ponds at nuclear power plant sites throughout the United States (*The Week* 2011, p. 13).

One alternative to storing spent fuel rods at nuclear power plant sites in cooling ponds is to entomb them in containers of steel and concrete, and this method is being used in some locations in the United States and Germany, but the cost is in the tens of billions of dollars. A second alternative is to bury the rods, and in the 1980s the U.S. government attempted to prepare a burial site at Yucca Mountain in Nevada where the rods were to be stored 1000 ft below the mountain in special *nickel-alloy chambers* at a cost of approximately $20 billion. But there was a chance that the nuclear waste would leach down into the water table located 1000 ft below the storage area; therefore, the Yucca Mountain project was terminated in 2008 after having been on hold for numerous years (*The Week* 2011, p. 13).

Both Sweden and Finland are building underground nuclear storage facilities at Forsmark and Onkalo. These two facilities are projected to be available by 2020. At these sites, nuclear fuel rods will be sealed inside "corrosion-resistant canisters, bedrock, and *bentonite*," and as the bentonite is exposed to water it swells and seals the spent fuel rods and protects the fuel rods from earthquakes and underground water flow (*The Week* 2011, p. 13).

### 13.2.4 NUCLEAR FUSION

*Nuclear fusion* involves combining light atoms (*isotopes of hydrogen*, deuterium, or *tritium*) to form the energy gas *helium* while releasing an enormous amount of energy. Unfortunately, this process is only achieved at temperatures of over 100 million degrees when the material is fully ionized and referred to as *plasma* (one of the four states of matter: solid, liquid, gas, and plasma). The only methods for containing the plasma at these temperatures are magnetic fields, or *inertial confinement* (initiate nuclear fusion reactions by heating and compressing a fuel target, typically in the form of a pellet most often containing a mixture of deuterium and tritium), using lasers or *high-energy particle beams* to compress the fusion fuel; therefore, nuclear fusion is currently not a viable energy source.

Research is being conducted using numerous lasers with power capabilities of up to 500 trillion watts to shoot hydrogen isotopes and crush them to create nuclear reactions. The focus of this research is to maintain high enough temperatures and pressures to cause ignition creating a self-sustaining chain reaction (*The Week* 2014).

## 13.3 COAL-FIRED POWER PLANTS

Coal-fired power plants burn coal to produce electrical energy. Once the coal is burned, the residual burnt coal becomes fly ash. The fly ash has to be either disposed of by storing it in retention ponds or reused to create other materials such as a replacement for cement in concrete. Storing fly ash in retention ponds creates environmental challenges since it contains toxic residue, and it needs to be monitored to ensure that it does not escape into the environment. There have been toxic spills of fly ash in retention ponds when the sides of the ponds failed and released fly ash into the surrounding area and adjacent rivers.

Calculating the cost of producing a kilowatt-hour of electricity from *coal* requires taking into account the following (Munier 2005, p. 220):

- The amount of residue from smoke filters dumped into the soil, and the cost to clean it up
- The cost of pollution produced by smokestacks from power plants, measured in carbon dioxide and other *sulfurous gases*, which leads to global warming and acid rain
- The energy and pollution caused by making boilers, turbines, condensers, electrical equipment, and so on
- The life-cycle assessment of coal extraction, transportation, and utilization, that is, how much energy—which translates mainly into carbon dioxide contamination—is spent to mine coal and how much energy is used to transport it to where it is consumed
- The number of people affected by pulmonary diseases due to smokestack gases

Gavorkin (2006, p. 31) indicates, “According to a 1999 report by the U.S. Department of Energy (DOE) one kilowatt of energy produced by a coal-fired power generating plant requires about five pounds of coal. Likewise generation of 1.5 kW hour of electrical energy per year requires about 7.4 pounds of coal and in turn it produces 10,000 pounds of carbon dioxide.”

New EPA regulations require coal-fired power plants to be retrofitted with scrubbers for reducing the amount of carbon dioxide released into the atmosphere, and by 2014 in the United States a high proportion of coal-fired power plants were retrofitted with this technology.

In the United States, clean coal technology is being used to follow the requirements for obtaining tax credits for carbon capture from coal-fired power plants.

There are two processes for carbon capture technology. One method captures the carbon generated from coal-fired power plants and pumps it back into the ground. In the second method, the $CO_2$ is sold to an oil company and it is injected as compressed gas into old wells to force more oil to the surface. This technology is called an enhanced recovery system.

## 13.4 HYDROPOWER ENERGY GENERATION

*Hydropower* energy generation accounts for 20% of the total electricity consumed throughout the world and 97% of the renewable energy electricity. Hydropower-generated electricity is able to handle fluctuations in energy demands much faster than other sources of energy since the amount of water flowing into the turbines generating the electricity could be altered by merely opening and closing the gates that allow water to flow through the turbines. The efficiency rating for hydropower is approximately 90% since almost all of the water passing through the turbines is converted into energy. For *fossil fuels*, the efficiency rating is approximately 40%. The cost of hydroelectric power is approximately one-third the cost of generating energy using fossil fuels or nuclear power (Langston and Ding 2001).

The drawbacks to utilizing hydropower include the high cost and the long length of time to build hydroelectric dams, the requirement for large areas of land, disruptions to the natural flow of rivers, the altering of animal and fish habitats, water shortages caused by low snow pack and rainfall levels, and the production of methane gas from the breaking down of vegetation. The damsite eventually causes heavy metals and other pollutants to accumulate behind the dam, and they might damage the mechanical components of the turbines and affect the operational efficiency of the dam (Langston and Ding 2001).

### 13.4.1 River Power Generation

Energy could be produced on rivers if they flow quickly enough to rotate a pulley placed above the water used to drive a pump or a generator. "The water flow rate is increased with a simple system that uses the low head pressure provided by the river flow. A permanent *magnet generator*, which has low maintenance, produces variable frequency and voltage output that is rectified to direct current (DC) to charge a battery bank. The power output is proportional to the cube of the flow velocity, so that at a water speed of 3 meters/second [9.84 feet/second] it could supply 2.35 kilowatts of power continuously" (Singh 1995).

## 13.5 ALTERNATIVE ENERGY

Alternative energy is energy generated by nontraditional sources. Some alternative energy sources have been used for centuries, such as windmills generating wind energy and waterwheels generating power for small manufacturing processes. There are other recent innovations in alternative energy production such as photovoltaic and fuel cells. It is difficult for alternative forms of energy to provide large quantities of electricity because of the lack of manufacturing facilities to produce them, difficulties encountered in the long-term storage of the electrical power generated, and the excessive cost of producing the required elements for generating many of the forms of alternative energy. Sections 13.1 through 13.15 introduce several alternative energy sources and provide information on their implementation and use.

## 13.6 COMBINED HEAT AND POWER TECHNOLOGY

Combined heat and power technology—also referred to as *cogeneration*—is used in industrial applications and high-rise construction. For one commercial high rise in New York City, the use of CHP technology meets 33% of the peak power demands and 70% of the annual energy requirements for the structure. Cogeneration plants produce electricity and also steam (*thermal energy*) from one fuel source such as natural gas. Natural gas is used to drive turbines, produce the steam used to heat a structure and water supplies, and also operate *chillers* for cooling systems. Excess steam is used for cooling by producing ice during off-peak hours.

Using CHP technology helps to reduce carbon emissions compared to conventional power systems such as electrical grid systems. Since the electricity does not have to be transmitted through transmission lines, there is no transmission loss. In industrial plants, the demand for energy is consistent most of the time; therefore, there are no issues related to major energy requirement fluctuations.

According to Langston and Ding (2001, p. 171), “The concept of cogeneration involves localizing electric power generation and capturing or harvesting the waste heat associated with the generation process and employing heat to do the work.” A typical cogeneration plant may

> include a gas turbine, which is directly linked to a generator, and a steam turbine, which also generates electricity, powered by waste heat captured from the gas turbine. The exhaust from the steam turbine could then be used for domestic hot water or as process steam. In this way the high-grade energy in the fuel is degraded in steps with useful work being done at each stage. Other byproducts, such as carbon dioxide for industrial use, could be captured as well, providing further benefits. (Langston and Ding 2001, p. 172)

### 13.6.1 COGENERATION MICRO TURBINES

There are also *micro turbines* using cogeneration technology to generate electricity; they are initially powered by gas or liquid fuels and low-Btu *landfill gasses* (LFGs). The exhaust is used to recover the generated heat. Micro turbines are available in sizes ranging from 30 kW to 60 kW, and they may be used in parallel to generate up to 1.2 MW of electricity. Micro turbines

> mix fuel with air to create combustion. This combustion turns a magnet generator, compressor, and turbine wheels on a revolutionary single shaft, air-bearing design at high speed with no need for additional lubricants, oils, or coolants. The result is a highly efficient, reliable, clean combustion generator with very low $NO_x$ emissions that, unlike diesel generators, could operate around the clock without restrictions. Unlike cycle gas turbines, these power systems use no water. (Gavorkin 2006, p. 144)

## 13.7 SOLAR POWER, PHOTOVOLTAIC CELLS, AND SOLAR CONNECTORS

*Thermodynamic conversion processes* are used with devices to collect solar heat. Two of these processes are (1) *Rankine cycle* (2) gas turbine technologies. Solar collectors harvest and concentrate the energy generated by the sun to heat a fluid, and then the fluid generates electricity. One system in Australia at the Australian National University has a *paraboloidal mirrored dish*. This is the "world's largest paraboloidal dish solar concentrator, with 489 $m^2$ of mirror aperture area. At the focal plane it produces an average concentration of 2,100 suns over a disk with a diameter of 530 mm (20.9 in.), and a peak concentration of 14,000 suns. It focuses sunlight on a receiver in which water is converted to steam that is piped to a generator. To maximize output, the tilt and rotation of the dish is computer controlled to track the sun. This system could be scaled up to hundreds of megawatts" (Australian National Laboratory 2014). Other systems use collectors that focus the sun into pipes containing oil, and the oil is used to heat the steam driving a *turbo generator*.

To understand PV conversion, the following background is provided:

> The direct conversion of sunlight into electricity is achieved by a process called the photovoltaic effect (photo = light, voltaic = electrical potential) discovered by a French physicist, Edmund Becquerel. The first solar cells were made of *selenium* in the 1880s with a 1%–2% efficiency (the percentage of available sunlight energy converted by the cell into electrical energy). By the mid-1950s Bell Telephone Labs had achieved 4% efficiency with *silicon* PV cells. The majority of power modules in use since 1955 are crystalline silicon or thin-firm *amorphous silicon*. Other thin film materials include *cadmium telluride* (CdTe) and *copper indium diselenide* ($CuInSe_2$ or CIS).
>
> When light shines on semiconducting materials, the *photons* (parcels of light energy) impart enough energy for some of the electrons to jump from a bound state to a free conducting state, leaving behind a hole which acts as a positive charge. The holes move by way of neighboring electrons exchanging places with it. To make this useful, a cell is made from either two different semiconductors or the same but impregnated with different "impurities" to create a junction (as close as possible to the surface of where sunlight is absorbed) that separates into positive and negative changes. This polarization of charges forms a voltage and when connected to an external load it produces a direct current (DC). The magnitude of this current is proportional to the intensity of the light. Cells wired together form a module, and modules wired together form a panel. A group of panels is called an *array* and several arrays form an array field. (Langdon and Ding 2001, p. 184)

### 13.7.1 SOLAR CELLS

*Solar cells* work in both sunny and cloudy conditions since it is the radiation absorbed rather than direct sunlight that powers the system. There are three types of solar cells: (1) *monocrystalline* (single crystal construction), (2) *polycrystalline* (semicrystalline), and (3) amorphous silicon. Monocrystalline cells have been used for several decades, and they require pure silicon created through a process called czochralsky or the *floating zone technique* (vertical configuration molten silicon has sufficient surface tension to keep the charge from separating). To create solar cells, the monocrystalline cell is grown on a seed extruded from a silicon melt. The silicon rods are created during the process by using *carbide thread* to slice them into 0.2 mm and 0.4 mm thick wafer disks. The wafer disks also require grinding, polishing, cleaning, doping (introducing impurities into pure crystals), and application of antireflective coating, all of which are labor-intensive and expensive processes (Gavorkin 2006).

Three additional manufacturing processes being investigated for future use in producing solar cells are (1) thin film cells of crystalline layers of cadmium telluride (CdTe) or copper indium diselenide ($CuInSe_2$) that adhere to a carrier base; (2) gallium arsenide cells are highly efficient and are currently used in the space program but they are costly to produce, and *gallium* is a rare metal and arsenide is poisonous; and (3) tandem or *multi-junction cells* are two layers of solar cells, which are more efficient (Gavorkin 2006).

### 13.7.2 PHOTOVOLTAIC CELLS

Polycrystalline photovoltaic cells are manufactured at a lower cost than monocrystalline wafer disks, but they are less efficient. To produce them, the silicon melt is cooled in controlled conditions where the temperature is reduced slowly. A silicon *ingot* is produced containing crystalline regions, but they are separated by grain boundaries and these cause a reduction in efficiency (Gavorkin 2006).

Amorphous PV solar cells are doped (introducing impurities into pure crystal to modulate the electrical properties and to create a PN junction [boundary of interface between two types of semiconductor materials] and an electrical field) during the manufacturing process and then inserted between two glass plates—the solar panel modules. This process is less expensive than the two previously mentioned processes; however, it requires a larger installation surface, the efficiency is lower, and there is a degradation process lasting over the life of the panels (Gavorkin 2006).

Photovoltaic systems use galvanized, plastic-coated steel sheets containing integrated solar cells, which convert sunlight into electricity. There are three layers of silicon solar cells in the stainless steel substrate that process the different sections of the light spectrum (ThyssenKrupp 2014). Figure 13.3 shows a photograph of a PV system embedded into the skin of a building.

When calculating the true cost of using PV cells, it is important to include the energy and contamination costs that “arise in the process of extracting, refining, and purifying metals to manufacture the silicon wafers employed in the production of photovoltaic cells” (Munier 2005, p. 221).

### 13.7.3 SOLAR CONCENTRATORS

*Solar concentrators*, such as Fresnel lenses, have “concentration ratios of ten to 500 times and they are mostly made of inexpensive plastic materials engineered with refracting features directing sunlight into small narrow junction areas of the cells. Module efficiencies of single crystalline PV cells, which normally range from 10% to 14%, could be augmented to in excess of 30%” (Gavorkin 2006, p. 8).

Solar panel arrays connect solar panels using either serial or parallel interconnections, and then they are mounted on *stanchions*, which are structures tilted toward the sun. Since solar cells only convert energy to a DC voltage, there needs to be a

**FIGURE 13.3** Photovoltaic skin on the Brisbane Supreme and District Court Building. (From Queensland Government, *Courts and Tribunals*, Brisbane, Australia, Accessed on February 17, 2015, http://www.justice.qld.gov.au/justice-services/courts-and-tribunals/our-courthouses/new-brisbane-supreme-and-district-court, 2015.)

method for storing the energy that they generate and the normal process is through charging batteries.

In the fall of 2007, a major utility installed a new technology for concentrating solar power and generating five times the amount of solar power. "Instead of using semiconducting material to convert light to energy, those familiar black PV panels, will use nothing more complicated than mirrors, lots of them, to concentrate some of the highest intensity sunlight in the world. The arrays heat water to drive turbines just as in an old-fashioned power plant" (U.S. News and World Report 2007, p. 47). To reduce the cost associated with developing the PV panels, the silicon wafers were slimmed down to form an ultrathin film deposited on glass.

In addition to heating with solar power, there are hybrid solar power and *gas absorption chillers* capable of producing air-conditioning by using geothermally heated water and solar energy. "A 1,000 ton absorption chiller could reduce electrical energy consumption by an average of 1 MW or 1 million watts" (Gavorkin 2006, p. 101).

Solar energy is not currently being used on many construction projects due to the high capital costs associated with the installation of solar energy power systems. If a firm is able to develop a portable solar energy system capable of generating enough power to meet the power requirements of large construction jobsites, then solar power might become a viable alternative to traditional sources of power in construction.

## 13.8 OSMOTIC ENERGY

The generation of *osmotic energy* and the desalinization of water are being explored in Norway, Japan, and Canada as methods for generating carbon-free renewable energy. Osmotic power is also called *salinity-gradient power* because it takes advantage of the lower concentration of water in saltwater that attracts freshwater. The freshwater is separated from the saltwater by a thin, permeable membrane, and the freshwater attempts to force its way through the membrane into the saltwater and as it does this pressure builds up and pushes the water through a pipe used to drive a turbine. This process will become more viable as soon as additional membrane manufacturers enter the market. Currently, only small amounts of electricity are being generated by osmotic processes (Halper 2010).

## 13.9 WIND ENERGY

Recent innovations in wind energy include the production of massive *windmills*, which are being manufactured and installed throughout the Midwest and the West Coast of the United States. These windmills are arranged in wind farms and take advantage of the power of the wind to drive turbines in the windmills, creating the electrical energy that is used to power homes and industries. Figure 13.4 shows a photograph of wind turbines along a major highway in Indiana.

Most wind turbines have power ratings between 250 W and 1.8 MWe. A 10 kW wind turbine—with average wind speeds of 12 mph—is able to provide enough electricity to power one household, and a 1.8 MWe turbine produces enough electricity to power 500 households (Gavorkin 2006). The true cost of wind energy needs to include “the amount of pollution caused by extracting raw materials used for the construction of blades and gear boxes for wind turbines, as well as for constructing and transporting the cement and steel towers supporting them” (Munier 2005, p. 221). To benefit from wind power, the wind turbines used are being modified and improved to increase their efficiency.

**FIGURE 13.4** Wind turbines along the highway in Indiana. (Courtesy of J. K. Yates.)

High efficiencies (40%) are achieved by using stronger and lighter materials for the blades to build higher output machines. A significant technological development is the variable speed turbine, which rotates at or near the optimum tip speed ratio for any given wind speed providing maximum power extraction. To convert the resulting variable output into a fixed frequency (and voltage), a power converter is fitted between the generator and the grid. A variable speed rotor extracts up to 15% more energy from the wind and makes more use of turbulent winds than a constant speed rotor. It also reduces material fatigue and maintenance costs, as the rotation does not have to be restrained to a fixed frequency.

Some of the problems caused by using wind energy are interference with television reception, noise (which could be reduced by improving blade designs and using nonmetal blades), and bird fatalities. Bird fatalities are being addressed by spacing wind turbines further apart and in the direction of migration, using paint on the blades contrasting with the surrounding area, and using a radio-frequency broadcast to discourage birds from flying close to the wind turbines.

Figure 13.5 shows the installed wind power capacity in the United States in each state, as measured by annual installed wind energy in billions of megawatts.

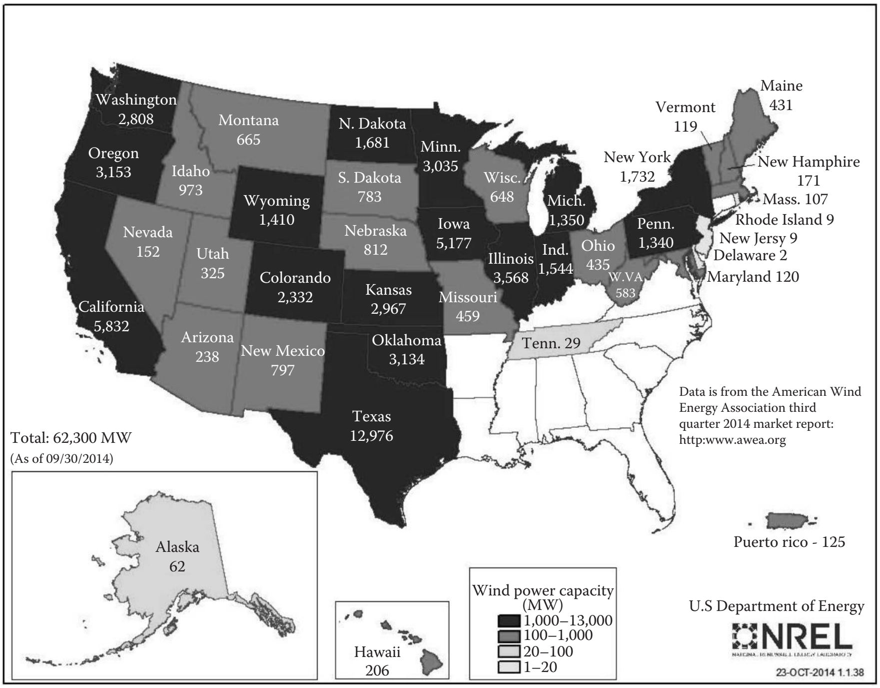

**FIGURE 13.5** Current installed wind power capacity in the United States. (From U.S. Department of Energy, *Energy Efficiency and Renewable Energy—Installed Wind Capacity*, Washington, DC, Accessed February 10, 2015, http://apps2.eere.energy.gov/wind/windexchange/wind_installed_capacity.asp, 2014.)

There is a large difference between the amount of wind energy produced in the top producing states versus the remainder of the states, and this indicates that wind energy is more viable in some states than in others due to climatic conditions.

Oregon and Maine are installing wind turbines off their coastlines, and these types of wind turbines do not have to be bolted to the seabed, as is required for fixed-foundation wind turbines. The floating 2 Mv wind turbines use a buoy and ballast system, allowing them to be installed further from the coastline, such as the ones that were installed 3 mi. off the coast of Portugal in 2011. The wind turbines being installed 15 mi. off the coast of Oregon are 6 Mv turbines hooked up to the power grid by an underwater cable. The wind turbines in Maine are 12 Mv floating turbines located 12 mi. off the coast (*Bloomberg BusinessWeek* 2014).

Another wind energy alternative is embedding wind turbines into the structural components of buildings. One example of where a wind turbine was embedded into a structure is the headquarters of the $22-billion sustainable city called Masdar, which was built in Abu Dhabi, United Arab Emirates. Figure 13.6 shows an overhead view of Masdar City. Masdar City is a carbon-neutral city with residential communities, offices, and the Masdar Institute of Technology, and it also provides research facilities for conducting sustainable research. Other wind turbine projects are being built throughout the world, and Figure 13.7 shows a Chinese high-rise building with embedded wind turbines located one-third and two-thirds of the way up the building. Figure 13.8 shows one of the wind turbines embedded in the Chinese building (Council on Tall Buildings and Urban Habitat 2014).

**FIGURE 13.6** Masdar City project. (From Masdar Initiative, *About Masdar City*, Masdar, Abu Dhabi, Accessed on December 19, 2014, http://www.masdar.ae/en/masdar-city/detail/one-of-the-worlds-most-sustainable-communities-masdar-city-is-an-emerging-g, 2014.)

**FIGURE 13.7** Chinese high-rise structure with embedded wind turbines. (Open source photograph.)

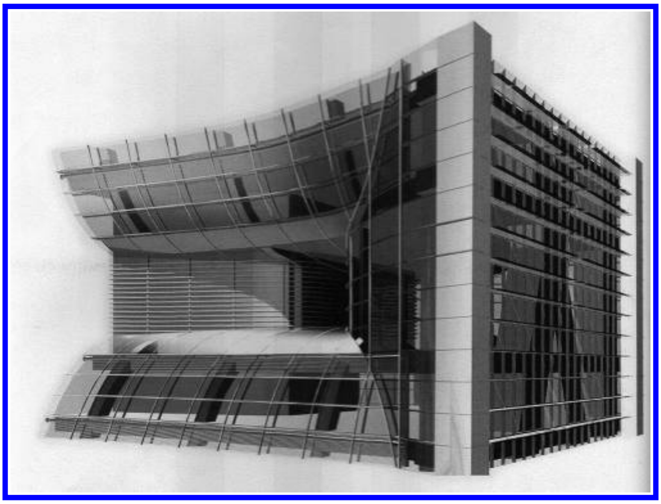

**FIGURE 13.8** Embedded wind turbine used in the Chinese high-rise structure. (Open source photograph.)

## 13.10 BIOMASS ENERGY

*Biomass energy* has been gaining in popularity during the past few decades. Its use is more prevalent in developing countries, where it accounts for 35% of the energy consumed in these countries. Worldwide, 15% of the energy produced is biomass energy. Some biomass energy is produced using gas turbines, where the biomass material is *gasified* using air and steam at high pressures and then the resulting gas is burned for fuel. “The hot combustion products are used in a generator to create electricity, while the hot turbine exhaust gasses are used for industrial applications or for additional power generation” (Langston and Ding 2001, p. 233).

Biomass energy is created by the “burning of wood, forest waste, crop residue, municipal waste, some industrial waste and some grains. Other biomass options are sawdust, peanut shells, *bagasse* [sugar cane waste], rice hulls, and walnut shells” (Munier 2005, p. 244). Biomass energy is produced by burning any of these items for electricity or by mixing crop waste, wood, animal, or other waste with fuel to obtain methanol. Crop by-products such as starch or sugar are fermented through biological processes producing gases such as methane, carbon dioxide, and vapor, and then these are mixed with fuel and this is referred to as ethanol (Munier 2005).

According to Gavorkin (2006, p. 142), “Under oxygen-starved conditions, when biomass is heated at high temperatures, various hydrocarbon components break down and recombine to form an oil referred to as *pyrolysis oil*. Chemical oil, extracted from the oil called *phenol*, is the principal compound base for foams, adhesives, molded plastics, chipboards and plywood.” To calculate the cost of biomass energy, in addition to the costs of planting, fertilizing, watering, harvesting, processing, and transporting biomass products, the life-cycle cost assessment should also include “the manufacturing of components for methanol and ethanol production, and to make boilers, turbines, and generators, etc.” (Munier 2005, p. 245).

In addition to biomass products, the U.S. Biomass Research and Development Act of 2000 supports research programs for producing materials and chemicals from biomass feedstocks (Public Law 107–293 2002). Also, the U.S. Farm Security and Rural Investment Act of 2002 provides additional support for biomass research (Public Law 107–171 2002). This legislation provides a federal purchase program to help promote biomass products called the “Federal Biobased Product Preferred Purchasing Program” (U.S. General Services Administration 2015). This program was established by the U.S. Department of Agriculture in 2005 and provides information on the content of the biobased products purchased by the federal government.

## 13.11 GEOTHERMAL ENERGY

*Geothermal energy* exists in its natural state under the surface of the earth, and it has always been available as a source of heated water in geysers and hot springs. In recent years, geothermal energy is being used to cool homes in summer and heat them in winter using the relatively constant temperature of the ground.

Commercial geothermal steam plants use the water from hot water reservoirs or geysers, with temperatures above 300°F (148.9°C), or from wells drilled to depths of 2 mi. The steam released from beneath the surface of the earth may have to be *flashed* (hot water is pumped under great pressure to the surface, and at the surface the pressure is reduced and the water changes to a blast of steam) to remove carbon dioxide, nitric oxide, and sulfur, and then it is used to power generators. There are also binary steam plants using hot water resources with lower temperatures such as 100°F (37.8°C) to 300°F (148.9°C), where the hot water passes through heat exchangers heating a different fluid such as *isobutene* or *isopentane* to a boiling point lower than water. Once the fluid vaporizes, the steam created turns a turbine, creating electricity, and then the fluid is recycled back through the system and used repeatedly. The benefit of using binary plants is that they do not create pollution. In 2014, the estimated average cost of geothermal energy was approximately 4.5–7 cents/kWh, which is competitive with fossil fuel costs, but the main advantage is that geothermal power sources do not create pollution (Gavorkin 2006).

Several different geothermal heat pump technologies are currently in use, including the following (Lafferty 2012, p. 6):

- Exchanging heating and cooling capacities in large zoned buildings
- Heated and cooled radiant panels, including floors, walls, and ceilings
- Pool area dehumidification
- Pool heating or cooling
- Ventilation air heating and cooling
- Water-to-air heating and cooling, domestic and commercial
- Water-to-water heating
- Water–water cooling (chiller)

## 13.12 FUEL CELLS

*Fuel cells* are another alternative form of nonpolluting energy being harnessed for use in automobiles and other commercial applications. Fuel cells are *electrochemical cells* that consume fuels such as hydrogen, methanol, or natural gas. Fuel cells operate by

> taking up oxygen at the air *electrode* (*positive cathode*) and converting it to negative ions that diffuse through a membrane and *electrolyte* to react with positive *hydrogen ions* at the *anode* (*negative electrode*) to produce water. Electric current is the result of electrons given up by the hydrogen flowing over to the air electric via an external load. As an individual cell produces about one volt, any number of cells could be connected to form a fuel stack to produce a desired voltage up to hundreds of megawatts. (Langston and Ding 2001, p. 189)

## 13.13 TIDAL, WAVE, AND OTHER ENERGY SOURCES FROM THE SEA

*Tidal energy* is created in the sea by building dams with tunnels where the water from high tides enters a reservoir located behind the dam and turns a hydraulic turbine. When the tide reverses, the water flows through the turbines back out to sea. Wave energy is created when

> the *kinetic energy* of waves produces the rise and fall of a column of water within a conduit, which is connected with the open sea at its bottom. This column of water acts like a *hydraulic piston*, since during the rise, the water column compresses air above it, and this air is then used to drive a turbine generator. During the fall of the water, the water column sucks in air, which is again used to drive the turbine, since it could work in both directions. (Munier 2005, p. 256)

## 13.14 HEATED AND CHILLED BEAMS

Researchers at the Massachusetts Institute of Technology (MIT) have developed a new system for regulating room temperatures using heated and chilled beams. This is a process whereby chilling coils and hot water pipes are embedded into the lighting panels attached to air ducts. Motion detectors are in the system, and they activate the system when a room is in use and deactivate it when a room is not in use. This type of system allows rooms to be controlled individually rather than an entire floor or structure being dependent on one centrally controlled heating and cooling system. The water used to heat or cool the pipes is recirculated and reused throughout the system. Figure 13.9 shows a photograph of a heated and chilled beam system in an office, and Figure 13.10 is a diagram of chilled beams.

**FIGURE 13.9** Heated and chilled beams in an office. (From Massachusetts Institute of Technology, *Chilled Beams Hit the Roof*, Cambridge, Massachusetts, Accessed on December 19, 2014, http://mitei.mit.edu/news/chilled-beams-hit-roof, 2009.)

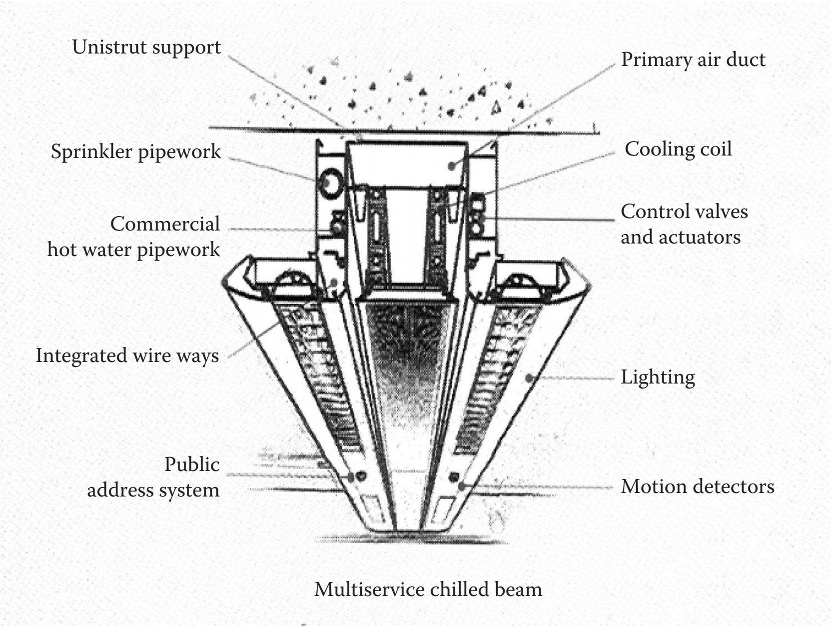

**FIGURE 13.10** Diagram of chilled beams. (From Massachusetts Institute of Technology, *Chilled Beams Hit the Roof*, Cambridge, Massachusetts, Accessed on December 19, 2014, http://mitei.mit.edu/news/chilled-beams-hit-roof, 2009.)

## 13.15 PHOTOVOLTAIC LOUVERS

In Germany, at the Technical University in Darmstadt photovoltaic systems were tested in three different ways by installing them on roofs and skylights and incorporating them into louvered door or window coverings where the angle facing the sun is automatically changed by a computer as the sun progresses through the sky during the day. These systems are operated using electrical and mechanical systems (Das Haus 2011). Figure 13.11 provides an example of a building retrofitted with PV louvers used to track the sun and provide solar power. The PV louvers are controlled by a computer system that adjusts the louvers during the day to follow the progress of the sun through the sky. This optimizes the solar potential of the PV panels embedded in each of the louvers.

## 13.16 ENERGY EFFICIENCY STANDARDS

In over 60 countries, there are policies, labeling requirements, and test procedures related to energy efficiency that apply to appliances, equipment, and lighting products. A Collaborative Labeling and Appliance Standards Program (CLASP) was created “to facilitate the design, implementation, and enforcement of energy efficiency standards and labels for appliances, equipment, and lighting products in developing and transitional countries throughout the world” (Energy Efficiency Standards 2007, p. 1). The CLASP and the Asia-Pacific Economic Cooperation (APEC) are the

**FIGURE 13.11** Building retrofitted with louvered photovoltaic panels. (From Das Haus, *Innovation in Renewables and Energy Efficiency*, Federal Ministry of Economics and Technology, Federal Ministry of Transport, Building and Development, Berlin, Germany, Accessed on December 19, 2014, http://www.efficiency-fromgermany.info/ENEFF/Redaktion/EN/Downloads/Publikationen/das_haus_%20innovation_in_renewables_and_energy_efficiency.pdf?__blob=publicationFile&v=5, 2011.)

organizations maintaining the *Global Energy Standards and Labeling Database*. This database includes a matrix containing information on different products "by regulation types, test procedures, and links to copies of regulations and implementing institutions" (Energy Efficiency Standards 2007, p. 1).

The Construction Specification Institute (2015)—in conjunction with BuildingGreen, Inc.—has developed a GreenFormat system. Product manufacturers submit their product data to the GreenFormat system, and through this system product data are made available to construction industry personnel.

## 13.17 ENERGY AUDITING

As defined in Chapter 1, energy auditing is a process for determining and evaluating the energy used by projects, structures, processes, operations, or an entire organization. Energy auditing allows firms to evaluate energy consumption and determine whether there are alternative methods or processes to help reduce energy consumption. The major steps in an energy audit are surveying and measuring energy consumption, data analysis, evaluation, and implementation. The data collection stage involves the following (Langston and Ding 2001, p. 265):

- A description of the site
- Invoices based on actual meter readings or estimates
- Periodic records of energy consumption and cost in the form of fuel invoices and accounts from suppliers of useful data

- Site records of main metered or submetered energy consumption readings and stock levels
- The nature of operations on site and the type of energy used

Once the data are collected, the total monthly energy consumption for each fuel type is converted to gigajoules (GJ), plotted on a graph to demonstrate the patterns of energy consumption, and analyzed to determine methods for reducing energy use. The total energy consumption per month could be converted to a monthly cost using the cost for each type of fuel used in the process being studied during the energy audit. After the analysis is complete, recommendations are prepared that provide suggestions on the areas where energy consumption could be reduced by changing energy consumption patterns, modifying existing equipment, installing new equipment, or using other methods for reducing energy consumption.

When determining the electric energy cost for a structure, it is important to note that the cost per kilowatt-hour is an average of several charges including *commissioning costs*, *decommissioning costs*, and bulk purchase rates. Firms may also charge a *peak bulk energy rate* when the power consumption exceeds the established allowable amount of energy. If the power used exceeds the established maximum, the power company may charge the peak bulk energy rate for the entire month rather than merely for the period it exceeds the allowable maximum for the month. The time at which most of the peak energy penalties occur is in the summer in the late morning to early afternoon when there are unusually high demands for power due to the use of air-conditioners.

Some power companies offer the option to electricity users to sign up for *off-peak* or *rippled power rates*. This allows the power company flexibility when the power demands exceed current supplies. Customers receiving the off-peak rate, which could be up to half the normal rate, need to have a backup heating system that the primary system defaults to when the power company shuts off electrical power to the main heating system during peak power use periods. The benefit to the customer is lower rates all year round, and the benefit to the power company is being able to service other customers during peak times without having unscheduled brownouts or blackouts to segments of the customer base.

## 13.18 SUMMARY

This chapter reviewed traditional types of energy sources, including hydrocarbon separation processes, hydraulic fracturing (fracking), liquefied natural gas production, nuclear power (fission and fusion), coal-fired power plants, and hydropower energy generation. Alternative energy and some of the relatively new and different processes and procedures for creating alternative energy were explored in this chapter to provide information on the available sources of energy for construction projects. Throughout the world, there are a variety of different projects creating alternative energy through the introduction of new processes capturing the energy of the sun, the wind, chemical reactions, natural gas, the ocean, or decomposing materials.

This chapter discussed alternative energy sources such as combined heat and power technology, solar power and photovoltaic cells, osmotic energy, wind energy, biomass energy, geothermal energy, fuel cells, and tidal and wave energy sources. This chapter also provided information on energy efficiency standards and energy auditing.

## 13.19 KEY TERMS

Amorphous silicon
Anode (negative electrode)
Array
Bagasse
Bentonite
Biomass energy
Bitumen
Boiling water reactors
Cadmium telluride
Carbide thread
Chillers
Coal-fired power plant
Cogeneration
Combined heat and power technology
Commissioning costs
Copper indium diselenide
Czochralsky
Decommissioning costs
Electrochemical cells
Electrode (positive cathode)
Electrolyte
Fission
Flashed
Floating zone technique
Flow back water
Fossil fuels
Fracking
Fresnel lenses
Fuel cells
Fusion
Gallium
Gas absorption chillers
Gasified
Geothermal energy
Gigawatts
Heat content
Heat rate
Helium
High-energy particle beams

Hydraulic fracturing
Hydraulic piston
Hydrofracking
Hydrogen ions
Hydropower
Ingot
Inertial confinement
Isobutene
Isopentane
Isotopes of hydrogen
Kilowatt
Kilowatt-hours
Kinetic energy
Landfill gases
Liquefied natural gas
Magnet generator
Megawatts
Micro turbines
Monocrystalline
Multi-junction cells
Nickel-alloy chambers
Nuclear battery
Nuclear fuel rods
Nuclear fusion
Off-peak power rates
Osmotic energy
Paraboloidal mirrored dish
Peak bulk energy
Phenol
Photons
Photovoltaic
Plasma
Polycrystalline
Pressurized water reactors
Pyrolysis oil
Rankine cycle
Regasification facilities
Rippled power rates
Salinity-gradient power
Solar cells
Solar concentrators
Stanchions
Sulfurous gases
Thermal energy
Thermodynamic conversion processes
Tidal energy

Tritium
Turbo generator
Uranium-238
Watts
Windmills

## 13.20 DISCUSSION QUESTIONS

13.1 Discuss how oil is extracted from tar sands.
13.2 Discuss why liquefied natural gas is a viable alternative to coal-fired power plants and explain how the liquefaction process works.
13.3 Explain how energy auditing is used to help reduce the amount of energy used by a firm.
13.4 Explain why nuclear fusion is not yet a viable method for obtaining energy.
13.5 What are the different types of solar cells?
13.6 What are the advantages and disadvantages of using hydropower to generate electricity?
13.7 What are thermodynamic conversion processes, and how are they used to generate electricity?
13.8 Discuss how photovoltaic conversion occurs and how it creates energy.
13.9 Discuss photovoltaic systems and how they are used in structures.
13.10 Discuss some of the methods for increasing the efficiency of windmills.
13.11 What are the five data collection stages of an energy audit?
13.12 Describe how nuclear fission reactions are able to produce electrical power.
13.13 Which industry sector consumed the highest level of energy in the years 2006 and 2009, and which one consumed the lowest level of energy?
13.14 Explain how biomass energy is generated.
13.15 Explain osmotic energy, and discuss whether it is a viable method for generating energy.
13.16 Discuss some of the problems occurring when using windmills to generate electricity.
13.17 Explain the major obstacle to using nuclear power.
13.18 Explain how combined heat and power technology is used to help reduce energy requirements in structures.
13.19 Discuss hydraulic fracturing and how it is used to extract natural gas from the earth.
13.20 What are the three feedstocks used in fuel cells?
13.21 Explain why isobutene or isopentane is used in binary geothermal steam plants.
13.22 Discuss what is done with the residual resulting from burning coal in coal-fired power plants.
13.23 How are energy efficiency standards used to help contribute to sustainable development?

13.24 What were the different percentages of energy generated by each type of energy source in 2013?

13.25 Which state has the highest annual installed wind power capacity, and which state has the lowest annual installed wind capacity potential?

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# 14 Leadership in Energy and Environmental Design Green Building Rating System

This chapter introduces the Leadership in Energy and Environmental Design (LEED) Green Building Rating System certification process currently being used for evaluating the sustainability of buildings. The LEED green building initiative was started in the United States in 1998 by the U.S. Green Building Council (USGBC), and it uses components of the Building Resource Energy Environmental Assessment Model (BREEAM) system developed in the United Kingdom in 1990.

This chapter provides an overview of the LEED Green Building Rating System, including a description of the system and its development by members of the USGBC. It also includes information on LEED certification, LEED standards for different types of structures, LEED certification levels, and how the rating system and categories are applied to buildings. The *credits*, *prerequisites*, *subcategories*, and possible points are described in the context of the LEED v4 for Building Design and Construction (LEED BD+C) Rating System. A sample LEED certification checklist is included in this chapter along with a description of some of the benefits of obtaining LEED certification.

## 14.1 LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN CERTIFICATION

The LEED Green Building Rating System is a voluntary, consensus-based national rating system and certification program for sustainable buildings developed by members of the USGBC. Many segments of the building industry are represented by members of the USGBC, including architects; building owners; contractors; engineers; federal, state, and local code and regulatory officials; financiers; product manufacturers; real estate developers; and utility providers.

There are five rating systems that apply to multiple project types (U.S. Green Building Council 2015a):

1. Building design and construction
    - New construction and major renovation
    - Core and shell
    - Schools
    - Retail
    - Hospitality

  - Data centers
  - Warehouses and distribution centers
  - Healthcare
2. Interior design and construction
  - Commercial interiors
  - Retail
  - Hospitality
3. Green building operations and maintenance
  - Existing buildings
  - Schools
  - Retail
  - Hospitality
  - Data centers
  - Warehouses and distribution centers
4. Neighborhood development
  - Plan
  - Built project
5. Homes
  - Homes and multifamily low-rise homes
  - Multifamily midrise homes

Initial versions of the LEED Green Building Rating System promoted a whole-building approach to sustainability by recognizing performance in five environmental categories:

1. Sustainable site development
2. Water efficiency
3. Energy and atmosphere
4. Materials and resources
5. Indoor environmental quality

An additional category, innovation in design, awards points for sustainable building expertise and design features not covered under the five categories. One other category, regional priority, acknowledges the importance of local conditions.

The LEED certification process recognizes structures meeting the green building requirements of the USGBC. The LEED certification process promotes expertise in green building by offering project certification, professional accreditation, training programs, and related resources. The USGBC launched LEED v4 in November 2013 as a more rigorous and detailed version of the LEED Green Building Rating System, and this version includes new concepts such as product transparency, whole-building life-cycle analysis, and newer energy standards.

Members of the USGBC evaluate and update the LEED certification process. The LEED v4 for Building Design and Construction (LEED BD+C) Rating System includes *regionally weighted credits*, online registration and certification processes, and planned integration with Building Information Modeling (BIM) software to help monitor the viability of various sustainability strategies and technologies.

**TABLE 14.1**
**Top 10 Countries with Gross Square Meters and Gross Square Feet of LEED-Certified Space**

| Rank | Country | LEED-Certified Space Gross Square Meters (millions) | LEED-Certified Space Gross Square Feet (millions) |
|---|---|---|---|
| 1 | United States | 595.73 | 17,176.29 |
| 2 | Canada | 17.74 | 190.95 |
| 3 | China | 14.30 | 153.92 |
| 4 | India | 11.64 | 125.29 |
| 5 | South Korea | 3.84 | 41.33 |
| 6 | Taiwan | 2.98 | 32.08 |
| 7 | Germany | 2.90 | 31.21 |
| 8 | Brazil | 2.85 | 30.68 |
| 9 | Singapore | 2.16 | 23.25 |
| 10 | United Arab Emirates | 1.82 | 19.59 |

*Source:* Data from U.S. Green Building Council, *Infograhic*: *LEED in the World*, Washington, DC, Accessed on February 10, 2015, http://www.usgbc.org/articles/infographic-leed-world, 2014.

Many government agencies are incorporating LEED initiatives or equivalent processes into their projects. In the United States, by 2014 there were more than 6,412.6 million gross square feet (595.73 million gross square meters [GSMs]) of LEED-registered projects, and over 44,270 projects were registered to LEED (U.S. Green Building Council 2015a). The top 10 countries with gross square meters (gross square feet) of LEED-certified space in 2014 are shown in Table 14.1.

## 14.2 LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN CATEGORIES FOR BUILDING DESIGN AND CONSTRUCTION

The LEED initiative provides information for design team members to use when they are creating sustainable projects and as an evaluation system to assess sustainability achievements according to industry standards. The LEED checklist for projects includes different sustainability categories and a scoring system. The total number of points achieved is used to determine an overall LEED green building rating of certified, silver, gold, or platinum. The following are examples of the LEED categories for Building Design and Construction (BD+C): New Construction and Major Renovation with related sustainable strategies (U.S. Green Building Council 2015b, p. 1):

1. Location and transportation (LT): These credits encourage non-sprawl projects with access to a variety of transportation options, or projects built on sites with development limitations:
    - Access to quality transit
    - Bicycle facilities
    - Green vehicles
    - High-priority site

- LEED for neighborhood development location
- Reduced parking footprint
- Sensitive land protection
- Surrounding density and diverse uses

2. Sustainable sites (SS): These credits stimulate strategies that minimize impacts to ecosystems and water resources:
    - Construction activity pollution prevention
    - Heat island reduction
    - Light pollution reduction
    - Open space
    - Rainwater management
    - Site assessment
    - Site development-protect or restore habitat
3. Water efficiency (WE): These credits foster more efficient use of water resources, thereby reducing potable water consumption:
    - Cooling tower water use
    - Indoor water use reduction
    - Outdoor water use reduction
    - Water metering
4. Energy and atmosphere (EA): These credits encourage improved building energy performance by using effective active and passive strategies:
    - Advanced energy metering
    - Building level energy metering
    - Demand response
    - Enhanced commissioning
    - Enhanced refrigerant management
    - Fundamental commissioning and verification
    - Fundamental refrigerant management
    - Green power and carbon offsets
    - Minimum energy performance
    - Optimize energy performance
    - Renewable energy production
5. Materials and resources (MR): These credits promote the integration of sustainable building materials and waste reduction:
    - Building life-cycle impact reduction
    - Building product disclosure and optimization
    - Construction and demolition waste management
    - Construction and demolition waste management planning
    - Storage and collection of recyclables
6. Indoor environmental quality (IEQ): These credits reward strategies for improving indoor air quality and access to daylight and views:
    - Acoustic performance
    - Daylight
    - Enhanced indoor air quality strategies
    - Environmental tobacco smoke control
    - Interior lighting

  - Low chemical-emitting materials
  - Minimum indoor air quality assessment, performance, and management plan
  - Quality views
  - Thermal comfort
7. Innovation (IN): These credits promote innovative design measures not covered under the six LEED credit categories:
   - Achievement of sustainability goals in excess of stated LEED requirements
   - Development of a sustainable education program
   - LEED-accredited professional (LEED AP) on the design team
8. Regional priority (RP): These credits respond to regional environmental priorities for projects in distinct geographic regions.

There are also integrative process requirements that encourage the inclusion of interdisciplinary team members during the predesign phase.

Total credit weightings are based on points, which maintain consistency across rating systems. The base is 100 points in the six categories, plus an integrative process requirement of one point, and two additional categories for up to ten bonus points. The LEED Green Building Rating System provides methods for obtaining points based on the six categories. In addition, there are prerequisites, subcategories, and credits for each category totaling to the possible points. The number of prerequisites and points per category are shown in Table 14.2.

The four LEED green building certification levels, and the point ranges required for each level, are the following (U.S. Green Building Council 2015a):

- Certified: 40–49 points
- Silver: 50–59 points
- Gold: 60–79 points
- Platinum: 80–110 points

It is possible to address several credits with one strategy, as demonstrated by Figures 14.1 and 14.2. The building shown in Figure 14.1 displays a louvered canopy extending out from the curtain wall. The louvered canopy allows for multiple benefits in the areas of energy performance, open space, thermal comfort, and quality views.

Figure 14.2 shows improvements in energy performance, interior light, daylight, and quality views achieved by using high-performance windows.

## 14.3 ADDITIONAL COST OF LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN CERTIFICATION

Some studies have determined that there are additional costs associated with incorporating sustainable elements into a structure to achieve one of the LEED certifications. In one study, the additional cost was estimated as being between \$2 and \$5 per square foot (\$2 and \$5 per 0.0929 $m^2$) for basic certification (Kibert 2008,

## TABLE 14.2
## Number of LEED Prerequisites and Points per Category

| Category | Prerequisites | Points |
|---|---|---|
| Integrative process | 0 | 1 |
| Location and transportation | 0 | 16 |
| Sustainable sites | 1 | 10 |
| Water efficiency | 3 | 11 |
| Energy and atmosphere | 4 | 33 |
| Materials and resources | 2 | 13 |
| Indoor environmental quality | 2 | 16 |
| Innovation | 0 | 6 |
| Regional priority | 0 | 4 |
| Total possible points | | 110 |

*Source*: Data from U.S. Green Building Council, *Leadership in Energy and Environmental Design*, Washington, DC, Accessed on February 18, 2015, http://www.usgbc.org/leed, 2015b.

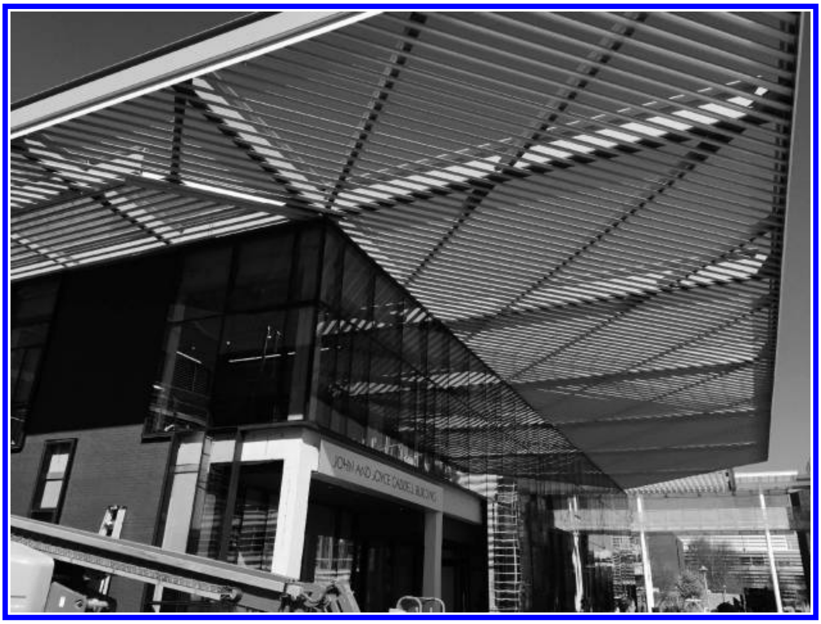

**FIGURE 14.1** Caddell building construction, Georgia Institute of Technology, Atlanta, Georgia. (Courtesy of Daniel Castro-Lacouture.)

p. 327). For the higher levels of LEED certification, cost premiums were estimated by reviewing 33 buildings and the premiums were as follows (Kibert 2008, p. 327):

- Platinum: 6.5%
- Gold: 1.82%

**FIGURE 14.2** Study lounge high-performance windows; Mason Building, Georgia Institute of Technology, Atlanta, Georgia. (Courtesy of Daniel Castro-Lacouture.)

- Silver: 2.11%
- Certified: 0.66%
- Average: 1.84%

Since this study was conducted, the cost of integrating sustainable elements into structures has declined because of process improvements. The additional costs associated with each of the LEED certification levels vary with the type of structure and other variables, and costs should continue to decline in the future.

## 14.4 LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN–ACCREDITED PROFESSIONAL AND REGISTERING WITH THE U.S. GREEN BUILDING COUNCIL

Firms may either compile their own documentation for the LEED assessment or hire a trained LEED assessor. If a LEED accredited professional is part of the design team, then credits are awarded for his or her participation. The USGBC is the organization that performs LEED assessments, and it also determines LEED scores. Each credit is worth one point and is awarded on the basis of actions that help to reduce environmental impacts.

When the members of a firm decide to seek LEED certification for a potential project, the project team first registers with the USGBC at the level of certification that they hope to achieve during the project. Registering with the USGBC at the inception of a project allows design team members access to the USGBC website and the appropriate templates for tracking the project. The certification process does not proceed until the end of construction, although in newer versions of the LEED certification process credits are awarded for sustainable activities occurring during the design phase.

## 14.5 LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN CERTIFICATION CHECKLIST FOR NEW CONSTRUCTION AND MAJOR RENOVATIONS

The USGBC uses a checklist when it evaluates a project under review for LEED certification. The checklist allows the USGBC to determine the level of certification on the basis of the total number of points awarded to the project. Table 14.3 provides a list of the prerequisites, credits, and points possible for LEED v4 for BD+C: New Construction and Major Renovation projects.

## 14.6 BENEFITS OF LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN CERTIFICATION

According to the USGBC, the following are some of the benefits of green structures (Kibert 2008, p. 330):

- Achieve more predictable results.
- Benefit the community.
- Boost employee productivity.
- Create value for tenants.

**TABLE 14.3**
**Example of LEED v4 for BD+C: New Construction and Major Renovation Checklist**

| Yes | No | Category | Credit Descriptions | Points |
|---|---|---|---|---|
| | | *Integrative process* | | 1 |
| | | *Location and transportation* | | 16 |
| | | Credit | LEED for neighborhood development location | 16 |
| | | Credit | Sensitive land protection | 1 |
| | | Credit | High-priority site | 2 |
| | | Credit | Surrounding density and diverse uses | 5 |
| | | Credit | Access to quality transit | 5 |
| | | Credit | Bicycle facilities | 1 |
| | | Credit | Reduced parking footprint | 1 |
| | | Credit | Green vehicles | 1 |

(*Continued*)

## TABLE 14.3 (Continued)
## Example of LEED v4 for BD+C: New Construction and Major Renovation Checklist

| Yes | No | Category | Credit Descriptions | Points |
|---|---|---|---|---|
| | | *Sustainable sites* | | 10 |
| Y | | Prerequisite | Construction activity pollution prevention | Required |
| | | Credit | Site assessment | 1 |
| | | Credit | Site development—protect or restore habitat | 2 |
| | | Credit | Open space | 1 |
| | | Credit | Rainwater management | 3 |
| | | Credit | Heat island reduction | 2 |
| | | Credit | Light pollution reduction | 1 |
| | | *Water efficiency* | | 11 |
| Y | | Prerequisite | Outdoor water use reduction | Required |
| Y | | Prerequisite | Indoor water use reduction | Required |
| Y | | Prerequisite | Building level water metering | Required |
| | | Credit | Outdoor water use reduction | 2 |
| | | Credit | Indoor water use reduction | 6 |
| | | Credit | Cooling tower water use | 2 |
| | | Credit | Water metering | 1 |
| | | *Energy and atmosphere* | | 33 |
| Y | | Prerequisite | Fundamental commissioning and verification | Required |
| Y | | Prerequisite | Minimum energy performance | Required |
| Y | | Prerequisite | Building level energy metering | Required |
| Y | | Prerequisite | Fundamental refrigerant management | Required |
| | | Credit | Enhanced commissioning | 6 |
| | | Credit | Optimize energy performance | 18 |
| | | Credit | Advanced energy metering | 1 |
| | | Credit | Demand response | 2 |
| | | Credit | Renewable energy production | 3 |
| | | Credit | Enhanced refrigerant management | 1 |
| | | Credit | Green power and carbon offsets | 2 |
| | | *Materials and resources* | | 13 |
| Y | | Prerequisite | Storage and collection of recyclables | Required |
| Y | | Prerequisite | Construction and demolition waste management planning | Required |
| | | Credit | Building life-cycle impact reduction | 5 |
| | | Credit | Building product disclosure and optimization—environmental product declarations | 2 |
| | | Credit | Building product disclosure and optimization—sourcing of raw materials | 2 |

(*Continued*)

**TABLE 14.3 (Continued)**
**Example of LEED v4 for BD+C: New Construction and Major Renovation Checklist**

| Yes | No | Category | Credit Descriptions | Points |
|---|---|---|---|---|
| | | Credit | Building product disclosure and optimization—material ingredients | 2 |
| | | Credit | Construction and demolition waste management | 2 |
| | | *Indoor environmental quality* | | 16 |
| Y | | Prerequisite | Minimum indoor air quality performance | Required |
| Y | | Prerequisite | Environmental tobacco smoke control | Required |
| | | Credit | Enhanced indoor air quality strategies | 2 |
| | | Credit | Low emitting materials | 3 |
| | | Credit | Construction indoor air quality management plan | 1 |
| | | Credit | Indoor air quality assessment | 2 |
| | | Credit | Thermal comfort | 1 |
| | | Credit | Interior lighting | 2 |
| | | Credit | Daylight | 3 |
| | | Credit | Quality views | 1 |
| | | Credit | Acoustic performance | 1 |
| | | *Innovation* | | 6 |
| | | Credit | Innovation | 5 |
| | | Credit | LEED accredited professional | 1 |
| | | *Regional priority* | | 4 |
| | | Credit | Specific credit | 1 |
| | | Credit | Specific credit | 1 |
| | | Credit | Specific credit | 1 |
| | | Credit | Specific credit | 1 |
| | | Totals | Possible points | 110 |

*Source:* Adapted from U.S. Green Building Council, *LEED v4 for Building Design and Construction: New Construction and Major Renovation Checklist*, Washington, DC, Accessed on February 19, 2015, http://www.somervillema.gov/sites/default/files/documents/Leedworksheet.pdf, 2015b.

- Designed for cost-effectiveness.
- Increase property value.
- Recover higher first costs, if there are any.
- Reduce liability.
- Take advantage of incentive programs.

The USGBC has also suggested that green structures help address other issues, such as (Kibert 2008, pp. 330–331):

- Deteriorating power grid problems, such as power quality and availability
- Global warming
- High electric power costs
- Increases in operating and maintenance costs for state facilities
- Possible water shortages and waste disposal issues
- Rising incidence of allergies and asthma, especially in children
- State and federal pressure to reduce criteria pollutants
- The effect of school environments on children's ability to learn
- The health and productivity of workers

The following list provides some of the benefits of having a LEED-certified structure according to the U.S. Green Building Council (2015a):

- Enforcement of complete implementation of designed green features
- LEED brand association
- Third-party validation of green features and degree of sustainability
- Incentives or requirements from public agencies, including:
  - San Jose, California: offering an array of resources to projects pursuing LEED certification such as financial incentives, awards, and streamlined permitting processes
  - Oregon: having a business energy tax credit program for projects achieving a LEED silver rating or higher
  - Arlington, Virginia: waiving height or density limitations for LEED-certified projects
  - Many cities, states, and federal agencies, including the Government Services Administration, having mandated LEED for public buildings

## 14.7 SUMMARY

This chapter introduced the LEED Green Building Rating System certification process, which was designed to assess the sustainability of structures, and the role that the USGBC plays in this process. The types of credits, prerequisites, subcategories, and possible points for the rating system were discussed, and a LEED v4 for BD+C—New Construction and Major Renovation checklist-detailing the credits for each LEED category was provided in this chapter. This chapter also reviewed some of the benefits of having LEED certification for structures provided by the USGBC.

## 14.8 KEY TERMS

Core and shell
Credits
Green structures
Prerequisites
Regionally weighted credits
Subcategories

## 14.9 DISCUSSION QUESTIONS

14.1 Discuss what is required for a structure to achieve one of the four different LEED certification levels.

14.2 Discuss the three most important benefits of a structure having LEED certification.

14.3 Explain what the LEED Green Building Rating System is and how it is used to determine the sustainability of a structure.

14.4 What are the main LEED categories that contain related sustainable strategies included in the LEED certification system?

14.5 What is the objective of having LEED certification?

14.6 Which segments of the building industry are represented in the USGBC?

14.7 What are the benefits of registering with the USGBC at the inception of a project attempting to achieve LEED certification?

14.8 What aspects of the LEED rating system would directly affect the implementation of productivity improvement techniques?

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# 15 Sustainability Organizations and Certification Programs

There are a variety of different sustainability organizations throughout the world addressing issues related to sustainable development, providing information about sustainability, and offering sustainability certification programs. This chapter discusses sustainability organizations and their rating systems and provides insight into how they operate. Some of the sustainability organizations discussed in this chapter are country-specific organizations, and others are global organizations. Several of the sustainability organizations mentioned in this chapter have certification rating systems for buildings.

## 15.1 INTERNATIONAL GREEN CONSTRUCTION CODE

The International Green Construction Code (IgCC) was released in March 2012 by the International Code Council (ICC), and it is used to help regulate the construction of new and existing commercial structures. It is one of the few codes addressing sustainability for the entire construction project and its site “from design through construction, certificate of occupancy and beyond” (International Code Council 2015, p. 1). The code acts as an overlay to the existing set of international codes, including provisions of the International Energy Conservation Code and ICC–700, the National Green Building Standard, and incorporates NSI/ASHRAE/IES/USGBC Standard 189.1–2014, Standard for the Design of High-Performance Green Buildings, as an alternative path to compliance (International Code Council 2015, p. 1). The code covers the following areas (American Institute of Architects, the U.S. Green Building Council, and the Illuminating Society of North America 2009, p. 3):

- Site development
- Land use
- Preservation of natural and material resources
- Indoor air quality
- Energy-efficient appliances
- Renewable energy systems
- Water resource conservation
- Rainwater collection and distribution systems
- Recovery of used water (gray water)

The development of the IgCC was sponsored by the American Institute of Architects and the American Society for Testing and Materials (ASTM) International:

> The International Green Construction Code is not a rating system, nor is it intended to replace them. It is a code intended to be adopted on a mandatory basis. Unlike most rating systems, the IgCC primarily consists of minimum mandatory requirements. The IgCC contains a new regulatory framework that facilitates both jurisdictional customization and flexibility for owners and designers. (International Code Council 2012, p. 1)

The model code language becomes law when

> it is adopted by the appropriate state or local authority charged with governing construction. The *International Green Construction Code* offers flexibility to jurisdictions that adopt the code by establishing several levels of compliance, starting with the core provisions of the code, and then offering "jurisdictional requirement" options that can be customized to fit the needs of a local community. Jurisdictions can add additional guidance through the use of "project electives" provisions. (International Code Council 2012, p.1)

As of June 2014, the IgCC, or its components, have been adopted in the United States by the following states as a voluntary standard or an optional compliance path (various sources):

- Arizona
- Colorado
- Florida
- Maryland
- New Hampshire
- North Carolina
- Oregon
- Rhode Island
- Washington
- Washington, DC

## 15.2 NSI/ASHRAE/IES/USGBC STANDARD 189.1–2014, STANDARD FOR THE DESIGN OF HIGH-PERFORMANCE GREEN BUILDINGS

NSI/ASHRAE/IES/USGBC Standard 189.1–2014, Standard for the Design of High-Performance Green Buildings was championed by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) and created with assistance from members of the U.S. Green Building Council, Illuminating Engineering Society of North America (IESNA), and American Institute of Architects (American Institute of Architects, the U.S. Green Building Council, and the Illuminating Society of North America 2009). The purpose and scope of this standard are the following (Haselbach 2008, pp. 18–19):

Purpose: To provide minimum requirements for the design of high-performance, green buildings to

- Balance environmental responsibility, resource efficiency, occupant comfort and well-being, and community sensitivity
- Support the goal of meeting the needs of the present without compromising the ability of future generations to meet their own needs.

Scope: This standard provides minimum criteria that

- Address sustainable sites, water use efficiency, energy efficiency, a building's impact on the atmosphere, materials and resources, and indoor environmental quality (IEQ)
- Apply to new buildings and major renovation projects (new portions of buildings and their systems): a building or group of buildings, including on-site energy conversion or electricity-generating facilities, which utilize a single submittal for a construction permit or which are within the boundary of a contiguous area under single ownership

The provisions of this standard do not apply to the following:

- Buildings not using either electricity or fossil fuels
- Single-family houses, and multifamily structures with three stories or less above grade, manufactured houses (mobile homes), and manufactured houses (modular)

This standard should not be used to circumvent any safety, health, or environmental requirements.

## 15.3 BUILDING RESOURCE ENERGY AND ENVIRONMENTAL ASSESSMENT MODEL

The Building Resource Energy and Environmental Assessment Model (BREEAM) was created in the United Kingdom in 1990, and it was selected as the “worldwide best program for environmental assessment” at the World Sustainable Building Conference in Tokyo in 2005 (Atkinson et al. 2009, p. 9). The areas assessed in terms of environmental impact using the BREEAM include “energy, transport, health and well-being, water, materials, waste, pollution, land use, *site ecology*, and management” (Atkinson et al. 2009, p. 9).

The BREEAM is maintained by an education charity called the Building Research Establishment Trust; it is operated by a sustainability board of unpaid independent stakeholders, and it is accredited by the United Kingdom Accreditation Services (UKAS) (Atkinson et al. 2009). The BREEAM licenses independent assessors who evaluate structures to determine their environmental impact, and if they meet the BREEAM guidelines they are awarded certification. The assessment process consists of pre-assessments, information gathering, and formal assessments. The BREEAM also provides an international version allowing adaptations for local conditions such as climate, regulations, and markets.

In the United Kingdom, the Department of Communities and Local Government (CLG) released the Code for Sustainable Homes in 2007, and it is closely allied to building regulations and government policies. The Building Research Establishment Global operates process and license certifiers. “The method sets mandatory minimum standards against energy, water, construction and household waste, materials and lifetime homes that relate to key government targets and policies and it has six potential star ratings" (Atkinson et al. 2009, p. 11).

## 15.4 U.S. DEPARTMENT OF ENERGY–ENGINEERING BUILDING TECHNOLOGY PROGRAM

The Department of Energy-Engineering Building Technology Program has a "network of research and industry partners to innovative, cost-effective, energy-saving solutions for homes and buildings" (U.S. Department of Energy 2015, p. 1). This office provides technical assistance on energy efficiency and renewable energy, including advice on issues or goals, tools, maps, and training. This agency also provides "resources addressing strategic energy planning, policy, financing, data management, and technologies to help implement successful energy efficiency and renewable energy projects" (U.S. Department of Energy 2015, p. 1). The areas where they provide assistance are the following (U.S. Department of Energy 2015, p. 1):

- States and communities
- Bioenergy
- Geothermal
- Homes and buildings
- Hydrogen and fuel cells
- Manufacturing
- Solar energy
- Vehicles
- Water
- Wind

The Department of Energy-Engineering Building Technology Program is also discussed in Section 2.6.

## 15.5 LOS ALAMOS NATIONAL LABORATORY SUSTAINABLE DESIGN GUIDE

Elements of the *Los Alamos National Laboratory Sustainable Design Guide* are discussed in Section 3.9 and in Sections 11.1 and 11.2. "The LANL Sustainable Design Guide provides specific guidance regarding the 'how-to' in implementing building sustainability goals defined in the design principles. The LANL Sustainable Design Guide provides detailed information required to design, construct, commission, and operate buildings and it charts the course for meeting most of the 'architectural character' principles outlined in the design principles" (Los Alamos National Laboratory 2002, p. 6).

## 15.6 GREEN ADVANTAGE

The Green Advantage Certified Practitioner (GACP) Certification is accredited by the American National Standards Institute (ANSI). Green Advantage (GA) is a green building certification system for construction field personnel. The GACP certification is awarded to candidates who pass an ANSI-compliant national standard exam developed by Green Advantage. Construction personnel earning the GACP designation demonstrate their competency, knowledge, skills, and abilities in green construction. The GACP is (Green Advantage 2015)

- Applicable across building trades
- Compatible with other green building rating systems such as Green Globes, Leadership in Energy and Environmental Design (LEED), ICC700, ASHRAE 189.1, and IgCC
- Means and methods focused with over 600 green building best practices
- Promoting achievement of the following:
  - Environmental goals
  - Health, safety, and productivity goals
  - Team collaboration and efficiency
  - Problem solving in the field
  - Implementation of construction best practices
  - Cost containment goals and reduced callbacks
  - Reducing building operational costs

The U.S. Green Building Council awards an innovation credit for the use of GACPs on eligible projects meeting the GA30 Green Advantage Field Personnel Specification, which requires 30% of contractor and subcontractor supervisors to be GACPs prior to, and throughout the life of, the project (Green Advantage 2015).

## 15.7 CHARTERED INSTITUTE OF BUILDING'S SUSTAINABILITY AND THE CONSTRUCTION INDUSTRY IN THE UNITED KINGDOM

The Chartered Institute of Building's Sustainability and the Construction Industry guidelines are discussed in Chapter 2 in Section 2.7. The CIOB provides policy statements on different topic areas relating to sustainability, and examples of the types of topics they address are waste minimization and management, reducing carbon emissions from buildings, and definitions for the term *zero carbon*. The CIOB also provides submissions to governments to promote its standards and views. Examples of submissions are strategy for sustainable construction, industry consultation on the code for sustainable buildings, *low carbon construction*, costs and benefits of energy efficiency measures, and measuring and reporting of greenhouse gas emissions companies in the United Kingdom.

The CIOB accredits university degrees in construction management and also provides courses and training in the area of construction management. The CIOB is one of the main professional organizations for construction managers in the United Kingdom. The CIOB has a royal charter to promote science, building, and construction in the United Kingdom.

## 15.8 ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency is discussed in Chapter 5 in Section 5.9.

## 15.9 COUNCIL ON TALL BUILDINGS AND URBAN HABITAT

The Council on Tall Buildings and Urban Habitat is a nonprofit organization formed in 1969 to be a resource for the design, construction, and operation of tall buildings. It is located on the campus of the Illinois Institute of Technology in Chicago, Illinois, and it provides a free database of information on tall buildings in many countries of the world. The CTBUH provides a forum for professionals throughout the world to serve on committees and working groups "focusing on aspects of the planning, design, construction and management of tall buildings and urban habitat across design, technical, and social fields" (Council on Tall Buildings and Urban Habitat 2015, p. 1).

## 15.10 GREENROADS EVALUATION PROJECT

The Federal Highway Administration developed national guidelines for a road building rating system, and a major global consulting firm, in conjunction with faculty members at the University of Washington in Seattle, Washington, created a road rating system called *GreenRoads*. The GreenRoads is a performance measuring system that

> outlines minimum requirements to qualify as a green roadway, including noise mitigation, storm water management, and waste management. It also allows up to 118 points for voluntary actions such as minimizing light pollution, using recycled materials, incorporating quiet pavements and accommodating non-motorized transportation. The GreenRoads team evaluates and rates projects for a fee, from certified, to silver, gold and ultimately evergreen. (GreenRoads Foundation 2015, p. 1)

The following are the GreenRoads category weights:

- Access and equity: 29%
- Construction activities: 13%
- Environment and water: 19%
- Materials and resources: 21%
- Pavement and technologies: 19%

## 15.11 SUSTAINABLE SITES INITIATIVE GUIDELINES AND PERFORMANCE BENCHMARK

The Sustainable Sites Initiative Guidelines and Performance Benchmark–2009 is the first green rating system for landscapes developed by a team with members from the American Society of Landscape Architects, led by the dean of the School of Architecture at the University of Texas at Austin, Texas, with participation by members of the Lady Bird Johnson Wildflower Garden and the U.S. Botanic Garden. This system was designed to encourage development, design, construction, and operation of eco-friendly landscapes. The Sustainable Sites Initiative provides a 233-page report *SSI: Guidelines for Performance Benchmarks 2009* and *The Case for Sustainable Landscapes* (Sustainable Sites Initiative 2009).

Sustainable sites have lower requirements for energy use. They do not consume as much water and natural resources; they generate less waste; and they minimize the impact on land compared to conventional design, construction, and maintenance techniques. In addition to social and economic benefits, sustainable sites help to clean the air and water, sequester carbon, reduce pollution, and help restore habitat and biodiversity.

The Sustainable Sites v2 Rating System is a

> complete set of prerequisites and credits used for measuring site sustainability. It contains the intent and requirements of each prerequisite and credit, the associated point levels for credits, recommended strategies, and key definitions. The 18 prerequisites and 48 credits total 200 points and four certification levels are distinguished by the percentage of credit points achieved. Additionally, projects employing innovative strategies and exemplary performance may receive bonus points. (Sustainable Sites Initiative 2015, p.1)

The areas covered by the Sustainable Sites Initiative are (Sustainable Sites Initiative 2015):

- Predesign assessment and planning
- Site design—water
- Site design—soil and vegetation
- Site design—materials selection
- Site design—human health and well-being
- Construction
- Operations
- Monitoring and innovation

## 15.12 BUILDING FOR ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY (BEES STARS)

The Building for Environmental and Economic Sustainability (BEES) initiative is a system developed by the National Institute of Standards and Technology (NIST) for performing life-cycle cost evaluations of construction assemblies. The BEES system is a software decision support system that includes economic and environmental performance data for building products. It uses the life-cycle assessment process set forth in the International Organization for Standardization (ISO) 14040 standards. Economic performance is measured

> using the ASTM international standard life cycle cost method (E917), which covers the cost of initial investment, replacement, operation, maintenance and repair and disposal. Environmental and economic performance are combined into an overall performance measure using the *ASTM Standard for Multi-Attribute Decision Analysis (E1765).* For the entire BEES analysis, building products are defined and classified based on the ASTM standard classification for building elements known as *UNIFORMAT II (E1557).* (Calkins 2009, p. 63)

The BEES system also allows users to provide relative weightings for different environmental impacts. Users are also able to designate the relative importance of environmental and economic impacts totaling to 100%. The system rates all competing products based on the *weighting system* provided by users.

### 15.12.1 ENVIRONMENTAL IMPACT ESTIMATOR AND ECOCALCULATOR

The Athena Environmental Impact Estimator and EcoCalculator is a system developed by the Athena Sustainable Materials Institute in Ontario, Canada. The Environmental Impact Estimator software program includes information for over 1000 building elements in the following areas (Calkins 2009, p. 65):

- Embodied primary energy use
- Global warming potential
- Pollutants to air
- Pollutants to water
- Solid waste emissions
- Weighted resource use

The EcoCalculator for Assemblies was commissioned by the Green Building Initiative (GBI), and it is maintained by the Athena Sustainable Materials Institute in Ontario, Canada. The Eco-calculator includes life-cycle cost assessment information and is used in conjunction with the impact estimator (Athena Sustainable Materials Institute 2015). The Ecocalculator is a structured Excel

> spreadsheet workbook, with worksheet tabs for various categories of structural assemblies (columns and beams, floors, etc.). On each worksheet, find the specific assemblies in the building project and enter the total square footage of each. Results are instantly displayed for embodied fossil energy use and several impact measures including global warming potential, acidification potential, eutrophication potential, and smog potential.
>
> EcoCalculator results take into account all life cycle stages: resource extraction and processing; product manufacturing; on-site construction of assemblies; all related transportation; maintenance and replacement cycles over an assumed building service

> life of 60 years; and the demolition and transportation of nonmetal materials to landfills. (Athena Sustainable Materials Institute 2015, p. 1)

## 15.13 GREEN STAR RATING SYSTEM

The Green Star Rating System was created in 2003 in Australia in conjunction with the Building Research Establishment. In recent years, the Green Building Council of Australia (GBCA) has modified the Green Star Rating System by adopting a system similar to LEED in the United States. The Green Star system includes seven versions (Green Building Council of Australia 2015, p. 1):

- Office v3
- Office interiors v1.1
- Education v1
- Multiunit residential v1
- Industrial v1
- Office design v2
- Retail center v1
- Healthcare v1
- Public building v1
- Office v2

The Green Star Rating System allows self-assessments by design team members, but the assessment has to be certified by the GBCA through the use of a third-party assessment panel. A minimum score of 45 (four stars) is required for a project to be certified by the GBCA. The following are the ratings used by Green Star (Green Building Council of Australia 2015):

- Four star rating (score 45–59) signifies “best practice.”
- Five star rating (score 60–74) signifies “Australian excellence.”
- Six star rating (score 75–100) signifies “world leadership.”

The categories evaluated in the Green Star system include the following (Green Building Council of Australia 2015):

- Management
- Indoor air quality
- Energy
- Transport
- Water
- Materials
- Land use and ecology
- Emissions
- Innovation

To assist with the scoring of points, difference types of calculators are provided, including (Green Building Council of Australia 2015):

- Greenhouse gas emissions
- Sustainable transport
- Access by public transport
- Potable water
- Sustainable products
- Ecological value
- Refrigerants' impacts

## 15.14 GREEN GLOBES

Another environmental assessment and certification program derived from BREEAM implemented by the Building Owners and Managers Association (BOMA) in Canada and the Green Building Initiative in the United States is Green Globes. This assessment program allows firms to perform *self-assessments* that are then verified by third parties. The Green Globes processes are accredited by the ANSI (Atkinson et al. 2009). The official Green Globes ANSI Standard was published in 2012. In the United States, the GBI, an accredited standards developer under the guidance of the ANSI, owns the license to promote and further develop Green Globes. There is a Green Globes rating system for new construction, for existing buildings, and for healthcare.

The Green Globes rating system has a maximum of 1000 points and a rating system of one to four green globes. The Green Globes rating system contains seven categories, each with subcategories (Kibert 2008, p. 64):

1. Project Management—Policies and Practices (50 points)
    a. Integrate design (20 points)
    b. Commissioning (20 points)
    c. Emergency response plan (5 points)
    d. Environmental purchasing (5 points)
2. Site (115 points)
    a. Enhancement of watershed features (15 points)
    b. Reducing ecological impacts (40 points)
    c. Site development area (45 points)
    d. Site ecology improvement (15 points)
3. Energy (360 points)
    a. Energy consumption (100 points)
    b. Energy demand minimization (100 points)
    c. Energy-efficient transportation (30 points)
    d. Renewable sources of energy (30 points)
    e. "Right-sized" energy-efficient system (100 points)

4 Water (85 points)
    a. Reducing off-site treatment of water (15 points)
    b. Water (35 points)
    c. Water-conserving features (35 points)

5. Resources, Building Materials, and Solid Waste (100 points)
    a. Materials with low environmental impact (40 points)
    b. Minimized consumption and depletion of material resources (30 points)
    c. Reduction, reuse, and recycling of waste (10 points)
    d. Reuse of existing structures (10 points)
    e. Building durability, adaptability, and disassembly (10 points)
6. Emissions and Effluents (70 points)
    a. Air emissions (10 points)
    b. Contamination of sewers and waterways (12 points)
    c. Integrate pest management (4 points)
    d. Land and water pollution (9 points)
    e. Ozone depletion and global warming (30 points)
    f. Storage for hazardous materials (5 points)
7. Indoor Environment (200 points)
    a. Acoustic comfort (25 points)
    b. Effective ventilation system (60 points)
    c. Lighting design and integration of lighting systems (40 points)
    d. Source control of indoor pollutants (45 points)
    e. Thermal comfort (35 points)

The Green Globes rating system project evaluations are accomplished by using questionnaires that are completed during design and construction. If a project receives 35% of the total available points (points are not counted if a part of the project is not related to specific points), it is eligible for certification and a certified verifier will visit the site to ensure that the project has achieved the points stated to have been achieved.

## 15.15 GREEN GUIDE TO SPECIFICATIONS

The *Green Guide to Specifications* was written by the Building Research Establishment in the United Kingdom and it is a rating system for construction elements using life-cycle cost analysis techniques to develop its ratings (British Research Establishment 2015). The life-cycle analysis elements that it evaluates are "energy, water, waste, raw material costs, and production impacts. It is used by designers, and those writing specifications, to help minimize the environmental impacts of buildings and/or provide evidence for BREEAM assessments of buildings they are designing or procuring" (Atkinson et al. 2009, p. 14).

## 15.16 BRITISH STANDARDS INSTITUTE BES 6001, RESPONSIBLE SOURCING OF CONSTRUCTION MATERIALS

In the United Kingdom, the British Standards Institute (CSI), the Building Research Establishment, and others have created a standard used for the responsible sourcing of construction products called *BES 6001*. This standard is for acceptance *sampling by attributes* and provides a brief summary of the attribute sampling schemes and plans. It describes specific types of attribute sampling systems. The BES 6001 standard

> enables construction product manufacturers to ensure and then prove their products have been made with constituent materials that have been responsibly sourced. The standard describes a framework for the organizational governance, supply chain management and environmental and social aspects that must be addressed in order to ensure the responsible sourcing of construction products.
>
> Independent, third party assessment and certification against the requirements of BES 6001 then give the organization the ability to prove that an effective system for ensuring responsible sourcing exists and added credibility to any claims made. (British Standards Institute 2013, p. 1)

## 15.17 FOREST STEWARDSHIP COUNCIL

The Forest Stewardship Council (FSC) was created to provide a system for monitoring the sustainable use of forests. The FSC provides a certification system designating whether wood products have been grown in a sustainable manner. The standards and policies of the FSC are based on the following ten principles (Atkinson et al. 2009, p. 20):

1. Benefits from the forest—to promote efficient use of forest resources to ensure economic viability and a wide range of environmental and social benefits
2. Community relations and workers' rights—to maintain, enhance, and respect long-term relationships with communities and workers
3. Compliance with laws and FSC principles—to cover all national and international laws and treaties/agreements to which the country is a signatory
4. Environmental impact—to conserve biodiversity and forest resources
5. *Indigenous people's rights*—to recognize and respect the right of indigenous people to land and resources
6. Maintenance of high-conservation-value forests—to maintain or enhance the attributes defining such forests
7. Management plan—to set out long-term objectives and the means of achieving them
8. Monitoring and assessment—to assess the condition of the forest, yields of forest products, chain of custody, management activities, and their social and environmental impacts
9. Plantations—to reduce the pressures on and promote the restoration and conservation of natural forests
10. Tenure and use rights and responsibilities—to be fully established and documented.

Additional information about the FSC is included in Chapter 11 in Section 11.7.

## 15.18 DESIGN QUALITY INDICATOR

The Design Quality Indicator (DQI) was started by the Construction Industry Council and released in the United Kingdom in 2003. A version was released in the United States in 2006, and an online version was made available in North America in 2008. The DQI is used on buildings to determine their design quality. The DQI uses a workshop conducted for design team members by a facilitator who assists design team members in setting project-specific goals for each of the DQIs. The three main elements of a DQI are building quality, functionality, and impact. The DQI is used to help design team members to understand "quality priorities, set targets, and monitor performance against them to evaluate design quality" (Design Quality Indicator 2015, p. 1). They do not set specific performance levels but provide an effective self-assessment process for use within the design process.

The DQI is a "Vitruvian" assessment, measuring design in the broadest sense, focusing on everything from a building's functionality to its build quality and the impact the building has on its occupants and its surroundings. These three factors measured by the tool are the same as the ones considered by the Pritzker Architecture Prize, widely considered the Nobel Prize of architecture: commodity, firmness, and delight (Design Quality Indicator 2015, p. 1).

## 15.19 CIVIL ENGINEERING ENVIRONMENTAL QUALITY ASSESSMENT AND AWARD SCHEME

The Civil Engineering Environmental Quality Assessment and Award Scheme (CEEQUAL) was developed in 2004 in the United Kingdom by members of the Institute of Civil Engineers (ICE) to provide a scheme for assessing the "environmental quality of the design and construction of major civil engineering projects" (Atkinson et al. 2009, p. 12). The CEEQUAL covers the following areas (Atkinson et al. 2009, p. 12):

- Ecology and *biodiversity*
- Effects on neighbors
- Energy and carbon
- Historic environment
- Land use
- Landscape
- Project management
- Relations with the local community and other stakeholders
- Transport
- Use of materials
- Waste
- Water

The CEEQUAL includes guidelines that are used for assessing the performance of the design and construction of projects, and it includes six types of awards recognizing achievements (Atkinson et al. 2009, p. 12):

1. Client and design award—applied for jointly by the client and the designer before construction starts
2. Construction award—applied for by the principal contractors
3. Design and build award—for project teams not including the client on design and construct and other partnership contracts

4. Design award—applied for by the principal designer
5. Whole project award (WPA)—applied for jointly by, or on behalf of, clients, designers, and principal contractors
6. WPA with an interim client and design award—where the stage in the design process at which the interim assessment is undertaken may be chosen by the applicant to best suit their needs and the procurement process

The assessments are audited by independent auditors licensed by CEEQUAL, Ltd. The evaluation process and the entities performing each of the five stages are the following (Atkinson et al 2009, p. 13):

1. Scoping—assessor and verifier
2. Assessment—assessor
3. Submission—assessor
4. Verification—verifier
5. Certification—CEEQUAL, Ltd.

## 15.20 COMPREHENSIVE ASSESSMENT SYSTEM FOR BUILDING ENVIRONMENTAL EFFICIENCY

"The *Comprehensive Assessment System for Building Environmental Efficiency* (CASBEE) was launched in 2004 by the Japan Sustainable Building Consortium. The CASBEE methodology is used to calculate a *Building Environmental Efficiency* (BEE) *Score* distinguishing between *environmental load reduction* and building qualify performance. This is adapted from the approach first developed by the *International Initiative for a Sustainable Built Environment* (iiSBE) in the form of *GBTool*" (Atkinson et al. 2009, p. 18). The four versions of Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) are (Atkinson et al. 2009, p. 18):

- Existing buildings
- New construction
- Predesign
- Renovation

Unverified CASBEE scores are submitted, along with other required documentation, for building permits in Japan. If the assessment receives third-party verification, then it could be used as a labeling system. The CASBEE assessment process utilizes a complex weighting system as part of the assessment applied to the following categories (Atkinson et al. 2009, p. 18):

- Energy
- Indoor environment
- Outdoor environment onsite
- Resources and materials

Within each headline category, there are layers of subcategories, such as individual issues and sub-issues, and each of the subcategories are also weighted during the assessment. The CASBEE system categorizes issues into quality measures and load reduction measures.

## 15.21 WORLD GREEN BUILDING COUNCIL

The World Green Building Council (WGBC) is a consortium of national green building councils working together to promote sustainability throughout the world. The WGBC represents 50% of the construction activity occurring throughout the world. It is “a network of national green building councils in more than one hundred countries, making it the world's largest international organization influencing the green building marketplace. The WorldGBC's mission is to strengthen green building councils in member countries by championing their leadership and connecting them to a network of knowledge, inspiration, and practical support. Green building councils are member-based organizations that empower industry leaders to effect the transformation of the local building industry toward sustainability” (World Green Building Council 2015, p. 1).

## 15.22 UNITED NATIONS ENVIRONMENT PROGRAMME

The United Nations Environment Programme reviews global environmental issues and develops United Nations sanctions for violation of environmental enforcement laws. It develops environmental policies through consensus and increases awareness of environmental degradation (United Nations Environment Programme 2015). The Sustainable Buildings and Construction Initiative of the United Nations is dedicated to the following (United Nations Environment Programme 2015, p. 1):

- Assessing global, regional, and national environmental conditions and trends
- Developing benchmarks for sustainable buildings
- Developing international and national environmental instruments
- Identifying and supporting the adoption of policy tools using a life-cycle approach to investment in the building sector
- Promoting improved support mechanisms for energy efficiency in buildings under the Kyoto Protocol
- Strengthening institutions for the wise management of the environment

## 15.23 SUMMARY

Sustainability organizations and certification rating systems were discussed in this chapter including domestic and global organizations. One of the original certification rating systems is the Building Resource Energy and Environmental Assessment Model developed in United Kingdom in 1990. This system was followed by development of the LEED Green Building Rating System in 1998 in the United States, and since then many other certification rating systems have been implemented throughout the world, including the Building for Environmental and Economic Sustainability

Stars, Green Star in Australia, Green Globes in Canada, Comprehensive Assessment System for Building Environmental Efficiency in Japan, the Civil Engineering Environmental Quality Assessment and Award Scheme in the United Kingdom, Design Quality Indicator, Forest Stewardship Council, *Green Guide to Specifications* in the United Kingdom, and GreenRoads in the United States.

This chapter provided background information on these certification rating systems along with information on other organizations promoting sustainability, such as the International Green Building Code; NSI/ASHRAE/IES/USGBC Standard 189.1–2014, Standard for the Design of High-Performance Green Buildings; U.S Department of Energy-Engineering Building Technology Program; Los Alamos National Laboratory; Chartered Institute of Building; Council on Tall Buildings and Urban Habitat; Sustainable Sites Initiative; and the Environmental Protection Agency.

## 15.24 KEY TERMS

Environmental load reduction
High-conservation-value forest
Indigenous people's rights
Low carbon construction
Sampling by attribute
Self-assessments
Site ecology
Weighting system
Zero carbon

## 15.25 DISCUSSION QUESTIONS

15.1 Discuss the areas assessed in terms of environmental impact using the Building Resource Energy and Environmental Assessment Model.
15.2 Discuss whether the *Green Guide to Specifications* is the same as or different from the other rating systems discussed in this chapter.
15.3 What are the three main elements of Design Quality Indicator?
15.4 What is the Comprehensive Assessment System for Building Environmental Efficiency used to calculate?
15.5 Discuss what makes the Building for Environmental and Economic Sustainability Stars initiative different from the other rating systems discussed in this chapter.
15.6 Discuss how the Sustainable Sites Initiative Guidelines and Performance Benchmark–2009 are used and who uses them.
15.7 What areas does the International Green Construction Code cover?
15.8 Explain how the Forest Stewardship Council standards and policies are different from the other rating systems discussed in this chapter.
15.9 Explain how the GreenRoads performance measuring system is used to rate roads.
15.10 What is the World Green Building Council?

15.11 Who developed the Green Star Rating System, and in which country is this system being used?

15.12 What is the Sustainable Buildings and Consortium Initiative of the United Nations dedicated to accomplishing?

15.13 Discuss the purpose of NSI/ASHRAE/IES/USGBC Standard 189.1–2014, Standard for the Design of High-Performance Green Buildings.

15.14 Which institute is responsible for accrediting structures to the Green Globes rating system?

15.15 Who was responsible for the development of the Civil Engineering Quality Assessment and Award Scheme.

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# 16 Sustainability Implementation Resources

This chapter presents five implementation resources that were developed to help members of engineering and construction (E&C) firms initiate sustainability programs for projects, assess the current level of the their sustainability, or evaluate the sustainability of their construction operations. The following are the implementation resources discussed in this chapter are

1. Sustainability Quick Start Guide
2. Sustainability Maturity Model
3. Advanced Sustainability Maturity Model
4. *Sustainability Index Metric* (SIM)
5. Checklist for Evaluating the Sustainability of Construction Jobsite Operations

The Sustainability Quick Start Guide is used for developing sustainability programs for construction projects, and it contains specific actions to be implemented during the front-end planning, design, and construction stages. The Sustainability Maturity Models provide guidance on how to assess the sustainability of current operations and refine and expand sustainability programs by evaluating actions during front-end planning, project financing, design, cost analysis (value engineering and life-cycle cost analysis), construction, start-up, operations, and facility end of life.

The Sustainability Index Metric is an assessment tool for evaluating the sustainability of vendors, suppliers, and fabricators to determine whether to include their services on a project. The SIM incorporates the energy consequences of extraction, manufacture, fabrication, and transportion of materials. The Checklist for Evaluating the Sustainability of Construction Jobsite Operations checklist is similar to the Leadership in Energy and Environmental Design (LEED) Green Building Rating System but it is used for evaluating sustainable practices during construction operations.

This chapter describes each of the implementation resources and include how they are being used in the E&C industry.

## 16.1 SUSTAINABILITY QUICK START GUIDE

The Sustainability Quick Start Guide is used by members of the E&C industry to help implement sustainability practices (Yates 2008). The Sustainability Quick Start Guide provides a tool for preparing a sustainability program for construction projects, and it includes specific steps to be followed during the front-end planning, design, and construction stages.

During the front-end planning phase, project personnel work with senior management to determine their commitment to sustainability and the current level of sustainability. The sustainability objectives are established in the design phase; then, they are integrated into the project execution plan as a sustainability plan. During the construction phase, the sustainability project execution plan is implemented and monitored and, when necessary, adjustments are made to sustainable practices to help increase the sustainability of construction operations. Table 16.1 contains the Sustainability Quick Start Guide.

### TABLE 16.1
### Sustainability Quick Start Guide

| Project Phase | Step | Description | Actions |
|---|---|---|---|
| Front-end planning | 0 | The project is approved and funded. | 1. Project kickoff meeting and development of the project execution plan. |
| Front-end planning | 1 | Provide information on sustainable practices. | 1. Review the sustainability documents with project implementation in mind. |
| Front-end planning | 2 | Justify sustainability project implementation. | 1. Develop cost/benefit analyses. |
| Front-end planning | 3 | Perform a gap analysis between implementation resources and the project expectations, goals, and commitments. | 1. Review each sustainability maturity matrix category for the current level of maturity.<br>2. Determine levels of maturity needed to initiate an effective Sustainable Construction Project. |
| Front-end planning and Design | 4 | Align project support and project expectations. | 1. Assess project organization versus the Maturity Model matrix.<br>2. Compile the results. |
| Front-end planning and Design | 5 | Obtain senior project support. | 1. Prepare results from steps 2, 3, and 4 in presentation format.<br>2. Review the presentation with senior leadership.<br>3. Obtain senior leadership's commitment to proceed in the establishment of a Sustainable Construction Project. |
| Design | 6 | Identify and engage champions. | 1. Define resource and time commitments to meet objectives.<br>2. Identify potential process champions and obtain approval from senior management.<br>3. Assign and engage champions in the development of the Sustainable Construction Project. |
| Design | 7 | Identify and engage other stakeholders and community support. | 1. Review project information and sustainability goals and expectations.<br>2. Solicit outside support and concerns to be addressed in step 8. |

(*Continued*)

**TABLE 16.1 (*Continued*)**
**Sustainability Quick Start Guide**

| Project Phase | Step | Description | Actions |
|---|---|---|---|
| Design | 8 | Develop a mission statement and the scope of the project. | 1. Establish a project leadership vision for a Sustainable Construction Project (how to measure success).<br>2. Define project objectives in establishing a Sustainable Construction Project.<br>3. Integrate Sustainable Construction Project into the project execution plan and other project documents. |
| Design | 9 | Develop a rollout strategy. | 1. Develop a rollout strategy in accordance with the culture of the organization. |
| Design | 10 | Define the tracking matrix and the reporting procedure. | 1. Develop a process flow map.<br>2. Develop project controls and standard reports.<br>3. Develop a communication matrix to report updates.<br>4. Monitor and report on the status of the goals and objectives.<br>5. Adjust the process as required to achieve objectives. |
| Construction | 11 | Develop a recognition/incentive project. | 1. Develop incentives that align and reinforce the vision of the Sustainable Construction Project. |
| Construction | 12 | Roll out the sustainability construction plan to project team personnel. | 1. Provide a strong deployment and communication plan. |
| Construction | 13 | Assemble, document, and publish best practices. | 1. Review the Sustainable Construction Project program periodically to incorporate alterative materials or initiatives for continuous improvement.<br>3. Publicize results to influence future projects. |

*Source:* Adapted from Yates, J., *Sustainable Industrial Construction*, Research Report 250–11, Construction Industry Institute, Austin, Texas, 2008.

## 16.2 SUSTAINABILITY MATURITY MODELS

Tables 16.2 and 16.3 show two *Sustainability Maturity Models* for assessing the current level of sustainability implementation and measuring progress on applying sustainable practices. The first model is used to assess overall corporate-level sustainability awareness, and the second model helps to assess the implementation of sustainability practices on specific projects.

## TABLE 16.2
## Engineering and Construction Sustainability Maturity Model One

| | | Project Implementation Level | | |
|---|---|---|---|---|
| | | Level 1 Basic | Level 2 Intermediate | Level 3 Advanced |
| Project phases | Procurement | Commit environmental standards for projects, and investigate realistic sustainable alternatives. | Set environmental and social goals for projects based on environmental standards and stakeholder consultations. | Social and environmental commitments are measurable and incorporated into project documentation and contracts. |
| | Business case rationale/ project financing | Develop estimates containing sustainable elements, and anticipate risks. | Use life-cycle cost assessment for decision making, and incorporate the costs and benefits of environmental and social goals. | Consider additional value-added activities. |
| | Design | Use a green design rating tool or standard to set goals reflected in the contract documents.<br>Provide reasonable life-cycle payback periods for design criteria. | Commit to achieving a certain level of certification and incorporating it into all project documentation.<br>Consider the impact on the community (construction through operations and closure) in design decisions. | Measure sustainability achievements and publish case studies of projects so others may use them as benchmarks.<br>Engage stakeholders in the design process and incorporate their concerns. |
| | Cost analysis | Use life-cycle cost assessment in value engineering approaches. | Consider pending regulations in design decisions. | Use tangible and intangible costs for carbon and other environmental risks. |

(*Continued*)

## TABLE 16.2 (*Continued*)
## Engineering and Construction Sustainability Maturity Model One

| | Project Implementation Level | | |
|---|---|---|---|
| | **Level 1 Basic** | **Level 2 Intermediate** | **Level 3 Advanced** |
| Procurement | Commit to a sustainable purchasing policy.<br>Consider local sourcing. | Commit to local sourcing, and measuring and reporting progress. | Extend sustainability policies into the supply chain. |
| Construction | Ensure that all contractors and subcontractors comply with permits and report any deviations. | Use local labor if possible, and focus on erosion control, storm water runoff mitigation, noise abatement, and traffic control. | Maximize the use of local labor, and provide training programs.<br>Coordinate with other entities and projects to achieve goals.<br>Commit to sustainable construction practices. |
| Start-up and operation | Consider all operating and maintenance costs in design and cost decisions. | Involve operations personnel in the design and commissioning processes.<br>Use environmental management standards, and commit to community health and safety programs. | Employ trained local labor, engage with community advisory boards, report data to stakeholders, and use the ISO 14001 environmental management standards. |
| Facility end of life | Incorporate plans to reclaim the area at the end of the useful life of the facility. | Plan for the reclamation process during the design phase. | Consider all of the effects facilities have on the surrounding area during both operation and demolition, and prepare mitigation plans. |

*Source:* Adapted from Yates, J., *Sustainable Industrial Construction*, Research Report 250–11, Construction Industry Institute, Austin, Texas, 2008.

## TABLE 16.3
## Engineering and Construction Sustainability Maturity Model Two

| Project Phases | Essence of Each Phase | Level 1 Regular Implementation | Level 2 Project Monitoring, Evaluation, and Improvement |
|---|---|---|---|
| Front-end planning | This phase creates a sustainability implementation plan encompassing all of the phases. | Consult LEED or similar certification guidelines.<br>Evaluate the economic environment and the social impacts of planned decisions. | Decisions are influenced by a desire for a higher certification rating.<br>Quantify inputs and outputs related to economic, environmental, and social impacts. |
| Project financing | Analyze the costs and benefits of incorporating sustainable practices. | Quantify sustainable practices including economic, environmental, and social costs and benefits. | Determine costs and benefits associated with sustainable strategies. |
| Design | Include and evaluate input from stakeholders on sustainable design alternatives. | Use sustainable design guidelines to incorporate sustainable alternatives.<br>Review all project systems for sustainable alternatives.<br>Involve contractors in sustainability constructability reviews. | Utilize Building Information Modeling to help monitor the incorporation of sustainable strategies. |
| Cost Analysis (includes Value Engineering (VE) and Life-Cycle Cost Analysis (LCCA)) | Evaluate the overall life-cycle costs to provide data on first costs versus life-cycle costs and savings. | Explore sustainable alternatives by evaluating life-cycle costs including cradle-to-grave considerations. | Monitor the incorporation of sustainable alternatives based on life-cycle cost assessment rather than first costs. |

(*Continued*)

## TABLE 16.3 (*Continued*)
## Engineering and Construction Sustainability Maturity Model Two

| Project Phases | Essence of Each Phase | Level 1 Regular Implementation | Level 2 Project Monitoring, Evaluation, and Improvement |
|---|---|---|---|
| Procurement | Locate and evaluate sustainable materials and products.<br>Review established guidelines such as Energy Star and the Federal Green Construction Guide for Specifications.<br>Evaluate sustainable materials and products including supply chains. | The specifications should include requirements for sustainable materials and products.<br>Use local materials if feasible.<br>Minimize hazardous waste and environmental impacts. | Document vendors and suppliers that provide sustainable products and materials.<br>Ensure suppliers focus on waste minimization.<br>Cultivate local sustainable suppliers. |
| Construction | Integration of sustainable alternatives during construction. | Processes established to implement and document sustainable practices at all levels.<br>Document deviations from proposed sustainable alternatives, and explain why they could not be implemented during construction. | Monitor construction operations.<br>Document the implementation of sustainable alternatives.<br>Evaluate additional sustainable options, and submit them to the design team for approval.<br>Ensure compliance to sustainable specifications.<br>Provide training if the workforce is not familiar with requirements. |
| Start-up and operation | Commissioning and operation to ensure operational efficiencies of the intended design. | Provide training and operating manuals to ensure proper start-up and operation. | Monitor operations to ensure that peak efficiencies are obtained and all systems are functioning according to the design guidelines. |

(*Continued*)

**TABLE 16.3 (*Continued*)**
**Engineering and Construction Sustainability Maturity Model Two**

| Project Phases | Essence of Each Phase | Level 1 Regular Implementation | Level 2 Project Monitoring, Evaluation, and Improvement |
|---|---|---|---|
| Facility end of life | The demolition phase was considered in the initial design including sustainable practices. | Execute demolition plans including salvaging, recycling, and reusing materials. | Monitor demolition, ensure the demolition plan is implemented, and document deviations from the plan. |

*Source:* Adapted from Yates, J., *Sustainable Industrial Construction*, Research Report 250–11, Construction Industry Institute, Austin, Texas, 2008.

## 16.3 CONSTRUCTION METRIC FOR ASSESSING SUSTAINABILITY

Many different *metrics* are available for assessing the progress of projects, but metrics for assessing sustainability practices for construction projects are disjointed and not as comprehensive as LEED certification procedures. The adoption of the LEED initiative by federal agencies, state and local governments, and the commercial building sector indicates that a similar system for construction would be a viable method for increasing the sustainability of construction projects (U.S. Green Building Council 2008).

This section discusses the Sustainability Index Metric, which is an assessment metric developed for use in the E&C industry when evaluating potential vendors, suppliers, and fabricators.

### 16.3.1 Sustainability Index Metric: Background

Metrics are used to measure the incorporation and use of processes and techniques. Metrics with common terminology are more effective than each firm having its own individual metrics, and they are useful to decision makers when they are developing quantifiable decisions. In the LEED rating system, there is a four-level certification system based on an evaluation of achievements toward meeting sustainability requirements for buildings, which uses a number of sustainability measures. The more sustainable elements that are incorporated into a project during its design, the higher the LEED rating. The LEED certification system provides checklists for quantifying the incorporation of sustainable elements for each category of credits in five main categories, as described in Chapter 14 in Section 14.1 (U.S. Green Building Council 2008).

Currently, there are no sustainability metrics specific to construction operations, but there are metrics for measuring individual components to determine their sustainability. The following are examples of some of the metrics available for assessing components of construction operations include

- Environmental
    - Discharges into water systems such as oil spills
    - Emissions resulting in greenhouse gases (GhGs)
    - Waste such as hazardous waste

- Social
    - Fatalities and worker safety
    - Forced labor and child labor
    - Social and community investment

- Economic
    - Energy consumed
    - Environmental expenditures
    - Raw materials consumed
    - Total water consumed

### 16.3.2 Sustainability Index Metric

The Sustainability Index Metric is a guide for decision makers, providing information on the sustainability of vendors and suppliers by including a system for rating different sustainable aspects of products and services in the supply chain. Although the LEED certification system is used to guide the design of, and provides a benchmark for, sustainable projects, it does not address the sustainable attributes of vendors and products used on construction projects. The SIM is a system used to measure total procurement supply chain sustainability via the aggregation of vendors and product SIM scores (Yates 2008). The SIM scores are based on the triple bottom line and include social, economic, and environmental impacts throughout the life cycle of products, and they encompass the following:

- Manufacturing and fabrication
- Assembly
- Transporting
- Installation
- Operation and maintenance
- Demolition
- Reuse

The three major components of the triple bottom line are economic growth, social progress, and environmental stewardship, and the three overlapping components are socioeconomic, eco-efficiency, and socio-environmental components (Battelle

2003). There are also subcomponents of each of these categories related to resource efficiency, safety and health, and other areas.

The development of a sustainability index (SI) should incorporate *submetrics* that are combined to create a SIM. Many submetrics have already been quantified, and examples are GhG emissions, water discharge, lost time accidents, and so on. Other areas such as human rights, ethics, and community impacts require the development of a quantifiable system to assess their impact on the environment.

Each of the firms involved in the supply chain for construction materials impacts all of the other companies along the supply chain. Therefore, to assess whether decisions related to sustainability will result in beneficial effects to the environment a metric needs to consider the entire supply chain, for example, debates on the merits of using biofuels versus gasoline. Besides considering GhG emissions from the use of biofuels, a comprehensive SIM should also include the following:

- Additional fuels used for growing biofuel feedstock
- Effects of using fertilizers
- Deforestation to provide biofuel feedstock
- Liberation of carbon dioxide from other soil uses
- Power used to process the feedstock into biofuels
- Social benefits to rural areas
- Water consumption

The SI for the production and use of biofuels is then compared to the SI for the production and use of gasoline to generate a total GhG impact assessment to be used when making decisions on which product to select for use during construction. One essential requirement for using the SIM is it should be a cumulative process, similar to a *value-added tax*. While each supplier determines their SI, they also need to add it to the sustainability indices of their suppliers to report their total SI. For example, the calculations for a steel producer to determine its SI are shown in Box 16.1.

## BOX 16.1 STEEL PRODUCTION SIM

| **Stage of Process** | **Index Rating** |
|---|---|
| SI from supplier number 1—coke producer | 35 |
| SI from supplier number 2—limestone | 5 |
| SI from supplier number 3—iron ore | 15 |
| SI from supplier number 4—recycled steel | 20 |
| SI for shipping materials to production plant | 10 |
| SI for shipping materials to customers | 10 |
| SI for steel producer based on triple bottom line | 30 |
| Total | 125 per ton of steel |

### BOX 16.2 STEEL PRODUCTION SIM

| **Stage of Process** | **Index Rating** |
|---|---|
| SI for steel producer (see Box 16.1) | 125 |
| SI from supplier number 1 | 10 |
| SI from supplier number 2 | 4 |
| SI from supplier number 3 | 8 |
| SI for shipping materials to the fabricator | 20 |
| SI for shipping materials to the customer | 20 |
| SI for steel fabricator based on the triple bottom line | 20 |
| Total | 207 per ton of steel |

Steel fabricators are the next step in the supply chain, and an example of an estimate for a steel fabricator SI is shown in Box 16.2.

If a decision maker has an SI estimate for each potential vendor and supplier, it helps him or her to be able to make a quantifiable decision on which supplier or vendor to use when purchasing a product.

Most firms currently make procurement decisions based on the triple constraints of (1) time, (2) money, and (3) scope. Decision makers develop either a formal or an informal bid analysis for each of these constraints. Decision makers then evaluate bids in relation to each of the constraints to determine which supplier meets their requirements. If time and scope are the same for all of the suppliers, then decisions are made based on costs. However, if a project includes liquidated damages then the schedule is the most important element and it overrides cost.

If a fourth constraint, the SI, is added to the other three constraints, it creates a *quadruple constraint* for decision making. Having an SI as part of proposals from suppliers provides a tool for decision makers to use when preparing bid analyses that include sustainability.

For example, if the aforementioned example on steel is extended to the next company in the supply chain, the engineering firm designing the structure, the decision maker in the engineering firm might use the SI to decide which of the steel fabricators submitting bid estimates has the lowest SI. The SI bid analysis total would resemble what is shown in Box 16.3.

This analysis shows that fabricator C has the lowest SI rating, indicating that this fabricator has the most sustainable supply chain and in-house processes.

A quadruple constraint would allow engineers to consider design alternatives achieving the lowest SI for projects. Engineers could also evaluate different alternative products such as whether a steel beam provides the best SI or whether some type of steel–concrete sandwich panel would be a more sustainable alterative. If the steel–concrete sandwich panel alternative was included, then the bid evaluation would resemble the contents of Box 16.4.

### BOX 16.3 STEEL PRODUCTION PLUS FABRICATOR SIS

| Suppliers Plus Fabricator A | Suppliers Plus Fabricator B | Suppliers Plus Fabricator C |
|---|---|---|
| 207 | 223 | 245 |

### BOX 16.4 SUPPORT MECHANISM TO SI

| Fabricator A | Fabricator B | Sandwich Panel |
|---|---|---|
| 207 | 223 | 189 |

Factors included in the SIM need to be appropriate for being included in the model, be verified for accuracy, and be quantifiable through a standard method allowing for direct comparisons between suppliers and vendors. The factors should also be comprehensive enough to prevent misleading choices but not too complicated so that vendors and suppliers would develop their own SIMs. The SIM should use existing, valid metrics already available in the industry. The following are some of the factors to be considered for inclusion in the SIM:

- Employee and contractor safety record
- Extraction processes for raw materials
- Programs available for using renewable energy resources
- Transportation methods for raw materials and finished products
- Types of energy consumed to produce products
- Waste management programs
- Whether a company assists suppliers in developing sustainability initiatives
- Whether a firm has an executive-supported sustainability program
- Whether a firm is certified to the ISO 14001 series of standards
- Whether a firm produces an annual sustainability report or reports on specific achievements
- Whether the buildings that a company owns are LEED certified

## 16.4 CHECKLIST FOR EVALUATING THE SUSTAINABILITY OF CONSTRUCTION JOBSITE OPERATIONS

This section provides a checklist to assist project and construction management personnel in evaluating whether they are successfully incorporating sustainable practices and materials into construction projects (Yates 2008). Chapters throughout this book cover the different topics in the checklist.

The checklist provides point values for each topic, section total, and then an overall score summing up the points for each section. The total possible points for all of the categories are 100. There are six categories of point totals indicating the sustainability of construction operations, and they are listed at the end of the checklist. The highest category is 90–100 and the rating received for this category is five stars, and the lowest category is <50, which is rated as zero stars and not sustainable.

**Checklist for Evaluating the Sustainability of Construction Jobsite Operations**

1. Site staging and logistics (29 possible points).
   a. Temporary parking (2 points possible).
      ☐ Recycled base course materials.
      ☐ Sustainable paving materials.
   b. Temporary offices (12 points possible).
      ☐ Computerized document control—paperless sites and recycled paper products.
      ☐ Equipment with sleep mode.
      ☐ Increase insulation in temporary structures.
      ☐ Investigate the use of Building Information Modeling (BIM) computer software.
      ☐ Layout to maximize sunlight.
      ☐ Lease or buy office furniture for temporary office.
      ☐ Modular structures.
      ☐ Provide recycle bins.
      ☐ Specify Electronic Product Environmental Assessment Tool (EPEAT) monitors and computers for site office equipment.
      ☐ Printers with duplex printing capabilities (double sided).
      ☐ Sustainable facilities and their placement.
      ☐ Sustainable sanitation facilities.
   c. Layout of the structure (5 points possible).
      ☐ Layout to maximize sunlight.
      ☐ Minimize disruption to the local community.
      ☐ Minimize the removal of natural vegetation.
      ☐ Reduce ecosystem encroachment.
      ☐ Reduce noise and spatial pollution.
   d. Material ordering, delivery, and laydown yard (5 points possible).
      ☐ Minimize material waste by ordering lengths not requiring cutting.
      ☐ Minimize the number of times materials are moved around the jobsite.
      ☐ Order in quantities packaged in bulk rather than individually.
      ☐ Reduce the amount of time delivery trucks wait to be unloaded.
      ☐ Select the location of the laydown yard to reduce energy requirements for moving materials.
   e. Efficient on-site transportation patterns (2 points possible).
      ☐ Perform a process analysis study, and implement recommendations.
      ☐ Perform a traffic study, and implement recommendations.
   f. Minimize the disruption to surrounding traffic (3 points possible).
      ☐ Perform a process analysis study, and implement recommendations.
      ☐ Reduce the number of material deliveries.
      ☐ Minimize distances for material deliveries.

Section 1 possible points: 29.
Section 1 total points: ____.

2. Site waste management plan (6 points possible).
    - Investigate and use recycling services.
    - Minimize disruptions to surrounding vegetation.
    - Mulch or compost vegetation debris.
    - Prepare and implement a toxic waste spill plan.
    - Resell reusable waste.
    - Use licensed hazardous waste disposal services.

Section 2 possible points: 6.
Section 2 total points: ____.

3. Site erosion control plan (ECS) (6 points possible).
    - Prepare and implement a site erosion control plan (5 points).
    - Follow Environmental Protection Agency regulations even in foreign countries with lower standards (1 point).

Section 3 possible points: 6
Section 3 total points: ___.

4. Post-construction site restoration (4 points possible).
    - Blend the site with the local community.
    - Involve local constituents in post-construction site restoration plan development.
    - Plan for erosion control after construction.
    - Plan for restoring similar amounts of vegetation, and implement the plan.

Section 4 possible points: 4.
Section 4 total points: ____.

5. Exterior dust and particulate control (3 points possible).
    - Analyze the air quality during construction on site and in the surrounding community.
    - Provide dust and particulate control measures, if necessary.
    - Temporary planting during construction.

Section 5 possible points: 3.
Section 5 total points: ____.

6. Transportation planning or using mass transit systems (1 point possible).
    - Arrange car pools, or have craft workers and management use mass transit systems.

Section 6 possible points: 1.
Section 6 total points: ____.

7. Waste management (3 points possible).
    - Provide systems for managing water consumption during construction.
    - Provide systems for recycling wastewater during construction.
    - Provide systems for water management of human waste.

Section 7 possible points: 3.
Section 7 total points: ____.

8. Energy and atmosphere (7 points possible).
   a. Heavy construction equipment fleet management (3 points possible).
      - Alternative fuels.
      - Hybrid-electric heavy construction equipment.
      - Remanufactured heavy construction equipment, engine repowering, engine upgrades, or diesel-retrofit technologies.
   b. Energy management during construction (4 points possible).
      - Contract with green providers for temporary power.
      - Sustainable alternatives for temporary utilities (phone, water, gas, and electric).
      - Sustainable energy sources.
      - Plan for peak energy use at the jobsite during off-peak times in the local community.

Section 8 possible points: 7.
Section 8 total points: ____.

9. Materials and resources (16 points possible).
   a. General material evaluation (4 points possible).
      - Evaluate the cradle-to-grave environmental costs when selecting materials.
      - Negotiate supply chain sustainability and ethics contracts.
      - Perform life-cycle cost assessments for materials.
      - Use a method for evaluating the sustainability of suppliers, such as the Sustainability Index Metric.
   b. Alternative sustainable materials (12 points possible). Investigate the following sustainable materials and use if possible:
      - Asphalt.
      - Carbon-fiber composites.
      - Cement.
      - Concrete aggregate.
      - Prefabrication.
      - Masonry.
      - Manufacture concrete on site.
      - Paints.
      - Prefabricate assemblies for steel structures.
      - Polyvinylchloride (PVC) products.
      - Steel.
      - Wood products.

Section 9 possible points: 16.
Section 9 total points: ____.

10. Material deliveries (7 points possible).
    a. Investigate alternatives for material deliveries (2 points possible).
       - Alternative delivery systems (truck deliveries are less efficient than rail or ship deliveries).
       - Methods for reducing transportation costs.

- b. Use resources available on the site (5 points possible).
  - Aggregates.
  - Asphalt.
  - Concrete.
  - Crushed rock.
  - Soil.

Section 10 possible points: 7.
Section 10 total points: ____.

11. Waste management (7 points possible).
    - Donate waste to community members or charities.
    - Formwork—use certified wood or reusable materials (steel, wood, and plastic).
    - Landfill diversion of waste (divert waste from being put into landfills).
    - Recycle waste.
    - Resell waste.
    - Return waste materials to inventory.
    - Small tools and supplies (minimize disposables and buy for durability).

Section 11 possible points: 7.
Section 11 total points: ____.

12. Lean construction (3 points possible).
    - Material delivery sequencing to avoid off-gassing and destruction.
    - Reduce waste factors in material orders.
    - Use just-in-time (JIT) delivery—minimize the layout area.

Section 12 possible points: 3.
Section 12 total points: ____.

13. Indoor environmental control (2 points possible).
    - Interior air quality control during construction—proper ventilation.
    - Paints, adhesives, and solvents—low volatile organic compounds (VOCs).

Section 13 possible points: 2.
Section 13 total points: ____.

14. Social impacts (6 points possible).
    - Improved relationships with impacted communities.
    - Minimize impact to surrounding community productivity during construction.
    - Minimize light pollution.
    - Noise and vibration reduction—develop and implement a plan for reduction.
    - Reduce community travel delays.
    - Reduce impact to real estate values.

Section 14 possible points: 6.
Section 14 total points: ____.
Checklist possible points: 100.
Checklist total points: ____.

The total ratings indicate the following:

| **90–100 Points** | **5 Stars** |
|---|---|
| 80–89 Points | 4 Stars |
| 70–79 Points | 3 Stars |
| 60–69 Points | 2 Stars |
| 50–59 Points | 1 Star |
| <50 Points | 0 Star—not sustainable |

*Source:* Adapted from Yates, J., *Sustainable Industrial Construction*, Research Report 250–11, Construction Industry Institute, Austin, Texas, 2008.

## 16.5 SUSTAINABILITY PROJECT EXECUTION PLANS

To demonstrate how the Checklist for Evaluating the Sustainability of Construction Jobsite Operations provided in Section 16.4 is used during the planning and execution of construction projects, three sample sustainability project execution plans are provided in Appendices D through F for projects located in Arizona, North Carolina, and Pennsylvania. Each of the sustainability project execution plans in Appendices D through F demonstrates how a project team plans and executes sustainable methods and processes during the construction stage of projects. The sustainability project execution plans included in the appendices are for two office structures and one rural construction project. All three of the sustainability project execution plans also provide information on how to plan the implementation of sustainable practices during construction.

## 16.6 SUMMARY

The implementation resources presented in this chapter are used by members of E&C firms to start implementing a sustainability program, assess the maturity of their existing sustainability programs, or evaluate the sustainability of their construction jobsite operations. The implementation resources included in this chapter are a Sustainability Quick Start Guide, two Sustainability Maturity Models, a Sustainability Index Metric, and a Checklist for Evaluating the Sustainability of Construction Jobsite Operations. Each of these implementation resources provides a tool for improving the sustainability of E&C projects.

The Sustainability Quick Start Guide provides members of firms with specific steps and actions to help develop sustainable projects during the planning, design, and construction stages of projects. The Sustainability Maturity Models provide two methods for assessing the current level of sustainability and the progress in applying sustainability practices for projects. The Sustainability Index Metric is used for assessing sustainability and the cradle-to-grave environmental consequences of using construction materials and the sustainability of potential supply chains. The Checklist for Evaluating the Sustainability of Construction Jobsite Operations provides an organized system for evaluating the sustainability of construction operations, and it is used as a rating system, similar to the LEED Green Building Rating System, to rate the sustainability of construction operations.

## 16.7 KEY TERMS

Metrics
Quadruple constraint
Submetrics
Sustainability index metric
Sustainability maturity models
Sustainability quick start guide
Value-added tax

## 16.8 DISCUSSION QUESTIONS

16.1 What are the four constraints on decisions related to procurement?

16.2 How could the Checklist for Evaluating the Sustainability of Construction Jobsite Operations be used to determine the sustainability of construction operations?

16.3 In the Sustainability Index Metric example for steel, what are the different sustainability indices used in the calculations derived from other processes in the supply chain?

16.4 What is the purpose of the two sustainability maturity models?

16.5 Discuss how the Sustainability Index Metric could be used to help assess the sustainability of products and services.

16.6 Explain how the calculations are performed in the Sustainability Index Metric.

16.7 What is included in the checklist for evaluating the sustainability evaluation of construction jobsite operations on plans for post-construction site restoration?

16.8 In addition to considering greenhouse gas emissions from the use of biofuels when using the SIM, what other six items should the considered?

16.9 Explain how the Sustainability Quick Start Guide could be used on E&C projects.

16.10 What is included in the checklist for evaluating the sustainability of construction jobsite operations on site waste management plans?

## REFERENCES

Battelle, R. 2003. *Compendium of Sustainability Reporting Practices and Trends for the Oil and Gas Industry.* Washington, DC: International Petroleum Industry Environmental Conservation Association and American Petroleum Institute. pp. 5–42. Accessed on January 13, 2015. http://www.commdev.org/compendium-sustainability-reporting-practices-and-trends-oil-and-gas-industry.

U.S. Green Building Council. 2008. *Leadership in Energy and Environmental Design.* Washington, DC. Accessed on January 13, 2015. www.usgbc.org/leed.

Yates, J. 2008. *Sustainable Industrial Construction*, Research Report 250–11. Austin, TX: Construction Industry Institute. Accessed on January 13, 2015. https://www.construction-institute.org/scriptcontent/more/rr250_11_more.cfm.

# 17 Sustainability in Engineering Design and Construction Summary

## 17.1 CONCLUSIONS

This book described the processes required to design and build sustainable construction projects and provided information on the types of sustainable practices being implemented during engineering design and construction operations. This book was written to help members of the engineering and construction (E&C) industry in making more informed decisions on whether to integrate sustainable practices into their E&C projects and to provide information on current sustainable practices. The following are the topics covered in this book:

1. Definitions for sustainability, sustainable development, and related topics and barriers and drivers for implementing sustainability practices
2. Sources of information on sustainability requirements
3. Government sustainability regulations and global treaties affecting the E&C industry
4. Current sustainability practices in the E&C industry and the obstacles to implementing them
5. Sustainable engineering design
6. Environmental laws related to sustainability and their implications
7. Life-cycle cost assessment models
8. Corporate-level sustainability practices
9. Project-level sustainability practices
10. Examples of global sustainability trends and implications
11. Sustainable construction materials
12. Sustainable heavy construction equipment
13. Traditional and alternative sources of energy
14. Leadership in Energy and Environmental Design (LEED) Green Building Rating System
15. Sustainability and certification organizations
16. Sustainability implementation resources

In addition, data and information were presented that were obtained from top-level E&C executives, including items such as the types of issues that members of E&C firms address related to toxic emissions, production of hazardous waste and nonhazardous waste, recycling or reusing construction waste by-products, and other sustainable practices.

Suggestions were provided throughout this book on alternative materials and processes for construction projects that are more sustainable, or require less embodied energy and produce lower levels of greenhouse gasses, than traditional materials.

Life-cycle cost assessment models were also discussed because they are effective methods for quantifying the tangible and intangible costs associated with incorporating construction materials into projects. Assessment models for quantifying social and environmental impacts were provided, and they included methods for quantifying user delays, loss of productivity, reductions in adjacent real estate property values, and other non-tangible items.

Implementation resources were provided including a Sustainability Quick Start Guide for implementing sustainable practices into projects and two Sustainability Maturity Models which are useful to members of firms when they are assessing how advanced their firms are in implementing sustainable practices. A Sustainability Index Metric (SIM) was discussed that helps members of E&C firms assess the cradle-to-grave environmental consequences of using different construction materials, suppliers, and fabricators. A Checklist for Evaluating the Sustainability of Construction Job Site Operations was also included, and it provides a method for evaluating the sustainability of construction operations in a manner similar to the LEED certification process.

Section 17.2 outlines some potential topics for further research that if pursued would provide members of the E&C industry with additional information on sustainability in engineering design and construction.

## 17.2 RECOMMENDATIONS FOR FURTHER RESEARCH

There are a variety of other E&C industry research topics that could be explored to determine the areas that would produce the most sustainable results for E&C industry members, and this section provides suggestions on topics for further research.

### 17.2.1 General Sustainability Research

This section includes suggestions for general sustainability research:

1. Testing and validating a construction assessment metric such as the Sustainability Index Metric.
2. Investigating whether the ISO 14000 series of standards, and whether obtaining ISO 14000 certification, benefits firms when they are designing and constructing projects and whether a method could be developed for quantifying the benefits of being ISO 14000 certified when building construction projects.
3. Developing a process for monitoring and reporting sustainable construction practices being implemented throughout the world and providing a mechanism for allowing E&C professionals to access information about these practices.

### 17.2.2 Social and Community Impact of Construction Operations Research

Suggestions for research related to the social and community impact of construction operations include

1. Developing a method for quantifying the social and financial benefits of producing yearly sustainability reports following the guidelines of the global reporting initiative.
2. Developing a method for quantifying the social impacts of construction operations.
3. Investigating case study projects focusing on providing social benefits to the local community during construction projects and determining the benefits to companies.
4. Developing a method for quantifying the spatial and noise pollution caused by construction operations.
5. Evaluating methods for reducing energy consumption to determine whether they are cost-effective when used on construction projects.

### 17.2.3 Construction Operations Sustainability Research

Recommendations for areas where additional research could be conducted related to sustainable construction operations are the following:

1. Developing a method for quantifying the benefits of designing sustainable engineering processes.
2. Determining methods for reducing the environmental degradation caused by construction operations.
3. Developing a method for determining the additional costs associated with implementing sustainable practices during construction operations
4. Investigating methods for minimizing the generation of waste by-products generated during construction operations.

### 17.2.4 Sustainable Construction Materials Research

Research topics related to sustainable construction materials that could be investigated include

1. Developing and validating a method for quantifying the environmental consequences associated with the production of construction materials.
2. Developing and validating a method for quantifying the environmental consequences of transporting construction materials.
3. Investigating and determining the applicability and financial benefits of using sustainable construction materials.

4. Investigating alternative methods for recycling, reusing, or remanufacturing construction waste by-products.
5. Investigating methods for evaluating and rating supply chains to determine whether they are using sustainable practices.

## 17.3 SUMMARY

All of the information provided in this book is applicable to not only engineering designers and construction professionals but also owners who prefer to create sustainable structures using environmentally friendly construction materials, methods, and processes. There are many other items involved in sustainable design and construction than merely having a structure LEED certified by the United States Green Building Council, or one of the other organizations providing rating systems and certifications for buildings. Sustainability begins during the design of structures; it should be woven into the procurement process all the way back to the extraction of raw materials and be practiced on a daily basis during the construction phase of projects. This book provides insight into a variety of techniques and processes for integrating sustainable practices into all of the phases of E&C projects and for ensuring that sustainability concepts are incorporated into every E&C decision.

# Appendix A: List of Commonly Used Acronyms and Organizations Related to Sustainable Practices

| Acronyms | Acronym Definitions |
|---|---|
| AASHTO | American Association of State Highway and Transportation Officials |
| ACERT | Advanced Combustion Emissions Reduction Technology |
| AIA | American Institute of Architects |
| ANSI | American National Standards Institute |
| AP | Accredited Professional |
| APP | Affirmative Procurement Program |
| ASHRAE | American Society of Heating, Refrigeration, and Air-Conditioning |
| ASTM | American Society for Testing and Materials |
| BEE | Building Environmental Efficiency |
| BEES | Building for Environmental and Economic Sustainability |
| BES | British Environmental Standard |
| BOMA | Building Owners and Managers Association |
| BRE | Building Research Establishment |
| BREEAM | Building Resource Energy Environmental Assessment Model |
| BRET | Building Research Establishment Trust |
| BSI | British Standards Institute |
| BVQI | Bureau Veritas Quality International |
| CAFE | Corporate Average Fuel Economy |
| CASBEE | Comprehensive Assessment System for Building Environmental Efficiency |
| CCA | Chromated copper arsenate |
| CEEQUAL | Civil Engineers Environmental Quality Assessment and Award Scheme |
| CEN | Comite European de Normalisation (European Committee for Standardization), Commission for European Normalization |
| CEQ | Council on Environmental Quality |
| CERES | Coalition for Environmentally Responsible Economies |
| CERLA | Comprehensive Environmental Response Compensation and Liability Act |
| CIB | Counseil International de Batiment |
| CIOB | Chartered Institute of Building |

(*Continued*)

| Acronyms | Acronym Definitions |
|---|---|
| CLASP | Collaborative Labeling and Appliance Standards Program |
| CPG | Comprehensive Procurement Guidelines |
| CSA | Canadian Standards Association |
| CSH | Codes for Sustainable Homes |
| CSI | Canadian Standards Institute |
| CSI | Construction Specification Institute |
| CSR | Corporate social responsibility |
| CTBUH | Council on Tall Buildings and Urban Habitat |
| CW | Certified Wood |
| DEF | Diesel exhaust fluid |
| DfD | Design for disassembly |
| DIS | Dutch Institute for Standardization |
| DJSGI | Dow Jones Sustainability Group Index |
| DOE | Department of Energy |
| DPF | Diesel particulate filters |
| DQI | Design Quality Indicator |
| DRT | Diesel retrofit technology |
| EC | Environmental collaboration |
| ECA | Environmental Conservation Association |
| EGR | Exhaust gas recirculation (engines) |
| EIA | Environmental impact assessment |
| EIS | Environmental impact statement |
| EMA | Environment management accounting |
| EMAS | Eco Management and Audit Scheme |
| EMAT | Economically most advantageous tender |
| EMS | Environmental Management System |
| EPA | Environmental Protection Agency |
| EPEAT | Electrical Product Environmental Assessment Tool |
| EPP | Environmentally preferable purchasing |
| FAA | Federal Highway Administration |
| FEMA | Federal Emergency Management Administration |
| FNCSD | Finnish National Commission on Sustainable Development |
| FRP | Fiber-reinforced polymer (composites) |
| FSC | Forest Stewardship Council |
| GACP | Green Advantage Certified Practitioner |
| GBCA | Green Building Council of Australia |
| GBI | Green Building Initiative |
| GG | Green Globes |
| GhG | Greenhouse gas |
| GRI | Global reporting initiative |
| GS | Green Seal |
| GS | Green Star |
| HC | Hydrocarbon |
| HVAC | Heating, ventilating, and air-conditioning |
| IAQ | Indoor air quality |

(*Continued*)

| **Acronyms** | **Acronym Definitions** |
|---|---|
| IC | Intelligent compaction |
| ICC | International Code Council |
| IE | Industrial ecology |
| IEQ | Indoor environmental quality |
| IESNA | Illuminating Engineering Society of North American |
| IFEN | French Institute for the Environment |
| IgCC | International Green Construction Code |
| iiSBE | International Initiative for a Sustainable Built Environment |
| ILUC | Indirect land use change |
| ISG | Integrated starter generator |
| ISO | International Organization for Standardization |
| KPI | Key performance indicator |
| LANL | Los Alamos National Laboratory |
| LCA | Life cycle assessment |
| LCC | Life cycle costing |
| LCCA | Life-cycle cost assessment |
| LCCI | Life-cycle cost impact |
| LCIA | Life-cycle inventory analysis |
| LCM | Life cycle management |
| LEDO | Lebanese Environment and Development Observatory |
| LEED | Leadership in Energy and Environmental Design |
| LFG | Landfill gas |
| LM | Locally manufactured |
| LOP | Loss of productivity |
| LSDF | Low-sulfur diesel fuel |
| MFA | Material flow analysis |
| MMM | Mining, metals and minerals (industry) |
| MSDS | Material Safety Data Sheet |
| NCEPC | National Committee on Environmental Planning and Coordination |
| NEPA | National Environmental Policy Act |
| NIST | National Institute of Standards and Testing |
| NPDES | National Pollutant Discharge Elimination System |
| ODS | Ozone-depleting substance |
| OHSAS | Occupational Health and Safety Advisory Services |
| OIA | Office of International Affairs |
| ORD | Office of Research and Development |
| OSHA | Occupational Safety and Health Administration |
| PEL | Permissible exposure limit |
| PM | Particulate matter |
| POP | Persistent organic pollutants |
| PV | Photovoltaic |
| PVC | Polyvinylchloride |
| QHSE | Quality, Health, Safety, and Environment |
| RC | Recycled content |
| RCRA | Resource Conservation and Recovery Act |
| RFS | Renewable Fuels Standard |

(*Continued*)

| **Acronyms** | **Acronym Definitions** |
|---|---|
| RR | Rapidly renewable |
| RSM | Responsible Sources Model |
| RSCM | Responsible Sourcing of Construction Materials |
| SA | Sustainability assessment |
| SAFE | Sustainability Assessment by Fuzzy Evaluation |
| SARA | Superfund Amendments and Reauthorization Act |
| SCI | Social cost indicator |
| SCM | Supply chain management |
| SDR | Sustainability development report |
| SEER | Seasonal energy efficiency ratio |
| SFA | Substance flow analysis |
| SFI | Sustainable Forestry Initiative |
| SIM | Sustainability Index Metric |
| SQM | Sustainable quality management |
| SRG | Sustainability Reporting Guide |
| SRI | Solar reflective index |
| SSI | Sustainable Sites Initiative |
| SWPPP | Storm water pollution prevention plan |
| TCO | Total cost of ownership |
| TEPPFA | The European Plastic Pipes and Fittings Association |
| Tg | Teragrams (1 trillion grams) |
| Title 24 | California Code of Regulations—Energy Efficiency Standards for Residential and Nonresidential Buildings |
| TSCA | Toxic Substance Control Act |
| TSP | Trisodium phosphate |
| UKAS | United Kingdom Accreditation Services |
| ULCOS | Ultra-low carbon dioxide steel |
| ULSD | Ultra-low-sulfur diesel (fuel) |
| UNCED | United Nations Conference on Environment and Development |
| UNEP | United Nations Environment Programme |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UNGC | United Nations Global Compact |
| USEEIA | U.S. Energy Efficiency Information Administration |
| USGBC | United States Green Building Council |
| VOC | Volatile organic compound |
| WBCSD | World Business Council for Sustainable Development |
| WCED | World Commission on Environment and Development |
| WEC | World Energy Council |
| WGBC | World Green Building Council |
| WHO | World Health Organization |

*Source:* Yates, J. 2008. *Sustainable Industrial Construction Research Report* 250–11. Austin, TX: Construction Industry Institute. pp. 169–171.

# Appendix B: Countries That Have Ratified the Original Kyoto Protocol Treaty (March 2014)

Afghanistan
Albania
Algeria
Angola
Antigua and Barbuda
Argentina
Armenia
Australia
Austria
Azerbaijan
Bahamas
Bahrain
Bangladesh
Barbados
Belarus
Belgium
Belize
Benin
Bhutan
Bolivia
Bosnia and Herzegovina
Botswana
Brazil
Brunei Darussalam
Bulgaria
Burkina Faso
Burundi
Cabo Verde
Cambodia
Cameroon
Canada
Central African Republic
Chad
Chile
Columbia
Comoros
Congo
Cook Islands
Costa Rica
Cote D'Ivoire
Croatia
Cuba
Cyprus
Czech Republic
Democratic People's Republic of Korea
Democratic Republic of the Congo
Denmark
Djibouti
Dominica
Dominican Republic
Ecuador
Egypt
El Salvador
Equatorial Guinea
Eritrea
Estonia
Ethiopia
European Union
Fiji
Finland
Former Yugoslav Republic of Macedonia
France
Gabon
Gambia
Georgia
Germany
Ghana
Greece
Grenada
Guatemala
Guinea
Guinea-Bissau
Guyana
Haiti
Honduras
Hungary
Iceland
India
Indonesia
Iran (Islamic Republic of)
Iraq
Ireland
Israel
Italy
Jamaica
Japan
Jordan
Kazakhstan
Kenya
Kiribati
Kuwait
Kyrgyzstan
Laos People's Democratic Republic
Latvia
Lebanon
Lesotho
Liberia
Libya
Liechtenstein
Lithuania
Luxembourg
Madagascar
Malawi
Malaysia
Maldives
Mali
Malta
Marshall Islands
Mauritania
Mauritius
Mexico
Micronesia (Federated States of) Monaco
Mongolia
Montenegro
Morocco
Mozambique
Myanmar
Namibia
Nauru
Nepal
Netherlands
New Zealand
Nicaragua
Niger
Nigeria
Niue
Norway

(*Continued*)

Oman
Palau
Panama
Papua New Guinea
Paraguay
Peru
People’s Republic of China
Philippines
Poland
Portugal
Qatar
Republic of Korea (South Korea)
Republic of Moldova
Romania
Russian Federation
Rwanda
Saint Kitts and Nevis
Saint Lucia
Saint Vincent and the Grenadines
Samoa
San Marino
Sao Tome and Principe
Saudi Arabia
Senegal
Serbia
Seychelles
Sierra Leone
Singapore
Slovakia
Slovenia
Solomon Islands
Somalia
South Africa
Spain
Sri Lanka
Sudan
Suriname
Swaziland
Sweden
Switzerland
Syrian Arab Republic
Tajikistan
Thailand
Timor-Leste
Togo
Tonga
Trinidad and Tobago
Tunisia
Turkey
Turkmenistan
Tuvalu
Uganda
Ukraine
United Arab Emirates
United Kingdom of Great Britain and Northern Ireland
United Republic of Tanzania
United States (signed but not ratified)
Uruguay
Uzbekistan
Vanuatu
Venezuela
Vietnam
Yemen
Zambia
Zimbabwe

*Source:* Data from United Nations Framework Convention on Climate Change, *Status of Ratification of the Kyoto Protocol*, Bonn, Germany, http://unfccc.int/kyoto_protocol/status_of_ratification/items/2613.php, 2015.

## REFERENCE

United Nations Framework Convention on Climate Change. 2015. *Status of Ratification of the Kyoto Protocol*. Bonn, Germany. Accessed on June 15, 2015. http://unfccc.int/kyoto_protocol/status_of_ratification/items/2613.php.

# Appendix C: Sustainability in Engineering Design and Construction Questionnaire

## C.1 RESEARCH INTENT DESIGN AND CONSTRUCTION FOR SUSTAINABILITY FOR ENGINEERING AND CONSTRUCTION

The problem to be addressed by the proposed research is to define for engineering and construction industry personnel what sustainability is at the project level with a specific focus on industrial construction projects in the following sectors of the industry: petrochemical, utilities, pulp and paper, power generation, manufacturing and mining. The research will also provide information on commonly used sustainability practices; why they are used; how they are used; and what the potential benefits are, on a project-level basis, of incorporating these practices into construction projects. This topic needs to be addressed so that members of engineering and construction firms in the industrial sector are able to make more informed decisions on whether to implement sustainable practices on their construction projects and to help them determine the economic impact of sustainable project implementation processes. In addition to the economic impact to firms, sustainability has to be analyzed in relation to social and environmental benefits and to provide information on whether the implementation of sustainable practices would have a positive effect on the reputation management of firms.

Analyzing sustainability, as it applies to large-scale construction projects, requires analyzing it from both an environmental and a social impact perspective. The areas in construction directly related to sustainability issues include resource efficiency, sustainable designs and materials, social and community impact of projects, supplier and vendor environmental and social responsibility, environmental impacts of production operations, the environmental footprint of structures, responsible supply chains and procurement, and compliance with government regulations.

The primary purpose of this research is to write a primer on sustainability that will be applicable to the planning, design, and construction of capital investment projects in the industrial construction sector. The primer will provide members of the engineering and construction industry with knowledge on the sustainable practices currently being used on industrial construction projects and why these practices are being implemented. It will also provide information that helps assist members of the E&C industry in making decisions on whether to implement sustainable practices on industrial construction projects.

The objectives of the research are to

1. Define sustainability as it applies to design and construction in the industrial sector.

2. Provide a framework that advances the industry's understanding and implementation of sustainability best practices, and write a sustainable design and construction—industrial construction primer.
3. Investigate whether a metric for sustainability reporting, such as the Leadership in Energy and Environmental Design (LEED) metric system that is used in the building industry, could be developed for the construction industry.
4. Provide recommendations for further research in the area of sustainability in industrial construction that will validate the use of recommended best practices.

The Sustainable Design and Construction for Industrial Construction research project is being funded by the Construction Industry Institute's Research Team (RT) 250, and it is being conducted by the principal investigator, Dr. J. K. Yates, and research assistants at the Ohio University, Athens, Ohio.

**Construction Industry Institute**
**Research Team 250**
***Design and Construction for Sustainability in Engineering and Construction*** **Research Project**
**Sustainability in Engineering and Construction Questionnaire**

**Company Code**

**Please complete the questionnaire and return it to the Principal Investigator. The information provided on this page will be detached from the remainder of the questionnaire and secured for confidentiality (see the attached *Confidentiality Statement* for the process used to maintain confidentiality) and a company code will be added to the survey.**

**Definition of Sustainable Development and Corporate Sustainability in Construction**

For the purpose of the research project the definition for *Sustainable Development* is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" and Corporate Sustainability is defined as "a business approach that creates long-term shareholder value by embracing opportunities and managing risks deriving from economic, environmental, and social developments". The 'Triple Bottom Line' (economic, environmental, and social value) in design and construction includes approaches such as: "design for the Environment, context sensitive designs, value engineering, life-cycle cost analysis, and Leadership in Energy and Environmental Design (LEED) certification for building projects. Sustainable construction techniques include implementing a sustainable design, meeting or exceeding sustainable design specifications, developing strategies to minimize and reuse construction waste and spoils, optimizing asset efficiency, and pursuing the highest level of LEED certification possible" (Constantine Samaras, *Sustainable Development and the Construction Industry - Status and Implementation*, 2004, Carnegie Mellon p. 1).

**INSTRUCTIONS**

Please fill in the information based on your experience related to industrial construction projects, their design, or their development. If you do not know the answers to any of the questions check "Do Not Know". For the questions with check boxes click on the appropriate box. If the check boxes are not visible on your computer put an "X" to the right of the appropriate phrase. To exit a textbox click on the next textbox or another item.

**Part I General Company Information:**

1. Name:
2. Division/Department:
3. Job Title/Position:
4. Name of Firm:
5. Address of Firm:
6. Phone Number:

---

Everything above this point will be removed from the survey to maintain confidentiality.

**Company Code**

7. Major Products/Services:

8. Industry (Check all that apply)

Industrial Con. ☐
Heavy/Highway ☐
Mining/Metals ☐
Power ☐
Manufacturing ☐
Commercial ☐
Building ☐
Petrochemicals ☐
Utilities ☐
Heavy/Highway ☐
Residential ☐
Institutional ☐
Gas Production ☐
Pulp and Paper ☐

9. Type of Company: Private ☐ Government ☐

10. Type of Firm:
Owner ☐
Engineering ☐
Supplier ☐
Design/Build ☐
Contractor ☐
Other ☐
Architecture ☐
(Please State)

11. What percentage of work is performed in the following manner?

Lump Sum
Unit Price
Cost Plus a % Fee
Cost Plus a Fee
Other

12. Countries of Operation:

13. Nature of Ownership/Legal Structure:

Sole Proprietorship ☐
Corporation ☐
Partnership ☐
Employee-Owned ☐
Publically Traded ☐
Do Not Know ☐
Privately Held ☐
N/A or Other ☐

14. Size of company: $ Volume: $ 0–$10 million ☐ $10–$50 million ☐

$50–$100 million ☐ $100–$500 million ☐
$500 million–$1 billion ☐ $1 billion ☐

15. Average Number of Projects Per Year:

1–5 ☐ 5–10 ☐ 10–20 ☐ 20–30 ☐ 30–40 ☐ 40–50 ☐

16. Average size of projects installed cost: $1–$10 million ☐ $10–$50 million ☐
$50–$100 million ☐ $100–500 million ☐
$500 mill.–$1 bill. ☐ Over $1 billion ☐

17. Average Number of Engr./Con. Man Hours Per Project:

1,000 to 5,000 ☐ 5,000–10,000 ☐ 10,000–50,000 ☐
50,000 to 100,000 ☐ 100,000–500,000 ☐ 500,000–1,000,000 ☐
1,000,000 to 5,000,000 ☐ 5,000,000–1 billion ☐ Over 1 billion ☐

18. Number of employees: 0–100 ☐ 100–500 ☐
500–1,000 ☐ 1,000–5,000 ☐
5,000–10,000 ☐ 10,000 to 50,000 ☐
Over 50,000 ☐

**Part II – Corporate Level Sustainability Information** Please select the choice that best describes the approach of the firm to each question:

1. Are environmental considerations and impacts included in the design documents for projects?

**Yes** ☐ **If Yes, on what percentage of projects?** ☐
**No** ☐ **Do Not Know** ☐

Are the considerations due to regulatory compliance or other measures "beyond compliance"?

**Regulatory Compliance** ☐ **Beyond Compliance Measures** ☐

2. Is environmental sustainability considered when determining the expected project life cycle of a capital project including ultimate disposal and dismantling?

**Yes** ☐ **If Yes, on what percentage of projects?** ☐
**No** ☐ **Do Not Know** ☐

**If Yes, please provide examples of environmental sustainability considerations that are included in life cycle analysis.**

3. Are environmental and sustainability social issues evaluated that could impact the successful completion of a project?

**Yes** ☐ **If Yes, on what percentage of projects?** ☐

**No** ☐ **Do Not Know** ☐

**If Yes, when are sustainability social issues evaluated and how?**

4. Is a structured approach used when considering project design and material alternatives that includes sustainability considerations?

**Yes** ☐ **No** ☐ **Do Not Know** ☐

**What types of alternatives are considered?**

5. Does the firm have a corporate strategy on sustainability (overall corporate sustainability program)?

**Yes** ☐ **No** ☐ **Do Not Know** ☐

**If Yes, please briefly describe the corporate sustainability strategy.** ☐

**If No, will one be established in the future?**

**Yes** ☐ **No** ☐ **Do Not Know** ☐

6. What are potential barriers to implementing a successful industrial construction sustainability program? (Check all that apply)

Capital cost concerns ☐
Not required by regulations ☐
Need a practical implementation plan ☐
Need to show a positive rate of return ☐
Potential barrier to competitiveness ☐
Not sure how to do it or measure it ☐
Not sure if it will be profitable ☐
Other ☐ (Please List Below)

7. What are the drivers to the implementation of sustainability development in the Industrial Construction Sector? (Check all that apply)

Owners ☐
Government ☐
Media ☐
Profit ☐
Other ☐
Nongovernmental Organizations ☐
Public Awareness of Sustainability Issues ☐
Competitive Differentiation ☐
Quality of Life for Future Generations ☐
(Please List Below)

8. Do owners provide sustainability guidelines that are followed by the firm during the design and construction of industrial construction projects?

**Yes** ☐ **No** ☐ **Do Not Know** ☐

9. Does the firm participate in corporate Global Reporting Initiatives (GRI)?

**Yes** ☐ **No** ☐ **Do Not Know** ☐

10. Does the firm belong to the Dow Jones Sustainability Index (DJSI)?

**Yes** ☐ **No** ☐ **Do Not Know** ☐

11. Has the firm implemented the ISO 14,000 series of environmental management standards and received certification to them?

**A. Implemented ISO 14,000** ☐ **Not Implemented ISO 14,000** ☐
**Do Not Know** ☐ **N/A** ☐
**B. Certified to ISO 14,000** ☐ **Not Certified to ISO 14,000** ☐
**Do Not Know** ☐ **N/A** ☐

**Part III - Project Level Sustainability Information**

1. On what percentage, or what number of projects, has the firm implemented sustainable development policies?

**Percentage** ☐ **Number** ☐ **Do Not Know** ☐

2. On projects that are managed by the firm what procedures or actions are implemented related to sustainable development?

3. What are the benefits in terms of social, reputation, or economics that resulted from implementing sustainability practices? **Do Not Know** ☐

4. Has the firm benefited economically from implementing sustainability development practices?
**Yes** ☐ **No** ☐ **Do Not Know** ☐

**If Yes, please describe the economic benefits to implementing sustainability development practices.**
**If No, please describe what other benefits the firm has gained by adopting sustainability development practices.**

5. What specific technologies have been implemented during the construction of projects to reduce energy use during construction? **Do Not Know** ☐

6. What processes are being used to recycle unused materials at the end of construction projects?

**Do Not Know** ☐

7. Are any processes being used to sell, or reuse, the material byproducts generated during the construction of industrial projects?
**Yes** ☐ **No** ☐ **Do Not Know** ☐

**If Yes, describe the processes.**

8. Are any local social conditions addressed during the construction of projects?

**Yes** ☐ **No** ☐ **Do Not Know** ☐

**If Yes, which social conditions and how are they being addressed during construction?**

9. Are sustainable alternatives to standard materials considered during the design stage of construction projects (examples of standard materials: concrete, steel, PVC piping, asphalt, wood, paint, etc) to improve life cycle environmental costs of industrial construction projects?

**Yes** ☐ **No** ☐ **Do Not Know** ☐

**If yes, explain what types of alternatives are considered and why they are considered during design.**

10. Does the firm have any standard techniques for measuring the benefits achieved by using sustainable practices on construction projects? (Examples: measuring effluent run-off or measuring noise levels by decibels) **Yes** ☐ **No** ☐ **Do Not Know** ☐

**If Yes what are examples of the types of techniques being used on projects.**

11. Are any new sustainability techniques being implemented during construction that improve resource efficiency such as labor efficiency, equipment efficiency, material resource efficiency, or the training of laborers (Examples: moving soil to a spoil pile on site rather than off-site to reduce energy usage in construction heavy equipment)?

**Yes** ☐ **If Yes, describe the techniques below.**

**No** ☐ **Do Not Know** ☐

12. Are any innovative designs, construction components, or construction practices being integrated into projects that include sustainable components?

**Yes** ☐ **No** ☐ **Do Not Know** ☐

**If Yes what are some examples of the innovative designs, construction components, and construction practices?**

13. Is the firm prequalifying vendors and suppliers on their sustainability practices or social responsibility practices?

**Yes** ☐ **No** ☐ **Do Not Know** ☐

**If Yes, describe the criteria used to prequalify vendors and suppliers.**

14. Are there any government regulations that relate to sustainability practices being followed by the firm on industrial construction projects?

**Yes** ☐ **No** ☐ **Do Not Know** ☐

**If Yes, list significant regulations followed on construction projects?**

15. Are any renewable energy sources being used during the construction of industrial projects?

**Yes** ☐ **No** ☐ **Do Not Know** ☐

**If Yes, describe which types of renewable energy sources are being used on projects.**

16. Are there any techniques, processes, or materials being used during construction to reduce the amount of waste being generated during industrial construction projects?

**Yes** ☐ **No** ☐ **Do Not Know** ☐

**If Yes, describe the types of techniques used to reduce waste generation.**

17. Is more construction waste being recycled into other construction materials, or materials that are reused for other purposes, than on construction projects built before sustainable practices were implemented on projects?

**Yes** ☐ **No** ☐ **Do Not Know** ☐

**If Yes, describe how the waste are being recycled or reused as other materials.**

18. Are any techniques being implemented on construction projects to reduce the amount of pollution generated during construction? (Examples: noise, dust control, or traffic congestion)

**Yes** ☐ **No** ☐ **Do Not Know** ☐

**If Yes, describe the types of techniques used to reduce pollution.**

19. What types of engineering design practices or standards are actively incorporating sustainable practices? **Do Not Know** ☐

20. Do mobilization, or demobilization, processes used by the firm include sustainable practices?

**Yes** ☐ **No** ☐ **Do Not Know** ☐

**If Yes, describe some of the sustainability processes used during mobilization and demobilization.**

21. Does the firm include sustainability considerations during constructability reviews?

**Yes** ☐ **No** ☐ **Do Not Know** ☐

22. Do project execution plans (construction management plans) include a section on sustainability practices?

**Yes** ☐ **No** ☐ **Do Not Know** ☐

23. Does the firm have a method for measuring metrics (quantifying the achievement of sustainable development) that relate to sustainability objectives that are used on construction projects?

**Yes** ☐ **No** ☐ **Do Not Know** ☐

**If Yes, describe the techniques for measuring metrics.**

**Part IV** If there is any additional information you would like to provide that was not covered in the interview please list it below. Are you willing to participate in a phone interview if further clarification is required for the answers you have provided in the survey? **Yes** ☐ **No** ☐

## C.2 DESIGN AND CONSTRUCTION FOR SUSTAINABILITY CONFIDENTIALITY STATEMENT

It is recognized that this research may involve the release of sensitive, or proprietary, information or data by members of the architectural, engineering, and construction industries or owners who hire firms that perform work in the industrial construction sector. Recognizing the need to protect this information and data, and the potential damage the release of such information might cause, the following standards will be used for protecting all of the information and data collected:

1. Keeping confidential any classified data until the originator of such information allows the researcher to handle such information without concern for confidentiality. If the originator does not allow the information to be released, it will remain confidential.
2. The data and information collected will only be used in numerical summaries without identifying the origin of the work. Each survey contains a company code that is listed at the top of the survey, and all of the data will be recorded by the company code, not by company name or any other affiliation that could be used to identify a company.

3. Prescribed administrative procedures will be followed in the identification, storage, and transmittal of information and data. These procedures include storing hard copies of the surveys in a locked filing cabinet that may only be accessed by the principal investigator, Dr. J. K. Yates. The surveys will not be stored online where their security could be compromised by computer hackers. The research assistant will only have access to surveys that are coded by company codes, not surveys containing company names and other company information.
4. The reproduction of information or data will only be done with written approval from the originator.
5. It is understood that the responsibility for safekeeping this confidential information and data will continue beyond the completion of the research project.

The data will only be used for the support of the research team the guidance of the academic researcher, and at no time will the Construction Industry Institute RT 250 members have access to raw, disaggregated data. Any data, or analyses based on the data gathered, that are shared with others or published will represent summaries of data from multiple organizations participating in the survey, which have been aggregated in a way that will preclude identification of proprietary data and the specific performance of individual organizations. Reports, presentations, and proceedings containing statistical summaries of aggregated company data may be used to support research team findings.

If you have any questions concerning the process that will be used to evaluate and protect the surveys, please contact the principal investigator.

*Source:* Yates, J. 2008. *Sustainable Industrial Construction Research Report 250–11.* Austin, TX: Construction Industry Institute, pp. 172–184.

# Appendix D: Sustainability Project Execution Plan–Office Complex, Scottsdale, Arizona*

## D.1 INTRODUCTION

The office complex represented by this case study outgrew its 150,000-ft$^2$ facility in Phoenix, Arizona. The proposed facility should meet the following criteria: (1) be located in the Phoenix metropolitan area (Phoenix, Scottsdale, Paradise Valley, or Tempe); (2) be a 300,000-ft$^2$ office and information technology development building; (3) not exceed a budget of $200 million; and (4) have a sustainable building costing $670.00/ft$^2$ ($7,211.80/square meter).

The managers of the office complex performed a market research study and a cost/benefit analysis to determine whether renovating the existing building or constructing a new structure was a more viable and sustainable option. Based on the cost/benefit analysis, the preferred option was building a new structure on a grayfield site in Scottsdale, Arizona. A consulting firm was hired to prepare an analysis of the local market, and during the analysis they considered the following elements:†

- Climate
- Commercial vacancy rates (26.1%)
- Existing development zones and trends
- Gray-, brown-, and greenfield site construction
- Mass transit system availability
- Number of days of sunlight
- Recruiting base for professionals and recent college graduates
- Staff relocation issues
- Overall quality of life, and the availability of recreational facilities and art galleries

Other considerations were respect for the community and all of its constituencies, ethnic diversity in hiring workers, preserving the natural landscape, and maintaining the ecological balance and native species of the Sonoran Desert.

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* Contributed by Donald McFadden, Lieutenant Colonel, United States army corps of engineers officer, Washington, DC.

† http://www.cbre.us/Asset Library/USOfficeMarketView-Q12012.pdf.

A potential corporate benefit of the project was the enhancement of the reputation of the firm as a leader among green corporations. Building a model office complex using a green and sustainable design would enhance the reputation of the firm. This project would provide the community with a model project for sustainable practices by employing sustainable construction processes such as:

- Ensuring air quality was considered
- Establishing worker training programs for developing vocational skills in the local community
- Hiring local subcontractors and workers
- Implementing noise and erosion control measures to protect and enhance the quality of life for citizens in the community
- Preserving cultural, historical, and archeological resources
- Protecting the community from the negative effects of construction
- Sourcing and purchasing materials locally
- Using an environmental impact statement to help make decisions related to protecting the environment

Community outreach programs focused on Native American and Hispanic communities when awarding contracts and providing employment opportunities. This enhanced goodwill in the community, created trust in the firm for local community members, and helped the firm remain an industry and community leader in sustainability.

The firm formed a contract with a local branch of a national architecture and engineering firm to design the green facility. The NSI/ASHRAE/IES/USGBC Standard 189.1-2014, Standard for the Design of High-Performance Green Buildings was used for this project, and the U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) platinum rating was the sustainability certification pursued for the structure.

## D.2 SUSTAINABILITY PROJECT EXECUTION PLAN IMPLEMENTATION

This appendix the incorporation of the sustainability project execution plan into the construction of the office complex in Scottsdale, Arizona. In many sections of the appendix, there is a summary paragraph highlighting the sustainability considerations for the processes explained in the section.

Figures D.1 and D.2 provide aerial photographs of the project site in Scottsdale. Figure D.1 shows on-site traffic patterns, waste disposal sites, buildings slated for demolition, and the building footprint. Figure D.2 shows the mass transportation system, off-site parking, on-site storage, and offices.

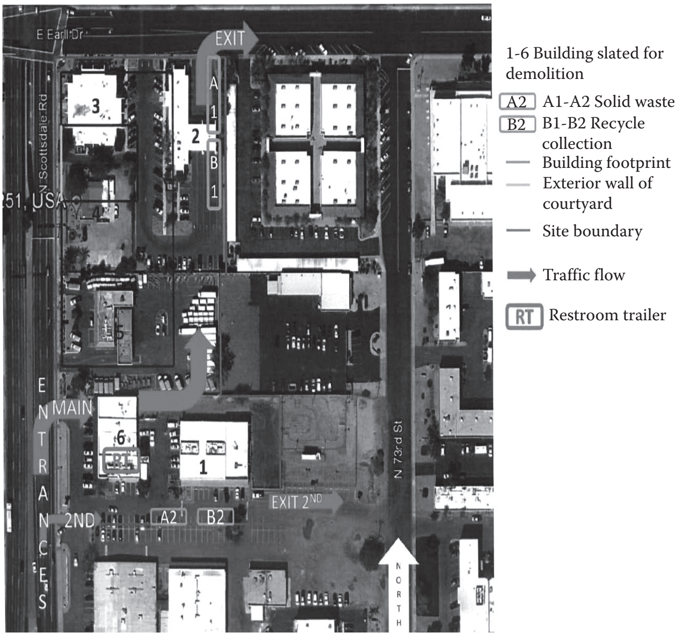

**FIGURE D.1** On-site traffic, waste disposal, demolition, and building footprint. (Courtesy of Donald McFadden.)

**FIGURE D.2** Mass transit, office parking, on-site storage, and offices. (Courtesy of Donald McFadden.)

## D.3 SITE STAGING AND LOGISTICS

This section explains the site staging and logistics for this project.

### D.3.1 Parking

A transportation and traffic plan was developed to validate the considerations listed in this section and to reduce the negative effects of construction on the community. The plan considered current traffic patterns, parking, mass transportation, and leasing space to accommodate parking and material delivery and storage.

#### D.3.1.1 Off-Site Parking

The firm leased an existing, vacant, paved parking lot and provided shuttle service for workers from the parking lot to and from the jobsite. This was an economical solution because of the high vacancy rate for commercial buildings and parking lots in the area.

*Sustainability considerations*: Leasing an existing parking area eliminated the need for temporary paving materials, pavement binders, and geotecstil (nonwoven geotextile used in road construction with high-tensile-strength, antiaging, and anti-acid fabric). It also minimized disruption to the existing site and the production of dust, and eliminated having to remove materials used for a temporary parking lot. Not using street parking benefited the local community, and it minimized the negative effects on local traffic patterns (Figure D.1).

#### D.3.1.2 On-Site Parking Areas

The existing asphalt parking areas on the jobsite were removed in three phases. The first phase was part of the general demolition of buildings three, four, and five. During the second phase, the asphalt surrounding building six was left in place to provide on-site parking until the new building reached 80% completion and on-site parking requirements were reduced. During the second phase, the existing asphalt was removed and the area surrounding building six was repaved and became a permanent parking lot. In phase three, the asphalt area used on site for vehicle movement east of the new building and surrounding building one (after demolition) was removed and replaced with a permanent parking area (Figure D.1).

*Sustainability considerations*: The actions mentioned related to on-site parking areas eliminated the requirement for temporary paving materials, use of pavement binders, and geotecstil fabric. Disruption to the existing site was minimized, and there was no removal of temporary materials or disturbing the site to build a temporary parking lot.

### D.3.2 Temporary Offices

As stipulated in the demolition plan, the buildings were demolished in three phases. During phase one, building two was demolished and this area was used for the primary solid waste and recycling, reuse, and resale collection sites. In phase two, buildings three, four, five, and six were demolished and this area was used for site preparation and construction. In phase three, building one was the last building demolished and before it was demolished it was used as the construction office, a site sanitation facility, and for on-site material storage.

*Sustainability considerations*: Using a phased demolition plan eliminated requirements for a temporary office building, temporary electrical lines, waterlines, and sanitary sewers, and this helped reduce carbon emissions.

### D.3.3 SANITATION FACILITIES

A restroom trailer was leased from a Phoenix firm, and it was directly connected to the city's potable water, sanitary sewer, and electrical systems in building six. The sanitary facilities remaining in building one were also used until late in the project. A sanitary sewer contractor cleaned the sanitary sewers.

*Sustainability considerations*: Using a restroom trailer reduced site disruption because the restroom trailer was leveled using only minor earthwork. It reduced carbon dioxide emissions because it was constructed using a recycled land–sea container, which is reusable, and it was sourced from a local vendor. Since the black and gray water was funneled into the city wastewater treatment stream, it reduced chemical usage and the risk of accidentally spilling waste. The restroom trailer helped promote health and hygiene at the site by providing hot water to the staff and work crews.

### D.3.4 OFFICE AUTOMATION

Office equipment including computers, printers, phones, and facsimile machines were leased from a local vendor in Phoenix, Arizona. The computers used on site had liquid crystal display (LCD) monitors, and all of the printers were duplex printers that used recycled paper. Electronic workstations provided project management personnel with access to construction documents, and this helped reduce the requirement for producing paper copies of documents.

*Sustainability considerations*: Renting computer equipment helped reduce carbon emissions caused by raw material extraction, manufacture, and transportation. Using recycled paper and duplex printers reduced deforestation and its negative impact on the environment.

### D.3.5 OFFICE FURNITURE

Used office furniture was leased locally and used in the temporary office at the jobsite.

*Sustainability considerations*: Leasing office furniture reduced carbon dioxide emissions by eliminating the emissions caused by raw material extraction, transportation, processing, and installation. The reused office furniture was returned to the vendor at the end of the project so that it could be used again.

### D.3.6 OFFICE POLICIES

The standard policies and procedures of the firm were followed during the construction of this project.

## D.3.7 SUSTAINABLE OFFICE PRACTICES

There were four areas where sustainable practices were integrated into office procedures, and they are discussed in Sections D.3.7.1 through D.3.7.4.

### D.3.7.1 Recycle Bins

Single-stream recycling was used for paper, plastic products, and glass, and a recycle bin was available at every workstation. A local recycling contractor was responsible for the removal and management of office-generated metal, paper (shredding of paper), plastic products, and toner cartridges.

*Sustainability considerations*: Recycling reduced the carbon dioxide emissions caused by raw material extraction and disturbing the environment to produce new paper, plastic, and metal products.

### D.3.7.2 Computerized Document Control and Software Standardization

All design documents followed the American Institute of Architects Guidelines for Computer-Aided Design (CAD) Layers and were produced using AutoDesk Design Suite 2013 and AutoDesk REVIT software. Written documentation was created using Microsoft Office Professional Suite 2013, and the project management software for this project was Primavera Project Management ($P^6$), which is an Oracle-based database. All of the computer software programs were standardized on site to ensure maximum use of electronic media, to reduce paper and toner consumption, and so they could be used for process analysis to streamline operations, coordinate just-in-time delivery, and reduce waste.

*Sustainability considerations*: Using compatible computer software programs reduced paper requirements, energy consumption, and demands on landfills. Fewer toner cartridges and chemicals were consumed for printing documents.

### D.3.7.3 Recycled Paper and Toner Cartridges

A vendor who used environmentally safe chemicals and recycled cartridges supplied the toner cartridges. The paper used was 100% recycled paper.

*Sustainability considerations*: Using recycled toner cartridges and paper reduced carbon emissions caused by raw material extraction, manufacture, and transportation. Using recycled paper reduced deforestation and minimized negative impacts on the environment and landfills.

### D.3.7.4 Paperless Sites

Electronic documents and workstations were available to provide electronic access to construction documents, reducing the requirement for paper copies.

*Sustainability considerations*: This reduced carbon dioxide emissions caused by raw material extraction, manufacture, and transportation, and it reduced deforestation and minimized negative impacts on the environment.

## D.3.8 MINIMIZING DISRUPTIONS TO THE LOCAL COMMUNITY

To help maintain goodwill in the community, transportation, storm water, and dust plans were established and they are covered in Sections 3.8.1, 4.1 and 4.1.2.

To help mitigate noise pollution, work arrival hours were between 6:00 AM and 7:00 AM, and departures were between 3:30 PM and 4:00 PM. This helped minimize negative impacts on commuters. The jobsite was in a commercial area with minimal residential encroachment. Work beginning and end times at local businesses varied throughout the community. There were two locations within one block of the construction site of concern: (1) the Cigna Health and medical offices and (2) an apartment complex.

*Sustainability considerations*: Minimizing disruption to the community was achieved by regulating noise levels within specific hours, and noise levels were subject to on-site monitoring.

### D.3.8.1 Mass Transportation

The Valley Metro provides mass transit light rail and bus transportation systems in the Phoenix, Scottsdale, and Tempe areas.[*] Bus transportation was available on two of the routes close to the construction jobsite. Bus route 72 runs north and south on Scottsdale Boulevard with two stops within one block on either side of the construction site. Bus route 29 runs east and west on Thomas Road (Scottsdale Boulevard and Thomas Road intersect near the southwest corner of the construction site) with six bus stops within two blocks of the construction site. Bus routes connect to light rail stations, which made the construction jobsite accessible by mass transportation from anywhere in the Phoenix metropolitan area. As mentioned in Section D.3.1, local parking was leased within a reasonable walking distance of the construction jobsite.

*Sustainability considerations*: Using mass transportation systems helped reduce traffic on surface streets and the amount of pollution, carbon dioxide emissions, and harmful chemicals negatively affecting the environment. In addition, using mass transit systems helped reduce the risks, and stress on, workers commuting to the jobsite.

### D.3.8.2 Material Delivery

Material deliveries were scheduled for two periods each day, one in the morning and one in the afternoon, to avoid conflicting with peak commuter and lunch time traffic. Morning deliveries occurred between 9:00 AM and 11:00 AM and afternoon deliveries between 1:00 PM and 3:00 PM. Material ordering was controlled using supply chain management (SCM) and just-in-time delivery (JITD), both of which helped to ensure sustainable and ethical sourcing of materials.

*Sustainability considerations*: Conscientious delivery scheduling improved the quality of life for members of the local community, helped minimize traffic disruptions, and reduced fuel consumption.

### D.3.8.3 Site Entrance and Traffic Pattern

A one-way traffic pattern was established on site with two entrances and two exits. Both entrances were on Scottsdale Avenue. Traffic entering the jobsite used the northbound lanes to prevent crossing oncoming traffic and to reduce disruptions to the flow of traffic. The two exits included East Earl Drive, with vehicles exiting to the east with

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[*] http://www.valleymetro.org/planning_your_trip/bus_rail_link/.

the flow of traffic, and North 73rd, where vehicles were able to exit either to the north or to the south. The two exits were located in areas where the vehicles exiting the site did not conflict with the flow of traffic or vehicles entering the site. Material deliveries, waste removal, and recycling vehicles entered at the first entrance, and unloading and pickup sites were established in front of, and in the back of, the structure.

*Sustainability considerations*: Delivery scheduling is a quality of life issue for the local community; therefore, deliveries were scheduled to minimize traffic disruption and promote worker safety.

### D.3.9 On-Site Material Storage

On-site material storage and breakdown was provided in two areas (Figure D.2). Site one, identified as the office and material storage area, was used to store materials sensitive to sunlight and temperature. Site two, identified as the lease storage area, was used to store non-sensitive materials. Establishing a central material storage area reduced the movement of materials on site and the risk of accidents. It also facilitated bulk ordering of materials, enabled just-in-time delivery, and provided for secure storage.

*Sustainability considerations*: Loading vehicles to their maximum allowable weight and minimizing the number of trips and disruption to local traffic patterns reduced vehicle emissions. Off-gassing was also reduced (caused by the improper storage of materials and material waste).

### D.3.10 WASTE: RECYCLING, REUSING, SALE, STORAGE, AND REMOVAL

The development of the waste management plan began in the design phase. A waste manager was appointed to coordinate all aspects of waste removal. Two sites, as shown in Figure D.1, were designated as areas for depositing waste to be disposed of through recycling, reuse, resale, or donated to nonprofit organizations. The waste consisted of demolition and construction waste, and recoverable building components resulting from the three phases of building demolition. Having designated waste disposal areas that were routinely monitored helped to ensure the efficient collection and removal of waste and the safe management of site traffic. Site-generated waste was reduced by specifying preassembled and prefabricated building components and using standard material dimensions when designing the building to minimize requirements for cutting materials from standard dimension materials.

The waste management plan considered the disposal of plant and tree matter during the site preparation phase to ensure that plant and tree materials were composted or chipped when it was not possible to reuse them or relocate them to another site. The waste management plan enhanced site safety by placing waste collection areas outside the area of workflow. Waste management for all levels and categories was subcontracted to a local firm. All categories and types of waste and recycling, unless they were reused at the job site, were removed from the site to a transfer station located in Phoenix, Arizona.

The waste management plan included the following:

- Appointing a site waste manager
- Collecting waste materials during all stages of the project

- Composting or chipping waste plants and trees
- Defining waste disposal streams, reducing the amount of waste, reusing materials whenever possible, recycling materials, recovering components and parts, and disposing of materials in landfills
- Developing a hazardous waste spill plan
- Establishing a cost/benefit measurement program
- Establishing a site waste management policy
- Establishing an on-site collection area for reusable materials, materials to be recycled, recoverable components and parts, materials for resale, and materials to be disposed of in landfills
- Segregating materials by categories such as bricks, flooring, timber, concrete, glass, asphalt, packaging, and hazardous waste

*Sustainability considerations*: An efficient waste management plan reduced the impact on landfills, energy consumption, pollution caused by the extraction of raw materials, and manufacturing and transportation of materials.

## D.3.11 SITE UTILITIES

This section addresses the site utility aspect of the sustainability project execution plan.

### D.3.11.1 Electrical Systems

Temporary on-site electrical power was drawn from existing service lines, which were part of the demolished buildings, and the electrical power was metered and distributed throughout the site.

*Sustainability considerations*: Emissions from on-site gasoline and diesel fuel generators were eliminated, which reduced the amount of energy consumed from fossil fuels. But using existing service lines also involved consuming energy generated by commercial power plants.

### D.3.11.2 Communication Systems: Telephone and Cable

Telephone and cable service for telephone and computer communications were drawn from existing service lines in the demolished buildings and distributed throughout the site.

*Sustainability considerations*: Using existing telephone and cable lines eliminated the need to install temporary cables, which reduced disruptions to the jobsite and the surrounding community.

### D.3.11.3 Water Systems

Using existing, on-site waterlines eliminated trips to the jobsite by water trucks for water delivery, dust abatement, and other requirements and reduced traffic congestion and eliminated the requirement for storing water on site.

*Sustainability considerations*: Using on-site water reduced vehicle emissions, fuel consumption, and on-site vehicle movement.

## D.4 SITE ABATEMENT AND SAFETY

This section provides information on site abatement and safety issues.

### D.4.1 Storm Water Pollution Prevention Plan

This section addresses the storm water pollution prevention plan (SWPPP) included in the sustainability project execution plan.

#### D.4.1.1 Erosion Management Plan

The Scottsdale area averages 8 in. of rain per year. However, when it does rain flash flooding creates problems since the amount of precipitation during a single rain event is high and the soil is not able to absorb all of the moisture in the area. An SWPPP was implemented to help manage and control erosion, and it included slope blanketing, silt retention barriers, and ponds to prevent the introduction of silt into creeks, streams, and receiving waterways. The site topography was considered, and on-site and off-site runoff was channeled into a catchment basin. Runoff was contained on site or filtered through silt retention barriers before it left the site. The general erosion control measures used during construction were

- Installing temporary and permanent soil stabilization measures such as mulches, matting, or chemical soil binders
- Minimizing the runoff volume flowing onto the site from adjacent areas
- Minimizing the size of the area disturbed and the time period of disturbance
- Preserving vegetation whenever possible, and quickly replanting disturbed areas
- Reducing the volume and velocity of storm water runoff from the site*

*Sustainability considerations*: Erosion control measures helped preserve the ecological balance of local waterways, protected aquatic life and plants, and prevented eutrophication.

#### D.4.1.2 Dust Management Plan

The dust management plan identified sources of dust and particulate matter such as material handling and storage, haul and traffic areas, and site entrance and exit points. It also located dust receptors such as sensitive areas, schools, areas in the residential community, hospitals, freeways, and roads. Dust-generating activities were identified and categorized as part of site preparation, construction, or demolition. Watering and wind barriers were prescribed by phase. Dust management was a 24 hours a day, 7 days a week process. Water and dust suppressants and temporary stabilization were applied to all unpaved surfaces where vehicles traveled or operated. The weather was monitored to anticipate the effects of wind on the jobsite. Physical barriers restricted vehicle movement into and out of the jobsite, and reusable grizzlies (pressure washers) and wheel

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*Maricopa Country, V.A. 2009. *Drainage Design Manual for Maricopa County Erosion Control: Principles and Practices*, Table 3-1.

washers prevented mud from being transported out of the jobsite and onto city streets. All loaded vehicles leaving the job site were covered with a tarp, and all empty vehicles were cleaned to prevent *track out* or *carry out* of soil. Mechanical sweeping was used if the track out and carry out measures failed, and all incidents of tracking out or carry out were documented.

*Sustainability considerations*: Reducing the generation of dust and particulate matter minimized silting in local waterways and the negative impact on aquatic plants and animals in the region. Dust has a negative impact on the health and standard of living of the local population. In addition, Scottsdale is in a region that relies heavily on air-conditioning. Dust clogs condenser coils and reduces the life span of heating, ventilating, and air-conditioning units.

### D.4.1.3 Noise Management Plan

The noise management plan is covered in Section D.3.8.

### D.4.1.4 Site Security

Site security was provided by a security firm located in Phoenix, Arizona.

*Sustainability considerations*: On-site security protects the environment and workers against accidental spills and chemicals being released due to vandalism and theft.

## D.4.2 SITE RESTORATION

This section discusses the measures used for restoring the site to its natural habitat.

### D.4.2.1 Replanting

The replanting goal was to use 100% plant material native to the Scottsdale area, eliminating the need for on-site irrigation. The landscape was restored to its natural state to help improve the quality of life for the staff working in the building. The Desert Botanical Garden in Phoenix, Arizona and the Arizona Native Plant Society were consulted to determine the best approach to *xeriscape* landscaping (landscaping reducing the need for supplemental water from irrigation) and to help develop a list of applicable species of trees, scrubs, vines, ground cover, succulents, cacti, perennials, annuals, and grasses.[*] All plantings conformed to the Land Division of the city of Scottsdale, and landscape and native plant ordinances.[†]

### D.4.2.2 Existing Plants

The interior courtyard was a test garden to restore endangered plant species to the site. The staff member courtyard location protected the most mature plants and trees. No mature plants were introduced to the site unless they were being relocated as a protection measure. The areas between the building and the street and the parking areas were planted with native grasses and trees. Native trees were selected to provide maximum shade in the parking areas. All of the plants on site scheduled to be retained were protected by barriers or blanketing. Any mature or endangered plant material in the building footprint were carefully removed to an off-site nursery and reused.

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[*] http://www.dbg.org/.

[†] http://www.scottsdaleaz.gov/codes/.

*Sustainability considerations*: Restoration of the site to its natural state protected native plant species, reduced water consumption, and improved the quality of life for staff members by providing a landscaped, outdoor break area.

## D.5 DESIGN CONSIDERATIONS

This section discusses the design considerations included in the sustainability project execution plan.

### D.5.1 Layout of the Structure

The site was five contiguous lots running north to south, parallel to Scottsdale Boulevard. The lot orientation and the building square footage requirements placed the long axis of the building north and south on the lot. The building is C shaped with an enclosed courtyard inside the C. The building architecture is Spanish Revival to blend with the existing architecture of the area and the historical aspects of the local community.

Since most of the building does not have a southern exposure, a greenhouse roof was established on the long axis of the building with skylights providing natural light to the second floor. A series of louvers, located inside the greenhouse roof, allow natural light in while blocking direct sunlight. The louvers are controlled by a series of sensors regulating their position in relationship to the movement of the sun, the amount of light being emitted, and the interior temperature.

The first floor spaces requiring low light have natural light provided by a fiber-optic cable connected to solar collectors on the roof and to lighted walls in the bathrooms, utility rooms, and other areas. Natural light was also maximized by the specification of large windows on the first floor with overhangs to reduce heating, ventilating, and air-conditioning requirements.

*Sustainability considerations*: Given the constraints of the building, the use of innovative methods of funneling natural light to the first floor was an additional method for maximizing the use of natural sunlight and it reduces the energy requirements for lighting and heating, ventilating, and air-conditioning.

### D.5.2 Building Material Evaluation and Specification

The U.S. Department of Commerce, National Institute for Standards and Technology's (NIST's) Building for Environmental and Economic Sustainability (BEES) software was the standard used for evaluating the building materials on this project. The BEES software measures environmental and economic performance. Environmental performance is measured from raw material extraction, manufacture, transportation, installation, use, and recycling to waste management. Cost performance is measured from first cost to future cost. The BEES software allows flexibility when considering and assigning weights to each of the following when making material evaluations:

- Acidification
- Cancerous effects

- Criteria air pollutants
- Ecological toxicity
- Eutrophication
- Fossil fuel depletion
- Global warming
- Habitat alteration
- Indoor air quality
- Noncancerous effects
- Ozone depletion
- Smog formation
- Water intake[*],[†]

The AutoDesk REVIT (Building Information Modeling) computer software program was used to evaluate "material qualities and properties, energy performance, lighting quality, site disturbance, and perform what-if comparisons between various materials and building systems."[††] During the design process, standard material sizes were specified to reduce on-site cutting and loss of material. In addition, prefabricated and preassembled components were identified and specified, and this minimized material loss, on-site noise and dust pollution, and delivery requirements to the jobsite.

## D.5.3 MATERIAL EVALUATION

This section provides information on the different procedures used to evaluate materials for the project.

### D.5.3.1 Building Design and Performance

The NSI/ASHRAE/IES/USGBC Standard 189.1—2014, Standard for the Design of High-Performance Green Buildings was used as the construction standard for this project. The U.S. Green Building Council LEED program was the certification standard.

An independent commissioning agent was hired to ensure that all of the building systems were functioning properly and as designed at the point of occupancy and annually thereafter to ensure proper building performance.

### D.5.3.2 Material Selection

The final determination of building materials was made after an evaluation using the BEES and REVIT data.

### D.5.3.3 Cost/Benefit Analysis

A cost/benefit analysis was performed to evaluate the full life-cycle costs (cradle to grave) of materials from raw material extraction to reuse, recycle, or landfill disposal. This was critical to ensuring long-term energy, and material consumption

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[*] http://www.nist.gov/el/economics/BEESSoftware.cfm.

[†] http://www.cooperhewitt.org/blog/2011/05/05/bees-online-tools-for-evaluating-green-building-materials.

[††] http://usa.autodesk.com/revit/white-papers/

(through maintenance and repair) was minimized throughout the entire life cycle of the building.

### D.5.3.4 Social Cost/Benefit Analysis

A social cost/benefit analysis (SCBA) was performed to provide a framework for evaluating the social costs/benefits of the project and their effects on different groups of people and communities. It is a quantitative tool for evaluating projects to determine whether the total benefits to a group justify the societal costs. This requires a complex set of considerations because costs and benefits accrue to different groups at different points in time. The SCBA, which is similar to an environmental impact statement, started with a definition of the project describing the needs or requirements of the project and the specific project objectives, and then different constraints to the project were considered in the evaluation.

### D.5.3.5 Life-Cycle Assessment

Life-cycle assessment (LCA) techniques consider the cradle-to-grave energy consumed during the construction process. Life-cycle cost assessments include energy consumed to transport raw materials to processing plants, from processing plants to a distributor, from the distributor to the construction site and the transportation energy consumed during the disposal of materials. This technique was used on this project to help assess materials under consideration for use.

### D.5.3.6 Local Material Sourcing

Locally sourced materials were incorporated to the greatest extent possible to reduce the amount of transportation energy consumed, the cost of transportation, and vehicle emissions. The distance from the source is not necessarily a measure of efficiency in transportation. The method of transportation has a large impact on the energy consumed and its cost. The contract clauses pertaining to materials in the prime contract were also applicable to subcontractors for obtaining and specifying materials acceptable according to the BEES from environmentally ethical manufacturers and vendors.

### D.5.3.7 Supply Chain Management

Incorporating supply chain management during the project increased the efficiency of the management of materials, and using local sourcing helped to ensure that materials were delivered on time to keep the production milestones on track. Using supply chain management kept the architect and the engineer, the general contractor, subcontractors, suppliers and vendors, and manufacturers involved in the construction process. The basic management tools used to coordinate supply chain management were bills of materials, specifications (from REVIT), and production schedules from Primavera Project Management ($P^6$).

*Sustainability considerations*: Selection of the most environmentally friendly and sustainable building materials reduced carbon dioxide and energy emissions. This was balanced against a cost/benefit analysis to ensure that operating and building maintenance costs were minimized, and at the end of the useful life of the building materials would be reused or recycled. On-site waste generation and material loss were reduced by specifying standard size materials or by using off-site prefabrication and preassembly for building components. Using project time lines, material delivery schedules, and specification management helped ensure timely delivery of the project without wasting time and effort on having to do rework and also saved energy, transportation costs, and minimized community and traffic disruptions.

### D.5.3.8 Alternative Sustainable Materials

The alternative sustainable materials considered for use in this project are discussed in Sections D.5.3.8.1 through D.5.3.8.6.

#### *D.5.3.8.1* Steel

The building, including the frame, decking, interior and exterior fixtures (sandwich panels), and finishes, was made of recycled steel and assembled on site. Preassembly was accomplished off site when practical.

*Sustainability considerations*: The steel frame could be reused during renovation after the building is no longer being used in its current configuration. Steel is 100% recyclable without losing any of its structural properties.

#### *D.5.3.8.2* Concrete

Concrete containing fly ash was used for the foundations, paving in direct sunlight areas, and floor decking. Concrete was not manufactured on site because of the proximity of Cigna Health and medical offices close to the site.

*Sustainability considerations*: The use of fly ash concrete reduced the environmental impact and energy consumption required to produce concrete.

#### *D.5.3.8.3* Wood Products

Wood products for general construction requirements were from certified sustainable sources. Wood products for interior finishes were sourced from reclaimed wood sources from building demolition.

*Sustainability considerations*: Using sustainable wood sources helped to ensure that the wood was harvested in a sustainable manner. Using reclaimed wood eliminated the requirement for raw material extraction.

#### *D.5.3.8.4* Asphalt

Asphalt surfaces for parking areas used recycled asphalt from the site. The asphalt was used in shaded areas.

*Sustainability considerations*: Using recycled asphalt reduced the requirement for raw material extraction and the impact on landfills to accommodate waste asphalt. Using asphalt in shaded areas reduced the heat island effect on the site, which helps reduce energy requirements for air-conditioning.

#### *D.5.3.8.5* Copper

Copper piping was used for plumbing applications because it is durable, flexible, and safer; resists corrosion; and does not outgas, as is the case with materials such as polyvinylchloride (PVC).

*Sustainability considerations*: Copper is 100% recyclable, is safer than alternative PVC and PEX materials, and has a longer service life than other materials.

#### *D.5.3.8.6* Paints, Finishes, and Adhesives

The paints, finishes, and adhesives used were water based and low volatile organic compounds (VOCs). Constructors and occupants of the building primarily experience the benefits of using low- or no-VOC products.

*Sustainability considerations*: Water-based paints, adhesives, and finishes do not contain formaldehyde, halogenated solvents, mercury or mercury compounds, pigments of lead, cadmium, chromium VI, or their oxides or aromatic hydrocarbons, thus reducing air and environmental pollution.

### D.5.4 Conservation

This section discusses the energy and water conservation techniques used for this project.

#### D.5.4.1 Energy

Based on the temperate climate, and the number of days of daylight in the Scottsdale area, solar voltaic panels were installed on this project. It was not possible to obtain a net zero building in the area of electricity because of the constraints of the jobsite.

*Sustainability considerations*: Solar power provided approximately 33% of the power requirements for the buildings, reducing reliance on the electrical power grid and carbon emissions from coal and fossil fuel power plants.

#### D.5.4.2 Water

A dual water collection and distribution system was used to provide potable water to sinks and drinking fountains and gray water to toilets and urinals for flushing. A storm water collection system collected storm water in a cistern for irrigation in the event of a prolonged drought.

*Sustainability considerations*: The proposed water systems reduced freshwater consumption in an already water-scarce environment.

## D.6 SOCIAL RESPONSIBILITY PLAN

This section provides information on the social responsibility plan, which was part of the sustainability project execution plan.

### D.6.1 Subcontractor Selection

Subcontractors, material suppliers, and other support services were evaluated against sustainable and ethical standards set by the Small Business Administration (SBA) 8A Companies in the Phoenix, Scottsdale, and Tempe areas. The SBA Office at Luke Air Force Base, Phoenix, provided support to validate the certification and standing of all 8A companies prior to the formation of contracts. There was an outreach program to local members of Native American tribes to locate companies, professionals, students, tradesmen, and laborers from the Yava Pai, Pima-Maricopa, and Tohno O'Dham tribes in the Phoenix region of Arizona.

### D.6.2 CULTURAL AND ARCHEOLOGICAL ASPECTS

Even though the archeological, historical, and cultural impact statements addressed cultural and archeological issues, members of Native American tribes (Yava Pai, Pima-Maricopa, and Tohno O'Dham) were asked to participate in the construction process to ensure that Native American equities were protected in the construction process. Similarly, members of the Hispanic community in the Scottsdale area were engaged to ensure their participation in the construction process.

*Sustainability considerations*: The use of SBA 8A and Native American companies whose contract performance and ethics were validated enhanced the development of small businesses in the Scottsdale region. In addition, outreach to the Native American community provided an opportunity for individual employment for professionals with skills supporting the project, provided internship opportunities for college students to help them develop skills and an employment history, and created job opportunities for trades and laborers from the Native American communities. Including members of Native American and Hispanic communities in the construction process helped protect their equities in the historical and archeological issues related to the site and reduced the possibility of objections to the project.

### D.6.3 COMMUNITY IMPACT

The major impact of this project on the local community was to commuter traffic and to businesses in the immediate area. Traffic and environmental considerations were addressed in previous sections. The site was on the south side of a well-developed and upscale business, shopping, and hotel district of Scottsdale. This project facilitated the spread of redevelopment and the expansion of this zone in Scottsdale. There was a high commercial vacancy rate in the area, but this redevelopment project helped increase property values.

# Appendix E: Sustainability Project Execution Plan: Bessemer One, Sentinel Building, Bessemer Office Park, North Carolina Case Study*

## E.1 GENERAL INFORMATION

A sustainability project execution plan for the Sentinel Building, building one in the Bessemer Office Park in North Carolina was created to integrate sustainable construction practices into the project. The project was a $5.5-million, two-story, 25,000 $ft^2$ (2,322 $m^2$) suburban office building on a 2-acre, greenfield coastal site including 8,000 $ft^2$ (743.22 $m^2$) of office renovation.

The building is a structural steel structure, with a concrete slab on grade, wood roof trusses, and asphalt shingles. The shell is clad in Hardie board (concrete) siding, and it has aluminum storefront glazing and aluminum awnings. The site work included clearing and grubbing long leaf pines and scrub underbrush consisting mostly of native wild grasses, wax myrtle, and wild holly. The asphalt parking area and the building footprint required excavating one foot (.3048 m) of unsuitable, wet, and heavily organic soil. In addition, two retention ponds were used for storm water storage.

The primary objectives of the plan were to promote a corporate culture of sustainability, maximize the sustainability of construction operations, and leverage team synergy to create innovative best practices. Achieving these objectives required the participation, input, and commitment of all of the project management team members.

The sustainability project execution plan was designed to provide a framework for implementing sustainable construction practices. The plan incorporated sustainable practices into the project to help minimize the impact of the project on society including practices such as energy conservation, pollution elimination, and waste diversion. The success of this initiative was dependent upon the project manager and project management team members and how they executed the plan.

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* Provided by Parker McGee, national construction manager, timber block, Connelly Springs, North Carolina

The plan provided information on what was to be implemented, how it should be implemented, and why it was being implemented, along with who was responsible for executing each of the items in the plan. This appendix discusses specific aspects of the construction processes, or related logistics, where sustainable methods or practices were integrated into construction operations. Successful implementation of the sustainability project execution plan required collaboration among the project management team members, well-prepared and well-presented quality assurance meetings, disciplined quality control inspections, training meetings with subcontractors and staff members, and daily emphasis on the requirements and purpose of the plan.

References to the appropriate section in the main body of this book pertaining to the items being discussed in each section are also included in the sustainability project execution plan. The book references are cited by section number in parentheses at the end of each section they pertain to in the plan.

### E.1.1 Sustainability through Submittals

Major factors in the sustainability of any project are materials, process elements, and systems. The areas analyzed were durability of materials, embodied energy, pollution from source material extraction and/or manufacturing, transportation costs and pollution, pre-consumer and postconsumer recycled content, and life-cycle cost.

### E.1.2 Document Maintenance

During the execution of the project, the project superintendent maintained a computer file containing copies of the construction sustainability plan daily checklists and completed items were marked on the checklists along with suggestions for improvements, ratings for each subcontractor regarding his or her commitment to sustainable construction, and any evidence of the subcontractors' commitment to sustainability or lack thereof. Samples of the blank forms used for the documents recorded in the computer file are provided in Sections E.14 through E.17. These sample forms contain Form A: Site Sustainability Checklist, Form B: Sustainable Practice Innovation Submittal Form, Form C: Requirement Responsibility Table, and Form D: Subcontractor Sustainable Construction Commitment Rating Form. The information in these forms was reviewed at project completion to revise and update the plan for future projects.

### E.1.3 Competent Person

The Occupational Safety and Health Administration (OSHA) concept of a competent person was modified and adapted for use in this plan. The OSHA defines a competent person as a person authorized to take corrective action and one who is able to recognize existing and predictable hazards. For this project, the designated competent person was the project engineer.

The project engineer was trained on sustainability strategies, he reviewed the sustainability plan prior to construction, and he had the authority to halt operations until a major sustainability deficiency was corrected by the party directed to correct it. The project engineer was responsible for communicating the sustainability plan at meetings and facilitating weekly sustainability meetings. During this project, sustainability practices were enforced as strictly as the OSHA regulations. All of these actions and policies communicated the serious commitment to a culture of sustainability and increased the quality of the execution of the plan (U.S. Department of Labor 2011).

## E.2 SITE STAGING AND LOGISTICS

This section explains the site staging and logistics plan incorporated into the sustainability project execution plan.

### E.2.1 Temporary Parking

After the parking lot footprint was excavated, instead of importing fill for the prebase course subgrade, crushed shell was delivered and placed in this area. This prebase course provided a stable, well-drained, and high-albedo surface for use during construction operations. The white shell, having a solar reflectivity index greater than 0.29, relieved the heat island effect of a dark subgrade. The shell also acted as a filter and stabilizer for the soil during rain events (U.S. Green Building Council 2005, 2014) (Section 11.5).

Next, retention ponds were excavated and the parking lot drainage system was connected to the retention ponds. The measures outlined in the environmental control systems plan were implemented and maintained during the project. The processes outlined in the storm water pollution prevention plan (SWPPP) helped prevent sediment and construction pollution from exiting the limits of disturbance and reaching natural waterways. If sedimentation reaches natural waterways it impacts water flow and the health of fish and increases eutrophication, which destroys wildlife habitat (Environmental Protection Agency 2007) (Section 1.7.13).

An area equivalent to the size of six standard parking spaces closest to the building entrance was allocated as preferred parking to any trade, vendor, or supplier operating a partial zero emissions, zero emissions, hybrid-electric, electric, or biofuel-powered vehicle. These parking spaces were clearly marked with signs indicating their use. All other vehicles, except for vehicles with disability parking permits, had to park in the designated parking area at the center of the jobsite in the rear. Having preferred parking encouraged and rewarded trade partners for upgrading their fleets to vehicles that reduce carbon dioxide emissions and promote environmental benefits that would have an impact beyond this project. The enforcement procedures included a verbal request to move noncompliant vehicles for first offenses, a written warning to the respective supervisor for a repeat offense, and finally a $100.00 fine for the offender and a meeting with the supervisor of the offender for the third offense and any thereafter. This system was supported by subcontractor agreements (U.S. Green Building Council 2005, 2014).

### E.2.2 FIELD OFFICE AND STORAGE

The site plan indicated that the temporary field office would be located in the right rear corner of the parking lot. This reduced the length of the temporary utility lines, clutter in the staging areas. This location also provided sunlight to the temporary field office. The temporary field office was a converted and repurposed shipping container that was equipped with skylights to minimize requirements for electric lighting on sunny days. The air-conditioning equipment was Energy Star rated, and all of the office furniture was used office furniture. Small tools not already in the tool inventory were purchased as used tools. All of the temporary storage structures were repurposed shipping containers. Lighting for the storage containers, and for the temporary non-task building, was provided by light-emitting diode (LED) floodlights powered by individual photovoltaic panels and motion sensors. This requirement reduced energy and grid electricity consumption, increased the use of off-grid energy, and reduced the carbon footprint of the project. The field staff assembled and installed these lights in series or as light trees, as shown in Figures E.1 and E.2. (Sections 7.11, 7.12, 7.15, and 7.22)

### E.2.3 SANITATION FACILITIES

Portable toilets were provided by an outside service that transported the wastewater from the on-site portable toilets to the North Charleston Sewer District Waste Water Reprocessing Facility for reprocessing into potable water. All portable toilets were equipped with hand-washing stations for worker sanitation and health (U.S. Department of Labor 2011).

**FIGURE E.1** Photovoltaic panel for temporary lighting and storage area lighting. (Courtesy of Parker McGee.)

**FIGURE E.2** Light-emitting diode floodlight with battery and motion sensor powered by photovoltaic panel. (Courtesy of Parker McGee.)

### E.2.4 Consumables and Recyclables

All purchases of consumables and office products such as cups, paper towels, printer paper, paper clips, and other items conformed to the Comprehensive Procurement Guidelines of the Environmental Protection Agency (EPA) that specify environmentally friendly products and the minimum recycled content requirements for products. In addition to the purchase of products compliant with the Comprehensive Procurement Guidelines of the EPA, containers for collecting office recyclables were provided inside the field office to assist in achieving the 75% waste diversion goal discussed in Section E.5 (Section 5.9).

## E.3 MATERIALS AND RESOURCE MANAGEMENT

This section discusses the materials and resource management techniques integrated into this project.

### E.3.1 Material Deliveries

There were two site entrances and exits for material deliveries, and they were pseudo-circular driveways with a parking lot in the center. Trucks were directed to enter the site at the main construction entrance and proceed to the unloading area in front of the main entrance or to the laydown yard on the right side of the parking lot. After being unloaded, all of the trucks were directed to proceed to the second construction gate, which was a one-way exit during construction. Signs indicating the proper direction of traffic were installed by the field staff. This minimized the turnaround time for deliveries and helped to reduce carbon dioxide emissions, the amount of time required for moving traffic around the site, and delivery costs.

There was a specific delivery schedule during construction. Trucks delivered materials to the site when they were fully loaded, and returns were made on regularly scheduled trucks leaving the site. These measures reduced the number of material delivery trips to and from the site. All material deliveries occurred in the early morning to help minimize the amount of pollution generated on high-ozone days. For this project, it was assumed that all days were high-ozone days (Sections 3.4.1 and 3.6).

This project observed and enforced a *no idle* policy. All vehicles not in the queue to enter or exit the jobsite, or required to be running to power hydraulics, were required to turn off their engines. This policy helped minimize carbon dioxide emissions, noise pollution, and the life-cycle costs generated on site. The enforcement procedures were a verbal request to turn off vehicle engines for a first offense, a written warning to the respective supervisor of the offender for a repeat offense, and finally a $100.00 fine and a meeting with the supervisor of the offender for the third offense and any thereafter. The field staff installed signs emphasizing the no idle policy. This system was supported by subcontractor agreements (Section 3.4, Section 6.5, and Sections 7.15 and 7.16).

### E.3.2 DELIVERY TRUCK FUEL

Any suppliers or vendors delivering or picking up materials, or any service truck providing waste collection services, using alternate fuel vehicles were entitled to a fuel rebate of $1.00 per gallon based on an estimate of the diesel fuel required to service the project (fuel was over $4.00 per gallon during this project). The superintendent verified and approved all requests for rebates. The intent of this policy was to encourage trade partners to equip their fleet with environmentally responsible vehicles, or to use environmentally responsible fuels, and reward them with a modest subsidy in recognition of their additional costs. This reduced the amount of carbon dioxide generated by the project and encouraged an investment that should have sustainable ramifications far beyond this project. Eligible fuels were hybrid-electric, electric, diesel, natural gas, and biofuels (U.S. Green Building Council 2005, 2014) (Sections 12.3).

### E.3.3 MATERIAL STAGING AND PERSONNEL

This project employed two material handlers who loaded and unloaded materials between the hours of 7:00 AM and 12:00 PM and who were also available for general labor and cleanup in the afternoons. The project engineer trained the two material handlers in simple rigging techniques and allowed them to assist with light hoisting activities (this was possible because this was a non-union job). The material handlers assisted the delivery drivers in unloading trucks and distributing materials at the first staging location at the building entrance, and at the second location at the laydown yard on the right side of the parking lot. These laborers also assisted any trade unloading and distributing materials and tools, reviewed the building and the site to ensure general housekeeping compliance requirements, and assisted with the sorting of recyclables. The intent of this policy was to encourage morning deliveries, decrease truck turnaround times, increase trade productivity, maintain good housekeeping, reduce life-cycle costs, and reduce the number of times materials were handled at the jobsite. The impacts on sustainability were lower carbon dioxide emissions, increased traffic speed and efficiency, improved job safety through cleanliness, and a reduction in the use of fuels consumed in handling materials multiple times (Section 3.6 and Section 6.4).

### E.3.4 Sustainable Supply Chains and Local Sourcing

The contractor considered the sustainability of the supply chain of all vendors and suppliers and their sustainable practices as a critical dimension when awarding contracts. The design professional and the owner selected most materials; therefore, the design professional and the owner limited the range of suppliers. However, the choice of other materials such as concrete form material, shoring, blocking, and temporary bracing were at the discretion of the contractor, and his discretion was exercised in favor of suppliers with verifiable sustainable supply chains. The contractor also evaluated the sustainability of each material using life-cycle cost analysis before awarding a contract. For example, when purchasing form material or other wood products only bids from those vendors who were able to verify the Forrest Stewardship Council certified their products were considered for inclusion in the project.

This is an area where the contractor was able to extend the project's influence beyond the physical constraints of the site and to reward and encourage companies to improve their sustainability and the sustainability of their supply chains. The contractor also evaluated resources based on the distance they were transported to the site. The sustainable construction goal was to ensure that 40% by cost of all building materials were regionally extracted and manufactured. Regional is defined as a circular area around the site with a 500 mi. (804.67 km) diameter. These policies impacted every facet of sustainable development depending on the nature and reach of the material and supply chain (U.S. Green Building Council 2005, 2014) (Section 1.5; Sections 3.5, 3.6, and 3.11; Section 9.6; and Section 11.0).

## E.4 LEAN CONSTRUCTION

This section provides information on the Lean construction techniques used on this project.

### E.4.1 Just-in-Time Delivery

The superintendent scheduled material deliveries following the just-in-time delivery process. Just-in-time delivery is a scheduling method in which material inventories are the minimum quantities necessary for immediate fabrication and installation.

This system minimized the amount of physical space devoted to material storage, the number of times materials were handled, reduced damage to materials, and provided a safer work environment.

### E.4.2 Material Waste Reduction

Whenever possible, the contractor verified that the materials purchased for construction were panelized, prefabricated, or precut to required lengths and dimensions, especially Construction Specification Institute Division Five metals and Division Six wood and plastics. Material takeoffs assumed the minimum of the standard range for each material waste factor to minimize material waste. This supported the project sustainability goal of diverting 75% of the waste stream by minimizing the size of the waste stream, reducing the demand for new materials and associated packaging, and had the added bonus of reducing direct construction costs (Section 7.13).

## E.5 SITE WASTE MITIGATION PLAN

This section explains the procedures outlined in the site waste mitigation plan.

### E.5.1 Clearing Debris and Topsoil

The waste diversion goal for this project was 75%, which means that 75% of all of the waste generated by construction operations was diverted to somewhere besides a landfill. Measures supporting this goal included the following. All trees cut down during the clearing of the site were chipped or mulched on site, and the mulch was reused in locations specified on the landscape plan. Surplus material was offered free of charge to any interested neighbor through the use of signs and a notice board. When there was mulch left at the completion of the project, the leftover mulch was sent to a local biomass electric generation facility or, depending on its quality, to a facility where it was processed into paper pulp.

A similar protocol was followed for topsoil. When there was leftover topsoil, the landscape subcontractor took possession of the remainder and ensured that it was used locally on other projects. This minimized the hauling and subsequent emissions generated by exporting the material by truck to a pit. Reusing organic material reduced the demand on area landfills and helped achieve the project goal of 75% waste diversion (U.S. Green Building Council 2005, 2014) (Section 9.2).

### E.5.2 Resale of Reusable Waste

Another process supporting the project goal of 75% waste diversion involved the returning of unused materials to vendors and the marketing and sale of useable or repurposable materials. Any material that could not be returned but was still new or serviceable was advertised for sale on Internet websites and local notice boards. The material was segregated from other project materials, and assistance was provided to individual purchasers in loading the materials. Materials were delivered by company pickup trucks to locations within a 15 mi. (24.14 km) radius of the site. If any material was not sold, it was donated to a local charity, such as Habitat for Humanity. This policy had a positive impact on the project budget, encouraged interaction with the surrounding community, promoted local commerce, reduced demand for the manufacture of new resources, and reduced pressure on local landfills (U.S. Green Building Council 2005, 2014) (Sections 7.17 and 7.18).

### E.5.3 Recycling

The most important initiative supporting the project goal of 75% waste diversion was the construction of a recycling collection center on the right side of the site, immediately adjacent to the building under construction. The center consisted of several containers, each labeled to allow for the segregation and sorting of waste before the waste was deposited into the containers. Even though the vendor operated a local transfer station, the increased cost to sort the waste justified having personnel sort the materials. One recycling container was used for brick, asphalt, and concrete. A second container was for gypsum products such as drop ceiling tiles and wallboard. The third container was for the collection of steel and other metals. The fourth container was used to collect all other types of recyclable materials, such as plastic products, aluminum cans, glass in assorted colors, newsprint, and cardboard. A small container was available for garbage not appropriate for any of the other four containers, and these items were sent to landfills (Massagee 2012; U.S. Green Building Council 2005, 2014) (Section 1.5; Section 2.7; Sections 7.7, 7.16, and 7.19; and Section 9.3).

### E.5.4 Toxic Spills

During a toxic spill event, the source of the flow of waste was immediately capped unless doing so jeopardized the health and/or safety of any employee. If the spill could not be contained, the job superintendent, or other responsible party, called 911. For all toxic spills, the project manager was notified immediately. Once a spill was contained, the project manager contacted a licensed hazardous waste cleanup and disposal service and made arrangements for cleanup.

Proactive measures to prevent spills required the field staff to inspect the condition of containers with toxic materials in them on a daily basis. Special notes were made of any rusty or deformed containers, and arrangements were made for their disposal or replacement. Twice a day, at the beginning and end of the shift, all vehicles and equipment were checked for leaks. Any equipment needing repair was tagged and locked out or removed from the jobsite. All tagged and locked-out equipment required a fluid collection device to be placed under the leak to prevent the leak from contacting the ground until the vehicle was repaired or removed from the jobsite. The superintendent reiterated this policy at every weekly meeting with the workers and any time the work required the use, transfer, transportation, and/or consumption of toxic materials. The strict observation of this policy was imperative to the successful execution of the SWPPP and the protection of life and health of wildlife, plants, and humans (U.S. Department of Labor 2011).

## E.6 SITE EROSION PLAN AND CONTROL

This section discusses the site erosion plan and erosion control procedures for this project.

### E.6.1 Environmental Site Erosion Plan and Storm Water Pollution Protection Plan

Complete conformance with the environmental site erosion (ESC) plan and storm water pollution protection plan (SWPPP) was a condition of employment. All field staff members were held responsible for the maintenance of all systems and preventing the contamination of natural waterways and off-site storm water collection systems by sedimentation and other pollutants. Special emphasis was placed on the creation and germination of permanent bioswales, and the generous planting of native grasses such as sweet, switch, and Indian for soil stability and filtration. Periodic testing was conducted of the turbidity levels, along with other measures of water quality, of the water exiting the site. Sedimentation in natural waterways impacts water flow and the health of fish and wildlife and increases eutrophication, further destroying wildlife habitat (Environmental Protection Agency 2007) (Section 1.7).

## E.7 PLAN FOR POST-CONSTRUCTION SITE RESTORATION

This section introduces the plans used for post-construction site restoration.

### E.7.1 Parking Islands

All heavy construction equipment, vehicular traffic, and parking were restricted to areas designated as future hardscapes. The landscape plan addressed all other aspects of site restoration, which for this project involved plantings and paving. The only areas requiring restoration by tilling and backfilling were the parking islands. All of these areas were planted with live oaks and azaleas. This required turning the compacted soil within these areas and backfilling the areas with the sand and topsoil generated during the clearing process that had been stored on site. This abated vehicular compaction and reused the original topsoil, increasing soil permeability, and minimized the amount of soil removed from the site.

## E.8 EXTERIOR DUST, PARTICULATE, AND POLLUTION CONTROL

This section provides information on the exterior dust, particulate, and pollution control plan implemented in this project.

### E.8.1 Dust Control

Dust control was achieved through dust supression as explained in Section E.10.1.

### E.8.2 Equipment Particulate and Pollution Control

Specific measures for reducing or eliminating exterior airborne particulate matter and pollution, other than those described in other sections of this plan, apply to the emissions management of heavy and other construction equipment. The contractor included using hybrid-electric or electric earthmoving equipment as one of the primary award criteria in the solicitation and evaluation of site work contractors. The contractor did not award contracts to subcontractors who did not employ particulate filters (scrubbers), mufflers, and catalytic conversion equipment on their heavy construction equipment powered by internal combustion engines. Only the generators using biodiesel fuel were used on this project. The field staff enforced this requirement for the job. This policy helped reduce emissions, noise, and odors (Sections 12.2 and 12.3).

## E.9 COMMUTER TRANSPORTATION PLANNING

This section includes information on the processes used to assist commuter transportation planning for this project.

### E.9.1 Bike Storage

A secure bike rack was located within five standard parking spaces from the entrance of the structure for use by bike and scooter commuters. Workers were encouraged to use zero-fuel transportation or high-mileage scooters to commute to work. This policy was designed to reduce carbon dioxide emissions and traffic congestion both on site and in the surrounding area (U.S. Green Building Council 2005, 2014).

### E.9.2 Carpooling

Ten standard parking spaces, adjacent to the six slots at the entrance for the most fuel-efficient vehicles, were set aside for use by workers commuting in high-occupancy vehicles (HOVs). A HOV is defined as a vehicle transporting a driver and at least one passenger. The enforcement procedures were a verbal request to move noncompliant vehicles for a first offense, a written warning to the respective supervisor for a repeat offense, and finally a $100.00 fine and a meeting with the supervisor of the offender for the third offense and any thereafter. This policy was designed to reduce carbon dioxide emissions and traffic congestion both on site and in the surrounding area. This system was supported by subcontractor agreements (U.S. Green Building Council 2005, 2014).

## E.10 WASTE MANAGEMENT

This section discusses the waste management and mitigation techniques implemented in this project.

**FIGURE E.3** Repurposed intermediate bulk containers for non-potable water storage. (Courtesy of Parker McGee.)

### E.10.1 RAINWATER CAPTURE

Roofs of the temporary field office; storage containers; other temporary structures; and, when available, the roof of the building were temporarily guttered to fill a series of intermediate bulk containers (IBCs), as shown in Figure E.3. The gutters terminated at the top of the container. The containers, as shown in Figure E.3, could be moved with a forklift when they were full. This provided a supply of non-potable water for dust suppression, site mixed grout or concrete, cleanup, plumbing tests, and so on. Capturing rainwater reduced the requirement for purchasing fresh potable water for non-potable water applications, thereby reducing the demand on the municipal water system (U.S. Green Building Council 2005, 2014) (Section 7.16).

### E.10.2 BLACK AND GRAY WATER

Some of the water collected on site was reused for other purposes such as the ones discussed in Section E.2.3.

## E.11 ENERGY MANAGEMENT DURING CONSTRUCTION

This section explains the energy management techniques implemented during construction.

### E.11.1 GREEN POWER

An application for temporary power was submitted to a biomass vender and power was requested to be provided to the site, and ultimately the building, from a 95 MW biomass energy production partnership. This type of power was purchased directly with no further action. The objective of this process was to reduce the carbon footprint by avoiding the use of coal-fired power (Brock 2010; Center for Resource Solutions 2012) (Section 13.5).

### E.11.2 CARBON OFFSETS

The contractor arranged for the purchase of carbon offsets equal to the estimated carbon footprint of this project. The offsets represent a trade between the project and an unknown brokered partner who is operating below the allowable carbon dioxide emissions limit of the firm. Purchasing the excess capacity of the brokered partner enabled the project to be carbon neutral in voluntary observance of the Kyoto Protocol (3Degrees, Inc. 2011) (Sections 5.2 and 5.3).

## E.12 INDOOR ENVIRONMENTAL CONTROL

This section provides information on the indoor environmental control procedures that were part of this project.

### E.12.1 SOURCE CONTROL

There was no smoking at any time, during any stage of construction, inside the building footprint.

All paints, caulks, and sealants within the discretion of the general contractor were Green Seal (GS) certified. Green Seal is a nonprofit organization certifying paint products meeting the requirements of the International Organization for Standardization (ISO) 14024 environmental label standards for the standard GS–11: Paints. This standard was developed to restrict the creation of volatile organic compound emissions and to ban the use of toxic chemicals in paints. The intent of this policy is to protect the health of workers and the final occupants of the building by eliminating toxic chemicals from paint products (U.S. Green Building Council 2005, 2014) (Sections 11.0 and 11.1).

### E.12.2 BUILDING AIR FLUSH

During construction the building was left open for cross ventilation, and before occupancy the building was flushed with fresh air until 14,000 $ft^3$ (396.44 cubic meters) of fresh air for every square foot of floor space had passed through the building at a temperature of at least 60°F (15.6°C) and at a humidity of 60% or lower. During the flushing process and air-conditioning of the building while under construction, return air filters with a minimum MERV eight rating (filters particles over 2.20–3.00 μ with 70% efficiency) were used throughout the building. All heating, ventilating, and air-conditioning returns were sealed prior to system start-up and the seals maintained during the balance of construction (U.S. Green Building Council 2005, 2014) (Section 7.15).

### E.12.3 INDOOR PARTICULATE MATTER CONTROL

During construction of the building entrances, the field staff installed and maintained a cleanable 6-ft-long (1.83 m), or longer, particulate matter trapping system. This system was used to capture particulate matter to prevent it from being tracked into the building. This initiative helped to protect worker health and safety by limiting the amount of pollutants entering the building (U.S. Green Building Council 2005, 2014).

## E.13 SOCIAL IMPACTS

This section summarizes the social responsibility measures used for this project and their impact.

### E.13.1 Training and Education

Ongoing in-house and contracted training workshops were provided for employees on elements of sustainable construction throughout the project. Trade partners were encouraged to attend these workshops. Workshops on Occupational Safety and Health Administration rules and regulations, storm water prevention plans, green building, sustainable materials, energy management, alternate fuels, and air quality management were provided during construction. The training programs were adaptable, and when additional training topics were recognized these topics were added to the programs. The training programs helped to enhance the culture of sustainability and educate project team members on recognizing opportunities for improving sustainable construction operations (U.S. Department of Labor 2011) (Section 7.20).

### E.13.2 Light Pollution

The mitigation of nighttime security light pollution was achieved by adherence to the following guidelines. The site was located in a Lighting Zone Three (LZ3) (Lighting zone three is all other areas besides developed areas of national parks, state parks, forest land and rural areas; areas predominately consisting of residential zoning, neighborhood business districts, light industrial with limited nighttime use and residential mixed use areas; and high activity commercial districts in major metropolitan areas as designated by the local land use planning authority). All lighting was tested and adjusted after installation to ensure that no more than 0.20 ft (.061 m) candles of illumination were shining on the site boundaries. This minimized the disturbance of project-generated light on wildlife and citizens living in close proximity to the site (U.S. Green Building Council 2005, 2014).

### E.13.3 Communication and Neighbor Relations

The creation and maintenance of community, and neighbor, relations was an essential element of the project. Proactively introducing members of the firm to community members, and discussing the project with members of the community, prior to construction helped to establish expectations and indicated to members of the community that their concerns would be addressed during construction. Before construction commenced, a forum was conducted by the project manager for the purpose of involving the immediate community in the nature, intent, and goals of the project.

A large notice board was installed by the field staff at the front entrance of the project to provide announcements about the progress of the project in the form of days to completion, notices on the dates of the greatest noise and disturbance, and phone numbers of project personnel for community members to call and request information and provide their suggestions. The objective of these measures was to relieve community stress regarding the changes the presence of construction activities and the new building created and to foster goodwill (Sections 1.6 and 1.8).

## E.14 FORM A: SITE SUSTAINABILITY CHECKLIST

Name: ______________________________
Title: ______________________________
Date: __________

| | Yes | No |
|---|---|---|
| Previous day sustainability paperwork updated and filed | | |
| SWPPP and ESC measures in good condition | | |
| Enforced parking policies | | |
| Enforced the no idle policy | | |
| Checked recycle center for contamination | | |
| Lay down yard was organized and in good condition | | |
| Received only AM deliveries | | |
| Part-time crew arrived on schedule | | |
| Mulch and topsoil piles tarped and in good condition | | |
| Checked for equipment leaks before worked started in the morning | | |
| Checked for equipment leaks at the end of the work day | | |
| Rainwater capture system in good condition | | |
| Equipment emission control measures were in place and functioning | | |
| Portable toilets were on site and recently serviced and stocked | | |
| Security lighting in good condition | | |
| Notice board current, clean, and in good condition | | |
| OSHA hazard walk completed | | |
| Site housekeeping in good condition | | |
| Completed subcontractor sustainability tool box meeting | | |

Notes: ____________________________________________________________

______________________________________________________________________

______________________________________________________________________

## E.15 FORM B: SUSTAINABLE PRACTICE INNOVATION SUBMITTAL FORM

**Name:** ____________________________________________

**Title:** ____________________________________________

**Date:** ______________________

**Category of sustainable project execution plan to be amended:**

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

**How will the suggested innovation be implemented and in what manner is it sustainable?**

______________________________________________________________
______________________________________________________________
______________________________________________________________
______________________________________________________________

## E.16 FORM C: REQUIREMENT RESPONSIBILITY TABLE

| Responsible Party | Areas of Responsibility |
|---|---|
| Senior estimator | Sustainable supply chain research<br>Regional material sourcing<br>Prefabricated, precut, and panelized materials<br>Recycling<br>Sustainable heavy construction equipment<br>Sustainable equipment<br>Carbon offsets<br>Arrange for GS products<br>Arrange for site sanitation |

(*Continued*)

| Responsible Party | Areas of Responsibility |
|---|---|
| Project manager | Sustainable submittals<br>Long-term scheduling<br>Arrange part-time workers<br>Recycling<br>Green power<br>Training and education modules<br>Conduct prebuild forum<br>Community communication<br>Field community suggestions<br>Manage bonus program |
| Superintendent | Retention pond construction<br>Field office placement and hookups<br>Storage container placement<br>Establish site traffic pattern<br>Establish site loading areas<br>Coordinate the waste diversion plan<br>Light pollution management<br>Recycling<br>Toxic spills<br>Detailed schedule<br>Parking lot construction |
| Field staff (superintendent to perform or delegate) | Manage installation of rainwater capture system<br>Monitor sustainable equipment<br>Check for equipment leaks<br>Manage part-time workers<br>Consumables and recyclables<br>Fuel policy verification<br>Building flush<br>No idle enforcement<br>Parking enforcement |
| Project engineer | Weekly sustainability meetings with workers<br>SWPPP and ESC installation and maintenance<br>Installation of sustainability signage<br>Installation of particulate matter trap system<br>Maintain notice board and signs<br>Competent person<br>Installation of bike storage area<br>Part-time worker training<br>Communicate plan to subcontractors<br>Resale waste materials |

## E.17 FORM D: SUBCONTRACTOR SUSTAINABLE CONSTRUCTION COMMITMENT RATING FORM

**Instructions:**

Complete this form at the end of each phase. Submit an electronic copy with designation of *OK to Pay.*

**Name of company** ____________________
**Trade** ____________________
**Crew identified** ____________________
**Activity duration (days)** ____________________
**Name of evaluator** ____________________
**Date and time** ____________________

**Ratings** 1–10 (10=Perfect)

Owner attitude ____________
Foreman attitude ____________
Crew attitude ____________
Compliance ____________
**Total** ____________

**Deficiencies** Number ____________
Type ____________

Notes
____________________________________________

____________________________________________

**Subcontractor Initiatives**
Number ____________
Type ____________

Notes
____________________________________________

____________________________________________

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# Appendix F: Sustainability Project Execution Plan: HomeWaters (Formerly the Espy Farm) Farm Redevelopment, Spruce Creek, Pennsylvania Case Study*

## F.1 INTRODUCTION

This case study describes the sustainability project execution plan developed for the HomeWaters (formerly the Espy Farm) Club in Pennsylvania. The mission of the HomeWaters Club is to create and preserve fly-fishing sanctuaries for the enjoyment of anglers and to protect trout waters. The owners of HomeWaters work with private landowners, the local community, and future generations to uphold this mission. The HomeWaters Club central campus located in Spruce Creek, Pennsylvania has a view of the Spruce Creek and the Little Juniata River in central Pennsylvania.

This was a site restoration project for the property known as the Espy Farm at the confluence of the Little Juniata River and Spruce Creek in Spruce Creek, Pennsylvania. This project required the removal of existing agricultural structures from a 20-acre (8.09 ha) section of the farm, which was in agricultural production for most of the previous 70 years. The restoration project included grading and contouring the land to more closely resemble the natural contours of the area and improving the storm water management of the land adjacent to a 500ft (152.4 m) section of the Little Juniata River.

Phase One included the restoration and remodeling of a farmhouse on the property, which required repairing the roof, siding, and the main structure. The building gray water waste system needed to be repaired, since it historically discharged waste directly onto a hillside in close proximity to the facility water well. Phase Two involved restoring the farm site, and Phase Three required construction of two hospitality residences on the campus with a new utility infrastructure, a wastewater management system, and landscaping. One of the facilities is a triplex town house, and the other structure is a three-bedroom facility with dining and social rooms for campus and club functions. This plan explains the sustainability practices and products incorporated into the indoor and outdoor environments of the HomeWaters project.

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* Provided by Samuel Seltzer, senior construction project manager, Leonard S. Fiore general contractor, Altoona, Pennsylvania

Incorporating sustainability measures into construction management plans helps to significantly reduce the impact of a construction project on the local, regional, and global environment. Sustainable construction is a combination of many concepts applied to different areas and levels of a construction project. Sustainable alternatives include using natural materials, materials available locally, materials that are could be reused or recycled at the end of the useful life of the project, and materials that are harvested or salvaged from other construction projects or other recycled materials. Another focus area for sustainable construction is using renewable energy sources in all phases of the project. Reducing the use of energy in the extraction or production of building materials and sourcing materials as close as possible to the construction site both reduce energy consumption and pollution during the materials acquisition process. Sustainable construction also measures and gauges the level of pollution and waste in terms of toxicity to the environment and tries to reduce the volume of waste, as well as noise and spatial pollution.

## F.2 DESCRIPTION OF THE SUSTAINABILITY PROJECT EXECUTION PLAN

The project team was functioning at a basic sustainability maturity level, as shown in Chapter 16 in Table 16.2, but they did consider the intermediate and advanced Sustainability Maturity Model in Table 16.3 and investigated where the advanced items in Table 16.3 might be applied to this project. The project team was seeking positive stewardship measures and materials for the site and facilities. Although the project was not seeking Leadership in Energy and Environmental Design (LEED) certification, as part of the ownership and club vision the architect, project manager, and contractor investigated sustainable materials and processes and evaluated sustainable alternatives and practices.

The site was in a rural area with limited availability of resources, which required the transportation of materials and machinery for this project across long distances; therefore, a prime consideration when examining each phase of the execution of the project plan was using on-site materials that could be repurposed or harvested locally.

Protecting the land from the negative impact of construction activities was paramount in all decisions regarding the movement of equipment associated with construction activities and the staging of materials. Contractors and vendors were directed to specific activity areas and shown the areas that were off-limits to any disturbance or compaction. The site usage plan was enforced by the placement of stakes and yellow caution tape marking the site boundaries, and these helped to limit negative environmental impacts to the site.

To assess the overall implementation of the sustainability project execution project plan, the HomeWaters project team members held weekly status meetings every Friday at 3 pm. The Sustainability Maturity Model, shown in Table 16.2, was used as an assessment tool during the status meetings.

The sustainability project execution plan consisted of several sections addressing the major areas of sustainable development, as they applied to the HomeWaters project. Major emphasis was placed on minimizing disturbances to the site, and the waterways adjacent to the site. The materials chosen for the facilities were evaluated for their aesthetic quality and their sustainability. The plan outlines the criteria that help to increase the sustainability rating of the materials and subassemblies in the project. The management of runoff and equipment use were addressed in the plan, as well as the management of waste from construction activities. Plans for recycling demolition by-products for possible reuse on site or shipping to material companies and recycling centers were also included in the plan.

As with all projects having a multi-acre footprint, the social impact of the project on the local community was discussed and plans were developed to address noise pollution. The property and mission of the club are closely intertwined and revolve around the quiet enjoyment of recreational activities by club members and their guests. Minimizing visual distractions caused by viewing materials and construction vehicles, as well as noise and pollution from construction activities, was a priority when making decisions. Local traffic disruptions caused by the project were communicated to the community through updates that were broadcast to the community, and there were opportunities for community member involvement in discussions about the project at the beginning of construction operations.

## F.3 SITE STAGING AND LOGISTICS

Site sustainability addresses specific local environmental issues related to the facilities, surrounding landscape, and watershed. Site sustainability techniques focus on minimizing negative impacts to the construction project site; improving or returning the site to a natural, sustainable state; and constructing a viable storm water management system.

The site protection plan attempted to limit negative impacts of the project on the site and the surrounding area. Limiting soil erosion and runoff; preserving site vegetation, trees, and historical markers; as well as minimizing the amount of dust and noise pollution emanating from the site were all part of the sustainability project execution plan.

### F.3.1 Temporary Parking

The HomeWaters Club was in full operation during the construction project. As a club focused on hospitality and the enjoyment of its members and guests, all of the disruptions or inconveniences caused by construction employee vehicles on the property were avoided if at all possible. The site was minimally compacted, and disturbances caused by the temporary parking of contractor vehicles were mitigated by restricting parking areas. Club guest activity peaked between the hours of 6 am and 8 am as members and guests began preparing for their daily outdoor activities. Members and guests returned to the facilities between 5 pm and 8 pm for dinner and evening meetings. No contractors were allowed to be on the site before 8 am or after 5 pm so they would not disturb club activities.

All contractor parking was limited to a small area to the east of the construction trailer. All parking was limited to the north side of the lane and on the lane itself. No vehicles were allowed to park on the grass on either side of the lane. The grass area was not allowed to be used for the maneuvering of vehicles either prior to or after parking. All new contractors and subcontractors were made aware of the site compaction and parking rules before being allowed to drive a vehicle on site. It was the responsibility of the hiring contractor and the project manager to enforce the site temporary parking rules and to educate all personnel working at the site about the social impact of vehicle operations on club property.

### F.3.2 TEMPORARY EQUIPMENT PARKING

Construction activities required bulldozers, backhoes, excavators, dump trucks, cranes, skid steer loaders, and other heavy construction equipment. It was the responsibility of the contractor and the project manager to schedule the arrival and temporary storage of all of the heavy construction equipment used for the project. No equipment was permitted to be on the construction site during periods of nonuse unless approved by the project manager. For the purpose of this project plan, a period of nonuse was defined as a period of 48 hours of continuous nonuse.

Equipment used for two or more consecutive weeks was permitted to be on the jobsite over a 48-hour nonuse period, such as a weekend, with permission from the project manager. There were no circumstances where a piece of heavy construction equipment was allowed on a grass area or any area not part of the construction site. Parking for nonuse periods, which was approved by the project manager, was on the lane adjacent to the construction trailer, or at the end of the river lane, to the east of the wood chip storage pile. In no case was a construction vehicle operated in the large fields adjacent to the Little Juniata River. Overnight and nonuse vehicle parking was a limited compaction area and never exceeded a perimeter of 40 ft (12.19 m) from the wood chip storage pile.

### F.3.3 TEMPORARY OFFICES

The project required rental and placement of a temporary office for use at the construction site. There was an environmental benefit to having the construction trailer as an office on site as it allowed the contractor to avoid making several trips back and forth on a daily basis from company offices. It also served as a central location for maintaining the plans and documents for the project. The office was available for contractor meetings; meetings with stakeholders for progress updates; storing small equipment, parts, replacement blades, cords, and bits; as well as overnight storage of small construction tools. The site was only minimally compacted by the temporary office.

Use of the construction trailer was limited to 8 am to 5 pm Monday through Friday to reduce the negative social impact of construction personnel arriving and departing from the trailer during peak activity periods for members and guests. The trailer was located on the permanent gravel parking lot at the intersection of River Road and Mountain View Lane. This location did not cause any compaction or disturbance to the environment and did not disrupt club parking or social activities. The construction trailer was removed from the property by April 1 st, the area surrounding the construction trailer was restored to the condition that it was in prior to staging, and all traces of construction activity were removed from the jobsite.

## F.3.4 TEMPORARY SANITATION

The project had two temporary, portable toilets. The units were located next to the temporary construction office and staged in such a manner that the construction trailer blocked the view of the toilet facilities from members and guests of the club. The sanitation facilities were removed from the club property by the first of April.

## F.3.5 CONSTRUCTION MATERIAL STAGING

The site was minimally compacted and disturbed by the staging of construction materials during the project. Large stacks of materials were a visual disturbance and a negative social impact for the club members and guests. Materials were delivered to the site on an as-needed schedule and were kept as organized as possible. The project manager determined the specific placement of materials. No unscheduled materials were permitted on site unless they were loaded directly into the structures.

The HomeWaters sustainable project execution plan stipulated materials to be staged primarily in locations not impacting the site and the club member. It was important to place materials in close proximity to, if not precisely where, they were used. This reduced on-site transportation of materials and the wasting of time, transportation energy, and vehicle emissions.

*Special note on material staging*: There was concern that the two requirements (1) material quantity staging constraints (Lean—staged as needed) and (2) the transportation plan to reduce the number of deliveries of materials might be in conflict with one another. It was less disruptive to the club schedule to have fewer deliveries with each one having a larger volume of materials to be staged. Furthermore, with concern toward lowering the environmental impact of the project from transportation emissions and the overall transportation energy consumption, fewer deliveries with larger quantities of materials were considered to be more sustainable.

## F.3.6 DEMOLITION MATERIALS STAGING

Section F.3.5 covers material staging related to site compaction and visual pollution. The demolition of agricultural facilities created several staging and recycling opportunities for the project.

### F.3.6.1 Materials Sold to Recyclers

Materials such as metal roofing, troughs, metal fencing, and gates were sent to recyclers, and there was a metal dumpster on site for the purpose of accumulating metals for recycling. The dumpster was clearly labeled for metal recycling and was only used for metals. It was the responsibility of the general contractor and the project manager to ensure that all employees used the metal dumpster. The dumpster was on site for ten days during the demolition of the structures. The timing of metal dumpster staging and its removal was coordinated with the demolition contractor and the project manager.

#### F.3.6.2 Materials Sold for Reuse

There was an 8 am meeting each day of the demolition process, and during this meeting the project team validated the identification of each item in the building that was to be sold for reuse. Several of the farm items, which were operational, were sold prior to the demolition of the agricultural structures. These items represented an opportunity to extend the life of the products and to improve the sustainable strategy for the HomeWaters project. In addition to the agricultural products placed back into operation at another location, water tanks, doors, tractor tires, and assorted other items were identified and sold for reuse. These items were clearly labeled and removed during the demolition phase and immediately staged onto a flatbed trailer. The trailer was removed daily and emptied at the storage facility of whoever had purchased the items.

#### F.3.6.3 Materials Recycled and Repurposed on Site

All of the concrete found on the property was cut, broken up, and loaded into a concrete crusher. The concrete was then crushed and used for roads and parking lots on the property. The concrete was staged where it was removed, so there was no impact on any club property not originally under a nonporous concrete surface.

#### F.3.6.4 Hazardous Material Disposal

The project demolition contractor provided a small hazardous material trailer for the agricultural yard that was used for collecting hazardous material. All pressure-treated fencing, products containing asbestos, fuel containers, and tanks were sent to a special hazardous materials landfill. Hazardous materials were not comingled with nonhazardous waste at any time.

### F.3.7 WASTE CONTAINER STAGING

A waste trailer was staged on site during the construction phase of the project. The waste trailer was located adjacent to the construction office trailer, and it was used for construction or food waste during the demolition and construction phases of the project. This trailer was placed on the permanent gravel parking lot and did not in any way negatively affect the HomeWaters club property.

### F.3.8 ON-SITE TRANSPORTATION PRACTICES

On-site transportation was limited to the minimum necessary for construction and materials movement. No one was permitted to use a vehicle for personal transportation on the club property. All unattended heavy construction equipment and vehicles were required to have their engines off (not idling). The goal of the transportation plan was to control and improve air quality by reducing vehicle emissions during construction and to limit the generation of dust on site from workers driving on dirt roads and paths.

## F.4 SITE WASTE MANAGEMENT PLAN

To improve construction and demolition waste practices, the site waste management plan specified how construction materials and debris would be identified prior to the start of construction and how they would be recycled or reused once they were identified by project management personnel. The intent of this part of the sustainability project execution plan was to address the most commonly encountered materials on construction projects. The contractors hired to work on this project were provided with training sessions to ensure that these strategies were properly implemented during construction.

### F.4.1 Waste Wood Products

All waste wood products from the cedar logs, interior lumber, and cedar planks not treated with preservatives were used as fuel in fireplaces on the property. At the end of every day, all wood waste products were collected for staging in the fuel woodpile. Pressure-treated wood was segregated from the other wood and disposed of as a hazardous material.

### F.4.2 Toxic Spill Waste Plan: Spill Prevention and Control Plan

Hazardous waste includes pesticides, paints, cleaners, petroleum products, fertilizers, and solvents. When there was a hazardous material spill, it required immediate control and proper disposal. The project manager and the club manager implemented the control plan. All of the on-site personnel were responsible for spill prevention and containment. The project manager and the club manager identified the appropriate safety measures for the type of waste spilled and coordinated reporting and containment.

Notification of appropriate authorities such as the police, fire department, hospital, or municipal sewage treatment facility was done by the club property manager. The club property manager administered the club property procedures for spill notification. An immediate response to the spill involved containing, diverting, isolating, and cleaning up the spill. The Environmental Protection Agency sheets for Best Management Practices (BMPs) were in the office of the club manager and the construction trailer office. Spill response equipment, including safety and cleanup equipment, was in the office of the club manager.

### F.4.3 Hazardous Waste

All pressure-treated fencing, asbestos-containing products, and fuel containers and tanks were sent to a special hazardous material (Haz Mat) landfill. Hazardous material was not comingled with nonhazardous waste at any time. Hazardous materials have a long list of side effects and harmful consequences for humans and the environment. Items were not assumed to be nonhazardous unless they were identified as such by a demolition hazardous material expert. Sustainable projects seek to remove and contain all hazardous materials from the environment, and it was the stated goal and mission of the project team, and of the HomeWaters Club, to manage this waste in a responsible manner.

## F.5 SITE EROSION CONTROL PLAN

Erosion was limited and contained with the erosion and sediment control (ESC) measures stipulated in the project site-engineering documents. All ESC measures were described and illustrated in detail on the Spring Ridge final plan from the consulting firm in pages 1 through 31. The plans were available in the construction trailer office. The preapproved ESC plans were not modified or adjusted without the signature of the engineer and a state of Pennsylvania official–approved stamp on the plans.

## F.6 PLAN FOR POST-CONSTRUCTION SITE RESTORATION

Contour grading, seeding, and landscaping were illustrated on the final Spring Ridge plan from the consulting firm. No modifications or adjustments to any of the preapproved grading, landscaping, or seeding plans were performed without the signature of the consulting engineer and a state of Pennsylvania official–approved stamp on the plans.

### F.6.1 Storm Water Retention Area

The storm water retention basin area was designed and constructed to slowly filter and release the storm water captured from the storm water drains back into the environment. The engineering of the materials and layering of geotextile and stone was carefully evaluated and studied so that the basin would control the runoff carrying pollutants or causing erosion if it was left to run unimpeded into the Little Juniata River. Vehicles or heavy construction equipment were not allowed to be driven on or through the basin, as it was a non-compaction area and was seeded with a grass seed mixture native to the area.

### F.6.2 Removal of Erosion and Sediment Control Measures

The erosion and sediment control (ESC) measures in place were only removed by direct order of the project manager. The ESC measures were under the jurisdiction of the Huntington County Department of Environmental Protection inspector. All correspondence between the project stakeholders and the Huntington County Department of Environmental Protection inspector involved the HomeWaters project manager.

## F.7 EXTERIOR DUST AND PARTICULATE CONTROL PLAN

This section discusses the procedures for controlling dust and particulates during this project.

### F.7.1 CONCRETE CRUSHING

Dust and particulate control in the concrete crushing operation required a constant supply of water from spray nozzles on the crushers. The team operating the crusher activated the water pumps before starting the crusher and verified that they were operational prior to start-up. It was critical for the suppression of dust to leave the water sprayers on for at least five minutes after shutting down the crusher.

### F.7.2 STONE AND TILE CUTTING

This project required all stone and tile cutting to be performed with a wet saw when the materials were suitable for a wet saw. If the materials and location required the use of a dry saw, an assistant used a hose with a fine sprayer nozzle to wet down the surface materials during cutting operations.

### F.7.3 WOOD CUTTING AND SAWING

All workers used personal protection equipment (PPE) while working on the project site. All sawing activities required the use of eye protection, respirators, and hand and hearing protection. Fine dust and particles from sawing could cause multiple respiratory and eye issues such as swelling and inflammation to more serious injuries.

## F.8 TRANSPORTATION PLANNING

The energy required to transport materials in the construction industry is normally evaluated as the sum of the energy to bring a part or a material from the manufacturer or the supplier to the jobsite. Life-cycle assessment analysis techniques expand this to include a more global perspective of cradle-to-grave assessment. The project leaders analyzed the cost of transportation energy and its footprint from the time a material was first extracted from its source, in all phases of its production, construction, and demolition, to its recycling or final disposal. This life-cycle assessment process provided a superior choice of one product over another, even when the cost, function, and availability assessments indicated that all of the choices were equal.

The following were some of the transportation considerations

- Being aware of and limiting the needless movement of materials
- Not needlessly repositioning equipment
- Not using vehicles for personal transportation
- Turning off all equipment engines when they were not in use

## F.9 WASTEWATER MANAGEMENT PLAN

This section provides information on the wastewater management plan for this project.

### F.9.1 Water Use

All construction activities were required to use the water supply of the main clubhouse. The supply valve for the main water and the pump power supply were unlocked by the club manager or the project manager for the supply line to function.

### F.9.2 Water Recycling

If there were any situations identified where water could be recycled after cleaning, washing, or wetting down operations, the sustainability project execution plan recognized these opportunities and capitalized on the savings. Water is a precious commodity, and it is, and always will be, a priority for HomeWaters to preserve and conserve water whenever and wherever possible.

### F.9.3 Sanitation

Sanitation facilities were provided by the contractor in such a manner as to not be visible while they were on the job site. Section F.3.4 explains the sanitation facilities.

## F.10 ENERGY AND ATMOSPHERE UTILIZATION PLAN

This section discusses the energy and atmosphere processes implemented in this project.

### F.10.1 Temporary Cellular Signal Booster

Due to the remoteness of the construction jobsite, the project team and club manager provided a cellular signal boost repeater for the jobsite that was located in the construction trailer office.

### F.10.2 Water Systems

The jobsite only had access to one water system, as described in Section F.9.1.

### F.10.3 Temporary Heat and Power

Construction activities required temporary heat and power until the utility lines were installed and activated for the new structures. Power generators are noisy, not energy efficient, and cause pollution; therefore, generators were confined to the actual use period and shared by multiple contractors up to the load limit of each generator. Care was taken in the handling of fuel for the generators since spills and leaks might trigger a hazardous spill response. At no time was fuel for the generators stored inside a structure. It was stored at least 20 ft (6.1 m) away from the generators or other heat sources on a flat, level surface. Improper handling of fuel was a major violation of the sustainability project execution plan and was cause for termination.

## F.11 SUSTAINABLE MATERIALS USE PLAN

This section discusses the sustainable materials incorporated into this project.

### F.11.1 Life-Cycle Cost Assessment

A life-cycle cost assessment highlighted options costing more in the construction phase but offering savings in the operation phase. The only way for a designer to realize the best value for the owner was to provide a complete life-cycle cost assessment for all of the components of the project. A life-cycle assessment of the project expands the assessment to include the production, construction, operation, and disposal phases of each component of the project. The sustainability or green assessment of the project materials also included a valuation analyzing the transportation, operational, and embodied energy of each component. See Section F.8 for additional information on life-cycle cost assessments.

### F.11.2 Paints

Sustainable paint products were used for the interior and exterior of the facilities. Sustainable paints have low or no volatile organic compounds (VOCs), are water based, and contain 100% acrylic technology. These products improve indoor air quality, whereas VOCs create greenhouse gases, and the use of no- or low-VOC paint helps the global environment. The project manager and the club manager approved all paint products.

### F.11.3 Siding

All of the exterior siding that was added to the facilities was natural wood, which is preservative free. The primary siding was poplar bark because of its durability. It is natural, sustainable, reclaimable, long lasting (up to 80 years), and maintenance free. Bark House exterior shingle siding is cradle-to-cradle certified at the gold level for material content, recyclability, and manufacturing characteristics (Highland Craftsmen 2010). Natural, split, and untreated cedar was the second option for the exterior siding with the decision on which material to be used being made by the design team. Modern sustainable forestry techniques make cedar an excellent renewable resource for homebuilding. Cedar siding outlasts most other exterior siding materials, and when it reaches the end of its useful life cedar siding is 100% biodegradable (Pacific Cedar Supply–CedarTec 2010).

### F.11.4 Wood Finishes

The Sustainable Forestry Initiative (SFI) is a fully independent agency promoting forest management practices to protect water quality, wildlife, and biodiversity. Chain of custody (COC) is the path of raw materials from an SFI-certified source through processing, manufacturing, and distribution until they form a final product ready to be sold. All products were sourced from companies meeting the SFI–COC standards for responsible forest management. All interior walls in the facilities, soffits, and the underside of porch roofs were constructed from tongue and groove cedar and tongue and groove hemlock. No finish was applied to the wood to eliminate VOCs associated with coatings. Western red cedar and Western hemlock are attractive, all-purpose woods harvested from sustainable forests in the western part of North America.

### F.11.5 Decking, Columns, and Railings

The porch decking on two of the new facilities was natural red cedar, as described in Section F.11.4. No finish was applied to the porch floor decks to eliminate the volatile organic compounds that would be in wood coatings. The third structure being restored had a composite decking material installed on the deck of the covered porch. Red cedar logs were used for interior and exterior railings and columns, and they were sustainably harvested from dead timber in Pennsylvania, Virginia, and Missouri. Transportation energy and life-cycle cost analysis were factored into the wood purchase decision.

### F.11.6 Stone

Stone for exterior applications on porch pillars and foundations was sourced from the stone walls on the club property. The stone walls built during the last 100 years were made from stones harvested from the farm fields and discarded to the sides of the fields. The discarded piles of stones were used as the stone base for all natural stone finishes on the project. There was virtually no energy expended on this product, since there was no transportation or process energy required with the exception of the energy used to cut the stones and to drive a truck 1 mi. (1.61 km) to the edge of the farm fields and 1 mi. (1.61 km) back to the jobsite.

### F.11.7 Aggregate

All base aggregate for the roads and the parking lots was sourced from the crushed concrete generated on the club property. All aggregate used for base material, top dressing of the roads, parking lots, and gravel fill under the slab and along the footers and walls was sourced from the closest supplier and quarry.

### F.11.8 Roads and Parking Lots

The roads and parking lots were not paved on the club property. All of the roads were made of three layers of aggregate and crushed concrete top dressed with a compacted layer of 2 RC aggregate. The use of gravel in these areas improved absorption of rainwater and helped limit storm water runoff, thus decreasing the rapid movement of concentrated chemicals from the roadways directly into the storm water basin.

### F.11.9 Doors

All interior and exterior doors were of alder wood sourced from certified SFI companies. Alder is also eco-friendly since it is a fast growing tree, the trees are replaced when harvested, and SFI loggers are certified to sustainable forestry initiatives.

### F.11.10 TOPSOIL AND FILL

The cut and fill for the site was calculated to limit the amount of fill and topsoil having to be trucked to the jobsite. Costs were reduced by storing the excavated and cleared materials for use later on during the project.

## F.12 MATERIALS AND RESOURCE TRANSPORTATION PLAN

This section explains considerations related to the transportation of materials reviewed when selecting materials for this project.

### F.12.1 MATERIALS

Many of the sources of materials for this project are discussed in Section F.11. Aggregate and stone were harvested and repurposed to minimize transportation energy. All outside sources of materials were rated by their distance from the project site, and preference was given to local suppliers and tradesmen. Several sources were identified in the sustainability project execution plan, and others had credentials such as SFI to be considered for use.

### F.12.2 CONSTRUCTION WORKERS

When considering the cost of the materials in terms of energy requirements for transportation, the cost of the energy required by the installer to commute to and from the jobsite was also be considered. Amish tradesmen in the local area were used for this project because they are excellent craftsmen, and they have a low impact on the energy used to complete installation since they commute together in a one-horse-drawn buggy to the project site. They eat their meals on site and travel home together, all of which has a low impact on greenhouse gas levels.

## F.13 INDOOR ENVIRONMENTAL CONTROL PLAN

Information related to air quality during and post construction is provided in the following sections in this appendix:

- F.3.8
- F.7.1
- F.7.2
- F.7.3
- F.10.3
- F.11.2
- F.11.4
- F.11.5

## F.14 COMMUNITY SOCIAL IMPACT PLAN

This section provides information on the community and social impact of the project.

### F.14.1 IMPACT ON REAL ESTATE VALUES

This project had a positive impact on the Spruce Creek Township. The sustainable use of land, removal of the agricultural concrete structures, and sustainable handling of human and animal waste helped to revitalize the property. The project structures are at the entrance to the Spruce Creek Valley and are a source of pride to the community.

### F.14.2 LIGHT AND NOISE POLLUTION

The real estate development, and use as a residential recreational property, represents a significant reduction in the activity the property experienced as a farm. The property is quieter because there are no longer farm tractors and semi tractor–trailers operating in the area delivering and shipping livestock and feed. The noise and odors associated with livestock were eliminated by the removal of the operating farm.

### F.14.3 COMMUNITY RELATIONSHIPS

The community relationship plan included having a grand opening and open house for the town residents and the township board to thank them for their cooperation during the project. The project manager met with the township board at their monthly meetings during the project to update township officials on the status and progress of the project, and this promoted open communication with township residents.

## F.15 LEAN CONSTRUCTION

This section provides the Lean construction techniques incorporated into this project.

### F.15.1 JUST-IN-TIME DELIVERY

See Section F.3.5, the special note in Section F.3.5, and Section F.8.

### F.15.2 REDUCING WASTE FACTORS

Material takeoff quantities and lengths for the tile, stone, timber, lumber, and composite materials selected produced minimum amounts of scrap and waste. For instance, logs were ordered in 4, 6, and 8 ft (1.22, 1.83, and 2.44 m) lengths all the way up to 18 ft (5.49 m), and each length was specific to each application. Workers checked with the project manager or the construction manager before selecting logs and lumber.

### F.15.3 MATERIAL SEQUENCING

Material sequencing was a complicated part of the project, and it followed the special note in Section F.3.5, Section F.8, and Section F.12.1. There was a commitment to providing sustainable decisions based on the cost of the transportation energy of materials to the site, social disruption to the club and local activities, movement and repositioning of materials on the site, and life-cycle cost of an installed material.

### F.15.4 PROJECT PHOTOGRAPHS

Figures F.1 through F.5 show photographs of the project after its completion.

**FIGURE F.1** HomeWaters main building back porch. (Courtesy of Samuel Seltzer.)

**FIGURE F.2** HomeWaters main building upper deck. (Courtesy of Samuel Seltzer.)

**FIGURE F.3** HomeWaters main building front deck renovation. (Courtesy of Samuel Seltzer.)

**FIGURE F.4** HomeWaters main building front deck side view. (Courtesy of Samuel Seltzer.)

**FIGURE F.5** HomeWaters main building front deck front view. (Courtesy of Samuel Seltzer.)

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