CHAPTER 1. INTRODUCTION

Background

An ever-growing number of agencies, companies, organizations, institutes, and governing bodies are embracing principles of sustainability in managing their activities and conducting business. This approach focuses on the overarching goal of emphasizing key environmental, social, and economic factors in the decision-making process. In many ways, sustainability considerations are not new, since they were often considered indirectly or informally in the past, but recent years have seen increased efforts to quantify their effects and to incorporate them in a more systematic and organized fashion.

There are many reasons for this emphasis on applying sustainability, among which are a growing recognition of how human activity affects the environment (e.g., climate change, ecosystem changes, non-renewable resource depletion) and a better appreciation for considering key societal factors (e.g., land use, access, aesthetics) and economic considerations (net benefits, life-cycle costs) in decision making. Thus, a focus on sustainability reflects a commitment to address the entirety of impacts associated with human existence, not only in monetary terms but also in terms of environmental and social impacts.

The criticality of implementing sustainability has become more acute in light of growing evidence suggesting that human activities are jeopardizing the health of the planet at a global scale and, by extension, the welfare and prosperity of future generations (IPCC 2007; IPCC 2014). For example, greenhouse gas (GHG) emissions, a commonly used surrogate for assessing environmental sustainability, are known to trap heat in the atmosphere and contribute to climate change (see call-out box on next page). The burning of fossil fuels (in manufacturing, electricity production, and transportation) is the largest contributor of GHG emissions, the most prevalent of which is carbon dioxide (CO_2). According to the Environmental Protection Administration (EPA 2013), and using 2011 data as the basis, the transportation industry (including cars, trucks, aircraft, rail, ships, and pipelines) accounts for over 27 percent of all human-caused GHG emissions in the U.S. (see figure 1-1); this is second only to the amount of GHG emissions attributed to the electric power industry. In addition, the construction of transportation facilities also contributes to GHG emissions, which are represented as part of the industry section. As a result, any significant reductions in GHG emissions made in the transportation sector will have an effect on the total amount of GHG emissions in the U.S.

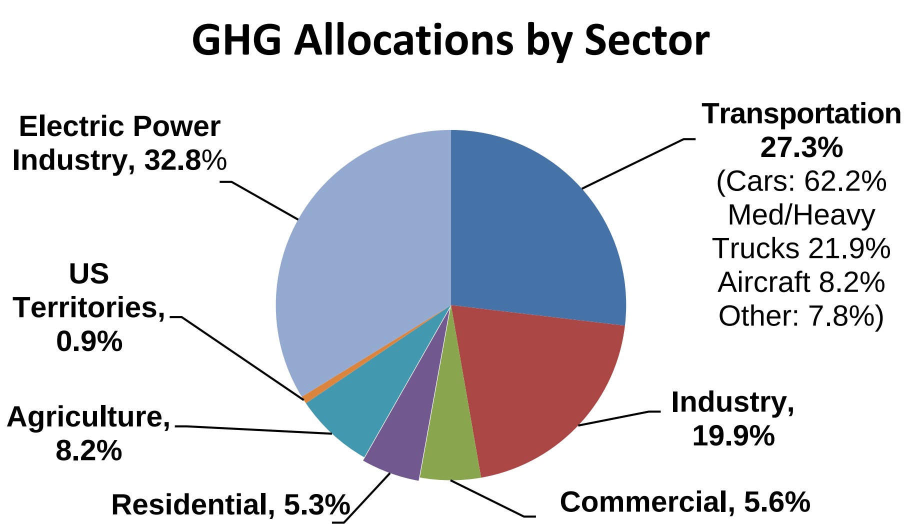

Figure 1-1. GHG emissions by economic sector in the U.S. (EPA 2013).

What is Sustainability?

Most definitions of sustainability begin with that issued by the World Commission on Environment and Development (WCED), often referred to as the *Brundtland Commission Report* (WCED 1987):

> *Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*

This definition is focused on the concept of "needs" and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs. In a shorter version of this, sustainability is often described as being made up of the three components of environmental, social, and economic needs, collectively referred to as the "triple-bottom line."

For many years, the economic component has been the dominant decision factor, but more recent years have seen the growing emergence of both the environmental and social components (even though there are some current limitations associated with their measurement and assessment). A focus on sustainability can then be interpreted in such a way that all triple-bottom line components are considered important, but the relative importance of these factors (and how each are considered) are case sensitive, very much driven by the goals, demands, characteristics, and constraints of a given project. Chapter 2 provides a more detailed discussion on this topic.

GHGs, GWP, and CO_2 e

Gases that trap infrared radiations (heat) in the Earth's atmosphere are referred to as greenhouse gases (GHGs). Once present in the atmosphere, most of these gases do not break down very quickly and thus can contribute to planetary warming over an extended period. Although the presence of GHGs makes our planet livable, excess GHGs produced due to human activity are believed to be contributing to global warming.

GHGs are generated by a variety of agricultural and industrial processes including raising livestock, burning of fossil fuels, solid waste, wood products, and production of portland cement and asphalt. GHGs of greatest concern are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases, with each exhibiting differences in their atmospheric concentration, the amount of time they remain in the atmosphere, and their ability to trap radiation.

Because each individual GHG has a different impact on global warming, it is useful to express them in a single equivalent unit so they can be compared. ***Global Warming Potential (GWP)*** *is a measure of the total energy that a gas absorbs over a period of time (typically 100 years) using CO_2 as the base unit. By definition,* ***CO_2****, which accounts for over 80 percent of all U.S. GHG emissions, has a 100-year GWP of 1. For comparison, according to the IPCC (2013):*

- ***Methane, which*** *accounts for about 10 percent of all U.S. GHG emissions, has a 100-year GWP of 34.*
- ***Nitrous oxide, which*** *accounts for approximately 5 percent of all U.S. GHG emissions, has a 100-year GWP of 298.*
- ***Fluorinated gases*** *[hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride(SF_6)] are synthetic GHGs that are typically emitted in smaller amounts; however, they are potent and sometimes referred to as High GWP Gases. The 100-year GWP of these materials is 140 to 11,700 for HFCs, 6,500 to 9,200 for PFCs, and 23,900 for SF_6.*

Carbon Dioxide Equivalent (CO_2e) *is the metric used to compare emissions from various GHGs based on their GWP. The CO_2e is computed by multiplying the amount of the GHG (usually mass) by its GWP. The GWP values are dependent on the time period considered, with 100-year GWP values commonly used for comparison.*

Additional information on GHGs is available on the EPA website:

http://www.epa.gov/climatechange/ghgemissions/gases.html

Importance of Sustainability in Pavement Engineering

The nation's roadway system is one part of a transportation network that provides mobility and access to a range of users. The roadway network is not only important to the nation's overall economic vitality by providing for the movement of freight and commodities, but it also provides societal benefits as well (e.g., access to schools, services, and work; leisure travel; and general mobility). There are more than 4 million miles of public roads in the United States, which includes 1 million miles of Federal-Aid roadways (FHWA 2013). In 2010, nearly 3 trillion vehicle miles traveled (VMT) were logged over those roadways, consuming more than 169 billion gallons of fuel in the process (FHWA 2010). And, based on 2008 data (the most recent available), the total expenditures for highways in the U.S. was $182.1 billion (FHWA 2010). Taken together, these numbers are staggering and demonstrate the magnitude of the investment in public roadways and the positive impacts of the system in providing movement, access, and mobility.

Pavements are an integral part of this roadway network. Pavements provide a smooth and durable all-weather traveling surface that benefits a range of vehicles (cars, trucks, buses, bicycles) and users (commuters, commercial motor carriers, delivery and service providers, local users, leisure travelers). Given their key role and widespread use, there is a unique opportunity to improve the sustainability of pavement structures with the potential to deliver tremendous environmental, social, and economic benefits. With regard to those components, listed below are just a few examples of how pavements can impact sustainability:

- Environmental component: energy consumption; GHG emissions; noise; air quality; stormwater treatment.
- Social component: safety (fatalities, injuries, property damage); smoothness; vehicle operating costs; GHG emissions; access, mobility; aesthetics.
- Economic: construction, maintenance, and rehabilitation costs; vehicle operating costs; crash costs.

Moreover, the current timing is such that transportation agencies and the general public alike are demanding increased consideration of sustainability principles and practices. This evolution in the role that transportation plays in society is well summarized as follows (AASHTO 2009):

> *Transportation's mission is no longer about just moving people and goods. It's much broader. Transportation fundamentally allows us to achieve economic, social, and environmental sustainability. Transportation supports and enhances our quality of life. As state transportation professionals, we need to model the way toward achieving a sustainable future…Sustainable transportation requires innovative approaches and partnerships like never before.*

Transportation and highway agencies are already making advancements to improve and enhance overall sustainability. Recent years have seen significant strides being made to better align current practices and technologies with more long-term sustainable strategies. In fact, the pavement engineering community has adopted a number of technologies as a way of improving sustainability, such as the increased use of recycled materials in pavement structures, the incorporation of modified binders to increase pavement performance, and the development of rating systems to measure sustainability. At the same time, there is considerable research being conducted on energy use, GHG emissions, and other impacts associated with pavement materials and construction activities to support the development of life-cycle assessment tools.

Nevertheless, there are no universal characteristics or design features that describe a sustainable pavement. Although a general sustainability framework for pavement can be defined, it is context sensitive in that each situation is unique, with specific needs depending on the location, climate, available materials, facility type, required level of service, and so on, as well as on the overall goals of the organization. Furthermore, it is important to recognize that, in some cases, it may even be counterproductive to try to introduce certain features that are thought to be sustainable without a complete assessment; for example, trucking in recycled materials from a great distance when an acceptable local aggregate is readily available could actually have negative environmental consequences.

About This Document

Although significant progress has been made in advancing the sustainability of pavements and pavement systems, there remain a number of complex issues and difficult challenges; a few of these are listed below:

- What are the appropriate sustainability factors to be considered over the life cycle of a pavement (from material extraction to the end-of-life)?
- How do the various materials used in paving applications impact the overall sustainability of the pavement system?
- How can pavements be effectively designed and constructed to meet the specific sustainability needs of a given project?
- How can the pavement community make more sustainable choices, given different facility types (interstates, state highways, local roads/streets), locations (climatic regions, urban vs. rural settings), and paving situations (new alignment, overlays, varying project sizes)? How does one consider trade-offs in the process?
- What methods are available to assess the sustainability of pavement systems?
- What implementation strategies are available for highway agencies to adopt more sustainable pavement practices?

All stakeholders in the pavement community—including owner agencies, designers, material producers and suppliers, contractors, consultants, and the traveling public—are embracing the need to adopt more sustainable practices in all aspects of their work, and are continually seeking the latest technical information and guidance available to help improve those practices. This document has been prepared to provide guidance to the pavement community on sustainability considerations in pavement systems, drawing from and synthesizing the large and diverse body of knowledge that currently exists on pavement sustainability. As such, it provides the currently available knowledge and information for designing, constructing, and maintaining pavement structures more sustainably, and has been structured so that it can adapt to new findings and new information as sustainability considerations continue to develop and evolve.

Scope

It is recognized that sustainability is a system characteristic, and pavements are but one part of the transportation system. It is the scope of this document to focus on pavements and describe how more sustainable pavement systems can be designed and constructed, but this cannot be done in total isolation from the transportation infrastructure system or from other systems in which pavements interact. Moreover, as described in chapter 2, the entire pavement life cycle is covered, from materials to design, from construction through the use phase, and from maintenance/rehabilitation to the end-of-life.

In this document, the pavement is defined as the structure constructed above the native subgrade soil, typically constructed in distinct layers and including compacted or stabilized subgrade, a bound or unbound subbase/base, and the riding surface (see figure 1-2). Broadly, this encompasses pavement structures in a number of different facility types, such as highways, streets, roads, shoulders, and parking areas, but the focus of this document is on pavement structures used in mainline paving and shoulders of highways/roadways. Furthermore, only paved roadways consisting of a semi-permanent surface are considered; this includes asphalt concrete (AC) pavements, which may be constructed with hot-mix asphalt (HMA) or warm-mix asphalt (WMA) technologies, and hydraulic cement concrete (HCC) pavements, which includes portland cement concrete (PCC). For the purposes of this document, all permanent surfaces constructed with asphalt materials are generically referred to as “asphalt” pavements, whereas all permanent surfaces constructed with hydraulic cement materials are generically referred to as “concrete” pavements.

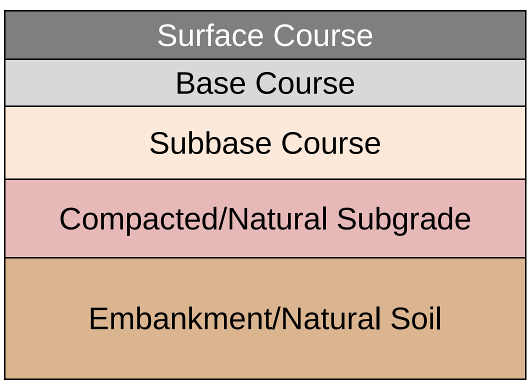

Figure 1-2. Basic components of a typical pavement system.

As a point of clarification, it is noted that there are a number of items related to a highway or roadway that are not included or considered in this document; examples include:

- Planning.
- Capacity.
- Roadway striping.
- Roadway signage and message boards.
- Barriers and other safety appurtenances.
- Ice and snow management.

- Roadside management.
- Drainage structures.
- Bridges and other structures.

Thus, it is reiterated that this document focuses exclusively on the sustainability considerations associated with the pavement structure and pavement materials, and only on those pavements constructed with a semi-permanent surface.

Target Audience

The primary audience for this document is state Department of Transportation (DOT) practitioners, and it is intended for designers, maintenance, material and construction engineers, inspectors, and planners who are responsible for the design, construction, and preservation of the nation's highway network. The overarching goal is to provide state DOT practitioners information to help design, specify, and construct a more sustainable pavement. However, other key stakeholders in the pavement community are also expected to benefit from the information contained in this document, including local roadway agencies, industry (suppliers, producers, contractors, and consultants), academia, and various public interest groups.

Document Overview

This document consists of eleven chapters, including this introductory chapter. The chapters closely mirror the critical phases in the pavement life cycle, allowing users to quickly and easily locate desired information. Each chapter generally follows the same layout, first providing general background information on the topic, then describing sustainability-related issues associated with the topic, followed by strategies or methodologies to address the issues identified, including the consideration of trade-offs. The chapter then concludes with a brief look at future directions and emerging technologies.

A description of the primary chapters in this document is provided below:

- **Chapter 2. Concepts of Pavement Sustainability**. This chapter presents the basic concepts of pavement sustainability and includes definitions, an overview of the pavement life cycle, a framework for considering sustainability issues and trade-offs, and an overview of how sustainability can be quantified and measured.
- **Chapter 3. Materials Considerations to Improve Pavement Sustainability**. Chapter 3 reviews the common materials used in paving applications—including aggregate, asphalt, and cementitious materials—and describes how these materials affect the overall sustainability of the pavement system. The scope is from the materials acquisition until the materials arrive at the construction site, either on grade or at the plant.
- **Chapter 4. Pavement and Rehabilitation Design to Improve Sustainability**. This chapter addresses techniques for improving the sustainability of pavements during the design process, for both asphalt and concrete pavement structures. The focus is on new pavement design and structural rehabilitation, including reconstruction and overlays.
- **Chapter 5. Construction Considerations to Improve Pavement Sustainability**. This chapter briefly reviews the key elements to be considered to enhance the sustainability of construction for both asphalt and concrete pavements. The chapter includes discussions on specifications, construction setup and operations, construction equipment fuel and

emission reduction, management and handling of construction materials, construction quality assurance, and effective lane closures.

- **Chapter 6. Use-Phase Considerations**. Chapter 6 identifies the critical sustainability impacts associated with pavement structures while they are in service, and includes discussions on rolling resistance, safety, noise, heat island effects, lighting, and stormwater management.
- **Chapter 7. Maintenance and Preservation Treatments to Improve Sustainability**. This chapter presents common maintenance and preservation treatments used for asphalt and concrete pavements and describes opportunities for enhancing their sustainability through careful treatment selection, material considerations, treatment timing and application, and treatment design and construction.
- **Chapter 8. End-of-Life Considerations**. Chapter 8 discusses the impacts of the end-of-life (EOL) phase on the sustainability of both asphalt and concrete pavements. Critical issues and strategies for improving the sustainability of this phase of the pavement life cycle are presented.
- **Chapter 9. Pavement Sustainability within Larger Systems**. This chapter presents various sustainability impacts that are not addressed elsewhere in the manual, including such items as aesthetics, historic and cultural identity, multi-modal design, and local ecosystems. These impacts can influence decisions even though they are often not easily quantifiable.
- **Chapter 10. Assessing Pavement Sustainability**. Chapter 10 provides information on measuring pavement sustainability and why it is important. An overview of sustainability rating systems is provided, along with a summary of life-cycle assessment (LCA) and life-cycle cost analysis (LCCA) procedures.
- **Chapter 11. Concluding Remarks**. This chapter offers some concluding remarks by briefly summarizing some of the technologies, innovations, and trends in pavement sustainability and by providing a listing of recommended implementation activities for moving forward.

An appendix is included that presents a glossary of terms used throughout the document. In addition, a stand-alone executive summary has been prepared that summarizes the contents of each chapter and captures the main points and primary considerations.

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