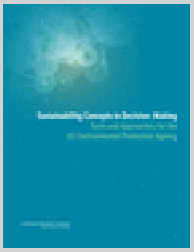

Sustainability Concepts in Decision-Making: Tools and Approaches for the US Environmental Protection Agency

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Sustainability Concepts in Decision-Making

Tools and Approaches for the US Environmental Protection Agency

Committee on Scientific Tools and Approaches for Sustainability

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Science and Technology for Sustainability Program
Policy and Global Affairs Division

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Preface

Several years before requesting this report, the US Environmental Protection Agency (EPA) asked a committee established by the National Research Council to advise it on how to strengthen the analytic and scientific basis of sustainability as it applies to human health and environmental protection.

That committee's report *Sustainability and the U.S. EPA* (referred to as the Green Book), published in 2011, was characterized by some as a document analogous to the "Red Book", which was prepared in 1983 by another National Research Council committee and summarized the framework for risk assessment and risk management (RA/RM) used in the federal government at that time. The Red Book has profoundly influenced the integration of the RA/RM paradigm into EPA's efforts to carry out its mission to protect human health and the environment. The paradigm continued to develop over the years and is now widely used in the agency, as summarized in the 2014 EPA report, *Framework for Human Health Risk Assessment to Inform Decision Making*.[2] Thus, the Green Book was met with the expectation that it would have immediate effects on EPA's risk-management decisions by applying a new framework that was based on sustainability principles and a more holistic assessment of environmental, economic, and social factors in decision-making.

The Green Book recommended a general sustainability framework that incorporated a Sustainability Assessment and Management (SAM) process. Among several recommendations, the Green Book committee challenged EPA to develop a "sustainability toolbox" that would contain a variety of analytic tools needed to implement the SAM process. Some issues remained unresolved in the Green Book, however, including recommendations on which tools or approaches were most applicable and how EPA would match the tools to the diversity of decisions facing the agency.

Those unresolved issues prompted EPA to reach out again to the National Research Council to form the present committee to provide advice on operationalizing specific recommendations in the Green Book. In particular, the Statement of Task (SOT) (see Appendix A) directed the Committee on Scientific Tools and Approaches for Sustainability to address seven key aspects of implementing tools and approaches that would be used in the SAM process, with the specific charge to focus on analytic and scientific tools, methods, and approaches and not recommend specific policy choices. The present report was prepared by the committee in response to that SOT.

EPA recently released Strategic Plan 2014-2018, which stresses the importance of sustainability assessments in pursuing the major goals of the organization. Clearly, there is a strong desire in EPA's current management to incorporate more sustainability considerations or concepts into activities throughout the organization, including the decision processes in the agency's statutory and enforcement contexts.

However, there are indications that a sustainability framework has yet to become broadly integrated into the agency's activities. For example, the 2014 EPA report on risk assessment mentioned above considers "sustainability" as just one of several factors informing EPA's risk-management decisions. Other considerations include laws and regulatory requirements; economic analyses; technologic, political, and public and social considerations, and risk-characterization analyses. This approach is quite different from the Green Book's recommendation that EPA "include risk assessment as a tool, when appropriate, as a key input into its sustainability decision making." Implementation of a sustainability framework after 30

[2]EPA/100/R-10/001 April, 2014.

years of reliance on the RA/RM framework in EPA's decision-making context will probably require some time and considerable effort in the agency.

Interest in sustainability outside EPA continues to grow in intensity. Many US cities tout their "sustainability" plans, and several major cities have had such plans in operation for several years. Private-sector companies have embraced many of the principles of sustainability and established sustainability programs. Some publically traded corporations have a chief sustainability officer who reports to the CEO and has broad powers to influence strategic decisions, such as R&D priorities. Many of the EPA regions have also initiated sustainability programs tailored to their own conditions. Federal agencies are also actively promoting sustainability efforts in their internal operations, partly in response to Executive Order 13514, which required all federal agencies to develop sustainability performance plans. As would be expected, the number of tools, approaches, and methods being used or under development is staggering.

Given that intense interest in sustainability issues in all sectors of society, why haven't the concepts already been integrated into decision-making in federal regulatory agencies, including EPA? That question is beyond the scope of this committee, but it highlights the fact that integration of environmental, economic, and social factors into federal decision-making can face many barriers, such as disagreements over the appropriate spatial and temporal regimes for sustainability analyses. EPA historically has focused primarily on the environmental pillar through the lens of the RA/RM paradigm. It is thus not surprising that most of the efforts related to integration of sustainability into decision-making have taken place within reasonably well-defined geographic boundaries (local or regional studies), economic boundaries (such as corporate supply chains), or time frames (for example, less than two generations). A further barrier to more rapid transition to a sustainability paradigm at the federal level is the difficulty in defining the term *sustainability* so that one can know in advance the definite characteristics of a sustainable society.

In the SOT, EPA requested advice on several issues related to application of tools and approaches to inform decision-making. In brief, these included

- Identification of the most appropriate tools for assessments used to inform EPA decisions.
- Data needs, strengths, and weaknesses of the tools.
- Applicability of the tools to decisions that cross geographic, population, and generational boundaries.
- Utility of the tools for screening purposes to assess the need for more in-depth assessments.
- Uncertainty in results of assessments that use the tools.
- Use of the tools for postdecision evaluation in the sustainability framework.
- Research and development needs to enhance the utility of the tools in incorporating sustainability concepts into decision-making.

The committee found the SOT to be challenging, to say the least, even though it does not call for advice concerning particular decisions that EPA needs to make. Given the plethora of available tools and methods, the large number of sustainability indicators, the wide variety of decisions facing EPA, and the long history of reliance on the risk-assessment framework to inform most EPA decisions, it is clearly beyond the scope of this committee to provide prescriptive advice to EPA on the use of specific tools for specific decisions. In providing broadly applicable actionable advice to EPA on sustainability tools and approaches, the committee recognizes that the incorporation of sustainability into EPA decision-making will be an evolutionary process.

As noted in EPA's risk-framework document, sustainability is among several factors that inform risk-management decisions. The committee hopes, however, that consideration of sustainability factors will play an increasing and more influential role in reaching difficult risk-management decisions, including a much broader assessment of tradeoffs that go beyond the boundaries of a single pillar, within the social, environmental, and economic pillars. The urgency of this journey is unavoidable in the face of several megatrends that are highlighted in the report as well as the inevitable challenges in meeting US and global economic and social needs while managing the risks to current and future generations associated with those actions. It is my hope that this report will provide an additional foundation for EPA's journey in leading the efforts to achieve a more sustainable future.

Finally, I wish to acknowledge the dedicated efforts of my committee members, whose technical expertise and thoughtful deliberations on this complex topic have enriched this report. I enjoyed the opportunity to work with such a distinguished group. I also express my appreciation to the members of the National Research Council project staff for the very effective support they provided to the committee.

Michael C. Kavanaugh, *Chair*
Committee on Scientific Tools and
Approaches for Sustainability

Acknowledgments

The National Research Council assembled a committee of 17 members who had expertise in sustainability science, green design, exposure science, risk assessment, risk management, public health, environmental transport and fate, pollution prevention, energy technologies, life-cycle analysis, agriculture, ecology, economics, sociology, and environmental law. The committee members also had experience with scientific tools and approaches for sustainability that are used in industry and in other countries. (Appendix B contains biographic material on the committee members.)

This report has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council Report Review Committee. The purposes of the independent review are to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We thank the following for their review of this report: Paul T. Anastas, Yale University; Kenneth J. Arrow, Stanford University; Dallas Burtraw, Resources for the Future; Alison C. Cullen, University of Washington; Laura Draucker, World Resources Institute; Daniel C. Esty, Yale Law School; Courtney G. Flint, Utah State University; Al Iannuzzi, Johnson & Johnson; Jerald L. Schnoor, University of Iowa; and Daniel Sklarew, George Mason University.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of the report was overseen by the review coordinator, Armistead G. Russell, Georgia Institute of Technology and the review monitor, Robert A. Frosch, Woods Hole Oceanographic Institution. Appointed by the National Research Council, they were responsible for making certain that an independent examination of the report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of the report rests entirely with the committee and the institution.

Over the course of its study, the committee held two public information-gathering sessions. On November 21, 2013, the committee heard from Lucy Greetham (Ecovative Design, LLC) and Elizabeth Craig, Brooke Furio, Al McGartland, Jeffery Morris, Nena Shaw, E. Ramona Trovato, and James Woolford (US EPA). On December 12, 2013, the committee heard from Kevin Dooley and Sarah Lewis (The Sustainability Consortium), Al Iannuzzi (Johnson & Johnson), Stewart Leeth (Smithfield Foods), Robert Perciasepe (US EPA), Andrew Place (Center for Sustainable Shale Development), Carter Strickland (New York City Department of Environmental Protection), and Ron Voglewede (Whirlpool Corporation).

The committee is grateful for the assistance of the National Research Council staff in preparing this report. Staff members who contributed to the effort are Raymond Wassel, project director; James Reisa, director of the Board on Environmental Studies and Toxicology; Mark Lange, program officer; Kara Laney, program officer; Constance Karras, research associate; Keri Stoever, research associate; Norman Grossblatt, senior editor; Mirsada Karalic-Loncarevic, manager of the Technical Information Center; Radiah Rose, manager of editorial projects; Ricardo Payne, program coordinator; Orin Luke, senior program assistant; and Ivory Clarke, senior program assistant.

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Summary

In its current strategic plan, the US Environmental Protection Agency (EPA) describes a cross-agency strategy to "advance sustainable environmental outcomes and optimize economic and social outcomes through Agency decisions and actions, which include expanding the conversation on environmentalism and engaging a broad range of stakeholders." EPA relies on the definition of *sustainability* provided in Executive Order 13514: "to create and maintain conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations. The definition indicates that the term sustainability is both a process and a goal. In this report, the committee focused its efforts on sustainability as a process, rather than a goal or a prescriptive end state.

The agency's pursuit of sustainability is fully compatible with its mission to protect human health and the environment. The agency recognizes that its traditional approaches to risk reduction and pollution control cannot fully achieve many of its current objectives and long-term and broad environmental- quality goals. Such megatrends as population growth, climate change, the rapid growth of urban areas, greater consumption of natural resources, and continuing demands for existing and newer materials for industrial applications in a global economy are causing EPA and other organizations—both public and private—to re-examine their roles and capabilities.

Sustainability has evolved from a theory and an aspiration to a growing body of practices. The evolution includes a transition from the development of broad goals toward the implementation of specific policies and programs for achieving them and the use of indicators and metrics for measuring progress. Without losing focus on its existing regulatory mandates, EPA is incorporating sustainability considerations into its decision-making about potential environmental, social, and economic outcomes, and this involves shifting from a focus on specific pollutants in an environmental medium (air, water, or land) to a broader assessment of interactions among human, natural, and manufactured systems. For example, a sustainability assessment of drinking water resources would go beyond water quality and quantity and perhaps assess the efficiency of water use, influences of wetlands and other ecosystems, competing societal demands for water (including domestic use and production of food and biofuels), sources of water contaminants (including land use), and climate change scenarios that impact supply and quality. EPA has indicated that it will need to consider the use of a variety of analytic tools and approaches for assessing the potential sustainability-related effects of its decisions and actions in response to complex environmental challenges.

EPA asked the National Research Council to convene a committee to examine applications of scientific tools and approaches for incorporating sustainability considerations into assessments that are used to support EPA decision-making. In response, the National Research Council convened the Committee on Scientific Tools and Approaches for Sustainability. The committee evaluated case studies of the application of sustainability tools, examined a variety of public–private partnerships to assess new methods of collaboration for research and development and problem solving, and assessed emerging issues to identify opportunities for EPA to incorporate sustainability concepts and tools into its decision-making process.

(The statement of task is presented in Appendix A.) More specifically, the committee examined the application of scientific tools and approaches in the Sustainability Assessment and Management process. That process was recommended in the 2011 National Research Council report *Sustainability and the U.S. EPA*[1] and is intended to assess options for optimizing environmental, social (including human health), and economic outcomes in EPA decisions. The committee was not asked to recommend specific policy choices.

TOOLS AND METHODS TO SUPPORT ENVIRONMENTAL PROTECTION AGENCY DECISION-MAKING

The committee found that a broad array of sustainability tools and approaches are potentially applicable in assessing possible environmental, social, and economic outcomes in EPA's decision-making context. **EPA should use concepts of sustainability to strengthen a systems-thinking approach in using current and future tools and approaches, as necessary, to support EPA decision-making. The agency has many opportunities to incorporate sustainability considerations by applying those tools and approaches across the spectrum of its activities and it should do so rapidly.** ***(Recommendation 3.1.1)*** The scientific foundation and analytic tools used to support decisions in a sustainability context will benefit from new knowledge and better use of existing knowledge.

A recent EPA report, *Sustainability Analytics: Assessment Tools and Approaches*, summarizes 22 types of tools and methods for conducting sustainability assessments. Some tools are well developed and have been widely used throughout EPA, and others are in the development stage or have been used in the agency only recently. Box S-1 briefly describes some of the tools included in the EPA report to illustrate the diversity available. EPA has taken a good first step in developing this initial report. It provides a reasonable and informed baseline survey of sustainability tools.

EPA's *Analytics* report discusses the strengths and limits of specific tools, but it does not apply a consistent set of criteria to them. To address that need, the committee developed an approach for rating each tool presented in the *Analytics* report, which involves applying general evaluation criteria that are relevant to the current state of development and use of the tools for sustainability analyses. Examples of the criteria include the adequacy of support for the tool, on the basis of existing methodological references, and the degree of consensus among stakeholders and the scientific community as to how the method should be used. In general, a few tools—benefit–cost analysis, life-cycle assessment (LCA), and risk assessment—are relied on much more than others, and they tend to have solid scientific bases and a long history of use. Those tools are mature and accepted, their use is supported by data, and EPA uses them in its decision processes. The committee considers them to be promising for use by EPA in supporting integrative sustainability decisions, especially in the near term. Although there are differences in the extent to which the tools have been developed and applied in EPA, the committee found no basis for designating any tools to be generally more appropriate than others for sustainability analyses. The choice of a tool should be based on matching of its attributes to the needs for a given situation.

EPA should consider using a consistent set of criteria to evaluate sustainability tools and carry out assessment exercises that are similar to the one conducted by the committee (see Chapter 3) and should periodically update its views and experiences in using relevant sustainability tools. ***(Recommendation 3.2.2)*** That approach would help to identify opportunities for improvement and identify considerations in selecting tools for a particular decision or application. In addition to involving internal users of the tools, EPA may find it valuable to involve external users, for corroboration.

Ecosystem-services valuation is an example of a critical and emerging tool in support of sustainability considerations that needs improvement. EPA has developed a number of programs and guidance documents regarding the valuation of ecosystem services. Using those, the agency can continue to lead the development of the tool. **EPA should continue to develop ecosystem service valuations to characterize, quantify, and monetize the types of ecosystem services that have been difficult to valuate in the past (for example, nutrient cycling and biodiversity).** ***(Recommendation 3.3.4)*** In particular, these

[1]The report is often referred to as the Green Book.

BOX S-1 Various Sustainability Tools and Methods

- *Economic benefit–cost analysis* organizes and evaluates information in a transparent way so that decision makers-can understand the ramifications of their actions. Potential effects (economic and others) are clearly documented, whether or not they can be monetized.
- *Ecosystem-service valuation* measures values associated with changes in an ecosystem, its components, and the services (such as flood protection) that it provides for human well-being.
- *Risk assessment* evaluates the likelihood and magnitude of adverse consequences. It can estimate whether and to what extent public health or the environment will be affected if an action is taken.
- *Exposure assessment* addresses the contact of humans and other organisms with chemical and other stressors.
- *Environmental-justice analysis* evaluates disparities in exposure and risk and other factors for minority populations and low-income populations to inform equitable decision-making.
- *Life-cycle assessment* considers all relevant aspects of a product, process, or system over its life cycle (from raw-material extraction through product manufacturing to end-of-life disposal, reuse, or recycling) to identify unanticipated effects anywhere in the cycle as a result of an action. It does not address actual effects or risks.
- *Environmental-footprint analysis* evaluates human demand on ecosystem services to support a particular level or type of consumption. It can focus on a single indicator (such as carbon) or a specific location (such as a particular ecosystem). It usually is narrower in scope than a life-cycle assessment.
- *Chemical-alternatives assessment* evaluates hazards to human health and the environment that are attributable to the functional alternatives of a specific chemical to guide the selection of safer alternatives and to identify unintended effects.
- *Green chemistry* considers the design of chemicals, products, and processes to eliminate the generation, use, reuse, or disposal of hazardous substances.
- *Green engineering* evaluates and compares environmental effects of processes and products, focusing on the reduction of pollution generation and minimization of human health and environmental risks.
- *Collaborative problem-solving* involves the collaborative engagement of stakeholders to address a particular concern about sustainability considerations.
- *Design charrettes* are a type of stakeholder engagement tool to develop a mutually agreed-on vision of future development, usually regarding land-use planning decisions.
- *Social-impact assessment* assesses possible social effects of an intervention or other action. It often relies on knowledge gained through collaborative efforts.
- *Futures methods* include broad reviews of information, interview of experts, analysis of trends, and development of futures scenarios to anticipate conditions that may affect sustainability outcomes.

efforts should focus on the development and use of ecological production functions that can estimate how effects on the structure and function of ecosystems will affect the provision of ecosystem services that are directly relevant and useful to the public. Where ecological production functions do not exist, research and development efforts should seek to improve and strengthen the current methods on the basis of ecological indicators.

The EPA *Analytics* report indicates that the tools and approaches currently included should not be considered the only ones that could be applied to a particular decision. A potentially important approach that was not included is the consideration of the social cost of carbon. It is an estimate of the monetized damage (usually expressed on a per ton basis) associated with the effects of an incremental increase in greenhouse gas (GHG) emissions and based on a particular climate-change scenario at a particular point in the future. It allows government agencies to evaluate and incorporate the social benefits of reducing GHG emissions as part of the development of ways to mitigate climate change. **Given the prominence of climate-change mitigation issues for EPA and the fact that the estimation of the social cost of carbon focuses explicitly on future benefits and costs of current decisions—an important component of sustainability—EPA should include it in its *Analytics* report in the near future. *(Recommendation 3.2.3)***

EPA should develop guidelines for preparing a sustainability assessment that is analogous to its report *Guidelines for Preparing Economic Analyses*.[2] ***(Recommendation 3.3.1)*** That could be accomplished, particularly in the near term, by adding a chapter to the existing guidelines that addresses sustainability tools and their inclusion in benefit–cost assessments. It will be important for EPA to identify a home for the responsibility to maintain and update the guidance on the use of sustainability tools.

APPLYING SUSTAINABILITY APPROACHES TO ENVIRONMENTAL PROTECTION AGENCY DECISION-MAKING

Decision-making and most other activities undertaken by EPA are driven by congressional mandates, presidential directives, and voluntary or discretionary initiatives stemming from policy priorities. The committee evaluated case studies and other examples of leading sustainability practices to illustrate the use of sustainability tools in a variety of agency and non-EPA activities. Some tools were used at a screening level, and others were applied with more quantitative rigor and depth.

Sustainability Thinking

On the basis of the case studies, the committee found that EPA could incorporate sustainability considerations into a wide variety of its activities, including ones that are driven by legal requirements. For example, through its Design for the Environment (DfE) program, the agency joins with manufacturers to apply collaborative problem-solving and various screening-level and quantitative analytic tools (such as chemical-alternatives assessments and LCAs) to help buyers to identify products that perform well and are cost-effective and relatively safe for the environment. Although the DfE program is independent of the Toxic Substances Control Act (TSCA), it uses many of the same tools. The goal of determining whether alternative chemicals are safe for the environment augments the goal of the pre-manufacture notice (PMN) evaluations that are required under TSCA, but the goals of assessing cost effectiveness and performance go beyond the TSCA evaluations. The lessons learned from the DfE program could be applied to the PMN process as it evolves. **Before considering the requirements and constraints relevant to a particular activity, EPA should use a systems thinking approach for incorporating sustainability concepts and applying the appropriate tools, at least at the screening level or in identifying alternative actions.**[3] ***(Recommendation 4.1)*** The applicability of the tool depends on the context of the problem.

A case study on site remediation (see Chapter 4) illustrates how consideration of the sustainability pillars (social, environmental, and economic dimensions) can be incorporated into the application of specific selection criteria used for remedy selection. LCA was used to evaluate remediation alternatives by considering GHG emissions, water pollution effects (eutrophication), air pollution effects (particulate matter emissions), and natural-resource depletion (water consumption) related to each remediation alternative. Economic and social factors included cost effectiveness of the remedy and its effects on the local community, such as increased traffic associated with transporting materials to the site.

For every major decision, EPA should incorporate a strategy with the goal of assessing the three dimensions of sustainability (economic, social, and environmental) in an integrated manner. EPA should apply tools and approaches in a manner best suited to the type of problem being addressed. The selection of a particular tool for an application should be informed by the type, adequacy, and availability of the data needed, and other criteria suggested by the committee in this report. *(Recommendation 3.1.2)*

[2]The report provides guidelines for performing economic analyses for environmental regulations and policies, including the analysis of benefits, costs, and economic effects.

[3]Generally, systems thinking involves a comprehensive understanding of the mechanisms and feedback effects of interrelated parts or subsystems that work together—in either a coordinated or uncoordinated fashion—to perform a function

Life-Cycle Considerations

In a sustainability context, a value chain consists of all the major business functions from product research and development and extraction of raw materials to the post-consumer fate of a product. EPA traditionally focuses on reducing emissions or waste releases from individual source categories or individual sources within a geographic region irrespective of their relationship to, or effect on, the sustainability performance of the business functions that comprise the larger value chains. Systematic life cycle considerations over a full value chain can identify potential effects that may not be accounted for through traditional approaches that focus on individual source categories. For example, the increasing use of natural gas instead of coal for electricity generation can result in an aggregate reduction in GHG emissions from the electricity-production sector, because combustion of natural gas results in less GHG emission, per unit of energy released, than combustion of petroleum or coal. However, if methane (the primary constituent of natural gas and a potent GHG) leaks along the natural-gas value chain, much of or all its GHG advantage over the use of coal can be lost. **EPA should use approaches that allow consideration of potential life-cycle effects associated with business functions along the entire value chain.** ***(Recommendation 4.2)***

To facilitate the further use of life-cycle thinking and the development and use of LCA, EPA should:

- **Continue educational and research support programs to develop and implement guidance that illustrates how a variety of qualitative to quantitative LCA approaches can be utilized within EPA decision-making.** ***(Recommendation 3.3.2)***
- **Develop quantitative guidance for applications of combined probabilistic risk assessment and LCA approaches, which can be used in concert to examine a fuller array of issues relevant to a decision.** ***(Recommendation 3.3.2)***
- **Collaborate with other federal agencies, the private sector, and other non-governmental organizations to promote and support the development of new datasets for LCA relevant to major agency decisions, such as those related to water and land use, and continue development of and encourage use of life-cycle impact assessment methods.** ***(Recommendation 3.3.3)***

Uncertainty Analyses

Uncertainty analyses are notably lacking in the application of many of the tools. For example, according to the Renewable Fuel Standard (RFS)[4] EPA must ensure that renewable fuels meet lower life cycle GHG emission thresholds than traditional petroleum-based fuels. Corn-based ethanol must achieve performance standards of 20% lower life cycle GHG emissions than gasoline. EPA compared point estimates of the life cycle GHG emissions of petroleum-based gasoline and of fuels derived from renewable biomass and determined that corn-based ethanol meets the RFS threshold criteria. As part of a case study (see Chapter 4), the committee considered the results of a risk analysis of the likelihood that corn ethanol could meet the policy target of a 20% reduction from the baseline of petroleum gasoline. The results indicate that a substantial range in potential values surrounded the point values for GHG emissions used by EPA. If uncertainty and variability are accounted for, corn-based biofuels may result in life cycle GHG emissions closer to (or greater than) those of gasoline, with respect to the 20% reduction required by the RFS. Similar results were observed for other biofuels. **EPA should develop a process to determine when uncertainty analysis is an essential component of the use of a tool. Such a process also would determine what level of an uncertainty analysis can be supported by the data in the use of a given**

[4]Through the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007, EPA was given the authority to set regulations in support of a national Renewable Fuel Standard. EPA's role is to ensure that transportation fuels have at least a minimum content of renewable fuels that are produced from renewable biomass.

tool, the relative importance of such an analysis for a specific decision, and whether the uncertainty analysis should be qualitative or quantitative. ***(Recommendation 4.3)***

Tracking Updates and Documenting Past Experiences

EPA should arrange for the use of a publicly available Internet-based mechanism (for example, an electronic wiki) to track updates about existing and emerging tools. ***(Recommendation 3.2.1)*** This process should allow visitors to suggest updates of documentation for existing tools and to identify new tools for EPA's consideration. Such a mechanism would help the agency update its tool descriptions and applications for specific tools in a more timely manner. **In addition, EPA should document and compile its experiences in developing and applying sustainability tools.** ***(Recommendation 4.4)*** The descriptions should comment on how the tools were used, their strengths and weaknesses, and data requirements. The insights gained from this compendium would inform the development of general guidance on the selection and application of the tools.

PRIVATE-SECTOR EFFORTS AND PRIVATE-PUBLIC PARTNERSHIPS

The last decade witnessed a dramatic expansion in the number and kinds of collaborative relationships created by non-government organizations (NGOs) and global companies in the context of addressing sustainability challenges. Using such tools as collaborative problem solving and LCA, these efforts introduced sustainability strategies and practices into companies' global value chains. That approach has been increasingly necessary as a fuller understanding of carbon, water, and other environmental footprints has revealed that a growing portion of a company's sustainability concerns (for example, air pollution, GHG releases, waste generation, and water consumption) are associated with activities that occur outside its own manufacturing operations, including activities associated with materials sourcing, supply-chain management, packaging, and consumer use of products.

Substantial advancement toward a sustainable future, however, requires the effective participation and leadership of government. Effective collaboration of government with institutions in the private sector and the NGO community will provide government officials with new insights and leveraged capabilities to improve performance on key sustainability indicators by defining performance requirements through a combination of regulatory and non-regulatory approaches. **EPA should use its ability as a convener to assemble non-governmental participants to define and implement value-chain–wide goals and performance outcomes. EPA should also use that ability to develop and deploy stakeholder engagement in diagnosing and addressing the most urgent environmental challenges and to assist in scaling efforts of the private and public sectors for broad application.** ***(Recommendation 5.2)***

Driven primarily by a quest for value creation— and through efforts to reduce waste and other business costs, gain access to new markets, and bolster brand image—many leading companies have spent considerable time and resources over the last 2 decades in attempting to integrate sustainability considerations into their day-to-day operations. A select number of successful enterprises in specific business sectors have undertaken more transformational sustainability initiatives. Many of these were already successful enterprises that had a history of innovation and sustained value creation. **EPA should leverage the sustainability experience of leading companies both to strengthen its decision-making and to incorporate sustainability performance, more broadly.** ***(Recommendation 5.1)*** For example, as EPA develops its GHG management policies, it should strive to learn from private sector experiences how well-designed economic incentives can approach sustainability objectives.

Learning how successful firms have used sustainability tools and approaches can provide an important incentive for other companies to do the same. It can also inform EPA's efforts to amplify the successes of private-sector sustainability initiatives, without inhibiting the creativity and commitment that has made such efforts possible. **EPA should seek to engage businesses that have not made as much progress in incorporating sustainability concepts into their business models as generally larger**

firms that have high-visibility brands. ***(Recommendation 5.3)*** EPA can help to inform those firms and other stakeholders about best sustainability practices and lessons learned by publicizing case studies on its Website and convening meetings of thought-leaders during which private-sector, government, and NGO participants share their experiences to improve the performance of these businesses.

One concept that business and industry have come to understand is that data are the fuel of sustainability assessments, programs, and progress. Higher-quality data make assessment and program implementation more effective. Many firms already engage in a great deal of voluntary reporting on a variety of sustainability indicators, but the full capabilities of mining the data for insights into advancing more sustainable strategies are still evolving. Important insights that could drive value to business, communities, and ecosystems are possible. **To the extent practicable under budget constraints, EPA should provide data-analysis capability for synthesizing large quantities of data from the private and public sectors.** ***(Recommendation 5.3)***

IDENTIFYING AND ADDRESSING NEW ISSUES

The ability to anticipate, assess, and manage challenges is at the heart of sustainability practices, and therefore plays a major role in addressing new issues and evaluating strategies that can minimize deleterious effects. With the continuation and strengthening of various global megatrends, the United States will probably undergo substantial economic, environmental, and social changes in the coming decades. Not only are the expected changes complex, but their occurrence is expected to be rapid. For example, advanced next-generation materials involving the use of nanomaterials or synthetic biology are likely to have substantial effects on our society. The rate at which challenges are likely to arise and their increased complexity will afford progressively shorter periods in which to assess the issues and, if necessary, to devise strategies to address them. **EPA should develop screening tools to assess new issues rapidly to support the selection of appropriate sustainability tools and approaches. Existing screening approaches, tools, and formal sustainability assessments should be automated further to accommodate the rapid throughput that new-issue responses will require.** ***(Recommendations 6.1.1 and 6.1.2)***

The considerable computing research and development already underway in EPA provide an excellent base for improving many sustainability tools and approaches and the capacity to create new approaches, tools, and models to support new issue identification and assessment. **EPA should leverage and enhance its advanced information-technology capabilities for integrating sustainability tools so that the outcomes of the combined use of tools and approaches can be simulated in a sustainability context in real time.** ***(Recommendation 6.2)***

Social-media platforms constitute new and effective forums that can engage stakeholders, allow rapid analysis and categorization of stakeholder input, and provide transparency to stakeholders on how the agency uses their input in its decision-making. **EPA should consider piloting "electronic jams" that reach out to the public in monitored on-line chat sessions that allow public input to be analyzed and additional value to be derived from it. In addition to the public-comment aspect of this approach, passive "crowd sourcing" can be useful in identifying new issues.** ***(Recommendation 6.3)***

SUSTAINABILITY AND ENVIRONMENTAL PROTECTION AGENCY DECISION-MAKING: AN EVOLVING FRAMEWORK

Through a combination of statutory mandates or through its own initiatives, EPA uses various decision frameworks for the application of analytic tools and approaches (examples of frameworks are risk assessment and risk management, market-based control programs, and voluntary programs). The various frameworks function in parallel and are in different states of transition or development. Integrating the frameworks on the basis of sustainability concepts would enhance EPA's ability to make decisions effectively to match the degree and scale of current and future challenges. **As EPA continues to evaluate and update its current decision-making tools and frameworks, it should strive to use sustainability con-**

cepts as an integrating principle for its strategic plan and implementation of its program responsibilities. The committee urges EPA to continue in its efforts to adopt or adapt the sustainability framework recommended in the 2011 National Research Council report *Sustainability and the U.S. EPA. (Recommendation 7.1)* Benefits of using sustainability concepts as an integrating principle include enabling EPA to achieve greater clarity of purpose throughout its various regulatory and non-regulatory programs, and to align its sustainability tools and approaches and their implementation with global, regional, and local megatrends; market developments; and expectations of stakeholder leaders.

In many instances, EPA has adapted its identification of priorities to recognize new generations of problems, modified its implementation strategies to take account of innovative thinking, and developed new tools and approaches for managing public health and environmental challenges. EPA has a good opportunity to embed sustainability considerations further into its decision-making and to communicate and disseminate its application of sustainability tools and approaches outside the agency. **EPA should embed the application of sustainability tools and approaches in its major activities in a manner that is consistent with its statutory authorities and programmatic experience. *(Recommendation 7.2)*** The committee has identified four kinds of activities in which EPA has substantial opportunities to apply sustainability tools and approaches more fully. Each of them builds on initiatives that EPA has implemented previously:

- Evaluation of regulatory policies for public health and environmental protection and approaches to emerging challenges. To ensure effectiveness and accountability, regulatory standards and their enforcement are periodically reviewed to account for new scientific information, technologic innovation, and reviews of program effectiveness. Supplemented by such tools as data-quality management, risk assessment, LCA, economic analysis, peer review, management systems, public participation, and other forms of transparency, the integration of sustainability tools into EPA's standard-setting and enforcement role provides an important basis for advancing toward more sustainable health, environmental, and economic outcomes.
- Extending EPA's role in data management and synthesis to aid the investment community in collecting and synthesizing public comment and to provide advice on public-health and environmental issues that are material to the performance and governance of corporations. That would include filling information gaps in the commercial economy related to the ultimate disposition of economically valuable materials that can present health and environmental risks if they are not subject to a system of recovery and reuse and the monitoring and identification of problems and trends, many of which emerge in a non-regulatory context.
- Serving as a convener for collaboration in system-level solutions to leverage knowledge and problem-solving beyond the capability of any single institution or group, to foster cross–business-sector collaboration and, public–private partnerships and to design system-level evaluation approaches for specific value chains. This activity would build on EPA's experience with such issues as development of clean fuels, development of clean-burning wood stoves, and research on hormonally active agents (chemicals that have hormone-like activity).
- Using appropriate assessment approaches to identify new opportunities for incorporating sustainability concepts. Such approaches include those for identifying opportunities for material recovery or reuse over a life cycle, for evaluating pollution-related risks and risk-reduction opportunities by considering an entire value chain (not only individual sources or sectors), for integrating assessments of multiple individual risks that apply to cities, and for incorporating resilience assessments of urban infrastructure and other applications.

EPA has decades of experience in applying risk-assessment and risk-management decision tools to public-health and environmental challenges. Agency decision-makers need an expanded array of tools to understand relevant trends emerging from the changing dynamics of the economy (locally, regionally, nationally, and globally). By integrating sustainability tools and an existing suite of risk-assessment methods, EPA will become better informed about the changing nature of risks that it is responsible for reducing and will gain a system-level view of key interrelationships among economic–environmental–societal spheres of activities. The committee agrees with the National Research Council report *Sustainability and the U.S. EPA* recommendation that EPA include risk assessment as a tool, when appropriate, as a key input into sustainability decision-making. Applying an expanded array of risk assessment and other sustainability tools and approaches would enhance EPA decision-makers' understanding of the changing dynamics of the economy and risks associated with the change. **EPA should develop an integrated sustainability and risk-assessment–risk-management approach for decision-makers. Such an integrated approach should include an updated set of appropriate tools and methods for specific issues and scenarios, examination of how EPA can apply risk assessment and other sustainability tools throughout specific value chains, and selected postdecision evaluations to identify lessons learned and new opportunities to inform future decision-making.** ***(Recommendation 7.3)***

CONCLUDING REMARKS

Sustainability tools and approaches can play an increasingly influential role in decision making throughout EPA. Their application can provide a greater understanding of the environmental, social and economic implications of the agency's activities. The complexity of the challenges facing the agency and the nation make the use of these tools vital for protecting current and future generations, encouraging innovation in problem solving, and building solutions relevant to the scale of the problems encountered. The committee recognizes that incorporating sustainability tools into EPA's activities will take time and resources. The committee also recognizes that some of its recommendations may be difficult to undertake, and that sufficient resources may not be available to undertake them all in the near term. Therefore EPA will need to set priorities and develop a strategy for addressing them.

1

Introduction

In its 2014–2018 strategic plan, the US Environmental Protection Agency (EPA) indicates that its "traditional approaches to risk reduction and pollution control cannot always fully achieve its long-term and broad-environmental quality goals." The plan describes an agencywide strategy to "advance sustainable environmental outcomes and optimize economic and social outcomes through Agency decisions and actions, which include expanding the conversation on environmentalism and engaging a broad range of stakeholders" (EPA 2014a, p. 55) (see Box 1-1).

Incorporating sustainability considerations into EPA activities involves shifting from approaches focused on a single medium (air, water, or land) to assessments of interactions among humans and natural and manufactured systems. For example, a sustainability assessment of drinking water would go beyond water quality and quantity and perhaps assess the efficiency of water use, the influences of wetlands and other ecosystems, competing societal demands for water (including domestic use and production of food and biofuels), sources of water contaminants (including land use), and climate-change scenarios that affect supply and quality.

BOX 1-1 Cross-Agency Strategy: Working Toward a Sustainable Future

Advance sustainable environmental outcomes and optimize economic and social outcomes through Agency decisions and actions, which include expanding the conversation on environmentalism and engaging a broad range of stakeholders.

EPA will consider and apply sustainability principles to its work on a regular basis, collaborating closely with stakeholders. Our traditional approaches to risk reduction and pollution control cannot always fully achieve our long-term and broad environmental quality goals. The interplay between different environmental statutes and programs also requires renewed attention to improve "synergy" and long-term solutions. To this end, EPA will also embrace a commitment to focused innovation to support solutions that will advance sustainable outcomes. This cross-agency strategy advances the national goal of achieving "conditions under which humans and nature can exist in productive harmony and fulfill the social, economic, and other requirements of present and future generations," as established in the National Environmental Policy Act of 1969 (NEPA). This goal expresses a foundational concept in the President's Executive Order 13514, Federal Leadership in Environmental, Energy, and Economic Performance.

To integrate sustainability into the Agency's day-to-day operations, all headquarters and regional offices will routinely consider the following principles in their decisions and actions, as appropriate:

1. Conserve, protect, restore, and improve the supply and quality of natural resources and environmental media (energy, water, materials, ecosystems, land, and air) over the long term;
2. Align and integrate programs, tools, incentives, and indicators to achieve as many positive outcomes as possible in environmental, economic, and social systems; and,
3. Consider the full life cycles of multiple natural resources, processes, and pollutants in order to prevent pollution, reduce waste, and create a sustainable future.

Source: EPA (2014a, p. 55).

Several years before the present study began, the National Research Council issued *Sustainability and the U.S. EPA* (NRC 2011a), known also as the Green Book, in response to a request from EPA to strengthen the analytic and scientific basis of sustainability as it applies to human health and environmental protection. The Green Book presents a sustainability framework (see Figure 1-1) that calls for EPA decision-making to consider sustainability options and analyses that cover the three sustainability pillars (social, environmental, and economic domains). The framework includes steps for the selection of sustainability goals, indicators, and metrics. Indicators are measurements that provide quantitative information on important environmental, social, and economic trends (see Chapter 2). Metrics are units of measurement (such as tons of sulfur dioxide emitted per kilowatt–hour) and can be used to define how an indicator is being measured.

The framework also includes a sustainability assessment and management (SAM) approach (see Figure 1-2) to provide guidance to EPA on the sequence of steps for incorporating sustainability into decision-making. The objective is to maximize social, environmental, and economic benefits of a decision and to minimize the adverse effects of conflicts among the three pillars. The SAM process incorporates analysis of alternative options, including assessment of immediate and long-term consequences of alternatives.

The SAM process is a multistep process geared toward major decisions that could affect more than one pillar of the sustainability paradigm. However, it could be scaled down to address more minor or routine decisions. The first step in the process is to evaluate the level of analysis needed for the decision to be made. The next step is problem definition and scoping, which includes identification of options, preliminary planning of the analysis, stakeholder involvement, and opportunities for collaboration. (In general, stakeholders are interested parties affected by the decision.) The third step involves application of analytic tools. The major results are characterized in terms of tradeoffs and synergies among important social, environmental, and economic objectives to inform decision-makers. After actions are taken, there is followup evaluation of outcomes regarding important aspects of sustainability.

The Green Book recommended that EPA develop a suite of tools for use in the SAM process. "Collectively, the suite of tools should have the ability to analyze present and future consequences of alternative decision options on the full range of social, environmental, and economic indicators. Application of these tools, ranging from simple to complex, should have the capability for showing distributional impacts of alternative options with particular reference to vulnerable or disadvantaged groups and ecosystems" (NRC 2011a, p. 72). Appendix C presents additional information from the Green Book, including the full set of findings and recommendations on the SAM process.

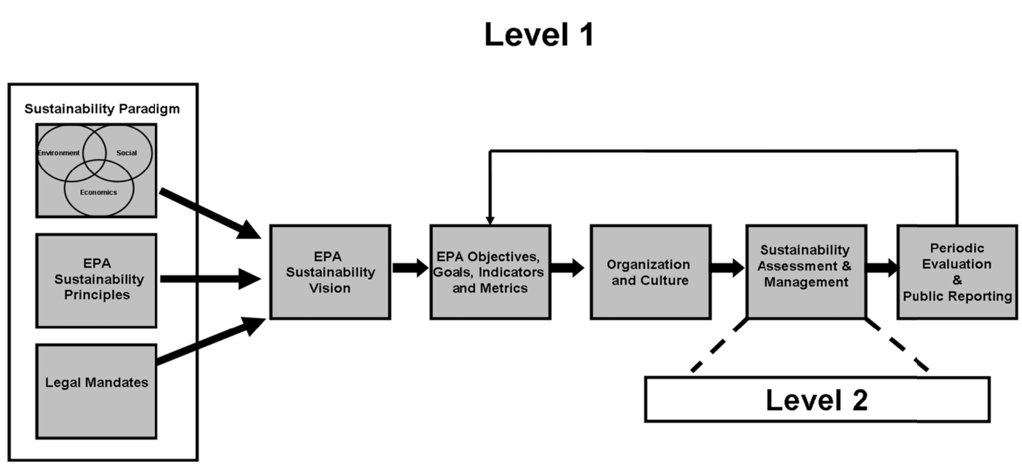

FIGURE 1-1 A sustainability framework for EPA sustainability decisions. Level 1 consists of components that define the agency. Level 2 is the sustainability assessment and management process (see Figure 1-2). Source: NRC, 2011a, p. 37.

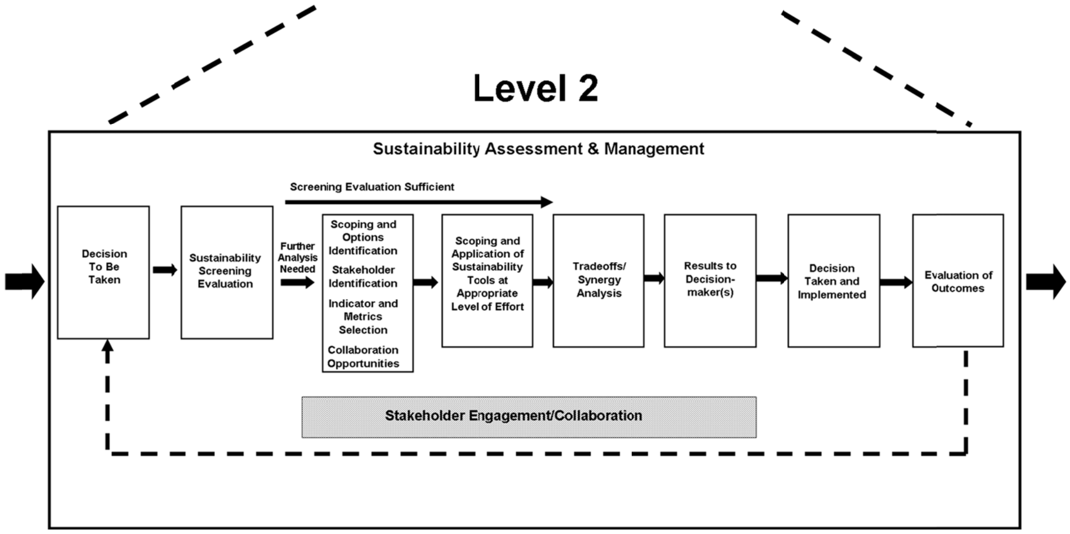

FIGURE 1-2 Sustainability assessment and management process. This is a component of the sustainability framework shown in Figure 1-1. Source: NRC, 2011a, p. 37.

After the completion of the Green Book, EPA undertook a number of activities in response to the report's recommendations (see Chapter 2). In addition, EPA asked the National Research Council to study the use of sustainability tools to elucidate the relationships among economic, social, and environmental aspects in addressing complex issues.

THE COMMITTEE'S TASK

The present committee was asked to examine applications of scientific tools and approaches for incorporating sustainability concepts into assessments used to support EPA decision-making. Using case studies it develops, the committee was asked to consider the application of analytic and scientific tools, methods, and approaches in the SAM process presented in NRC (2011a). It was asked to focus on analytic and scientific tools, methods, and approaches, not to recommend specific policy choices. (The committee's statement of task is provided in Appendix A.)

THE COMMITTEE'S APPROACH TO ITS TASK

In carrying out its task, the committee considered tools and approaches that EPA can use to operationalize sustainability concepts into assessments that support various agency activities. It is important to note that the committee has been asked to focus on analytic and scientific tools, methods, and approaches. It was not asked to advise EPA on how to address specific science-policy issues by using sustainability analytic approaches. The committee views the identification and development of sustainability assessment tools as an adaptive process of trial and error and continuous re-evaluation of the tools.

Regarding the definition of the term sustainability, the committee used the same definition that was presented in the Green Book and is used by EPA.

> Sustainability: "to create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations" (NEPA [1969]; EO 13514 [2009]).

The definition indicates that the term sustainability is both a process and a goal. As indicated in the Green Book, "Sustainability is a process because the United States and other countries are a long way from being sustainable, and it is thus necessary to create the conditions for sustainability (NRC 1999). Sustainability is also a goal. As sustainability is achieved in particular places and contexts, it is necessary to maintain the conditions supporting it in the face of social, technological, environmental, and other changes" (NRC 2011a, p. 12). In this report, the committee focused its efforts on sustainability as a process, rather than a goal or a prescriptive end state. The committee considered tools and approaches for analyzing the processes that contribute to three overlapping domains (or pillars): environment, social, and environment, which all contribute to sustaining human wellbeing.

The committee used EPA's recent report on *Sustainability Analytics: Assessment Tools and Approaches* (EPA 2013a) as a primary source of sustainability tools and approaches for its consideration. Because that report provides an overview of the data needs, major assumptions, strengths and limitations for each tool, the committee focused on a small set of tools for discussion to illustrate particularly valuable attributes for informing sustainability concepts. The committee also relied on a number of other EPA publications to identify applications of relevance to the agency and to consider how to facilitate the incorporation of the tools and approaches more broadly within the agency.

Using case studies, the committee considered the application of tools and approaches to the SAM process, but it did not attempt to assign tools to certain parts of the process. It focused its attention mainly on the general application of tools within the SAM process. The application of tools specifically for screening is presented in the first case study in Chapter 4, and needed improvements for these tools are discussed in Chapter 6. The report suggests where approaches could be used for postdecision evaluation of outcomes on dimensions of sustainability. However, it does not identify tools and approaches that are specific for evaluation of outcomes.

The committee realizes that implementing its recommendations will require resource expenditures. However, the committee was not asked to and did not attempt to estimate the implementation costs associated with its recommendations.

ORGANIZATION OF THE REPORT

Chapter 2 discusses factors and trends that are shaping the need for sustainability analytic tools and discusses EPA's efforts to incorporate sustainability concepts into its activities. Chapter 3 evaluates various tools that could be used to provide support for sustainability decision-making in EPA and identifies needs for improvement. Chapter 4 uses a series of case studies to consider the application of tools, methods, and approaches for incorporating sustainability concepts into EPA activities. Chapter 5 discusses private-sector initiatives and private–public initiatives that are relevant to decision-making in the agency. Chapter 6 considers important new issues that EPA is likely to face in applying sustainability tools and approaches. Chapter 7 discusses the evolving framework for sustainability and EPA decision-making, including opportunities to make sustainability the integrating core of the agency's strategic planning process and to embed the use of sustainability tools, discussed in previous chapters, into its activities. Chapters 3–7 present recommendations throughout the text; the final sections of those chapters summarize the main conclusions and recommendations.

2

Sustainability: From Ideas to Actions

Sustainability has evolved from an aspiration to a body of practices. The evolution includes a transition from the development of broad goals toward the implementation of specific policies and programs for achieving them and the use of indicators and metrics for measuring progress. A focus on the management of waste generated by societal activities and remediation of contaminated sites has broadened to include the use of new technologies and products that enable individuals and organizations to do more while creating less environmental impact. Businesses are coevolving collaborative and competitive strategies and initiatives that encourage innovation, regulatory change, and consumer choice in the pursuit of sustainability objectives. Individuals and organizations that are proponents of sustainability are more connected with other members of society through new social media that promote participation and transparency in the development and implementation of sustainability plans. Scientific endeavors are expanding from the study of single environmental media toward systems-focused, integrative research that deploys big-data capabilities and advanced analytics to assess effects over a broad range of considerations. Examples of results of sustainability initiatives include increased efficiencies in the use of energy and natural resources, the production of materials and goods that pose much less environmental hazard, and the construction of green buildings and communities.

That evolution is taking place against a backdrop of global forces and trends that are shaping how societies and the environment are interacting and changing. As those changes occur, institutional policies and approaches need to change in response. Societies are being challenged to move away from unsustainable practices toward ones that meet their needs while preserving or restoring the life-support systems of the planet (NRC 1999, 2011a).

In practice, sustainability initiatives explicitly strive to consider the broad assortment of factors and potential effects across an interlinked set of issues, both upstream and downstream of particular pollution sources, rather than focusing on potential health effects of particular environmental exposures. Sustainability approaches examine the sources of pollution and other challenges across entire value chains rather than focusing on individual point or area sources in specific economic sectors.

This chapter discusses various forces, trends, and considerations that are shaping sustainability concepts and sustainability practice. It also discusses Environmental Protection Agency (EPA) efforts to build consistency and continuity in the ways in which it incorporates sustainability concepts into its activities.

FACTORS THAT DRIVE THE NEED FOR SUSTAINABILITY TOOLS AND APPROACHES

Megatrends

Megatrends—including climate change, mega-urbanization, democratization of knowledge, and a renaissance in the development of industrial materials—present challenges to and opportunities for advancing sustainability initiatives.

Climate Change

Two recent scientific assessments find that climate change is already happening and that human activities—mostly related to energy and land use—are the primary cause of most of the change and that the resulting effects could undermine sustainability.

The Intergovernmental Panel on Climate Change (IPCC 2014) finds that greenhouse-gas (GHG) emissions increased steadily on a global scale from 1970 to 2000 and then more steeply from 2000 to 2010—1.3% and then 2.2% per year. It also finds that achieving some measure of climate safety will involve a dramatic global increase in the use of low-carbon energy (to 3–4 times the share of low-carbon energy in 2010) and a dramatic global decrease in GHG emissions (by 40–70% from 2010 emission levels) by the middle of the 21st century. In addition, it notes that "adaptation and mitigation choices in the near-term will affect the risks of climate change throughout the 21st century" (IPCC 2014, p. 10).

The third National Climate Assessment produced in 2014 by the US Global Change Research Program finds that "global climate is changing and this is apparent across the United States in a wide range of observations" (Melillo et al. 2014, p. 15). The assessment confirms an increase in extreme weather and climate events and other effects, which can threaten human health and well-being, damage infrastructure, affect water quality and water-supply reliability, and disrupt agriculture and ecosystems.

Managing climate change is viewed as a challenge of managing risks. Societies need to make decisions (about both mitigation and adaptation) and take actions in the face of considerable uncertainty to address the extent and magnitude of climate change and the severity of its local and regional effects. The focus is becoming less on predicting climate and more on how societies can make themselves more resilient in the face of changes that can no longer be avoided. Mitigation and adaptation are seen as constituting a down payment on a sustainable future.

Mega-Urbanization

More than half the global population is urban, so cities constitute a dominant habitat for humans. The drive to urbanize is a transformative process that permeates many aspects of development as societies seek the services that urban centers provide. The services include transportation systems, which depend heavily on fossil fuels and are a major source of GHG emissions; buildings, which are often designed to over-rely on nonrenewable resources; and infrastructure (especially sewer systems, roads, and transmission lines), which was not designed to withstand hazards of climate change and other natural events. Also, in ethnically diverse urban areas, language barriers can isolate groups from official communication in advance of and in response to hazard events.

The demographic shift to urban areas is closely related to the large increase of the global middle class and its increasing purchasing power that, in turn, drives greater consumption of resources (Guarín and Knorring 2014). Increased population growth rates and demographic shifts present complex challenges. For instance, in the near future megacities will not only be required to support a growing and diverse population, but an increasingly aging one as well. This trend will present a substantial challenge to the ability of megacities to provide needed services to an increasingly aging population.

This economic shift is opening large new markets as regions that have historically exported raw materials are beginning to import products and develop their service economies to meet the demands of their growing middle class. As with any major transformation, the benefits will also come with some downsides. The increased mobility that comes from rising car ownership, for example, will put increased pressure on road infrastructure and likely will result in vehicle emission increases that degrade air quality. In addition, the growth of the global middle class suggests an increased demand for resources in global markets for oil, food, and minerals.

Cities can serve as crucibles for innovation and often are massive economic engines that can account for substantial improvements in the efficiency of activities, such as energy production and use, transportation, and health-care delivery. They present an opportunity to develop new sustainability metrics, tools, and approaches that can be used to guide how cities are designed, built, and managed (NRC 1999). Urban areas also present an opportunity to increase understanding of human–environment interactions at the local level (NRC 2010). If increased urbanization is inevitable, it will be essential to find ways of making it more sustainable.

Democratization of Knowledge

Advances in electronic devices allow broad access to large amounts of information in a society. Such democratization of knowledge constitutes a dramatic change from the past. Coupled with the rapid expansion of computing capabilities, massive amounts of data enable highly advanced modeling and analysis that would have been unthinkable even 5 years ago and present new opportunities for sophisticated, evidence-based, and rapidly deployed sustainability assessments.

For example, high-performance computing has enabled the business, scientific, and regulatory communities to address a wide variety of complex problems in life sciences, health sciences, climate change, and many other spheres. The report *Computing Research for Sustainability* (NRC 2012a) describes the rich interplay between computing research and other disciplines in addressing the challenges of sustainability. The context provided by increased scientific and technical knowledge increases exponentially the value of the data collected. And high-performance computing and data analytics coupled with geographic information systems (GIS) leads to a growing ability to trace and track materials, supplies, and products around the globe with surprising accuracy and allows substantive improvements in documentation of the provenance of raw and processed materials. Such capability will be important in sustainability assessments in that it yields better data for sustainability tools and approaches, which in turn provide more accurate results.

Analysis of open-source data collected through social media can be a powerful tool in the execution of sustainability assessments. The value of social-media analytics lies in the opportunity to discover sentiments of millions of interested persons as expressed in on-line discussions and through direct solicitation of public comments. Powerful analytics make it possible to categorize and assess large numbers of public comments to obtain actionable insights and demonstrate responsiveness to public comment.

Materials Renaissance

New materials (such as graphene, quasicrystals, ceramics, shape memory alloys, nanomaterials, and thermoelectric materials) are being developed for industrial applications, such as enhanced production of transportation fuels, absorption of large volumes of oil from seawater by using porous nanostructructured fly ash, production of nanotransistors for microelectronic devices by using nanowires, repair of bones and teeth with biomaterials, treatment of drug-resistant bacterial infections with nanopolymer hydrogels, and purification of large quantities of freshwater at relatively low cost by using hybrid nanoscale materials. Such applications will present the challenge of understanding the potential unintended effects of the widespread use of the materials. A confounding issue associated in the development of a vast array of new materials is that they often become available for commercial use with little assessment of risks to the environment and health. For the promise of the materials to be realized, more purposeful assessments will be needed. It is unclear how many of the newly developed materials will lend themselves to the rapid screening assays developed for use in computational-toxicity assessments (EPA 2013b).

Public-Sector Policies and Initiatives

On an international level, the 2012 UN conference on sustainable development focused on pragmatic concerns related to sustainability, such as the green economy, green growth, and low-carbon development. The emphasis on building economic benefit from environmental protection reflected both the downturn of the global economy and the inevitability of climate change. Other international initiatives are embracing sustainability in their missions, emphasizing results-oriented interventions that make use of new technology and tools, alternative forms of financing, business opportunities, and leadership. For example, the UN Greening the Blue initiative builds best practices in energy and environment into UN peacekeeping and other missions, and it uses social media to catalyze change and ensure accountability. The World Bank's *World Development Report* (World Bank 2010) focuses on climate change and development and on the notion that a "climate-smart" world is within reach with targeted investments. At its 2014 meeting in Davos, Switzerland, the World Economic Forum devoted considerable time to high-level discussions of how to tackle climate change in the context of the global economic downturn.

In the United States, the Obama administration's lead-by-example initiative places sustainability at the forefront of the federal government's energy, water, and procurement targets. Executive Order 13514, *Federal Leadership in Environmental, Energy, and Economic Performance*, signed by the president in 2009, sets sustainability goals for federal agencies and focuses on improving environmental, energy, and economic performance. The order directs federal agencies to purchase sustainable products and services, improve efficiencies in water and energy use, and plan for climate adaptation (see Box 2-1). The potential effects of such practices on natural-resource consumption and on the kinds of materials flowing through supply chains are large because of the high volumes associated with the government's procurement activity.

Federal-agency partnerships with communities can promote local sustainability initiatives. For example, the Sustainable Communities Regional Planning (SCRP) grant program, which the Department of Housing and Urban Development (HUD) administers, supports locally led collaborative efforts among residents, municipal governments, and other interested parties with the goal of determining optimal ways to target housing, economic and workforce development, and infrastructure investment to create more jobs and regional economic activity. This is a key program of the Partnership for Sustainable Communities, in which HUD works with the Department of Transportation and EPA to coordinate and leverage programs and investment in federal housing, transportation, water, and other infrastructure entities to increase the prosperity of neighborhoods, provide accessible (available and affordable) transportation, and reduce pollution. The program has reached 74 regional grantees in 44 states and has assisted about 112 million people (HUD 2014).

Federal agencies are developing adaptation plans as part of the strategic planning recommended by the Interagency Task Force on Climate Change Adaptation and guided by Executive Order 13514. The plans consider the potential effects of climate change on government operations and the opportunities for adaptation in the context of effective natural-resource management. The president's 2013 Climate Action Plan enhances federal support for adaptation through the creation of a task force, which was launched in November 2013 and is made up of state, local, and tribal government officials; it advises the federal government on climate-related issues that communities face in the hope that this will help in determining how the government can assist local communities.

Many local efforts are facilitated by nongovernment organizations—such as ICLEI [International Council for Local Environmental Initiatives] USA, which began in 1995 and now serves as a global network for local governments for sustainability initiatives—and by a burgeoning service industry in which a growing number of companies are developing frameworks that are intended to have wide appeal. For example, ICLEI's Sustainability Planning Toolkit, which is based on the model pioneered by city of New York's PlaNYC, provides guidance in developing a sustainability plan for improving the livability of cities, towns, and counties (ICLEI 2009).

The emphasis of those efforts is on deriving economic benefit from environmental protection and smart growth, building resilient communities, using new communication tools better so that plans can address the desires of individuals and communities, providing people with knowledge and resources needed to realize their goals, and spurring local innovation. In multiple studies, two-thirds or more of the US public supports taking sustainable actions and supports government efforts to promote sustainability initiatives (Cohen, et al. 2005; Leiserowitz et al. 2005; Morales 2010; Smart Growth America 2011; Greenberg et al. 2014).

BOX 2-1 Leading by Example

In response to Executive Order 13514, EPA issued comprehensive procurement guidelines to promote the use of materials recovered from solid waste (also known as the buy-recycled program). EPA designates for purchase products that have high concentrations of recovered material. The agency also administers the Federal Green Challenge, which commits federal offices or facilities to an improvement goal of at least 5% per year in two of six target sectors: development waste, electronics, purchasing, energy, water, and transportation.

Leadership in Business and Industry

Perhaps the most rapid expansion of sustainability practice in the last decade has been in the private sector. Sustainability has become a greater business imperative, a source of competitive advantage, and an enabler of innovation. As described in Chapter 5, leading companies are seeking ways to lower their costs while building more efficient and sustainable operations, processes, products, and services. The focus of sustainability takes companies beyond mere compliance with government regulations to the creation of innovative products and services that give rise to new markets and revenue streams.

The Evolution of Sustainability Science

The scientific foundation and analytic tools used to support decisions in a sustainability context—regardless of whether the decisions are made by governments, businesses, nongovernment organizations, or individuals—will benefit greatly from new knowledge and better use of existing knowledge (NRC 1999; NRC 2011a). Such scientific capabilities as computational toxicology, remote sensing, and chemical screening are helping to build connections between the research domains of environmental sciences, economics, and sociology (Anastas 2012). Those advances are enhancing the development of sustainability science, a field of research recommended by the National Research Council report *Our Common Journey: A Transition Toward Sustainability* (NRC 1999) to address the special challenges of sustainability and sustainable development.

The *Proceedings of the National Academy of Sciences of the United States of America* (*PNAS*) describes sustainability science as "an emerging field of research dealing with the interactions between natural and social systems, and with how those interactions affect the challenge of sustainability: meeting the needs of present and future generations while substantially reducing poverty and conserving the planet's life support systems" (PNAS 2014). It is defined by problems, not by disciplines (Clark 2007). Kates et al. (2001) presented a theoretical framework for sustainability science.

In a review of a large database of publications, Bettencourt and Kaur (2011) observed that sustainability science coalesced around the year 2000 as a result of collaborations among various disciplines throughout the world in several decades. The number of scientific publications increased at a rate of around 15–20% per year from 1997 to 2007 (Clark 2007). In 2005–2008, five new journals on sustainability science were launched. Several recent books and articles review the evolution of the field (Ness, 2013), showing its orientation toward action, integrated assessments, and interdisciplinary approaches (Spangenberg, 2011; de Vries, 2012); expansion and diversification (Komiyama et al., 2011); contribution to resolving problems of science and society (Wiek et al., 2012); and treatment of issues related to urbanization (Weinstein and Turner, 2012), planning (Hamdouch and Zuindeau, 2010), and energy (Kajikawa, et al 2014).

Networks have been developed for improving discussion between scientists and practitioners (Clark and Dickson 2003; NRC 2006) and for linking knowledge with action and supporting decisions (NRC 1999; NRC 2006; Cash et al. 2002; Cash et al. 2003). Recent areas of emphasis include addressing the need for better understanding of human behavior in response to environmental change, the resilience of complex and adaptive systems, better ways to disseminate relevant knowledge, and better models for decision-support (Miller 2013; Miller et al. 2014) and ways of analyzing system components and their interrelationships (Liu et al., 2013).

Higher-education research centers, educational-degree programs, and interdisciplinary academic and research programs concerned with the environment and sustainability have grown considerably in the last several years (Ness 2013) and offer new partnership opportunities for EPA, business, and academic institutions. According to a 2013 survey by the National Council for Science and the Environment, there were 1,121 sustainability-science programs and centers in 236 universities; a 2012 census identified 1,151 academic units or programs that were offering 1,859 interdisciplinary environment and sustainability baccalaureate and graduate degrees in 838 colleges and universities (Vincent et al. 2013**,** p. 8). Those figures represents a 28% increase in the number of schools offering such programs and a 57% increase in the number of degree programs over a 4-year interval (Vincent et al. 2013). Such growth may be indicative of a shift in emphasis rather than of overall growth in education in the fields of science, technology, engineering, and mathematics (see Chapter 6).

Federal Science and Research Planning

In October 2010, the president's National Science and Technology Council reconfigured its main committee on environmental R&D to encompass sustainability to form the Committee on Environment, Natural Resources, and Sustainability (CENRS) to develop a comprehensive R&D program among federal agencies; ensure strong linkages among science, policy, and management decisions; encourage the use of sustainability science; and promote innovation. Officials in EPA, the White House Office of Science and Technology Policy (OSTP), and the National Oceanic and Atmospheric Administration serve as co-chairs of CENRS. In 2011, CENRS established a task force on Integration of Science and Technology for Sustainability, which includes EPA and 11 other federal departments and agencies, to define the research opportunities and needs in federal agencies. CENRS subcommittees, such as the Subcommittee on Global Change Research, are encouraged to develop their portfolios of programs with a view to sustainability outcomes.

The 2010 annual budget guidance memorandum to federal agencies from the directors of OSTP and the Office of Management and Budget identified science and technology for sustainability as having high priority for the FY 2012 budget, calling for "research on integrated ecosystem management approaches that bring together biological, physical, chemical, and human uses data into forecast models, assessments and decision support tools" that would address the presidential priority of "managing the competing demands on land, fresh water, and the oceans for the production of food, fiber, biofuels, and ecosystem services based on sustainability and biodiversity" (Orszag and Holdren 2010). Implementing those efforts requires interagency cooperation and joint programs, because no single agency has all the necessary expertise, data, or mandate to understand or mange the competing demands.

A 2103 National Research Council report, *Sustainability for the Nation: Resource Connections and Governance Linkages,* recommended that federal agencies supporting scientific research be given incentives to collaborate on sustained cross-agency research**.** The report also recommended that sustainability concepts be supported by a broader spectrum of federal agencies and that additional federal partners become engaged in science for sustainability (NRC 2013a).

SUSTAINABILITY IN THE ENVIRONMENTAL PROTECTION AGENCY

EPA's mission is to protect public health and the environment. Societal needs, megatrends, market interactions, and advances in scientific understanding—described in this report—are driving the agency to incorporate sustainability concepts into its planning and activities. As noted in the Green Book, EPA's mission is consistent with sustainability in that it fosters "human and environmental well-being at the same time for the benefit of present and future generations" (NRC 2011a, p. 9).

Figure 2-1 presents the agency's overall strategic goals, cross-agency strategies (which include "working toward a sustainable future"), and the agency priority goals for 2014–2015. The priority goals reflect EPA's present efforts to address climate change and improve air quality, improve water quality, promote green infrastructure development, reduce chemical risks, and enhance the livability and economic vitality of neighborhoods in and around waste sites (EPA 2014a). Sustainability can serve as an integrating decision framework covering all those priorities—not only as a way to think about problems but as a way to work toward their solutions across time horizons, geographic scales, and other considerations.

Four Priorities for Sustainability

In addition to establishing the goals and strategies mentioned above, EPA identified four priorities to advance sustainability (see Table 2-1). They were developed in recognition of legal constraints and of a desire to apply scientific tools and approaches in different circumstances and different modalities to move the sustainability agenda forward (Perciasepe 2013). With respect to the four priorities, EPA indicated (EPA 2014c, p. 1) that it will

- "Identify leveraging opportunities with communities, businesses, universities, and other stakeholders with which the agency is already working or should work to advance sustainability.

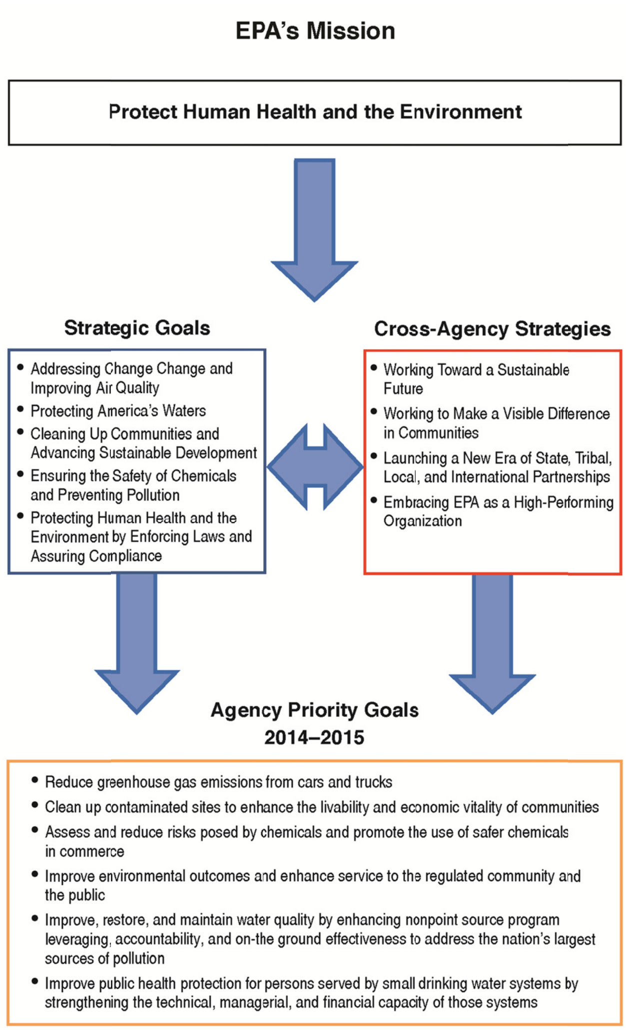

FIGURE 2-1 EPA's mission, strategic goals, cross-agency strategies, and priority goals. Source: EPA (2014a).

- "Identify opportunities to incorporate sustainability principles into regulatory, enforcement, incentive-based, and partnership programs.
- "Design a targeted strategy including identifying appropriate goals to advance the four areas.
- "Identify process and lessons learned through the four areas to be applied to other areas." (EPA 2014b, p. 1)

EPA's four priorities for sustainability provide a good beginning for establishing comprehensive, cross-medium activities. It is not peculiar to EPA that consideration of the environment pillar of sustainability has dominated, but many of the trends noted previously in this chapter reinforce the need to improve understanding of other aspects of human well-being—the social and economic pillars.

Incorporating Sustainability Considerations in All Activities of the Environmental Protection Agency

EPA's mission provides ample opportunities for incorporating sustainability into the broad array of the agency's activities (see Table 2-2). EPA's activities are in two general categories: required activities driven by congressional mandates or administration directives, such as executive orders, and voluntary or discretionary activities driven by agency policy priorities that are consistent with its statutory responsibilities for advancing the application of innovative methods and best practices related to a variety of public-health and environmental challenges. EPA's required activities (such as regulatory development and enforcement) stem from mandates and directives that tend to be related to specific environmental media (air, water, and land), pollutants (particular chemicals), responses (such as oil spills), issues (such as endangered species), or demographic groups (such as children). Voluntary activities afford greater flexibility for incorporating sustainability. Table 2-3 provides several examples.

Taken together, EPA's required, voluntary, and discretionary activities are wide in scope and scale and thus present the agency with considerable opportunities to incorporate sustainability considerations at multiple levels of activity (see Box 2-2). Even regulatory actions involve decisions that can begin to incorporate sustainability concepts through screening evaluations, problem scoping, or identification of alternative actions to be considered. For each activity presented in Table 2-2, several general questions can help to integrate sustainability thinking:

- How does the activity expand the scope from the environmental pillar to address the social and economic pillars?
- What sustainability-related outcomes does the agency seek to achieve for a particular activity? How does the activity advance the outcome?
- What tools and approaches could the agency use to achieve the desired outcomes?
- What types of processes or partnerships with industry, nongovernment organizations, or academe will mobilize action?

TABLE 2-1 EPA Sustainability Priorities (FY 2014)[a]

Priority	Initial Focus
Sustainable products and purchasing	Multistakeholder systems to define and rate sustainable products and purchasing
Green infrastructure	Storm-water management
Sustainable materials management	Food
Energy efficiency	Measures to enhance electricity-system efficiency that can support the president's Climate Action Plan

[a]The priority areas are the ones provided by EPA (Trovato and Shaw 2013). The priority areas are also discussed in Working Toward a Sustainable Future: FY 2014 Annual Action Plan (EPA 2014b).

TABLE 2-2 Some Potential Opportunities for Incorporating Sustainability Concepts into EPA Activities

EPA Activity	**Potential Opportunity for Incorporating Sustainability Concepts**
Program development	Responding to emerging issues and setting priorities when resources are limited
Internal guidance	Advising on the application of tools and approaches, such as risk assessment, benefit–cost assessment, life-cycle assessment, social cost of carbon analysis, ecosystem-services valuation, and systems analysis for sustainability
Research planning and cross-cutting strategies	Using workshops and other techniques to encourage an integrated, science-based process throughout the agency
Budget decisions	Using a sustainability perspective for planning and allocating funds in all types of activities
Regulatory and standards development	Conducting regulatory impact analyses that use sustainability approaches
Regulatory enforcement	Including consideration of best practices in reducing chemical releases into the environment and a broad array of expected impacts, including value-chain impacts
Knowledge transfer	Providing information on tools for remediation that advance sustainability outcomes
Permitting	Advising states, other federal agencies, and EPA regions on the preparation of environmental-impact statements that incorporate sustainability criteria
Superfund	Including in the process for arriving at a record of decision the broad consideration of possible effects of remediation alternatives and the potential for natural systems to advance remediation
General communication and education	Compiling a compendium of lessons learned by incorporating sustainability concepts into activities and disseminating best practices through communication, education, and other activities
Stakeholder, community, and congressional relations	Including explanations of sustainability concepts and tools used to incorporate them into specific EPA activities
State and tribe collaborations and assistance	Using interactions to test the application of innovative sustainability approaches

TABLE 2-3 Examples of Voluntary Programs in EPA to Advance Sustainability

Program or Type of Activity	**Objective**
Design for Environment[a]	Evaluate human health and environmental concerns associated with chemicals and industrial processes. Inform the selection of safer chemicals and technologies.
Green chemistry[b]	Design chemical products and processes that reduce or eliminate the generation of hazardous substances.
ENERGY STAR[c]	Support the deployment of energy-efficient products, practices, and services.
Sustainable Water Leadership Program[d]	Recognize water and wastewater utilities that demonstrate sustainable management approaches for promoting resource efficiency and protection.
People, Prosperity and the Planet Student Design Competition for Sustainability (P3)[e]	College competition for designing projects to advance sustainability—water, energy, agriculture, built environment, materials and chemicals, cookstoves, and green infrastructure.

[a]EPA (2014c).
[b]EPA (2014d).
[c]EPA (2014e).
[d]EPA (2013c).
[e]EPA (2014f).

Successful integration of multiple sustainability factors relies on

- Systems thinking and integrated approaches that address the connected aspects of multiple stresses or problems rather than focusing exclusively on solutions to individual problems.
- Decision-making that reflects the state of sustainability science, innovation, and knowledge about environmental, social, and economic consequences, alternatives, and tradeoffs.
- A sustainability framework, tools, and approaches for guiding actions.
- A process that asks initially what communities care about, identifies options, and uses relevant knowledge to identify sustainability indicators and metrics, select analytic tools to assess the options, and assess the outcomes.
- Management that is adaptive and flexible in addressing sustainability objectives among value chains, geographic regions, and time horizons; pursues collaborations and partnerships; seeks to be transparent and accountable in a more connected society; and ensures that decisions are achieving objectives.

Research and Development in the Environmental Protection Agency for Sustainability Science

In 2011, EPA began to reorganize its research programs to be as responsive as possible to the agency's science-priority needs and to advance sustainability science (see Box 2-3) (EPA 2012a). Early impetus for the realignment was provided by EPA's development of a sustainability research strategy in a systems-based multimedia context (EPA 2007). More recent motivations were provided by the Green Book (NRC 2011a) and guidance from EPA's Science Advisory Board (EPASAB 2010). The reorganization is intended to link the traditional regulatory program offices (air, water, and chemical safety) with broader sustainability-related concerns.

EPA's response to the Green Book recommendations also includes building capabilities needed to apply the sustainability assessment and management approach (see Chapter 1) by gathering analytic tools and approaches and indicators and metrics for sustainability assessment and management. For example, through the Sustainable Futures Initiative, EPA worked with industry and nongovernment organizations to develop computer-based models for industry to use in identifying risky chemicals in the early stages of development and in finding safer substitutes or processes before chemicals are submitted to EPA for approval (see also the case study on Design for the Environment in Chapter 4) (EPA 2012b)

In addition, EPA issued *A Framework for Sustainability Indicators at EPA* (EPA 2012c), which provides methods and guidance to support the application of sustainability indicators in EPA decision-making. Indicators are measurements that provide quantitative information on important environmental, social, and economic trends. The indicators presented in that EPA report are intended to be consistent with and augment the indicators in EPA's *Report on the Environment* (EPA 2014g),[1] which provides information on national conditions and trends in air, water, land, human health, and ecologic systems.

As shown in Figure 2-2, individual indicators can be relevant to one or more of the sustainability pillars. For example, the amount of fossil fuel consumed to produce energy for residential use is a sustainability indicator in the environmental pillar (region E in the figure). A more integrated indicator is change in the energy efficiency of residential heating and cooling equipment (region E$ in the figure) because energy efficiency is relevant to fossil-fuel use and cost savings. An example of a single indicator that is relevant to all three pillars (region SE$ in the figure) is per capita floor space of residential dwellings. Because the indicator correlates with energy consumption and economic status, it reflects aspects of financial prosperity, quality of life, and resource use (EPA 2012c).

[1]The *Report on the Environment* is a compilation of scientific indicators that describes the condition of and trends in US environmental and human health. The new version of the report is entirely Internet-based.

EPA has been involved in developing integrated indicators, such as environmental burden (ecologic-footprint analysis), flow and conservation of energy resources (energy budget), and regional economic health (Green Net Regional Product) (Campbell and Garmestani 2012; Gonzalez-Mejia et al. 2012; Heberling et al. 2012; and Hopton and White 2012).

BOX 2-2 EPA Activities in the Gulf of Mexico

As a first responder to environmental hazards, EPA was called on to make decisions about the use of chemical dispersants during the Deepwater Horizon oil spill in the Gulf of Mexico in 2010. EPA also chaired the Gulf of Mexico Restoration Task Force established in 2010, because it is the lead agency in restoring degraded environments and developing long-term programs for protecting the environment and human health. EPA was also a participant in the National Ocean Council, which was established coincidentally in the aftermath of the Deepwater Horizon oil spill to coordinate marine spatial planning for multiple human uses of near-shore marine areas, including the Gulf of Mexico.

The decision to use dispersant chemicals to promote the breakup of spilled oil into smaller droplets in the water before it could reach wetlands and the shoreline had implications for the locations and priorities for restoration in the near term and for sustainability considerations in the long term. The considerations include fate and effects of the dispersed oil, toxicity of the dispersant chemicals, and the health and economic well-being of gulf-states residents. Decisions at multiple levels need to consider the implications of system dynamics and environmental, social, and economic factors.

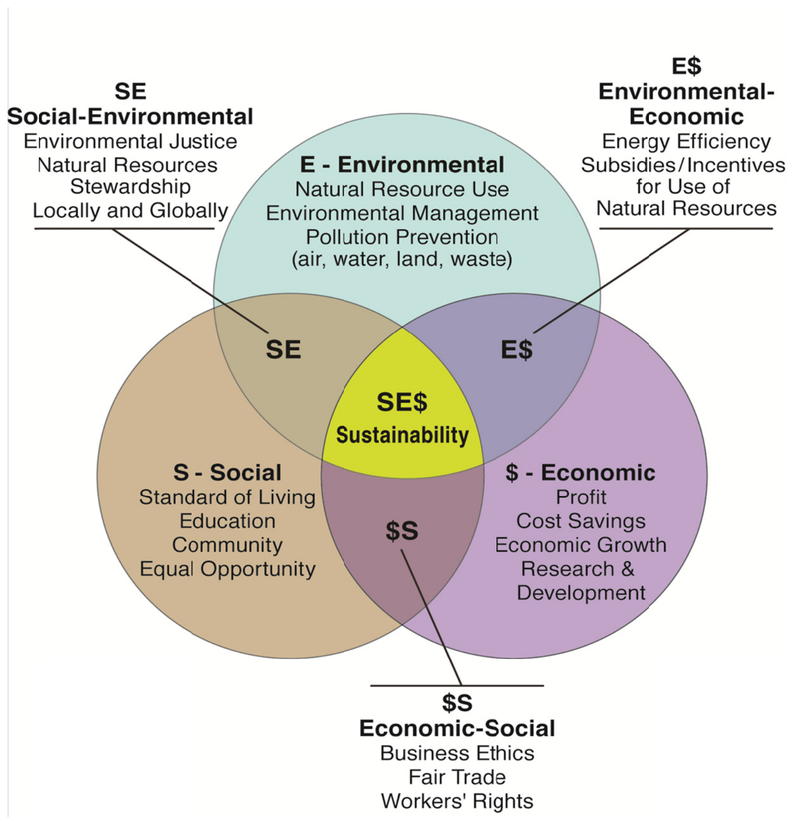

FIGURE 2-2 Three sustainability pillars, showing various indicators in their relevant domains. Some indicators are relevant to only one domain, and others are appropriate to more than one. Source: EPA 2012c, p. 7.

BOX 2-3 Research Programs of EPA's Office of Research and Development

Air, Climate, and Energy: Exploring the dynamics of air quality, global climate change, and energy as a set of complex and interrelated challenges.

Chemical Safety for Sustainability: Investigating ways of producing chemicals in safer ways and embracing principles of green chemistry.

Homeland Security Research: Protecting human health and the environment from the effects of terrorist attacks or accidental releases.

Human Health Risk Analysis: Understanding effects of pollutant exposure on biologic, chemical, and physical processes that affect human health.

Sustainable and Healthy Communities: Building a deeper understanding of the balance between the three pillars of sustainability.

Safe and Sustainable Water Resources: Maintaining drinking-water sources and systems and protecting water integrity.

After the Green Book was issued, EPA also prepared a report *Sustainability Analytics: Assessment Tools and Approaches,* which provides examples of science-based tools and approaches for conducting sustainability assessments once indicators are selected and corresponding metrics are identified (EPA 2013a). It is not intended to set policy or prescribe a process for implementing sustainability analytics. As discussed in Chapter 3, the committee used that EPA report as one of its bases for identifying the tools and approaches that it would consider in carrying out its study.

3

Tools and Methods to Support Decision-Making

INTRODUCTION

This chapter discusses various tools, methods, and approaches for incorporating sustainability concepts into assessments used to support US Environmental Protection Agency (EPA) decision making. It provides a more-detailed discussion of a small subset of the tools to illustrate what the committee believes are particularly valuable attributes of tools for informing sustainability considerations. Our discussion of this subset is intended to emphasize a major theme of this report: the identification of and development of sustainability assessment tools needs to be considered as an adaptive process of trial and error, learning by experimentation, and continuous re-evaluation of the tools. In short, EPA needs to consider the development and application of tools to inform sustainability as an on-going process, not an endpoint that is achieved prior to the integration of sustainability into decision making. In subsequent chapters, case studies are presented to consider the specific application of tools and methods for incorporating sustainability concepts into assessments used to support EPA decision making.

As discussed in Chapter 1, NRC (2011a) (known also as the Green Book) recommended that EPA develop a suite of tools for use in the Sustainability Assessment and Management (SAM) approach for assessing environmental, economic, and social aspects of activities to be undertaken by the agency. The Green Book also recommended that, collectively, the tools should provide the ability to analyze present and future consequences of various decision options. In addition, it recommended the tools should have the capability to show distributional effects (e.g., costs and benefits) of alternative options, particularly for vulnerable or disadvantaged groups and ecosystems. To reap the benefits from the application of these tools in a sustainability context, systems thinking is needed.

SYSTEMS THINKING

Generally, systems thinking involves a comprehensive understanding of the mechanisms and feedback effects of interrelated parts or subsystems that work together – in either a coordinated or uncoordinated fashion – to perform a function.[1] From an operational perspective, "applying a systems approach to sustainability provides a rigorous way to analyze the potential consequences of human intervention…it may reveal how actions taken by industry and consumers affect the environment, how efforts to protect the environment impact industry and consumers, or how impacts on one system can affect others and the larger whole" (EPA 2013a, p. 11). Understanding such connections has long been a central tenet of industrial ecology (Allenby 2006). Also, "cradle-to-cradle" (rather than "cradle-to-grave") design tenets popularized by McDonough and Braungart with the slogan "waste equals food" (McDonough and Braungart 1998, 2002) and The Natural Step Framework for Strategic Sustainable Development (Natural Step 2014) attest to the idea that business operations are deeply integrated into natural systems – and vice versa. At the core is the principle that waste (or output) from one system can be used as feedstock (or input) to another. Moreover, systems thinking applies at the product system level. Life cycle assessment (LCA) approaches have advanced over the last 20 years to provide a methodological framework for ensuring that

[1] See Holling (2001), Meadows (2008), and EPA (2013a) for a more detailed explanation of systems thinking.

an improvement in one sustainability issue (for example, energy consumption) would not create an unanticipated impact in another area or life cycle stage. Systems thinking is already core to successful programs such as Design for Environment (DfE), in which LCA is an integral component (see Chapter 4). EPA programs, such as DfE, provide the agency with the opportunity to build on the foundation of existing knowledge in order to infuse systems thinking into agency decisions and actions. System thinking at national, region, community, company, value chain, product category, and product levels is one of the fundamental premises behind a successful implementation of sustainability concepts into EPA decision making processes.

ESTABLISHING THE LEVEL OF ANALYSIS NEEDED FOR AN ACTIVITY

Chapter 2 discussed the wide range of EPA's activities in which sustainability considerations could be incorporated at multiple levels of activity. However, not all applications of the sustainability assessment tools need to be done at the same scope and level of detail. It would be impractical to apply the formal SAM approach to every narrow routine decision, such as permitting decisions on air emissions, that may affect small geographic areas. On the other hand, decisions that likely will have high impact for one or more sustainability pillars (such as a national policy decision or a power plant facility siting) would probably benefit from the SAM process.

EPA faces the challenge of incorporating sustainability tools and approaches into decision-making processes at an appropriately selected level of detail to assure that the systematic consideration of the three pillars of sustainability is assured. An important component of this challenge is to establish boundaries for the analysis in geographic extent and time. A sustainability screening approach, using a minimum input of data for rapid analysis, can help determine whether to undertake the SAM approach for any particular activity. If it is determined that this process should be undertaken, the screening tool could also provide guidance on the appropriate analytical tools to apply and on the appropriate degree of depth and scope of the analysis needed. Screening will help avoid undue delays in taking action to address environmental problems. It can determine the range and magnitude of potential impacts. The committee realizes that it will take time, resources and experience to incorporate sustainability broadly into EPA's activities. Chapter 7 discusses several kinds of major activities in which EPA has substantial opportunities to apply sustainability tools and approaches.

THE ENVIRONMENTAL PROTECTION AGENCY'S *SUSTAINABILITY ANALYTICS* REPORT

Scores of analytic tools and methods to support decision-making at EPA and elsewhere have been proposed and developed (e.g., EPA 2014h). Some of these tools have been tested and frequently applied for the purpose of considering more-sustainable uses of the environment and natural resources. Other tools could become more useful with additional development. In its recent report *Sustainability Analytics: Assessment Tools and Approaches* (referred to as the *Analytics* report), EPA summarizes 22 types of tools and methods used by the agency; it categorizes them under the pillars of sustainability: economic (4 types), environmental (10 types), and social (8 types) (EPA 2013a).[2] (A glossary of tools and approaches that was developed from the *Analytics* report is presented in Appendix D of this report.) The *Analytics* report also demonstrates the application of the tools by using 24 illustrative examples on topics which are similar to some of the case studies presented later in this report. The tools being considered include decision tools into which sustainability concepts can be incorporated. The tools do not operate at the same level of specificity; some are quite general while others could be used as part of another tool. For example, futures methods may be used in an economic benefit-cost analysis.

[2]Although the report shows 2013 as the publication year, it was not released to the public until 2014 while the committee was conducting its study.

EPA's *Analytics* report notes that it does not represent a comprehensive list of tools, but instead discusses tools recommended by subject matter experts across the agency. The report also indicates that it does not provide in-depth instructions for applying each assessment tool or approach, and it does not set policy or dictate a process for implementing sustainability concepts using any of the tools in the *Analytics* report (EPA 2013a). In addition, the report indicates "As these assessment tools and approaches are developed and applied, *Sustainability Analytics* will evolve: the assessment tools and approaches included in it will be more fully described; additional tools and approaches will be identified; and, information about sustainability metrics, indicators, datasets and indices will be included" (EPA 2013a, p 8). EPA has taken a good first step in developing this initial *Analytics* report. It provides a reasonable and informed baseline survey of sustainability tools.

The tools listed in the *Analytics* report for each of the pillars are generally categorized by the discipline within which they were developed. A similar categorization was used in a presentation to the committee by EPA officials (see Figure 3-1). Thus, the tools in the economic pillar are identified as those coming from the discipline of economics and include use of economic methods such as monetization or valuation. Tools presented in the social pillar category are focused on societal impacts as well as engaging the public in decision making, and are commonly associated with sociology, anthropology, political science, and geography. The tools listed in the environmental pillar category consider specific assessments for chemicals and alternatives as well as broader system-wide assessment tools. Many of these come from engineering and environmental sciences. While this categorization of tools may be useful for historical context in some instances and the *Analytics* report indicates the application of tools can involve more than one pillar, the identification of a tool with a specific pillar is potentially very misleading. For example, the report presents benefit-cost analysis (BCA) in the pillar of economics, which suggests it focusses exclusively or largely on that discipline, but BCA has long been used to inform decisions relevant to the environmental and social pillar as well (EPA 2014h). This categorization in the *Analytics* report is inconsistent with the report's discussion of BCA, which acknowledges that valuation of nonmarket goods is an important part of BCA. The *Analytics* report also notes that environmental effects which cannot be monetized should be listed and considered in decisions. Given the importance of BCA and its potential for informing all three pillars, the committee chose it as one of the tools for more-detailed discussion in this chapter.

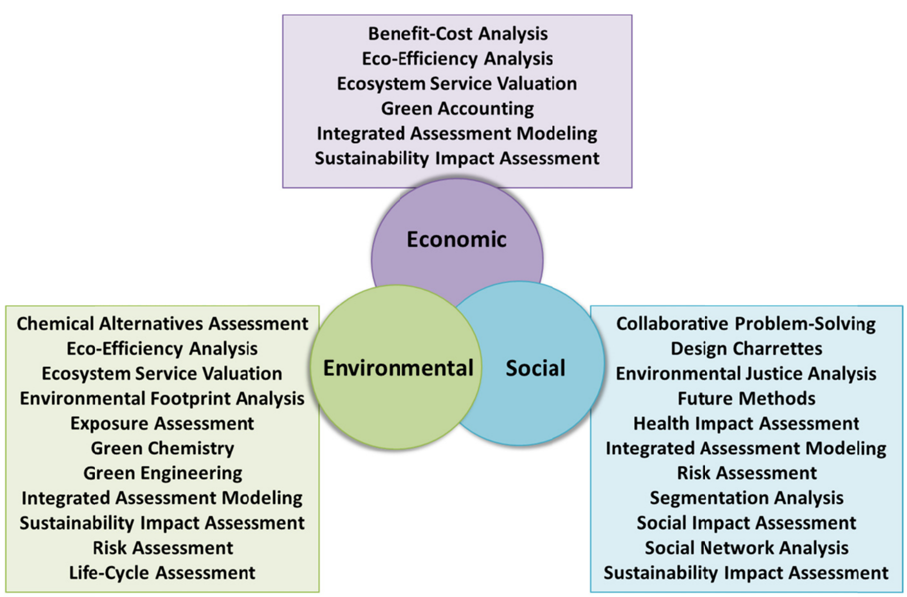

FIGURE 3-1 EPA's categorization of tools into single pillars of sustainability. Source: Trovato and Shaw 2013.

Another example of how the *Analytics* report presents a limited breadth of possible contributions for a tool is related to life-cycle assessment (LCA). In the report, LCA is defined as applying only to products. However, LCA is able to represent an accounting of the inventory and effects of products, processes, or systems, and there have been a wide array of developments with respect to LCA approaches, databases, and applications. The *Analytics* report does not mention EPA's substantial investment in LCA, including database development and impact assessment, primarily in the Office of Research and Development. Applications of LCA in EPA program offices have been more limited. A discussion of the other current development and application efforts of LCA would be useful, noting, for instance, that EPA is represented in an interagency group that focuses on LCA, including the General Services Administration and the US Department of Agriculture. There have also been substantial efforts by international organizations, such as the UN Environment Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC), and private organizations to apply and adapt LCA.

The *Analytics* report indicates that the tools and approaches currently included should not be considered the only tools that could be applied to a particular activity. It also indicates additional tools and approaches will be added as it evolves. A potentially important tool that is currently not included is the recently developed approach for considering the social cost of carbon (SCC), which has aspects of economic tools similar to BCA. SCC is an estimate of the monetized damage (usually expressed on a per ton basis) associated with the effects of an incremental increase in greenhouse gas (GHG) emissions and based on a particular climate-change scenario at a particular point in the future. Integrated assessment models, which are used to produce such estimates, rely on assumptions about the relationship between GHG emissions and temperature change and temperature and associated damages (NRC 2010). Given the prominence of climate mitigation issues for EPA and the fact that the social cost of carbon focusses explicitly on future benefits and costs of current decisions–a significant component of sustainability–its inclusion in the *Analytics* report in the near future is important (see additional discussion later in this chapter). Another omission from the report is a discussion of the role of managing uncertainty and variability with decision support tools. Failure to understand and address uncertainty and variability in the application of decision support tools can lead to an inappropriate interpretation of results. Their consideration in a sustainability context is discussed later in this chapter.

In the *Analytics* report, the link between the tool and how it can be used to provide information to support decision making related to sustainability is often not made. For example, the report did not explain explicitly how ecosystem services valuation can inform sustainability and how it could do so more effectively with additional research and development. Furthermore, the report needs to include more discussion of tradeoff situations where one or more of the sustainability pillars could be at odds with one another (e.g., achieving more environmental sustainability for future generations may result in less economic activity that can affect low income members of the current population disproportionately). As discussed in the Green Book, sustainability tools will need to inform decisions involving considerations of tradeoffs (as well as synergies). Further discussion of this context in the *Analytics* report is warranted.

EPA's sustainability analytics report should be considered a living document with appropriate updates on a regular schedule. Future versions of the report should provide additional discussion of integrative applications of the tools and how a tool can be used to provide information to support decision making involving tradeoffs, where one or more sustainability pillars could be at odds with one another. New tools identified would be added. *(Recommendation 3a)*

SUSTAINABILITY TOOLS AND METHODS ASSESSMENT

Some tools and approaches presented in the *Analytics* report are well developed and have been widely used throughout EPA, and others are in the development stage or have been used within the agency only recently. Although the *Analytics* report discusses the strengths and limits of specific tools, it does not apply a consistent set of criteria across all of the tools. Doing so would help identify opportunities for improvement and identify considerations in selecting tools for a particular activity. To illustrate the application of a consistent set of criteria, the committee rated each tool presented in the *Analytics* report, based on the members' experience and expertise, and by applying seven general criteria in a qualitative manner that are relevant to the current state of development and use of the tools for sustainability analyses.

- Documentation - how well documented the tool is, by existing references available about the method or potential applications.
- Accepted Use - the degree of consensus among stakeholders and the scientific community of how the method should be employed.
- Maturity - the extent to which the scientific basis for the tool has been developed to support a particular type of decision.
- Software - the availability of software in the public domain to support applications of the tool.
- Screening - suitability of the tool for screening-level analyses to inform subsequent decisions about the appropriate depth of additional analyses.
- Data - extent to which adequate data exist, or will likely soon exist, to support tool development and application.
- Extent of Usage - assessment of the overall role of the tool in EPA decision making to date.

The committee's rating of the tools in Appendix E should be viewed as an example of the type of ongoing assessment needed to develop and refine a full suite of sustainability assessment tools. Because the exercise may have been influenced by the degree of the committee's familiarity with the extent of development of some of the tools, the rating results should not be used as a basis for excluding any tool from consideration or for selecting the appropriate tools for a given EPA decision.

The committee finds that the tools differ widely in the underlying amount of R&D and other support generally available or in EPA. A ratings exercise may be useful for identifying priority R&D areas for tools planned to be foundational in the EPA decision suite going forward. For tools that EPA sees as strategically valuable, ongoing R&D support will be needed to help attain the visions expressed in EPA's strategic plan.

Future efforts by EPA to track and categorize tools, e.g., in future updates to the Sustainability Analytics report, could adopt similar or entirely different criteria. A useful addition to criteria would be associated with the applicability of tools in certain contexts. In general, applicability of a tool in a sustainability context is a major criterion relative to the others considered. However, applicability was not included in the committee's rating exercise because its determination is context specific. All of the tools are potentially applicable, but each tool has various strengths, limitations, and data requirements that influence whether they are actually applicable to a particular issue. Assessment of applicability is complicated by specific instances of tools (e.g., life cycle assessment in general could be applicable to many decisions, but specific LCA software tools or methods may be applicable in only specific contexts).

Various tools listed in the Figure 1-1 and Appendix E are inherently integrative across sustainability pillars, and it is not surprising then that there was significant appreciation of them by the committee. The perceived high performance of these tools (including BCA, exposure assessment, risk assessment, and LCA) by the committee suggests that continued integration of tools in support of EPA decision making are likely to lead to higher overall value. The committee's rating exercise helped to frame its discussion of the tools, and led to a focus on a subset of them.

In general, a small number of tools is relied on much more than others, and these largely have more solid scientific bases for their use. These tools are mature, accepted, have data, and EPA continues to use them in its decision processes. The committee thus considers them to be particularly promising with respect to their applicability by EPA for use in supporting integrative sustainability decisions, particularly in the near term. Even though there is a range in the extent to which the tools have been developed and applied within EPA, it is important to note that the committee does not consider that a hierarchy of tools exists with respect to selection. Choosing a tool should be based on the needs for a particular application. It may be useful for EPA going forward to evaluate the sustainability tools by using a consistent set of criteria selected by the agency, along with periodic updating of EPA's view and use of relevant sustainability tools (e.g., in future iterations of the Sustainability Analytics report).

> **EPA should consider using a consistent set of criteria to evaluate the tools and carry out assessment exercises that are similar to the one conducted by the committee with the agency's own internal users of these tools, or a larger set of external stakeholders for corroboration. The assessments should help to identify opportunities for improvement and identify considerations in selecting tools for particular activities.** ***(Recommendation 3b)***

INDIVIDUAL TOOLS AND APPROACHES

The committee chose a small set of tools for discussion in this section to illustrate particularly valuable attributes for informing sustainability concepts. The discussion considers how sustainability considerations are currently incorporated into the use of these tools, and how sustainability could be incorporated to a greater extent with additional research and development. Our discussion of particular tools should not be interpreted to mean those tools are most appropriate, or that tools not discussed are inappropriate.

Risk Assessment

In 1981, the first article of the first issue of *Risk Analysis, An International Journal*, by Stanley Kaplan and John Garrick (1981) defined risk assessment. The essence of their paper was to address three questions:

1. What can go wrong?
2. What are the chances that something with serious consequences will go wrong?
3. What are the consequences if something does go wrong?

Later analysts (for example, Greenberg et al. 2012) added three other questions that address risk management:

4. How can consequences be prevented or reduced?
5. How can recovery be enhanced, if the scenario occurs?
6. How can key local officials, expert staff, and the public be informed to reduce concern and increase trust and confidence?

Risk assessment is thus a tool for evaluating the relative merits of various options for managing risk. It can be applied in an engineered-systems context to assess possible effects due to a system failure (e.g., a tailings storage facilities at power plants). It can also be applied in a public health context to address health effects resulting from exposures to chemical contaminants or some other stressor. Ecologic risk assessments evaluate the likelihood that adverse effects to ecosystems including plant or animal communities would result from exposures to environmental stressors. Risk assessment is also applied to episodic natural events (e.g., hurricanes and floods) and harmful human acts (e.g., terrorism).

Risk assessment and risk management have been integral to EPA's decision-making (especially with respect to regulations to protect human health) to assess the potential consequences of options it is considering (see Box 3-1). In general, EPA has focused its risk-based decisions on reducing risk in response to human or ecologic exposures to individual stressors (usually single chemicals or pollutants) in particular environmental media). Previous NRC studies have provided detailed advice on the risk assessment and risk management framework (e.g., NRC 1983, 1994, 2009). NRC (1983) elucidated a four-step process for risk assessment: hazard identification, dose-response assessment, exposure assessment, and risk characterization.

BOX 3-1 Examples of EPA Actions Informed by Risk Assessments

- Pesticide usage restrictions.
- Hazardous waste site remediation goals and approaches.
- Regulation of hazardous materials usage, storage and disposal.
- National ambient air quality standards.
- Emissions standards for hazardous air pollutants.
- Ambient water quality criteria for surface waters.

Source: EPA (2014i, p 1).

BOX 3-2 Recommended Principles for Uncertainty and Variability Analysis

1. Risk assessments should provide a quantitative, or at least qualitative, description of uncertainty and variability consistent with available data. The information required to conduct detailed uncertainty analyses may not be available in many situations.

2. In addition to characterizing the full population at risk, attention should be directed to vulnerable individuals and subpopulations that may be particularly susceptible or more highly exposed.

3. The depth, extent, and detail of the uncertainty and variability analyses should be commensurate with the importance and nature of the decision to be informed by the risk assessment and with what is valued in a decision. This may best be achieved by early engagement of assessors, managers, and stakeholders in the nature and objectives of the risk assessment and terms of reference (which must be clearly defined).

4. The risk assessment should compile or otherwise characterize the types, sources, extent, and magnitude of variability and substantial uncertainties associated with the assessment. To the extent feasible, there should be homologous treatment of uncertainties among the different components of a risk assessment and among different policy options being compared.

5. To maximize public understanding of and participation in risk-related decision-making, a risk assessment should explain the basis and results of the uncertainty analysis with sufficient clarity to be understood by the public and decision-makers. The uncertainty assessment should not be a significant source of delay in the release of an assessment.

6. Uncertainty and variability should be kept conceptually separate in the risk characterization.

[a]Source: NRC 2009, p. 120.

Uncertainty in quantitative risk assessments (such as those carried out using computational models) can arise from a lack or incompleteness of information, as well as incorrect information. Uncertainty analysis is rooted in understanding the level of confidence associated with a particular decision and the causes of the uncertainties. Uncertainty analysis is typically quantitative, and at the simplest level can be implemented by considering ranges for model input data (variables and parameters). Advanced uncertainty analysis methods could include simulation, in which statistical distributions for model values are used to produce a range of possible outcomes. As mentioned previously, variability is often considered along with uncertainty. It refers to actual differences in attributes due to heterogeneity or diversity in the system being considered. NRC (2009) also recommended principles for uncertainty and variability in a risk assessment context (see Box 3-2) but the principles are generally useful and relevant when considering the issues in the entire suite of EPA sustainability tools.

How Are Sustainability Considerations Currently Incorporated?

The Green Book found that the four-step risk assessment process, as envisioned by NRC (1983), is an important component and tool used to inform decisions in the SAM approach. Risk assessment can be used to inform considerations of sustainability concepts by estimating whether, and to what extent, public health or the environment will be affected if an action is taken. The Green Book recommended that EPA include risk assessment as a tool, when appropriate, as a key input into its sustainability decision making.

However, it is not always possible to address complex risk-related considerations quantitatively with the risk assessment approaches typically used by EPA. The approaches EPA relies upon have important limitations, including requiring large amounts of information and analyses, being applied mostly to existing problems rather than striving to prevent potential future problems from occurring, and taking excessive amounts of time to execute–particularly at the national level–when data are lacking (see NRC 2009 and 2011b for further discussion of the limitations).

Many of the broader public-health and environmental-health questions EPA is facing include multiple exposures to complex mixtures of chemicals. The traditional RA-RM approach does not adequately address this concern, particularly for communities that are especially vulnerable to environmental exposures by socio-economic stressors and disproportionate past exposures.

How Can Sustainability Considerations Be Incorporated Better?

In recognition of the limitations in approaching these complex issues, EPA has attempted to widen the context in which risk assessment is performed to include the early consideration of a broad range of decision options, and the cumulative threats of multiple social, environmental, and economic stressors to public health and the environment. In 2003, EPA released guidelines for cumulative risk assessments that include combined risks posed by aggregate exposure to multiple stressors–aggregate exposure includes all routes, pathways, and sources of exposure to a given agent or stressor (EPA 2003). However, there is substantial uncertainty in the approaches and the data for understanding outcomes for cumulative risks (EPA 2013b).

In addition, NRC (2009) pointed to the need for EPA risk assessments to take into account foreseeable consequences of possible decisions, including substitution risks (for example, considering the risks resulting from replacing one chemical used in commerce by another) and the potential for adverse outcomes associated with choices that might be taken by individuals affected by EPA's decision.

Research and Data Needs

New techniques are needed for broader characterizations of cumulative risks to better account for the full range of environmental stressors, particularly for environmental justice analyses (see Chapter 6). A broadening of the risk assessment and risk management paradigm raises the need for screening-level risk-assessment tools (such as databases, computer software, and other modeling resources) (NRC 2009). For example, the integration of risk assessment with LCA would allow EPA to consider a fuller range of issues relevant to a decision (see discussion later in this chapter).

Characterizing and reducing uncertainty throughout the risk analysis process is a major challenge. Given limited agency budgets, it is essential that EPA be more decisive about what outcomes are more likely to occur and those that are likely to be consequential in order for it to compare tradeoffs.

Without narrowing uncertainty, it is difficult to assess, in a broad manner, the advantages and disadvantages of options, for example, about processes used to manufacture a chemical or how to evaluate a proposed site for drilling for oil and gas production. EPA needs to quickly scope from possible events, to their likelihoods and then to their consequences in order to identify major hazards.

There is also a challenge for risk managers to assess the effectiveness of investments in reducing risks from environmental exposures, rebounding from episodic events, and communicating these to stakeholders. This will be especially important for decisions concerning climate adaptation. North et al. (2014) discusses processes for stakeholder and public engagement in the context of managing environmental risks. In addition, NRC (2008) assesses whether, and under what conditions, public participation achieves the outcomes desired.

For consideration of impacts on a regional scale, for example, one needs to know not only the expected economic consequences of an event or exposures to stressors, along with their uncertainties, but also the consequences of investing in various levels of prevention. EPA and other major federal agencies have been stimulating research in these areas, but it has become even more imperative because of the increasing pace of emerging challenges (see Chapter 6). The committee further discusses the relationship of risk assessment and risk management decision making to sustainability approaches in Chapter 7.

Welfare Analysis: Benefit-Cost Analysis and Cost-Effectiveness Analysis

Economic benefit-cost analysis (BCA)[3] and cost-effectiveness analysis (CEA) have been used for many decades to organize and evaluate information in support of decision making. Many textbooks provide overviews and definitions (e.g., Boardman et al. 2010). The conceptual foundations are described in an OECD document as:

> "The essential theoretical foundations of CBA [benefit-cost analysis] are: benefits are defined as increases in human wellbeing (utility) and costs are defined as reductions in human wellbeing. For a project or policy to qualify on cost-benefit grounds, its social benefits must exceed its social costs. "Society" is simply the sum of individuals" (OECD, 2006, pp. 16-17].

CEA is concerned with how to get societal benefits at the lowest cost possible. For example, reducing pollution or saving lives is qualitatively a benefit, and might be measured in terms of tons avoided or lives saved (but neither are valued in dollars). The key contribution is being able to describe "cost per unit of effectiveness" without full monetization. It is possible to have multiple endpoints of interest for cost-effectiveness comparisons so that more than one criterion can be evaluated. CEA differs from BCA in that it considers only the cost of achieving a given set of improvements and provides a metric for identifying the lowest cost strategy to achieve this given gain. CEA and BCA can provide useful information for decision making whether or not potential effects of interest are monetized. However, when a decision is related to a regulation, which prescribes a level of control or expenditure, CEA would be more appropriate.

How Are Sustainability Considerations Currently Incorporated?

A strict decision rule of adopting programs or policies that "pass" a benefit-cost test is consistent with an economic efficiency criterion, but may fail broader sustainability considerations. Even when other criteria are used in decision making, BCA and CEA tools provide valuable information to decision makers. Indeed, a well-established reason for not adhering to a strict benefit-cost analysis occurs when the program or policy has significant distributional concerns, i.e., the costs and benefits are not equally felt across income, geographic, or racial groups (Arrow et al. 1996). One of the benefits of BCA and CEA analyses is that they inherently help connect stakeholders to net effects (e.g., who the winners and losers are, who has to economically sacrifice to make others better off). This is a key consideration when thinking about sustainability.

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[3]The concepts of benefit-cost analysis (BCA) and cost-benefit analysis (CBA) are identical and used interchangeably.

A second reason commonly given for not adopting a strict benefit-cost test is that there are times when all ecosystem or environmental benefits cannot be monetized so that a decision rule that uses only monetized values risks adopting a policy that does not improve human wellbeing. An important recommendation of OMB (Circular A-94), also contained in EPA guidelines, is that all effects of a program or policy, whether they can be monetized or not, need to be clearly documented in either a BCA or CEA. This is another key tool in the context of sustainability and can be used as a general guide on how to qualitatively and quantitatively assess other sustainability metrics (for example see discussion below on ecosystem services valuation). It can also help when developing analyses of tradeoffs. Specifically, best practices in BCA recognize that there is a hierarchy of aspects that can be monetized, some that can be measured but not easily monetized, and some for which even measurement remains a challenge.

BCA and CEA are best considered tools for organizing information in transparent ways so that decision makers can understand the ramifications of their actions, regardless of the ultimate decision criterion they employ in choosing an action. Thus, BCA can provide information to support decision making within all three pillars of sustainability.

Sustainability has been defined in economics as a commitment to recognizing the welfare of future generations and to address intra-generational equity. Common distinctions are made between weak sustainability (a commitment to maintain a nondeclining or given standard of living over time) or strong sustainability (a commitment to preserve the stock of critical natural assets such as exhaustible or slowly renewable natural resources). See Pezzey (1992); Solow (1993); Stavins, et al. (2003) for definitions of these concepts.

Approaches that can be used to incorporate both weak and strong sustainability concepts in welfare analyses include:

- Use of distributionally weighted BCA (Boardman et al., 2010).
- Use of multiple discount rates (EPA 2014h).
- Inclusion of ecosystem or environmental impacts consideration even when impacts cannot be quantified or when monetary values are not assigned to quantified impacts (EPA 2014h).
- Presentation of the net benefits of a project broken down to reflect subpopulations of specific interest for social equity or environmental justice concerns such as income classes, geographic areas, racial groups, etc. (Farrow 2011).
- Economic Impact Analysis (such as, changes in prices, profits, plant closures, or employment) and distributional assessments (impacts on small businesses and cities, environmental justice analysis) (EPA 2014h).
- Consideration of multiple alternatives during the initial scoping of alternatives (EPA 2014h).

A recent and rather important development in the area of BCA is its emerging application to measures being considered for climate change mitigation. As mentioned previously, the sustainability tool for this purpose is SCC that is being used to incorporate the social benefits of reducing carbon dioxide (CO2) emissions into BCAs of regulatory actions that may have otherwise small impacts, but when combined with many other small impacts, lead to large cumulative global impacts. The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. The purpose of SCC estimates is to allow federal, state, and local agencies to evaluate and incorporate climate mitigation measures in their planning activities. The choice of discount rate is an important step in the computation of the SCC because it includes consideration of damages from climate change that are expected to occur far in the future, often to future generations. A scientific debate on the logic and ethical basis for choosing a discount rate in long time horizon problems has emerged (Arrow et al., 2013). EPA research into the appropriate choice of discount rate for its policies and programs is important. See Box 3-3 for additional details.

BOX 3-3 Social Cost of Carbon

A May 2013 technical support document (TSD) prepared by the federal Interagency Working Group on Social Cost of Carbon provides detailed information on the range of values of the social cost of carbon (SCC) that can be used (US Interagency Working Group on Social Cost of Carbon 2013). The SCC values (in 2007 dollars per metric ton of carbon dioxide) are averaged values from the application of three peer-reviewed integrated assessment models (IAMs); an IAM is a sustainability analytics tool included in the *Analytics* report.

The 2013 TSD provides updated values from the 2010 TSD (US Interagency Working Group on Social Cost of Carbon 2010) of SCC at discount rates of 2.5%, 3%, and 5% and a value that represents a 95th-percentile SCC estimate for all three IAMs at a 3% discount rate. That fourth value is included to represent greater than expected effects of temperature change. Considerations in choosing the appropriate discount rate for evaluating environmental problems, such as climate change, that are long-term and intergenerational are mentioned elsewhere in this chapter.

The SCC estimates in the 2013 TSD report are 50–70% higher than those reported in the 2010 TSD; this reflects updating of information in the IAMs. The substantial changes in revised model estimates over the short period of 3 years indicate the rapid increase in knowledge of the science and economics of climate change. Equally important, the changes reflect many uncertainties involved in the model estimates, which should be reduced as data and models improve.

In addition, a number of major private-sector companies are using internal carbon pricing as a strategic tool in their business planning (also see Chapter 5) (CDP 2014).

In the environmental pillar there has been a significant and ongoing scholarly effort to measure and monetize ecosystem services. EPA Guidelines for BCA already provide solid guidance on this issue. They suggest that the benefits of a change be expressed in physical or natural units, consistent with the view of reflecting all environmental changes, even if they cannot be monetized.

How Can Sustainability Considerations Be Incorporated Better?

Incorporation of sustainability considerations with the use of BCA and CEA can be enhanced through the following activities:

- When undertaking BCA projects with intergenerational impacts, consider using the lowest reasonable discount rate following the advice of Arrow et al. (2013)
- Use the most up to date SCC estimates when undertaking BCAs for major rules and regulations dealing with climate mitigation measures.
- Consider the extent to which costs and benefits vary among income, socioeconomic, racial, urban/rural, gender, and other class distinctions.
- Present costs and benefits estimates by income, age, race, and other relevant factors in CEAs, RIAs and other economic assessment that the agency uses. The purpose is to make those tools more useful in describing what groups will be most affected by a decision (e.g., regulation, permit, or cleanup action).
- For large projects or programs, when considering alternatives at the beginning of an analysis, identify at least one alternative that is specifically focused on concepts of sustainability.
- When doing ex-post BCA, include a discussion of whether there were alternatives that were not considered that might have achieved similar net benefits, but would have been more sustainable (e.g., would have has less impact on nonrenewable resources, would have generated fewer greenhouse gases while achieving the goal, or would have had less impact on a disadvantaged population). This approach would help focus on sustainability considerations for future planning.

Research and Data Needs

EPA should develop guidelines for preparing a sustainability assessment analogous to its *Guidelines for Preparing Economic Analysis* (EPA 2014h). *(Recommendation 3c)*

Developing the guidelines could be accomplished, particularly in the short run, by adding a chapter to the existing guidelines that addresses sustainability tools and their inclusion in BCA. It will be important for EPA to identify a home for the responsibility to maintain and update this guidance.

In its consideration of ex-ante modeling approaches for CEA, Fell and Linn (2013) provides a useful discussion of corresponding data needs.

Life-Cycle Assessment

LCA approaches to decision making involve consideration of all relevant aspects of a system over its life cycle (McDonough and Braungart 2002, SAIC 2006, and Hellwig and Canals 2014). The purpose of life-cycle approaches is to provide information to ensure that actions will not have unexpected or unanticipated effects elsewhere in the product system (such as a different life-cycle stage) or different effects (such as unexpected material-acquisition demands to increase energy efficiency). LCA also helps to ensure that users are aware that the implications of decisions are not isolated but are part of a larger system, improving the entire system—not just a single part of the system—for a longer term (UNEP/SETAC LCI 2004).

One may visualize the approaches along a continuum from qualitative screening (which provides early direction to a decision-making process) to semiquantitative assessment (which helps to substantiate improvement and effects along the system) to quantitative assessment (which provides confidence that the proposed actions or decisions will create improvements). The aquatic-toxicity field might offer an analogue. Early in an analysis of the potential effects of a chemical on the environment, a practitioner usually conducts a screening LC_{50} study that provides the general range of concentrations that should be used in a definitive LC_{50} study.[4] Similarly, a screening-level LC study can be used to help to define the effects or life-cycle stages for which additional data collection is warranted.

As mentioned previously, LCA is listed as one of the tools in EPA's *Analytics* report, but it is defined as applying only to products. More broadly, LCA is able to represent an accounting of the inventory and effects of products, processes, or systems. LCA comprises multiple steps that eventually lead to a life-cycle inventory (LCI) that sums the flows by environmental compartment for any chosen effects over the life cycle (such as total carbon dioxide emissions to air). A later step, life-cycle impact assessment (LCIA), transforms the inventory flows (such as carbon dioxide and sulfur dioxide emissions and energy use) into such effects as global-warming potential and acidification. Various methods of impact assessment, including the EPA-led TRACI (tools for the reduction and assessment of chemical and other environmental impacts) method (Bare 2011) relevant to the United States, are available in support of LCA studies. LCA methods can also be used to measure costs of assessing economic performance, but this application is in an earlier stage of development than the environmental applications.

LCA examines the potential effects associated with a product, process, or system. It can be combined with risk assessment to provide risk estimates over an entire life cycle rather than at a particular point. It can also be used to perform attributional analyses (to estimate effects associated with an existing product) and consequential analyses (to estimate effects associated with introduction of a new product into an economic system).

International Organization for Standardization (ISO) LCA standards 14040/14044 (2006) form the core approach for conducting an LCA study. They are also the basis of many related activities, such as carbon-footprinting protocols developed by the World Resources Institute/World Business Council on Sustainable Development and water-footprinting standards developed by ISO. Although it is not a con-

[4]An LC_{50} is the concentration of a substance in an environmental medium that kills 50% of the test organisms.

ceptually difficult method, LCA requires rigorous consideration of boundaries, flows, inventories, and effects. The formalization of the international standards provides a valuable technical foundation that does not exist for many of the other methods mentioned. However, the ISO LCA standard is not a recipe for performing LCA; rather, the standard provides the basic principles for and guidance on conducting an LCA study. One of the key elements of the standards is the importance of the Goal and Scope Definition element, the first step. In this element, there needs to be agreement on the purpose, intended audience and applications, boundary conditions, scope, and other key planning considerations. The ISO standards allow flexibility so that if the purpose of a study is to inform initial direction in identifying risks and opportunities, there can be leeway in boundaries and data quality. However, if the purpose of a study is to make an external claim about the superiority of one product over another or about their equivalence, additional requirements must be met.

Another critical design parameter is the choice and definition of a functional unit, for which effects are expressed as quantities per unit (for example, per kilowatt–hour of electricity) for the study. LCA is often used to explore inventories, effects, and opportunities in a relative fashion, for example, compared with previous design of a product system or of a competitor.

Recent decisions in the retail and green-building sectors, for example, have created a rapid increase in the application of LCA approaches in the United States. The increase has resulted in simplified computer-aided design tools. Moreover, EPA is taking a leadership role in an intergovernment group to advance the interoperability of national databases as part of a global network.

Finally, one of the most pressing applications of LCA is in support of public policy and decision-making. As LCA and its underlying databases and methods have matured, the desire to use it in support of major decisions has grown. For example, LCA was used in support of the federal renewable fuels standard to estimate the life-cycle carbon emissions of conventional and biobased fuels (see the biofuels case study in Chapter 4 for more information).

How Are Sustainability Considerations Currently Incorporated?

Although LCA approaches can be used to consider all sustainability pillars, studies using this tool usually have not considered all three pillars. UNEP/SETAC (2013) concluded that life-cycle sustainability assessments are possible; however, methodological improvements are needed, including data production and acquisition, and formats for communication of results (Valdivia et al. 2013). In terms of economics, LCA studies have considered the life cycle cost of the product or system in question (e.g., improvements in energy efficiency, roads, and other infrastructure) , which has helped to reinforce life cycle thinking by ensuring that first costs and recurring costs are considered. The life cycle community views that LCA consist of four phases (goal and scope definition, inventory, impact, and interpretation). These studies seek to translate LCA inventories into common impact metrics, and also have used the ISO LCA Standard to normalize these metrics into a per-capita basis, within the normalization portion of life cycle impact assessment. There have been efforts underway to add life cycle costing to some studies, but this is still early in the maturity of applying LCA. Moreover, some research is underway to explore how to incorporate social impacts into LCA studies.

Social and socio-economic LCA (S-LCA) aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle encompassing extraction and processing of raw materials; manufacturing; distribution; use; re-use; maintenance; recycling; and final disposal. S-LCA differs from other social impacts assessment techniques by its objects (products and services) and its scope (the entire life cycle). S-LCA usually targets direct effects (positive or negative) on stakeholders during the life cycle of a product. The effects may be linked to the behaviors of enterprises, socio-economic processes, or impacts on social capital. Depending on the scope of the study, indirect impacts on stakeholders may also be considered.

Guidelines for Social Life Cycle Assessment of Products (UNEP/SETAC 2009) provides direction for stakeholders engaging in the assessment of social and socio-economic impacts of product life cycles.

Benoit, et al (2013) explored the initial development of a social hotspots database (SHDB) that provides social risk information on 22 themes within 5 social impact categories: labor rights and decent work, health and safety, human rights, governance, and community impacts.

How Can Sustainability Considerations Be Incorporated Better?

There are various ways in which EPA could ensure that LCA is incorporated into sustainability assessments better:

- Strive to make LCI and LCIA results more readily comparable across pillars, such as by estimating costs associated with life-cycle impacts.
- Urge studies to go beyond mere LCIs and proceed to LCIAs, and interpretation of the implications of various design or technology options.
- Develop ways in which social issues, such as equity or environmental justice, could be assessed. As part of an overall sustainability tool box, monitor and engage in an understanding of the current development of S-LCA methodology and begin to pilot its applications.

Research and Data Needs

Over the last 20 years, EPA, other government agencies, industry, and life cycle practitioners have made considerable advances in the LCA methodology through their own efforts as well as efforts by efforts lead by SETAC, ISO and UNEP/SETAC Life cycle Initiative. In parallel, the life cycle data bases have grown rapidly as the demand for life cycle information to assess the potential trade-offs of multi-impacts (e.g., energy, water, GHG, and others) along a product's life cycle from material acquisition, manufacturing, logistics, use and end of life disposition.

The US Department of Agriculture (USDA), in collaboration with EPA, is leading the development of a 'digital commons' data base. The goal in developing the database is to provide open access LCA datasets and tools. The project is intended to make North American LCA data more accessible to the community of researchers, policy-makers, industry process engineers, and LCA practitioners. The initial focus is on providing data for use in LCAs of food, biofuels, and a variety of other bioproducts.

Complementary to the government-led data base efforts, industry associations have been collecting generic life cycle data on chemicals, plastics and other materials to inform decisions concerning raw materials acquisition through the end of initial processing (often referred to as cradle to gate). Companies that need more site-specific data or supplier specific data are collecting and using a combination of site-specific and generic data to inform product-design and materials-selection decisions.

Also, EPA and USDA are collaborating with the United Nations Environment Programme (UNEP) to develop a vision, guiding principles, and an approach for implementing a voluntary international network to promote LCA data accessibility, interoperability and applications. This effort builds on previous collaborations between EPA and the UNEP/SETAC Life cycle Initiative to develop Global Guidance Principles for Life Cycle Assessment Databases.

While LCIA methods have been developed, the US impact assessment methods have not received as much resources for research and development as those in Europe. Further development of the US-based TRACI method needs to be undertaken.

> **In recognition of the range of LCA approaches from qualitative to quantitative, additional guidance should be developed and implemented to illustrate how the approaches can be used in EPA decision-making. The guidance should address the combined application of risk assessment and LCA for evaluating the relative merits of various options for managing risk associated with the entire life cycle of products, processes, or systems. *(Recommendation 3d)***

The committee also notes that while some LCA studies have considered robust treatment of risk and uncertainty using probabilistic methods, most studies remain deterministic.

EPA should disseminate educational tools and examples that describe this additional quantitative step. *(Recommendation 3e)*

This would make rigorous LCA more commonplace and more worthy of use in emerging areas of sustainability assessment and public policy analysis.

The section above describes extensions of EPA guidance documents in support of BCA. While EPA has made various online LCA references available (e.g., the "EPA 101" documentation) (EPA 2014i), they are mostly summaries of general information on the ISO standard.

EPA should enhance the documentation by applying the same "identification-quantification-monetization" framework, used in describing BCA and CEA, to facilitate the adoption of a life cycle perspective in scoping problems and optimize the use of LCA as a sustainability tools. *(Recommendation 3f)*

This would help ensure that the potential impacts are considered, even if the LCA methods are not able to quantify or monetize them.

EPA should promote and support the development of new datasets relevant to major agency decisions, such as those associated with water and land use. *(Recommendation 3g)*

EPA is encouraged to continue its leadership role in the recently formed inter-governmental LCA platform group, whose initial purpose is to develop and advance the inter-operability of a database network.

Valuation of Ecosystem Services

The term ecosystem services refers to the benefits society receives from the spectrum of resources and processes provided by ecosystems through their functions–the interactions of plants, animals, and microbes with the environment (NRC, 2011a; NRC, 2013a). Ecosystem services is only one of the approaches that can be used to assess ecosystem sustainability, explicitly linking ecosystem structure and function to human reliance and values. Ecosystem system services valuation is the process of measuring values associated with changes in an ecosystem, its components, and the services it provides to human well-being (NRC 2004a). The valuation of ecosystem services is relevant to the area of welfare economics because ecosystem services include market and nonmarket goods. However, the ecological underpinnings of these services and the appreciation of these services to humans warrants a separate discussion in the context of sustainability. The services provided by ecosystems are generally divided into four categories: provisioning services (e.g., food, fiber, drinking water); regulating services (e.g., flood protection and pest control); cultural services (e.g., spiritual and aesthetic benefits); and, supporting services (e.g., soil formation, primary productivity) (MEA 2005). Ecosystem service studies have tended to focus on small changes in an ecosystem, but large-scale studies of ecosystem services such as Costanza et al. (1990) sought to monetize the value of wide scale changes in ecosystem services. EPA SAB (2009) recommends these steps for conducting ecosystem service valuation:

- Formulate the valuation problem and choose policy options to be considered, given the context within which the tool will be applied;
- Identify the significant biophysical responses that could result from the different options;

- Identify the responses in the ecosystem and its services that are socially important (have social value);
- Predict the responses in the ecosystem and relevant ecosystem services in biophysical terms that link to human/social impacts and hence to values; and,
- Characterize, represent, or measure the value of responses in the ecosystem and its relevant services in monetary or non-monetary terms. As with benefit cost analysis, non-market valuation of ecosystem services is an important and critical step (EPA 2014k).

By enabling policy makers to account for the services ecosystems provide, this tool informs planning, priority setting, and rule making, and can contribute to decision making based on sustainability grounds. In the past, EPA has used the concept of adversity of effects to public welfare (and, its link to ecosystem services valuation) in its review of secondary National Ambient Air Quality Standards (NAAQS) for ozone through vegetation damage related to ozone as well for secondary NAAQS for fine airborne particles relating to visibility degradation. More recently, EPA's 2012 proposal to establish NAAQS for oxides of sulfur and oxides of nitrogen to protect aquatic and terrestrial ecosystems relied heavily on monetized as well as non-monetized valuation of ecosystem services derived from attainment of the proposed standards (77 Fed. Reg. 20218 [2012]). Future incorporation of ecosystem services valuation into the sustainability context is expected to strengthen the EPA decision making process that has generally emphasized human health benefits through risk assessment and risk management paradigm.

How Are Sustainability Considerations Currently Incorporated?

EPA has developed a number of programs and guidance documents regarding valuing ecosystem services. These documents include the development of ecological production functions and procedures for developing ecosystem services valuation (EPA 2014k). This body of work provides a strong basis from which EPA can continue to lead the development of ecosystem services valuation. Those efforts illustrate a recognition of the importance of identifying the full suite of ecosystem services, not just those that are easily measured and valued. Nonetheless there remains inadequate understanding of many of the production relationships and values associated with the more difficult to measure services.

How the Valuation Process Could Be Incorporated Better

A number of steps can be taken to advance the science of ecosystem service valuation. However, for many ecosystem services there may be insufficient understanding of the ecological production functions or the societal values associated with those services, diminishing their consideration in sustainability analyses. For valuation of specific services, there may be considerable variation among different societal groups whose inclusion is necessary to ensure an equitable distribution of benefits (NRC 2012a).

Future Research and Data Needs

EPA should continue to develop ecosystem service valuations to characterize, quantify, and monetize the types of ecosystem services contributions that have been difficult to valuate in the past (e.g., value of nutrient cycling and biodiversity). ***(Recommendation 3h)***

EPA and other federal agencies should support efforts to develop new approaches to evaluate the effects on ecosystem services of national, regional, or local actions in ways that valuation methods can incorporate. ***(Recommendation 3i)***

In particular, R&D needs to focus on the development and use of ecological production functions that can estimate how effects on the structure and function of ecosystems will affect the provision of ecosystem services that are directly relevant and useful to the public.

Where ecological production functions do not exist, R&D should seek to improve upon and strengthen the current methods based on ecological indicators. ***(Recommendation 3j)***

EPA's R&D efforts should focus on developing and implementing the broader suite of applicable valuation methods including economic methods; measures of attitudes, preferences, and intentions; decision science approaches; and ecosystem benefit indicators and metrics. ***(Recommendation 3k)***

Such methods then could be employed in identifying services of importance to the public (as noted above), better capturing the full range of contributions stemming from ecosystem protection.

TOOLS, UNCERTAINTY, AND TRADEOFFS

The effective use of tools to incorporate sustainability considerations into EPA activities partly depends upon how their use recognizes and deals with uncertainty and thus helps decision-makers understand tradeoffs among options. Tradeoffs are the part of the decision-making process that requires balancing advantages and disadvantages of alternatives. In the case of sustainability, the ability to inform tradeoff decisions depends upon the capacity of the analyst to use the tools to isolate and describe key advantages and disadvantages of choices with respect to economic, environmental, and social aspects. Uncertainty and the ability to make well-informed tradeoff decisions are inexorably linked. If uncertainty is too great, there may be insufficient confidence to use a tool for decision-making purposes. Although the results of sustainability analyses are associated with uncertainty, it is important to understand how the tools can help to inform decisions. Assessment of climate change effects is a useful example. Many relevant decisions will need to be made, including those related to adaptation, despite uncertain knowledge about effects, geographic distribution, and costs.

A good way of illustrating the relationships between tools, uncertainty, and tradeoffs is with a hypothetical example (see Box 3-4). When sustainability tools produce results, decision-makers can make tradeoffs among the economic, environmental, and social consequences associated with each option, including changing the final design to a hybrid of the last two options. What is critical is that the decision-makers understand the uncertainty in the output produced by each tool, and highlighting these in their deliberations as they consider the next few years and the next 25, or so. In the case described Box 3-4, the key large uncertainties are likely to be exposure, representativeness of the population engaged compared to the potential user community, and the economic cost versus benefits of the reuse options as the impact the next three years versus the next 25 years.

Many decisions that involve sustainability involve considerations that go beyond the local scale to regional, national or even global. Decisions involving sustainability that are related to global climate change, for example, are marked by major uncertainty because some places will likely benefit (at least in the short term) and others will likely be devastated or experience a new normal. Nevertheless, even for these mega scale issues, analysts need to try to put appropriate uncertainty bands around their use of environmental, social and economic tools over spans that will range from a few years to perhaps a century. The tradeoffs clearly become even more difficult to make as the geographical and temporal scales expand.

KEY CONCLUSIONS AND RECOMMENDATIONS

Conclusion 3.1: The broad array of sustainability tools and approaches presented in EPA's sustainability analytics report are potentially applicable in assessing possible social, environmental and economic outcomes within EPA's decision-making context. Although some tools and approaches are more advanced and further developed than others, there is no hierarchy of tools with respect to selection. The applicability of the tool depends on the context of the problem.

BOX 3-4 An Hypothetical Waste Site

The future use of a large abandoned landfill in a suburban town is being discussed. It is not a Superfund site. Chemical contaminants flowed from the site into the underground aquifer, and public access to the site is not permitted. There are different views about what to do with the site. One is to do nothing. The second is to install a pump-and-treat system to contain the underground water contamination. The third is to incorporate pump-and-treat but to reclaim the site for walking and biking and as a meeting place for local environmental officials.

To make an informed choice from among the no-action, pump-and-treat, and light-redevelopment options, data need to be gathered and interpreted. The initial tools are exposure assessment, risk analysis, and environmental-footprint analysis. Uncertainty becomes an issue because unless there are good data about the location and concentration of the contamination, where it is heading, and at what speed, there is high uncertainty about how many people could be exposed by drinking water from the aquifer or by using the site for recreation. The above environmental tools are essential to determine whether the site needs to be remediated to keep local water supplies from being contaminated now and in the foreseeable future—in other words, to have a safe potable-water supply. The decision is likely to affect thinking about further development of the site, so the initial key uncertainty is in prediction of exposure; if the uncertainty is too high, it will be hard to make tradeoffs among the three options.

Social tools, most notably segmentation analysis and network analysis, are used to determine the size and attributes of the community—including the public, business, and not-for-profits—that support each of the three options. If it is a small site and the expected effects are localized, this is likely to be done with several focus groups or public meetings. The uncertainty here is related to the representativeness of the community included in the focus groups and public meetings. Public meetings are not usually attended by a representative group of community members. What would happen if millions of dollars were invested in a sustainable recreation site with a green building for a meeting place, and then few people used it? It is essential that some effort be made to increase the certainty that the stakeholders are representative of the body of potential users. One way to increase confidence is to build a collaborative process and use charrettes to determine whether there is a consensus about a plan for a sustainable green site on the abandoned landfill.

Economic tools are essential. BCA can be used to evaluate whether the benefits to the local population from using the site for hiking, for biking, and as a meeting place are likely to exceed the costs, but these estimates will be uncertain because they depend on the preferences of current residents and may not reflect future citizens' preferences (25 years hence) or a wide array of variables that can change future benefits and costs, such as general economic conditions in the region, development of other recreation sites in the region, and changing population attributes of the citizenry.

Recommendation 3.1.1: EPA should use concepts of sustainability to strengthen a systems-thinking approach in using current and future tools and approaches, as necessary, to support EPA decision-making. The agency has many opportunities to incorporate sustainability considerations by applying those tools and approaches across the spectrum of its activities and it should do so rapidly**.**

Recommendation 3.1.2: For every major decision, EPA should incorporate a strategy with the goal of assessing the three dimensions of sustainability in an integrated manner. EPA should apply tools and approaches in a manner best suited to the type of problem being addressed. The selection of a particular tool for an application should be informed by the type, adequacy, and availability of data needed and other criteria identified by the committee.

Conclusion 3.2: EPA has taken a good first step in developing the 2013 version of the Sustainability Analytics report. It provides a reasonable and informed baseline survey of sustainability tools.

Recommendation 3.2.1: EPA should arrange for the use of a publicly available Internet-based mechanism (for example, an electronic wiki) to track updates about existing and emerging tools. This process should allow visitors to suggest updates to documentation for existing tools and identify new tools for EPA's consideration. Such a mechanism would help the agency update its tool descriptions and applications for specific tools in a more timely manner.

EPA's sustainability analytics report should be considered a living document with appropriate updates on a regular schedule. Future versions of the report should provide additional discussion of integrative applications of the tools and how a tool can be used to provide information to support decision making involving tradeoffs, where one or more sustainability pillars could be at odds with one another. New tools identified would be added. (Recommendation 3a)

Recommendation 3.2.2: EPA should consider using a consistent set of criteria to evaluate the tools and carry out assessment exercises that are similar to the one conducted by the committee with the agency's own internal users of these tools, or a larger set of external stakeholders for corroboration. The assessments should help to identify opportunities for improvement and identify considerations in selecting tools for particular activities. (See Recommendation 3b)

Recommendation 3.2.3: A potentially important tool that is currently not included in the sustainability analytics report is the recently developed approach for considering the social cost of carbon (SCC). Given the prominence of climate-change mitigation issues for EPA and the fact that SCC focusses explicitly on future benefits and costs of current decisions–a significant component of sustainability–EPA should include it in its sustainability analytics report in the near future.

Conclusion 3.3: Various sustainability tools (such as benefit-cost analysis, life cycle assessment, and risk assessment) have been identified by EPA and agreed upon by the committee as being more mature and pervasive than others. The historical development of these tools and EPA's adoption of them into decision making serves as exemplars for the other tools. These mature tools also can continue to be improved through EPA's guidance and support.

Recommendation 3.3.1: EPA should develop guidelines for preparing a sustainability assessment analogous to its *Guidelines for Preparing Economic Analysis* (EPA 2014h). Developing the guidelines could be accomplished, particularly in the short run, by adding a chapter to the existing guidelines that addresses sustainability tools and their inclusion in BCA. It will be important for EPA to identify a home for the responsibility to maintain and update this guidance. (See Recommendation 3c)

Recommendation 3.3.2: To facilitate the further use of life cycle thinking and the development and deployment of life cycle assessment, EPA should continue educational and research support programs to develop and implement guidance that illustrates how a range of qualitative to quantitative LCA approaches can be utilized within EPA decision making. The quantitative guidance should include applications of combined probabilistic risk assessment and LCA approaches, which can be used in concert to examine a fuller range of issues relevant to a decision. (See Recommendations 3d-3f)

Recommendation 3.3.3: To facilitate the further development of LCA methods, EPA should collaborate with other federal agencies, the private sector, and other non-governmental organizations to promote and support the development of new datasets for LCA relevant to major agency decisions, such as water and land use, and continue development of and encourage use of life cycle impact assessment methods (e.g., TRACI). (See Recommendation 3g)

Recommendation 3.3.4: EPA should continue to develop ecosystem service valuations to characterize, quantify, and monetize the types of ecosystem services that have been difficult to valuate in the past (e.g., value of nutrient cycling and biodiversity). In particular, these efforts should focus on the development and use of ecological production functions that can estimate how effects on the structure and function of ecosystems will affect the provision of ecosystem services that are directly relevant and useful to the public. Where ecological production functions do not exist, R&D efforts should seek to improve upon and strengthen the current methods based on ecological indicators. (See Recommendations 3h-3k)

4

Case Studies of Applications of Sustainability Tools and Approaches

INTRODUCTION

Activities undertaken by the US Environmental Protection Agency (EPA) are driven by congressional mandates, presidential directives, and voluntary or discretionary initiatives (such as research-grant programs and initiatives involving partnerships with other organizations) that stem from policy priorities. As described in Chapter 2, EPA's activities include program development, development of internal and external guidance, strategic planning, research planning, budgetary decision-making, regulatory and standards development, enforcement, knowledge transfer, permitting, communication and education, and a wide variety of voluntary programs. To facilitate the consideration of sustainability concepts in relation to this broad array of activities, EPA has developed a report, *Sustainability Analytics: Assessment Tools and Approaches* (EPA 2013a), often referred to as the *Analytics* report, that presents various analytic tools and approaches.

This chapter illustrates the application of various tools and approaches listed in EPA's report by using five case studies. Some case studies involve the use of only a few of the tools described in EPA's report, and others involve the use of multiple tools that encompass the environmental, economic, and social dimensions in the sustainability assessment and management process. The committee selected case studies whose histories are well known to the committee members to consider the use of sustainability tools in a variety of agency activities, including voluntary initiatives and activities that EPA is required to undertake according to major legislative initiatives, such as the Clean Water Act. The case studies also illustrate a range in the depth and scope of tool applications—from screening-level assessments to more rigorous quantitative analysis. Table 4-1 lists the case studies considered, the relevant law and type of agency activity, and the sustainability aspects that are discussed. Table 4-2 identifies which of the tools listed in the EPA's report are included in the case studies. (A glossary of tools and approaches that was developed from the *Analytics* report is presented in Appendix D of this report.) It is important to note that the committee is aware that, for each case study, there are likely other sustainability tools which are often used in such activities at EPA. The committee did not intend to identify all the potentially important sustainability tools that already may be used–or could be used–in the context of a particular case study.

Each case study summarizes the context for the relevant decision or other activity, traditional analytic approaches used to support the activity, other tools that have been or could be applied to advance the consideration of sustainability concepts, and the expected value to be gained by applying the other tools. After the presentation of case studies, the chapter discusses the increasing use of natural gas for electricity generation as an exemplar that would benefit from applying sustainability tools in a systems (value-chain) context. Finally, the chapter provides general conclusions and recommendations derived from the case studies.

THE DESIGN FOR ENVIRONMENT PROGRAM

Through the Design for Environment (DfE) program, EPA partners with manufacturers to help consumers, businesses, and institutional buyers to identify products that perform well and are cost-effective and safer for the environment.(EPA 2014c). The program is voluntary but uses many of the tools used in Pre-Manufacture Notice (PMN) evaluations performed in accordance with the Toxic Substances Control Act (TSCA).

Traditional Approach

Companies that manufacture, import, or process any new chemical substance are required to report the chemical name and molecular structure, categories of use, amounts manufactured or processed, by-products from manufacture, processing, use, disposal, potential environmental or health effects of the chemical and its byproducts, and exposure information. EPA has 90 days from the submission of a notice to assess the risks posed by the new chemical or by a new use of an existing chemical. If the risks are deemed to be unreasonable, EPA is required to take steps to control them. If data contained in the notice are insufficient, EPA may require the submission of additional information.

In its screening analyses under TSCA, EPA makes extensive use of quantitative structure–activity relationships (QSARs). QSARs can be used to estimate environmental persistence, bioaccumulation potential, and toxicity on the basis of the structure of the chemical under consideration. Those attributes can be compared with attributes of the thousands of chemicals previously evaluated in accordance with TSCA (Zeeman, et al., 1993) to make a decision as to whether steps are necessary to control risks.

Tools for Including Sustainability Concepts

Although the DfE program is independent of TSCA, it uses many of the same tools. The goal of determining whether the chemicals are safe for the environment mirrors the goal of PMN evaluations under TSCA, but the goals of assessing cost effectiveness and performance go beyond the TSCA evaluations. To achieve the additional goals in the DfE program, EPA uses an analysis framework, referred to as a chemical-alternatives assessment, in which alternative products are screened, a small number of promising alternatives are identified from the screening, and the screened alternatives undergo additional evaluations. Several recent DfE evaluations illustrate the process.

TABLE 4-1 Relevant Laws, EPA Activities, and Sustainability Considerations for the Case Studies

Case Study	Relevant Law	EPA Activity	Sustainability Considerations
Design for the Environment (DfE) program	Toxic Substances Control Act (TSCA)	Screening new chemicals	Applying DfE lessons learned to TSCA-mandated screening approaches
Combined sewer overflows	Clean Water Act	Setting water-quality discharge limits	Applying green infrastructure approaches to meet discharge limits
Site remediation	Resource Conservation and Recovery Act; Comprehensive Environmental Response, Compensation, and Liability	Selecting remedies for soil and groundwater contamination	Including life-cycle assessments for remedy selection and public involvement for land-use decisions
Implementation of National ambient-air quality standards	Clean Air Act	Oversight of state implementation plans to attain the standards	Broadening emission-control planning
Renewable-fuel standard	Energy Independence and Security Act	Standard-setting	Augmenting life-cycle assessment with uncertainty analysis

TABLE 4-2 Sustainability Tools and Approaches Considered in Case Studies[a]

	CASE STUDIES				
TOOL OR APPROACH	**Design for the Environment Program**	**Combined Sewer Overflows**	**Site Remediation**	**Implementation of National Ambient-Air Quality Standards**	**Renewable-Fuel Standard**
Benefit–cost analysis			■	■	■
Ecoefficiency analysis					
Ecosystem-services valuation					
Green accounting					
Collaborative problem-solving	■	■	■	■	
Design charrettes			■		
Environmental-justice analysis		■		■	
Futures methods				■	
Health-impact assessment					
Segmentation analysis					
Social-impact assessment			■		
Social-network analysis					
Chemical-alternatives assessment	■				
Environmental-footprint analysis			■		■
Exposure assessment			■		
Green chemistry	■				
Green engineering	■				
Integrated assessment modeling					
Life-cycle assessment	■				■
Resilience analysis					
Risk assessment			■		■
Sustainability-impact Assessment					

[a]Each row represents a tool or approach listed in EPA's *Analytics* report (EPA 2013a). Each column corresponds to a case study in this chapter. A square indicates selection of the tool for consideration in the case study. The table is not intended to provide a comprehensive list of all the sustainability tools or approaches that are being used or could be used.

In September 2013, EPA issued a draft DfE evaluation of Flame Retardant Alternatives to hexabromocyclododecane (HBCD). HBCD is used primarily as a flame retardant in insulation products, such as expanded polystyrene, but it is a persistent organic pollutant and has been detected in breast milk, adipose tissue, and blood. Alternatives that reduce that environmental footprint were sought. In collaboration with industry, government, and academic experts, EPA performed a chemical-alternatives assessment screening. EPA notes that this screening “along with LCAs [life-cycle assessments], risk assessments, and other tools can be used to improve the sustainability profiles of chemicals and products. . . . DfE Alternatives Assessments establish a foundation that other tools can build on” (EPA 2014l, p. 1-4). In the preliminary screening, potential alternatives to HBCD were compiled on the basis of the scientific literature and input from experts in chemical manufacturing and product development in industry, government, and academe (EPA 2014l, p. 3-6). Two alternatives emerged, and EPA identified a series of toxicity, ecotoxicity, bioaccumulation, and environmental-persistence metrics for HBCD and the two alternatives. Although EPA does not make a specific recommendation regarding the choice of flame retardant, the alternatives assessment identifies potential substitutes, compares hazards, and supports decision-making by a variety of stakeholders (EPA 2014l, p. iv).

The HBCD and similar alternatives assessments (EPA 2014m, 2012d) illustrate the use of key sustainability analytic tools, including chemical alternatives assessments, collaborative problem-solving, green chemistry, and green engineering. To evaluate sustainability implications more fully, other analytic tools could also be applied. For example, the HBCD assessment does not consider the footprints of the manufacturing processes for HBCD and the alternative products. Coupling of such tools as LCAs and risk assessments with alternatives assessments would explore sustainability factors more fully.

EPA has performed LCAs through its DfE program, although typically not for the same products as for the alternatives assessments. For example, a life-cycle evaluation of current and emerging energy systems used in plug-in hybrid and electric vehicles was conducted through the DfE/ORD Li-ion Batteries and Nanotechnology Partnership (EPA 2013d). LCAs identified which materials and processes were likely to have the greatest impacts or have the greatest potential for improvement.

Expected Value Added by Applying Sustainability Tools

By convening public–private partnerships and using a variety of screening-level and quantitative analytic tools (such as alternatives assessments and LCAs) and indicators (such as ecotoxicity, human toxicity, bioaccumulation, and environmental persistence) that are relevant to sustainability, the DfE program has built well-accepted approaches that help consumers, businesses, and institutional buyers to identify products that perform well and are cost-effective and safer for the environment (EPA 2014c).

EPA should consider applying the lessons learned from the DfE program to the evolution of PMNs under TSCA. ***(Recommendation 4a)***

COMBINED-SEWER OVERFLOW

Combined-sewer systems are designed to collect precipitation runoff, domestic sewage, and industrial wastewater in a common pipe system that is usually linked to a treatment system. During periods of heavy precipitation runoff, the capacity of the combined-sewer system can be exceeded in such a way that untreated wastewater flows directly into a nearby body of water. EPA has established a combined-sewer overflow (CSO) policy to provide guidance to municipalities in meeting National Pollutant Discharge Elimination System limits under the Clean Water Act. EPA encourages municipalities to incorporate green-infrastructure approaches to help to reduce CSO discharges in their long-term control plans.

Traditional Approach

Under CSO policy, EPA typically expects a municipality to plan for the occurrence of four overflow events (or fewer) in a typical year within 20 years or less. In sensitive areas,[1] EPA has required higher levels of control (for example, Washington, DC, and Cleveland, OH). Municipalities and regulatory agencies have favored the use of "gray infrastructure"—sewer separation, storage tunnels, and additional treatment units—because they are considered to provide a high level of certainty that the allowable number of overflows will not be exceeded. In response to exceeding the allowable maximum, EPA (or a delegated state agency) typically issues an enforcement action, and the municipality is required to construct gray infrastructure by a particular date.

Tools for Including Sustainability Concepts

Green infrastructure—such as dry basins, wet basins, constructed wetlands, rainwater harvesting, infiltration basins, bioretention swales, green streets, pervious or porous pavements, vacant-lot repurposing, green roofs, impervious surface removal, and reforestation—may provide more benefits than those obtained with gray infrastructure. Such sustainability tools as collaborative problem-solving and environmental-justice analysis can be used to assess the benefits associated with those alternatives; the benefits include reduced capital expenditures, improved water quality, and more flexibility. Green-infrastructure initiatives can be used to improve areas where low-income or minority-group communities have been disproportionately exposed to environmental pollution, for example, by providing additional CSO control or transforming abandoned properties into recreational areas.

Expected Value Added by Applying Sustainability Tools

The value added through this approach is illustrated by activities undertaken in Cleveland. EPA entered into a consent decree with the Northeast Ohio Regional Sewer District (NEORSD), which serves 62 communities in the greater Cleveland metropolitan area (NEORSD 2012). The decree requires NEORSD to eliminate an estimated 4 billion gallons of CSO annually and achieve a level of control equating to 98% capture (and treatment) of combined sewage. The control measures are estimated to cost the district $3 billion in capital expenditures and will take 25 years to complete. During the consent-decree negotiations, an additional level of control (62.39 million gallons in a typical year) to be accomplished by upsizing tunnels at an estimated cost of $182 million was proposed. The parties agreed to a combination of cost-effective gray and green infrastructure to capture 44.18 million gallons in a typical year through green infrastructure at a prescribed expenditure of at least $42 million within 8 years (Figure 4-1). The NEORSD evaluated green-infrastructure control measures that addressed storage and treatment; stormwater storage, infiltration, and treatment; stormwater source reduction; and stormwater conveyance and separation (NEORSD 2014b).

EPA has just begun to evaluate CSO or sanitary-sewer overflow (SSO) issues from a sustainability perspective. Municipalities have had to make substantial investments in gray infrastructure to achieve targeted levels of control. Current systems have not been optimized, particularly with respect to nutrient-removal issues or tradeoffs between CSO–SSO control and stormwater control. That is particularly important because many of the CSO control programs are targeted at protecting recreational uses and many water bodies are not used for recreation during large storm events and can self-purify within a day or two (EPA 1977, p. 236).

In discussions among the US Conference of Mayors, EPA, and others, it became clear that existing approaches were resulting in capital expenditures beyond the point of commensurate benefits. EPA re-

[1]Examples of sensitive areas are waters with threatened or endangered species or public drinking-water intakes.

sponded by issuing an Integrated Municipal Stormwater and Wastewater Planning Approach Framework in June 2012 (EPA 2012e). Several communities have prepared integrated plans.

> **In addition to its consideration of pollutant-specific issues associated with CSO–SSO discharges (compliance with water-quality standards and total maximum daily load calculations), EPA should evaluate the costs and benefits of more holistic solutions. EPA should consider advocating the development and implementation of integrated plans where possible so that a municipality can use its resources to provide the greatest benefit in improving water quality.** ***(Recommendation 4b)***

In advocating integrated planning, EPA has the opportunity to help communities to incorporate sustainability analyses into plans, which can include a more comprehensive analysis of long-term CSO control plans or extending control projects for SSOs that appear to pose relatively low risks to human health and the environment.

SITE REMEDIATION

Through the Resource Conservation and Recovery Act and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund), EPA regulates site remediation and establishes guidelines for evaluating and selecting remedies to address soil and groundwater contamination. For Superfund sites, the process is clearly defined in the National Contingency Plan (NCP) (Federal 40 CFR, Part 300).

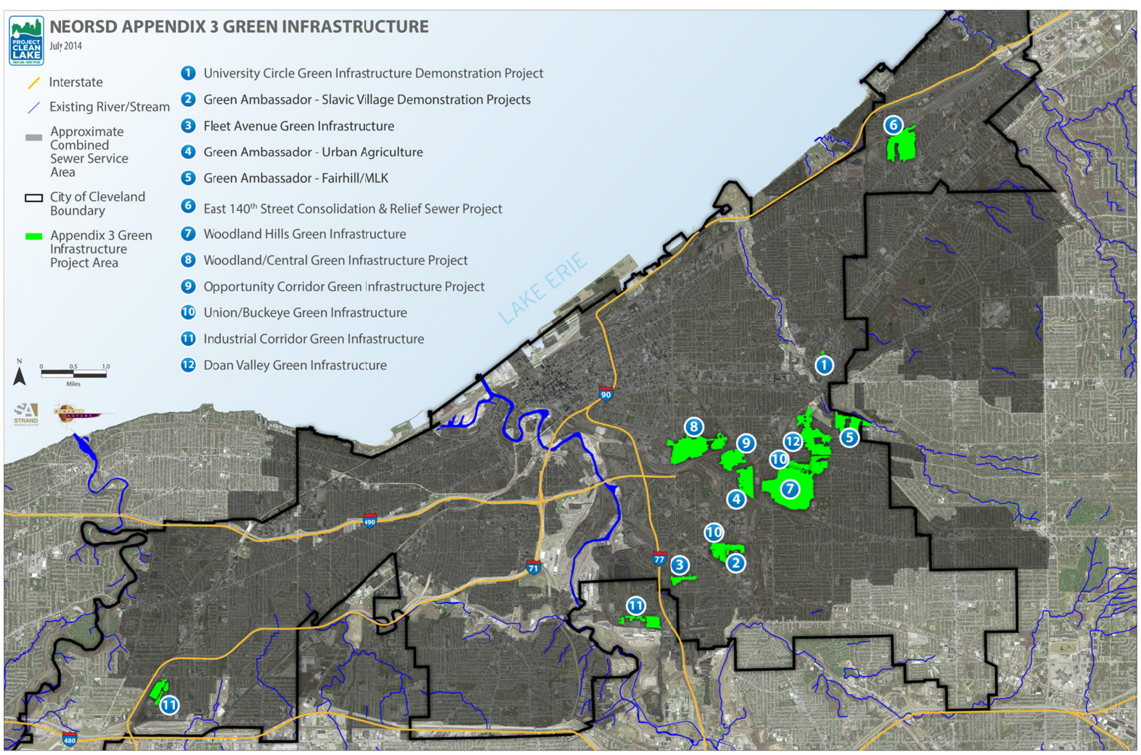

FIGURE 4-1 Green-infrastructure high-priority areas for the Northeast Ohio Regional Sewer District. Source: Courtesy of the Northeast Ohio Regional Sewer District, August 19, 2014. Reprinted with permission; copyright 2014, Northeast Ohio Regional Sewer District.

Traditional Approach

As directed by the NCP, remedial alternatives are selected and evaluated on the basis of nine criteria. Overall effectiveness in protecting human health and the environment and compliance with applicable, relevant, and appropriate requirements (ARARs) are considered "threshold criteria" that must be met by any alternative. Five criteria are considered "balancing": long-term effectiveness; reduction in toxicity, mobility, or volume of wastes; short-term effectiveness; implementability; and cost effectiveness. Finally, any remedy must meet state and community acceptance. The results of the evaluations are used by EPA to identity a recommended alternative. Sustainability factors are not designated explicitly as criteria to be considered but are implicit in some of the "balancing" criteria.

Each alternative must, at a minimum, be capable of meeting the two threshold criteria. Remedial alternatives are then assessed and compared with the balancing criteria.

Tools for Including Sustainability Concepts

Collaborative problem-solving, ecosystem-services valuation, and LCA can be incorporated into the remedy selection primarily as part of the assessment of alternatives based on the balancing criteria. That is illustrated by two case studies: a large coal-tar–contaminated site (Pitt-Consul) and a contaminated uranium-processing facility (Fernald).

Pitt-Consol Site

The Pitt-Consol site required extensive remediation to achieve site before sale of the property. Sustainability factors were evaluated for eight remedial options by using LCA software. Sustainability evaluation followed the Sustainable Remediation Forum nine steps for footprint and LCA: define the study goals and scope, define the functional unit, establish the system boundaries, establish the project metrics, compile the project inventory, assess the impacts, analyze the sensitivity and uncertainty of the impact-assessment results, interpret the inventory analysis and impact-assessment results, and report the study results (Favara et al. 2011). Social and economic factors were considered in the remedy-selection matrix by assessing the impacts on the local community and by considering the cost of the remedy. Remedy evaluations are summarized in Table 4-3.

TABLE 4-3 Ranking of Remedies Evaluated by Using LCA Model Results

Remedy	Overall Rank	Selected Sustainability Metrics			
		Climate change (kg CO_2-eq)	**Eutrophication (kg N-eq)**	**Particulate Matter (kg PM_{10}-eq)**	**Water Depletion (m^3)**
Smoldering combustion	1	4,970,000	706	6,700	7,400
Containment	2	5,100,000	899	10,400	17,900
In situ stabilization	3	3,820,000	2,140	15,800	16,900
Self-sustaining treatment for active remediation + excavation	4	16,000,000	2,930	31,900	164,000
In situ thermal stabilization	5	38,400,000	5,040	62,800	83,600
Air sparging	6	60,200,000	8,880	94,300	164,000
Excavation	7	41,900,000	7,890	93,000	395,000
Surfactant in situ chemical oxidation	8	59,800,000	18,500	135,000	1,680,000

The remedy chosen for the site, smoldering combustion, was selected because it projected lower material and energy requirements than the other options. The activities for implementing smoldering combustion were determined to have a low impact on the surrounding community in that smoldering combustion required much less transport of materials to the site than other remedies, and this would reduce traffic concerns. As shown in Table 4-3, smoldering combustion had lower life-cycle water use, eutrophication potential, particulate-matter emissions, and greenhouse-gas emissions than the other alternatives. Smoldering combustion also constituted a rapid and permanent solution to the contamination at the site and so would make the property more available for reuse.

This case study illustrates the use of LCA for evaluating remediation options. It demonstrates that, in addition to the traditional balancing criteria used to evaluate remedies, EPA could use criteria that explicitly evaluate environmental, economic, and social sustainability by applying tools that quantify the environmental footprints of alternative remedial strategies.

> **At contaminated sites where restoration of groundwater is considered unlikely in a reasonable time frame because of resource and technical limitations (NRC 2013b), EPA should consider sustainability factors holistically within the balancing criteria to modify the selected remedy in such a way that in the long term it meets all protectiveness criteria but achieves a more sustainable outcome. *(Recommendation 4c)***

Fernald Site

The Department of Energy (DOE) 1,050-acre Fernald site, in Crosby, Ohio, processed uranium ore for nuclear weapons. During the middle 1980s, contamination of wells and soils was found off site. Residents were concerned, and the issues were reported in the local mass media. In 1989, uranium manufacturing ended at the site; it was the last of nine US uranium-processing sites to end production of high-purity uranium. Waste management became the focus at Fernald, with a total cleanup cost of $4.4 billion. DOE, federal and state regulators, and the community agreed that it was imperative to involve local parties in remediation and future-use decisions about the site that the community, which is not far from Cincinnati, would need to live with in the foreseeable future. A sustainably protective system was deemed essential.

In 1993, the parties agreed to constitute a special advisory committee (see below) that would advise about a preferred future for the site, allowable residual risk and appropriate remediation levels, disposal options for onsite wastes, and remediation priorities. The group provided recommendations and for more than 20 years it has continued to play a role as the site has changed from uranium production to cleanup and then to a nature preserve and education center while the DOE has continued to manage the legacy of underground uranium contamination. The advisory committee has been involved in some difficult decisions, most notably how to transport waste off site (rail was selected) and how to manage onsite wastes (sequestration by cementation was selected). With the assistance of a charrette process[2] (see below), the advisory group created a vision of the site that has been realized with the opening of a multipurpose education center, walking trails, legally binding institutional controls, and continuing remediation of the legacy waste.

In making decisions associated with Fernald, some of the tools were required by laws and regulations (such as CERCLA) and were based on risk-related science, engineering and economic costs and benefits, exposure assessment, epidemiology, some version of ecosystem-services valuation, and collaborative problem-solving. Government and private-property owners and managers are required to follow federal and state site-closure requirements that demand modest public participation. DOE has closed hundreds of small sites around the United States that were in remote locations, and its actions were settled

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[2]Design charrettes are a type of stakeholder engagement tool to develop a mutually agreed-on vision of future development, usually regarding land-use planning decisions.

through negotiations with the federal EPA and state environmental-protection agencies. Some public involvement was part of the process; larger DOE sites and sites near substantial populations have created site advisory boards, which advise DOE about a variety of risk-related and future-use decisions.

The difference at Fernald was that DOE and its government partners recognized that more than just an engineered solution and mandated public involvement was needed; substantive input from an advisory committee with strong local representation was essential. DOE and other government agencies chose Eula Bingham, a resident of the state and a highly respected former health and safety official, to suggest members of an advisory committee. Using personal contacts, mailings, public meetings, and citizen networks, she recommended 14 members that were agreed on by the three government agencies to constitute a Fernald Citizens Task Force (FCTF). Representing a diverse set of skills and interests, the group began working in 1993 and was assisted by four ex officio members from DOE, US EPA, the Ohio Environmental Protection Agency, and the Agency for Toxic Substances and Disease Registry.

The FCTF used the charrette tool to develop "what if" scenarios to work through options. In the Fernald case, the charrette tool (FUTURESITE) allowed FCTF members to visualize and manipulate pieces that represented alternative land-use options for the site. Using charrettes and other risk-analysis tools, the FCTF was able to assess tradeoffs among alternative locations on the site and among options for transporting waste and the final form to store waste.

Charrettes are now widely used in urban and environmental planning and in architecture for helping clients and citizens to participate in the planning process. Visual impressions are critical, and environmental psychologists have found that visual impressions, smell, and touch are critically important in public reactions to alternatives. Most charrettes use or are at least enhanced by computer simulations. For example, in EPA's role in the environmental-impact analysis, when a new road or bridge is proposed, the Department of Transportation may use charrettes to illustrate the visual impact of placing a road, bridge, or other transportation asset on various alternative routes.

A Fernald committee continues to work with DOE, EPA, and the state on issues related to the site, and DOE has used a similar approach at the Rocky Flats (Denver region) and Mound (Ohio).

Although an impressive array of sustainability tools have been used at Fernald, more formal versions of social-impact assessment, social-network analysis, environmental-footprint analysis, health-impact assessment, and environmental-justice analysis could be used at this and other remediation sites, depending on the specific case in question. Arguably, some of those tools were implicitly part of the Fernald process. For example, to build the advisory team, the parties probably knew the key parties and players in the region and apparently choose wisely to enhance the group rather than include incompatible people. In other words, key elements of social-network analysis were part of this case study even if the tool was not named and practiced as it might be today.

Expected Value Added by Applying Sustainability Tools

EPA and other federal, state, and local government agencies and private landowners could benefit from applying some of the tools for site-remediation decisions described in these case studies. Federal agencies have spent many years at major remediation sites. An issue to consider is how transferable the lessons learned at the Fernald site are to other sites where the expected cost of cleanup is not billions of dollars but tens of millions of dollars.

IMPLEMENTATION OF NATIONAL AMBIENT-AIR QUALITY STANDARDS

Section 109 of the Clean Air Act requires EPA to set national ambient-air quality standards (NAAQSs) for ambient air pollutants considered harmful to public health and welfare.[3] EPA has set

[3]In the context of the Clean Air Act, *welfare* refers to the viability of ecosystems and agriculture, the protection of materials (such as monuments and buildings), and the maintenance of visibility.

NAAQSs for six "criteria" pollutants: ozone, particulate matter, nitrogen oxides, sulfur oxides, carbon monoxide, and lead (EPA 2012f). In designing plans to meet the NAAQSs, states develop state implementation plans (SIPs) that can involve the use of sustainability tools.

Traditional Approach

By law, EPA sets both primary and secondary NAAQSs that are based solely on protection of public health and public welfare. Primary standards are established to protect human health with an adequate margin of safety, and secondary standards are established to protect public welfare. As a result, EPA cannot consider issues related to economics and feasibility of achieving the primary, health-based NAAQSs in the standard-setting process. Once NAAQSs are set, EPA, states, and local agencies choose emission-reduction strategies, which are described in the SIPs. The SIPs can consider a variety of factors related to sustainability and other issues, including simultaneously addressing reductions in multiple pollutants.

Traditionally, SIPs have been pollutant-specific; that is, control strategies target only one pollutant at a time. The National Research Council (NRC 2004b, p. 130) discussed inefficiencies and other disadvantages of this single-pollutant approach in which the consideration of only individual pollutants causes the "relatively cumbersome SIP process [to be] undertaken for a pollutant such as ozone and then again for PM in a separate process and on a different timetable, despite the fact that the exposures are simultaneous, the sources are often the same, and the two pollutants share many common chemical precursors."

As part of the traditional SIP process, state and local agencies generally follow similar procedures in which emission-control options are identified and the cost and feasibility of each control option are assessed. From the identified options, state and local agencies select an overall control strategy and use air-pollution computer models to determine whether the strategy is sufficient to meet the NAAQSs. Implicit in the development of SIPs is the sustainability tool "futures methods" because the SIPs involve making projections of emissions under various future scenarios of growth of and control of emissions. If federally mandated control measures are not sufficient to attain the NAAQSs, additional, region-specific control measures are incorporated into the pollution-reduction strategy until the strategy is shown to meet the NAAQSs. Once the overall strategy is determined, SIPS are submitted to EPA for approval. The process is generally sufficient for single-pollutant management plans and has been successfully combined with benefit-analysis tools (such as BenMAP) (EPA 2014n) and cost-effectiveness tools to evaluate the health benefits and costs of various control strategies further.

Tools for Including Sustainability Concepts

Some sustainability tools are pervasive in the SIP and air-quality management process. For example, under Section 812 of the Clean Air Act, EPA performs estimates of the national costs and benefits of the Clean Air Act. The most recent assessment finds that the 1990 Amendments to the Clean Air Act provide $2 trillion in public health and welfare benefits at a cost of $85 billion (EPA 2013e). Similarly, states assess costs and emission-reduction benefits of control measures as they determine which control measures to incorporate into their SIPs. Other sustainability approaches selected case by case. For example, congestion-mitigation and air-quality improvement programs identify transportation projects, which are funded through the Federal Highway Administration, to simultaneously reduce transportation congestion and reduce emissions. Similarly, electric-utility demand-management programs seek to simultaneously reduce air-pollutant emissions at key times of day and the need for additional power-generation capacity by reducing electricity demand during peak periods.

States have encouraged the participation of stakeholders and consideration of environmental justice issues in their SIPs. Although still evolving, approaches that consider multiple pollutants in air-quality management commonly involve a variety of modeling (such as CMAQ (EPA 2014o)), energy modeling (such as MARKAL (EPA 2012g)), benefit-assessment tools (such as BenMAP), benefit–cost assessment (BCA) tools (EPA 2010a), and risk-assessment tools (EPA 2014p). A multipollutant approach and associated tools have been used by state agencies as in the case of Georgia (Cohan et al. 2007), by EPA as in Detroit (Wesson et al. 2010), and in cross-medium programs (such as biomass promotion in Massachusetts and mercury regulation in New Jersey).

Multipollutant approaches at the national level are less common, but several have been implemented by EPA, such as the nitrogen oxide cap-and-trade programs, or are being considered by EPA. For example, EPA plans to conduct multipollutant analyses in parallel with the traditional single-pollutant analyses used in setting NAAQSs. The parallel analyses would extend the integrated science assessments and health and welfare risk assessments that are used in setting individual pollutant NAAQSs to consider multiple pollutants simultaneously.

Expected Value Added by Applying Sustainability Tools

Examining the sustainability considerations of various concentration-reduction strategies has multiple potential benefits, including improvements in local and regional air quality regarding multiple pollutants simultaneously, minimization of potential adverse effects while maximizing benefits, consideration of multiple effects (environmental, health, sociologic, economic, and energy-related) of pollution-control strategies, development of cost-effective approaches that meet NAAQSs, ability to consider effects and tradeoffs to multiple media, and evaluations to determine expected amounts of emission reductions (credits) for inclusion of energy-efficiency measures in SIPs.

RENEWABLE-FUEL STANDARD

Through the Energy Policy Act of 2005 and the Energy Independence and Security Act (EISA) of 2007, EPA was given the authority to set regulations in support of a national renewable-fuel standard (RFS). EPA's role is to ensure that transportation fuels have at least a minimum content of renewable fuels, which are produced from renewable biomass. A national goal for 2022 of renewable-duel production of 36 billion gallons per year (about one-fourth of domestic transportation-fuel use) was established by EISA. Among its responsibilities under the RFS, EPA must ensure that renewable fuels meet lower life-cycle greenhouse gas (GHG) emission thresholds than traditional petroleum-based fuels.

The promotion and adoption of higher levels of biofuels caused substantial attention with respect to their sustainability effects compared with those of existing petroleum-based fuels (Jiang and Swinton 2009; Sheehan 2009; Williams et al. 2009; Gnansounou 2011; Lora et al. 2011). Economic issues included such aspects as the relative net economic benefits to consumers from the use of biofuels, the differences in location of fuel production fuel (domestic vs imported), moderation of oil prices, and job creation. Social issues included job creation, rural development, and the equity of using land and crops for fuel instead of food. Environmental issues included the relative energy and emission performance of the various fuels; potential water-quality effects, such as effects on hypoxia in the Gulf of Mexico from fertilizer runoff into the Mississippi River basin; and land use (NRC 2011c).

Traditional Approach

From the outset, EPA used a variety of tools to evaluate the environmental, economic, and societal effects of the RFS simultaneously. Among the environmental effects, EPA is required to ensure that life-cycle GHG emissions of renewable fuels are lower than those of petroleum-based fuels that they replace. For example, corn-based and cellulose-based ethanol must achieve 20% and 60% reductions in life-cycle GHG emissions, respectively, compared with gasoline. Making that comparison requires EPA to determine the baseline GHG emissions of petroleum-based fuels and of the renewable alternatives.

In support of the RFS, EPA's regulatory impact analysis (RIA) established deterministic estimates of life-cycle GHG emissions of petroleum-based gasoline and biobased feedstocks (EPA 2010b). An important issue addressed in the RIA for the RFS was the modeling of emissions from so-called indirect land-use change (ILUC). ILUC considers broader effects of agricultural soil disruption around the world as a result of local decisions about how to use land (Fargione et al. 2008; Searchinger et al. 2008). For example, diverting corn to the fuel market (instead of food) in the United States would be expected to lead to decreased supply of corn for use as food in the United States. That would increase pressure to grow corn in other parts of the world by either displacing other local crops or converting land to agricultural use. Such conversions would lead to higher GHG emissions and could be linked to the source decision to produce fuel from corn. Effects of ILUC are highly uncertain but have large estimated effects on life-cycle GHG emissions.

EPA's RIA supporting the RFS was perhaps the largest investment of time and effort by the US government to date involving the incorporation of LCA into public-policy decision-making. An important precedent set in the analyses was the selection of single-point values for life-cycle GHG emissions of various fuels. Although EPA's analysis of the scientific literature found relatively large ranges of values for GHG emissions, EPA inevitably defined a series of life-cycle emissions factors for the relevant fuels. They were all deterministic, fixed-point values and formed the basis of future decisions on whether fuels met the RFS. For example, values of 93 g of carbon dioxide–equivalent emissions per megajoule (93 g/MJ) and 75 g/MJ were determined for the baseline of gasoline and corn-based ethanol, respectively. The corn ethanol value barely meets the 20% reduction called for in EISA. Additional work by EPA has since set values for various other fuels (such as grain sorghum for ethanol). Of course, ILUC has a dramatic effect on the carbon emissions of biofuels, changing a roughly 60% reduction for corn ethanol without ILUC into only a 20% reduction compared with a gasoline-only scenario.

Managing the interests of the various parties requires approaches to combine stakeholder concerns. BCA methods were used to consider net benefits, including differences in prices of fuels and vehicle fuel economy. Sufficiently appreciating the complexity of the carbon emissions of biofuels as a replacement for petroleum-based fuels requires LCA. Considering the uncertainty of life-cycle carbon emissions requires risk assessment.

Tools for Including Sustainability Concepts

A wide variety of sustainability tools could be applied to the decisions related to the RFS, but in this case study the committee focused its attention on the issues related to uncertainty analyses. There was underlying variability and uncertainty in the available life-cycle data used in setting standards according to the RFS, but only a single deterministic life-cycle GHG emission value was set and published. The results were not explicitly expressed as mean values of a probabilistic distribution or otherwise mentioned as probabilistically-based. Various practices in LCA, however, demonstrated how to consider uncertainty and variability robustly in system results.

Not only from a sustainability perspective but from a policy-analysis perspective, it is important to consider more than single deterministic "point values", because many components of the system have various possible resulting emissions rather than a single value. By using ranges and probability distributions that represent potential values, a simulation can be performed to assess the likely comparative performance of fuels. In the end, such analytic methods could support an assessment of the performance of a renewable-fuels policy better. For example, given the probability distributions that represent ranges of life-cycle emissions, a risk analysis could assess the likelihood that corn ethanol could meet the policy target threshold of a 20% reduction from the baseline of petroleum-based gasoline.

Figure 4-2 summarizes estimated probabilities of carbon intensity throughout the life cycle of various transportation fuels (Kocoloski et al. 2013). As noted above, LCAs often use or report only a single value from such a distribution (such as the mean) and might not include the underlying analysis to create the probability distribution. Given the "baseline" of gasoline emissions to be compared, Figure 4-2 shows that various particular sources of biofuels may end up with emissions close to those of gasoline in terms of carbon intensity but also shows that mean values may differ by more or less than the thresholds required in accordance with the RFS.

Figure 4-3 represents the likelihood that particular biofuels (various points on the distribution as in Figure 4-2) have life-cycle carbon intensities compared with that of gasoline that meet their threshold (Mullins et al. 2010). The resulting display of the "risk of policy failure" shows the effect of the uncertainty inherent in the life-cycle data and other data given the relatively large uncertainties in the emissions. RIAs are an appropriate vehicle for incorporating a robust quantification and discussion of uncertainty.

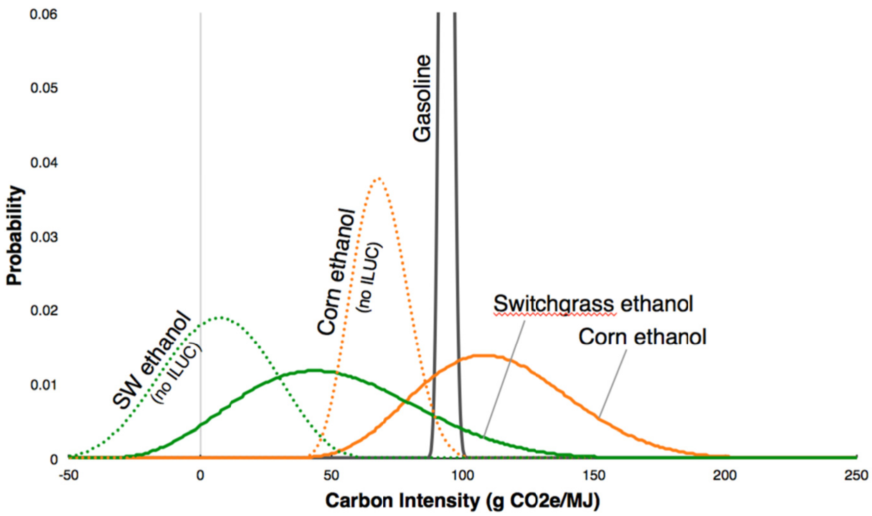

FIGURE 4-2 Probability distributions of estimated carbon intensity of various petroleum-based fuels and biofuels. For biofuels, two modeled cases are presented: full life cycle and life cycle without ILUC. Source: Kocoloski et al. 2013. Reprinted with permission; copyright 2013, *Energy Policy*.

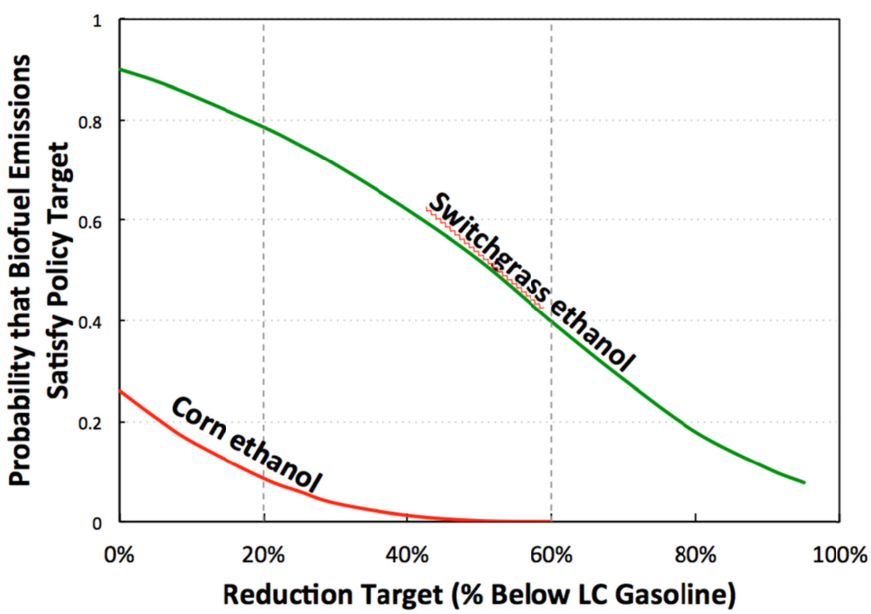

FIGURE 4-3 Probability that biofuel emissions are below those of gasoline (at 0%) or are below some policy target. The EISA target for corn fuels is 20% reduction and for cellulosic fuels is 60% (shown with vertical lines). Two modeled cases are presented: full life cycle and life cycle without ILUC. Source: Adapted from Mullins et al. 2010.

Expected Value Added by Applying Sustainability Tools

Additional applications of LCA in support of public policy and decision-making could be expected, for example, in broader consideration of carbon dioxide limits for energy-generation units that consider upstream methane emissions of natural gas–fired power plants. Such analyses could follow expanded methods similar to those described above to provide clear and robust demonstrations (and set best practices) of merging life-cycle, risk, and other analytic tools.

There are additional opportunities for application of sustainability approaches on different geographic scales that could point to practices and policies for mitigating adverse environmental effects associated with renewable fuels.

> **EPA should consider using BCA approaches for managing nutrient runoff from individual farms or watershed aggregations of farms to provide information for outreach that might stimulate conservation strategies.** ***(Recommendation 4d)***

Ecosystem-services valuations that address the tradeoffs between land-management practices and water-quality improvements on local, regional, and continental scales could potentially lead to the development of markets that provide incentives for both non–point-source and point-source reduction.

CONSIDERING GENERATION OF ELECTRICITY FROM NATURAL GAS IN A VALUE-CHAIN CONTEXT

A number of business sectors have recognized the growing interdependence of economic relationships that include economic, environmental, and societal effects that extend well beyond the boundaries of individual firms (see Chapter 5). The interdependence can be considered as a value chain, along which businesses add value to the initial input of raw materials through various functions that result in finished products.

In a sustainability context, a value chain consists of the following major functions:

- Product research and development.
- Extraction and consumption of raw materials.
- Transportation of raw materials for storage or for intermediate or direct processing.
- Manufacturing.
- Distribution and logistical operations to move a manufactured product to a business customer or consumer.
- Product use.
- Postcustomer use of a product.

EPA traditionally focuses on reducing emissions or waste releases from individual or regional source categories irrespective of their relationship to or effect on the sustainability performance of the larger value chains. The increased use of natural gas for electricity production in the United States serves as an example to illustrate additional opportunities for EPA to incorporate sustainability concepts into its decision-making. Figure 4-4 shows the infrastructure for natural gas in the United States and represents the value chain in a physical sense. Commercial activities along the chain include extraction of natural gas from underground reservoirs, processing to remove nonmethane components, shipping and trading of the cleaned gas, transmission (for example, through pipelines), storage, and distribution to end users for electricity generation, heating, industry feed stocks, and transportation fuel.

Driven by technologic innovations in horizontal drilling and hydraulic fracturing, natural-gas production is rapidly increasing in the United States. Domestic production is projected to increase 30% by 2035, and much of the gas will displace coal in electricity generation (EIA 2012). Some fuel-switching has already begun. Because electricity generation is the largest sector of energy use in the United States, accounting for about 40% of primary energy production, shifts to natural gas raise the potential for broad systemic effects—similar in breadth to the effects associated with the use of renewable transportation fuels. As natural gas continues to displace coal for electricity generation, changes in an aggregate sense can be expected to occur in

- Greenhouse gas emissions.
- Water use and water quality.
- Air quality (related to emission of criteria pollutants and air toxicants).
- Land use (for example, for extraction).

To support decision-making concerning the increased use of biofuels for transportation, EPA took a systems and LCA approach. Similar approaches are warranted for electricity generation, in which equally dramatic transformations are under way. Examining sustainability effects by using LCA in a natural-gas value-chain context provides important systematic perspective. For example, it is well established that when natural gas is burned to produce energy, GHG emission per unit of energy released is lower than that of the other two principal fossil fuels, petroleum and coal. However, if methane, the primary constituent of natural gas and a potent GHG, leaks along the natural-gas value chain, much of or all the GHG advantage of natural gas in combustion can be lost.

Similarly, several million gallons of water can be used in fracturing at a natural-gas well. Over an electricity-generation life cycle, however, the water consumption can be offset by the lower water use in natural-gas combined-cycle electricity-generation facilities than in existing coal-fired electricity-generation units (Scanlon et al. 2013).

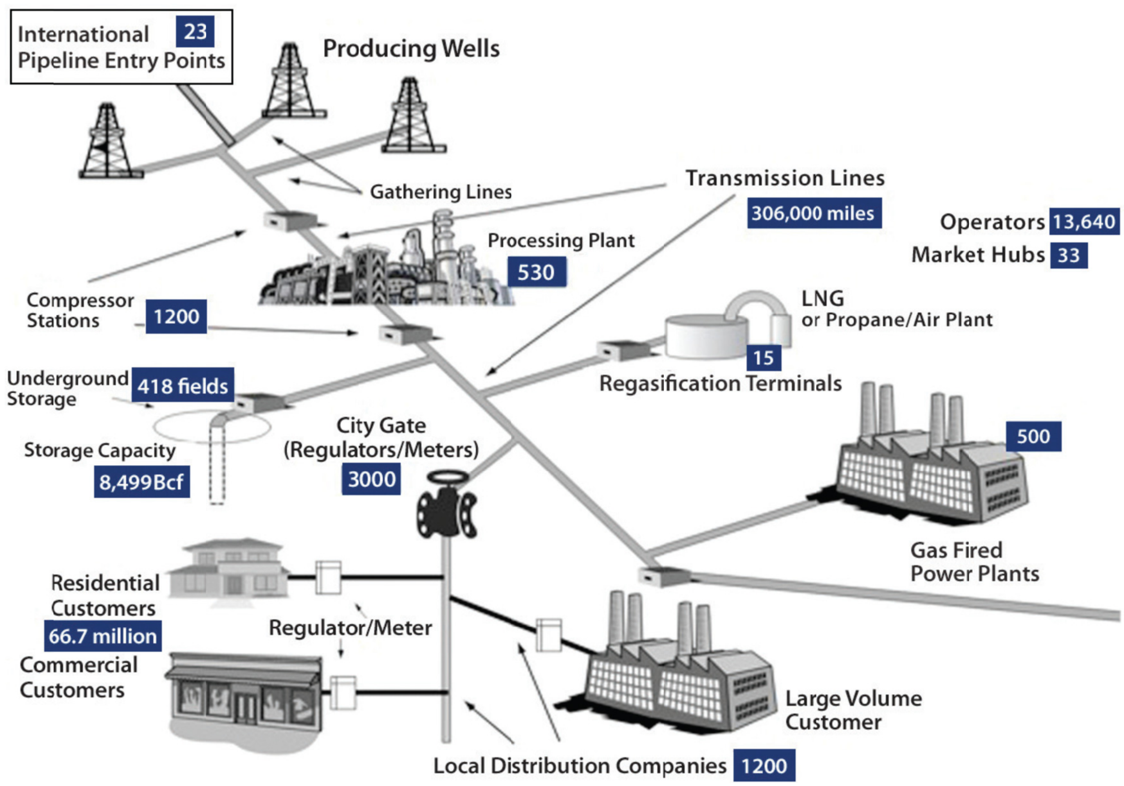

FIGURE 4-4 The natural gas infrastructure in the United States. Source: MIT 2010, p. 59. Reprinted with permission; copyright 2010, Massachusetts Institute of Technology.

As it develops regulations, such as those for carbon dioxide emission from electricity-generation units, EPA should consider applying sustainability tools, such as LCA, in a value-chain context. The benefits of doing so are expected to include

- Adoption of a more consistent or coordinated approach to the application of sustainability concepts in all major EPA decision-making programs.
- Development of a robust dataset to obtain a more comprehensive understanding of the total effects, which can guide decision-making that is less likely to have unintended consequences at different stages of the value chain.
- Identification of opportunities for cost-effective innovative approaches to reduce specific effects that go beyond what can be achieved with existing regulatory tools.
- Identification of new and more significant opportunities for collaboration with nongovernment organizations and the private sector.

CONCLUSIONS AND RECOMMENDATIONS

Key Conclusions and Recommendations

Conclusion 4.1: The case studies indicated that some sustainability tools were used at a screening level, and others were applied with more quantitative rigor and depth. EPA could incorporate sustainability considerations into a broad array of its activities, including ones that involve activities driven by legal requirements.

Recommendation 4.1: Before considering the requirements and constraints relevant to a particular activity, EPA should use a systems-thinking approach for incorporating consideration of sustainability concepts and applying the appropriate tools, at least at the screening level or in identifying alternative actions.

Conclusions 4.2: EPA traditionally focuses on reducing emissions or waste releases from individual or regional source categories irrespective of their relationship to or effects on the sustainability performance of the larger value chains. Life-cycle and systematic (value-chain) considerations can inform decision-making about potential effects that may not be accounted for through traditional approaches that focus on individual source categories.

Recommendation 4.2: EPA should use approaches that allow considerations of potential life-cycle effects associated with business functions along the entire value chain.

Conclusion 4.3: Uncertainty analyses are notably lacking in the application of many of the tools. The RFS case study shows how uncertainty and variability could be characterized. The case study also indicates the substantial range in potential values that surround the point values used by EPA. If uncertainty and variability are accounted for, corn-based biofuels may result in life-cycle GHG emissions closer to (or greater than) those of gasoline with respect to the 20% difference required by the RFS. Similar results were observed for other biofuels.

Recommendation 4.3: EPA should develop a process to determine when uncertainty analysis is an essential component of the use of a tool. Such a process also would determine what level of an uncertainty analysis can be supported by the data in the use of a given tool, the relative importance of such an analysis for a specific decision, and whether the uncertainty analysis should be qualitative or quantitative.

Conclusion 4.4: There is substantial variability in the application of the different types of sustainability tools by EPA and in the extent to which they have been applied.

Recommendation 4.4: Building on EPA's *Sustainability Analytics* report, the agency should document its experiences in developing and applying sustainability tools and compile them into a compendium. The descriptions should comment on how the tools were used, their strengths and weaknesses, and data requirements. The insights gained from such a compendium would inform the development of general guidance on the selection and application of the tools.

Other Recommendations

EPA should consider applying the lessons learned from the DfE program to the evolution of PMNs under TSCA. *(Recommendation 4a)*

In addition to its consideration of pollutant-specific issues associated with CSO/SSO discharges (compliance with water quality standards, total maximum daily load calculations), EPA should evaluate the costs and benefits of more holistic solutions. EPA should consider advocating the development and implementation of integrated plans, where possible, so that a municipality can utilize its resources to provide the greatest benefit in improving water quality. *(Recommendation 4b)*

At those contaminated sites where restoration of groundwater is considered unlikely in a reasonable time frame, due to resource and technical limitations (NRC, 2013), EPA should consider sustainability factors holistically within the balancing criteria to modify the selected remedy such that the final long-term remedy meets all protectiveness criteria, but achieves a more sustainable long-term outcome. *(Recommendation 4c)*

EPA should consider using cost-benefit analysis approaches for managing nutrient runoff from individual farms or watershed aggregations of farms to provide information for outreach that might stimulate conservation strategies. *(Recommendation 4d)*

5

Private-Sector and Private–Public Partnership Sustainability Initiatives: Applicability to Environmental Protection Agency Decision-Making

Many companies in the private sector, especially the world's largest and most brand-visible firms, have made substantial progress in operationalizing sustainability concepts by integrating these concepts into operations, strategy, and communications. Driven primarily by a quest for value creation—and realized through efforts to reduce waste, gain access to new markets, and bolster brand image—many leading companies have spent considerable time and resources over the last 2 decades in attempting to integrate sustainability considerations into their day-to-day operations. But much work remains to be done. A select number of successful enterprises in specific business sectors have undertaken more transformational sustainability initiatives. Many of them were already successful enterprises with a history of innovation and sustained value creation. Learning how successful firms have used sustainability tools and approaches can be an important incentive for other companies to do the same. It can also inform efforts of the Environmental Protection Agency (EPA) to amplify the successes of private-sector sustainability initiatives without inhibiting the creativity and commitment that has made such efforts possible in the first place.

This chapter reviews the primary drivers of sustainability initiatives in the private sector and discusses how companies have used sustainability tools—such as extensive collaboration, and life-cycle assessment (LCA)—to evaluate potential effects associated with their products. These are some of the tools considered in Chapter 3 and the applications are relevant to the SAM process. It also discusses initiatives outside EPA that involve the application of tools and approaches that are relevant to the sustainability focus areas presented in the agency's FY 2014 action plan (EPA 2014b). It is important to note that the tools and approaches developed by the private sector or through private-public partnerships are not applicable to all of EPA's mission-related activities.

CORPORATE DRIVERS OF SUSTAINABILITY INITIATIVES

A vast literature on why private firms choose to pursue sustainability initiatives has developed over the last 20 years, and the results have been fairly consistent. Companies have adopted practices to improve environmental and social performance for a host of reasons—from improved efficiency and legal compliance to broader strategic notions of competitive positioning and recruiting. But, as with most business initiatives that gain traction, the primary rationale is the quest for value creation, broadly defined.

Several studies have addressed the question of why firms choose to incorporate sustainability criteria into their management and strategy and have reported diverse rationales. The most well-documented of their motivations include improved environmental performance in operations (Florida and Davison 2001); improved public relations, company image, and community relations (Florida and Davison 2001; Morrow and Rondinelli 2002); improved regulatory compliance; and a quest for competitive advantage (Porter and van der Linde 1995a,b; Florida and Davison 2001).

The "green and profitable" argument took hold in the middle 1990s with a series of high-profile articles in *Harvard Business Review* and a host of empirical studies that showed a connection between improved environmental management and benefits for firms and communities (Hart and Ahuja 1996; Klassen and McLaughlin 1996; Rondinelli and Vastag 2000; Andrews et al. 2003; Potoski and Prakash 2005a,b). Such articles promoted the notion that improved environmental performance was linked to improved financial performance and many other benefits to companies. A key early insight was that pollution indicates waste and therefore is inefficient. "Going green" in this context moved from the realm of compliance into the world of profit maximization and the emergence of a new concept of a "triple bottom line", which includes social, environmental, and economic considerations (Hart 1997; Elkington 1998; Prakash 2000; Esty and Winston 2006).

Alongside increased globalization of manufacturing and operations over the last 2 decades, expectations emerged that firms would standardize practices, including how they manage social and environmental outcomes, irrespective of where they operate. More recently—owing to consumer and societal pressure and hypercompetitive global markets that demand and reward efficiency in the value chain—companies have begun to expect improved performance, measurement, and reporting by their key suppliers (Andrews et al. 2006). The standardization of practices through such management systems as provided by the International Organization for Standardization became a de facto requirement (and an explicit contractual obligation in such industries as automobile manufacturing) as a means to drive efficiency and manage risk (Prakash and Potoski 2006).

Sustainability initiatives have also quickly become a recruiting tool for companies that are looking to secure top talent. A recent survey by the nonprofit Net Impact showed that 53% of workers and 72% of students indicated that a job where they could make a difference was important or essential for their happiness (Net Impact 2012). Executives and managers understand the value of human resources for continued success and survival and are trying to make their companies more attractive to the current generation of workers, who expect more than a paycheck from their employers (Savitz 2013).

Demand from the investment community is also driving corporate sustainability initiatives. The demand comes not only through the traditional pathway of the socially responsible investment and divestment movements but increasingly from mainstream banks and private-equity firms. Nearly 80 financial institutions in 35 countries (including Bank of America, Barclays, and Citigroup) have adopted the Equator Principles for assessing the environmental and social risks associated with investment; these institutions cover over 70% of project finance in emerging markets (EP Association 2011). And private equity has begun to integrate sustainability concepts into investment decisions. Leading firms, such as KKR and The Carlyle Group, are forming partnerships with nongovernment organizations (NGOs) to integrate environmental and social governance (ESG) criteria into their portfolio companies both as a means to screen potential acquisitions and as a way to derive additional value from companies in which they have an ownership stake. The trend is growing beyond just those companies. A 2013 survey of the private-equity industry showed that 74% of private-equity firms that had assets under management from $500 million to over $350 billion had increased their ESG commitments in the previous 12 months (Hayward et al. 2013; MSP 2013).

In addition to providing such benefits as increased efficiency, image enhancement, and cost reduction, many firms have found sustainability initiatives to be a means of promoting innovation in products, processes, technologies, and business models. Indeed, prominent business scholars and strategists tout the ability of sustainability initiatives to drive innovation and argue that companies that fail to incorporate the pursuit of sustainability concepts as a goal and core value will fail to achieve competitive advantage in their sectors (Nidumolu et al. 2009). Many companies have used their sustainability assessments and programs to create innovative products and services, and in some cases they actually disrupt the status quo on the way to reshaping their businesses and creating new markets. Early and anecdotal findings suggest a causal relationship between sustainability leadership and innovation (Deloitte 2013).

While the various internal and external sustainability drivers continue to gain momentum among mainstream firms, the shareholder value model—as it is currently being implemented—is facing increased criticism because of its failure to address new sources of business risk. Such criticism has led some firms to shift the focus from a primacy of *shareholders* to that of *stakeholders*. A focus on stakeholders—if done correctly—can drive innovation and profitability, enhance reputation, and ultimately create shared value that aligns the interests of society with those of the firm (Porter and Kramer 2006). By extension, aligning its purpose with a broader array of actors creates opportunities for a firm to be more efficient, craft new product offerings, find solutions to seemingly intractable problems, and enhance its reputation (Freeman et al. 2007).

COLLABORATION AS CENTRAL TO OPERATIONALIZING SUSTAINABILITY CONCEPTS

A critical component of the evolution toward incorporating sustainability concepts is the growing practice of collaboration. Collaboration is familiar to most organizations that participate in environmental protection and sustainability decision-making. It is a normal feature of customer–supplier relationships, government and business partnerships, and other initiatives that jointly involve NGOs, universities, and other stakeholders. It is also a primary approach that many companies have taken to develop their sustainability plans.

As companies sought to improve their compliance with the growing number of public-health and environmental regulations in the 1970s and 1980s, they also began to explore opportunities to reduce pollution in economically sensible ways. Early pioneers included the 3M Pollution Prevention Pays program and the Dow Chemical Waste Reduction Always Pays (WRAP) initiative. Internal collaboration within a company evolved into external partnerships, such as the 1989 partnership between the Environmental Defense Fund (EDF) and McDonald's partnership to phase out polystyrene-foam clamshell packaging. Simultaneously, individual industry sectors began to develop environmental and other codes of performance for their members. The most prominent example was the chemical industry's Responsible Care initiative, established in 1988 in the United States,[1] which initially required all member companies of the Chemical Manufacturers Association (now the American Chemistry Council) to implement six performance codes as a condition of membership.[2]

The first decade of the 21st century witnessed a dramatic expansion in the number and kind of collaborative relationships created by NGOs and global companies. Examples of the collaborations include partnerships between EDF and other NGOs with Walmart to introduce sustainability strategies and practices into the company's global supply chain, between Coca-Cola and the World Wildlife Fund (WWF) to develop a global water initiative to protect critical watersheds and preserve water access for current and future users, between Marks and Spencer (which established a "Plan A" business plan to rethink and redefine its product value chain) and OxFam to develop a business process for recycling clothing to lower-income families, and between The Nature Conservancy (TNC) and Dow Chemical to explore the value of ecosystems and natural capital. In addition, Unilever developed its Sustainable Living Plan, a business strategy that aims to decouple environmental effects from the economic growth of the company and develop more sustainable products that can also ameliorate social problems.

EPA was a pioneer in efforts to create platforms for precompetitive collaboration for environmental protection. After the enactment of the 1990 Clean Air Act Amendments, EPA used its ability as a neutral convener to enlist the automotive and petroleum industries, state and local officials, NGOs, and other stakeholders to share research information and design a regulatory framework for cleaner fuels, a framework that was embodied in regulations in 1994. More recently, such initiatives as the Electronics Industries Code of Conduct, the Roundtable for Sustainable Soy, and WWF efforts to convene major food-commodity producers to incorporate sustainability concepts into their operations testify to the growing vitality of efforts to leverage the global marketplace for sustainable outcomes.

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[1]This initiative was developed several years earlier in Canada.

[2]In 2002, Responsible Care was upgraded to require implementation of a management system by all members of the American Chemistry Council. The management system was subject to independent certification by third-party auditors. In addition, individual companies had to report their performance on a variety of environmental and safety performance metrics publicly.

Appreciative Inquiry (a "system in the room" technique) is a method of finding innovative solutions and building relationships; it is a prime example of how to create mutual value for all stakeholders. Walmart used such a technique in 2008 at its Sustainability Index Summit to seek direction for its system that was being developed to measure and evaluate the environmental and social effects of its products. Over 2 days, the company held meetings with over 170 stakeholders, including executives, employees, suppliers, NGOs (both partners and critics), academics, consultants, and other experts. The group developed metrics that would potentially be used to score products and suppliers, and it brainstormed ideas for how such a system could be best rolled out. The outcome of the summit was the genesis of what eventually became The Sustainability Consortium (TSC), an ambitious effort that involves global companies, academe, and stakeholders in developing tools, methods, and strategies to stimulate a new generation of products and supply networks for the consumer marketplace.[3] TSC has over 90 corporate members whose combined revenues exceed $2.4 trillion (TSC 2013).

Several major insights relevant to EPA have emerged from this trajectory of collaboration, including the following:

- The scale of sustainability problems is vastly different from the scale of issues addressed by a previous generation of partnership participants. Today, global, regional ,and local problems exist simultaneously, and cross-institutional partnerships need to incorporate issues of scale into the design and structure of the collaboration agenda.
- On a global scale, no institution has the knowledge, resources, or other capabilities necessary to solve major problems, including climate change and the preservation of biodiversity, water supplies, and other natural resources, so new skill sets and innovative organizational strategies for identifying and managing collaboration opportunities must be developed.
- The ability and credibility to convene and manage large-scale collaboration is a major asset that can be implemented by governments and NGOs in cross-sector initiatives and by corporations and their partners throughout their value chains.
- Issues of transparency, reporting, and governance have become more important in ensuring public confidence in collaboration initiatives, in providing a clearer definition of accountability for delivery of performance results, and in identifying roles and responsibilities in multi-institutional and multisector undertakings (see Box 5-1).
- Each participating organization—government, business, NGO, or academic—should clearly define its own core competences and authorities for participating in a major collaborative action to add value to the entire enterprise of planning and actions.

EPA should use its convening ability to develop and deploy stakeholder-engagement processes to diagnose and address the most urgent environmental challenges and assist in scaling efforts of the private and public sectors for broad application in sustainability-related decision making. *(Recommendation 5a)*

[3]TSC is a sustainability researching organization that was developed in a joint effort of the University of Arkansas and Arizona State University supported by membership fees from stakeholders that comprise mainly private companies, other sustainability nonprofits, and academic institutions. The mission is to develop a system—called the Sustainable Measurement and Reporting Systems—to evaluate a consumer product's sustainability performance for the entirety of its supply chain. The main stated goal is to distill sustainability indicators identified into key performance indicators in which to evaluate the performance of consumer products. Some retailers appear to be adopting the work by TSC in differing approaches. Walmart seems to be committed to evaluating and ranking its suppliers in a systematic manner.

BOX 5-1 Embedding Transparency

The US Green Building Council's Leadership in Energy and Environmental Design (LEED) certification system has created an increase in demand for product transparency, with supporting life-cycle information, among end users of building products. For example, architects, designers, and building owners are requiring accurate life-cycle information. A number of design firms and specifiers are requesting product disclosures from building-product manufacturers. Similarly, the Sustainability Accounting Standard Board (SASB) is developing industry-based standards to guide disclosure and action on material sustainability issues for use in providing decision-useful information on US Securities and Exchange Commission forms 10-K and 20-F from both US and foreign companies. SASB is developing industrial standards for 80 industries in 10 sectors (SASB 2014).

On the basis of the past decades of experience (for example, see Box 5-2) and the magnitude of current and future sustainability challenges, future collaborative strategies and initiatives will probably need to encompass more innovative thinking for major transformational change. WWF and TNC, for example, are developing a global water standard that would encourage the application of best practices in water-resource management and water-quality protection. Given EPA's extensive knowledge and experience in developing water-quality standards, there is an innovation opportunity to learn and leverage the agency's expertise on a wider scale. The field of multisector, multistakeholder collaboration continues to encompass dynamic learning and represents one where specific institutions, such as EPA, will need to select carefully both the issues and the competences in which it can add value to existing efforts.

> **EPA should attach high priority to collaboration among its offices to develop decisions as an enterprise that balances tradeoffs and minimizes unintended consequences.** ***(Recommendation 5b)***

Engaging in collaborative problem-solving will help the agency to evaluate and anticipate such consequences.

> **EPA should develop nonregulatory tools or guidance on sustainability topics to engage businesses that have not made as much progress in incorporating sustainability concepts into their business model as have generally larger firms that have high-visibility brands.** ***(Recommendation 5c)***

Such tools and guidance would go a long way in helping underresourced small and medium enterprises around the United States and companies that have not yet felt market pressure to advance sustainability concepts in their operations but could derive substantial economic value from it.

SUSTAINABILITY INITIATIVES OUTSIDE THE ENVIRONMENTAL PROTECTION AGENCY

EPA has identified four cross-program priorities for sustainability-related activities in its FY 2014 action plan: sustainable products and purchasing, sustainable materials management, green infrastructure (or the private-sector analogue, green buildings), and energy efficiency (EPA 2014b). This section discusses examples of programs and other initiatives outside the agency that are relevant to EPA's activities.

Sustainable Products and Purchasing

Multiple, parallel efforts are under way to use life-cycle information in business management to consider products or services in a holistic way. Some of the initiatives intend to identify the most pertinent issues, which if known and targeted for improvement would lead to more sustainable products. For example, the Association of Home Appliance Manufacturers (AHAM) developed a sustainability standard for appliances (including refrigerators) that allocated points for various product-performance categories (AHAM 2012). Similarly, TSC has been working to develop an approach on hundreds of product categories, the Life Cycle Initiative of the UN Environment Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC) and the International Network of Product Sustainability Initiatives are collaborating on global principles and practices for analysis of hot spots (parts of the life cycle that can be especially important), and Johnson & Johnson's Earthwards® process involves the combined use of life-cycle screening and risk assessment to consider potential upstream and downstream effects and risks.

Typically, the environmental performance of products is evaluated case by case. A retailer's purchasing representative may meet with a supplier to discuss and negotiate different aspects of the product transaction. At that point, the supplier may communicate its sustainability efforts concerning the product. Depending on the retailer's sustainability interests, such an appeal by the supplier may prove to be attractive at the negotiating table. As one may expect, this approach is often time-consuming and lacks transparency, and there is uncertainty as to whether the retailer is achieving its sustainability goals in making its purchases. Centralized or consistent approaches are often lacking.

Some retailers may attempt to leverage existing information networks to incorporate their suppliers' sustainability information by using enterprise resource planning software. However, because the information that retailers receive from suppliers is inconsistent and nontransparent, it can be difficult to make decisions that are based on it.

Alternatively, large retailers that have enough leverage in the marketplace, such as Walmart, may opt to take a more top-down approach in achieving their sustainability goals. One such program is the Walmart Packaging Scorecard system. The system identifies nine categories of sustainability considerations:

- Greenhouse-gas (GHG) emissions related to production.
- Material value.
- Product-to-package ratio.
- Cube use.
- Emissions related to transportation of packaging materials.
- Recycled-content use.
- Recovery value of raw materials.
- Renewable energy used to manufacture packaging.
- Innovation.

BOX 5-2 The Flame Retardants in Printed Circuit Boards Partnership

From the perspective of business, many of EPA's Design for the Environment (DfE) projects not only have been successful but they have created a collaborative means to achieve better outcomes through multistakeholder teams. An example is the DfE Flame Retardants in Printed Circuit Boards [PCBs] Partnership. Diverse experts in industry, environmental NGOs, academe, and EPA combined their differing points of view to produce a report that provides objective, evidence-based information designed to assist members of the electronics industry incorporate human-health and environmental considerations into decision-making efficiently when selecting flame retardants for PCB applications (EPA 2014q). The project resulted in an set of flame-retardant chemical profiles that can be used in conjunction with LCA and performance and cost considerations to make informed choices in selecting a functional flame retardant for PCBs. The report that contains the profiles is used by electronics firms. EPA's approach yielded the outcome desired, and the businesses involved indicated a willingness to participate in future projects of a similar nature.

Walmart sent suppliers a clear message on the intent, goals, and expectations with regard to participation in the scorecard system. The system allowed Walmart a clear indication of whether it is achieving its identified goals and targets.

A new effort is under way to develop global principles and practices on hot-spot analysis. The UNEP–SETAC Life Cycle Initiative[4] aims to create a system that uses life-cycle information as the platform for assessing the environmental performance of countries, sectors, product categories, and products. The purpose of the hot-spot analysis flagship project is to develop a framework within which organizations will gain a fuller understanding of environmental or social issues whose improvement would have a substantial effect in advancing sustainability goals.

Traditionally, EPA's regulations and policies pursue single-issue solutions. As business strategies gradually shift to practices considered to be going "beyond regulation", EPA is positioned to be able to foster the incorporation of sustainability concepts in its internal decision-making and to influence the private sector with regard to products and purchasing.

As EPA considers life-cycle approaches in a sustainability context, it should leverage ongoing work by such organizations as TSC and the UNEP–SETAC Life Cycle Initiative. *(Recommendation 5d)*

Sustainable Materials Management

Sustainable materials management (SMM) is an approach to serving human needs by using or reusing resources productively and sustainably throughout their life cycles—from the point of resource extraction through postconsumer use of a product. It seeks to optimize the amount of materials involved and minimize all the associated environmental effects while striving for economic efficiency and accounting for social considerations (EPA 2013f).

Current SMM approaches focus heavily on the purchasing habits and end-of-life management by the consumer. EPA looks extensively at solid-waste streams in the United States and provides continuing reporting of waste composition and recycling habits. In addition, through its use of Federal Green Challenge, Food Recovery Challenge, Electronics Challenge, and SMM Data Management System, the agency provides opportunities for other government agencies and private businesses to challenge each other to improve practices in procurement and waste management. The challenge programs are voluntary and provide recognition in addition to the intrinsic benefits of SMM.

However, material choices are made far upstream of the consumer. If SMM is considered in the processes of providing natural resources for producing goods and providing services, more comprehensive effects can be realized and the choices made downstream for distribution and end-of-life management can be facilitated. This is where a life-cycle approach to SMM provides additional value.

If one considers SMM to be analogous to the budgeting that a company undertakes to ensure financial sustainability, LCA may be considered analogous to the accounting required to track finances, evaluate the efficacy of the budget, and set goals for improvement. The UNEP–SETAC Life Cycle Initiative's hot-spot analysis, AHAM's appliance standard, and TSC's SMRM are examples of LCA projects that have identified and set priorities among hot spots. Establishing a system of categorizing products and identifying high-priority hot spots on the basis of life-cycle information will facilitate an understanding of the effects and opportunities for improvement. LCA, including hot-spot analysis, can provide many benefits:

- Quantitative comparisons of purchases.

[4]Joint partnership between United Nations Environment Programme (UNEP) and Society of Environmental Toxicology and Chemistry (SETAC).

- Priority-setting for improvements through hot-spot identification.
- Ability to set targets for internal goals and for suppliers.
- A clearer communication of expectations in developing purchasing policies.
- Encouragement of cleaner production and extended producer responsibility, inasmuch as LCA includes effects of disposal of products.
- Clear communication to the public.

Some companies and industries have taken it upon themselves to perform LCA studies of current products or potential new products. Two examples are presented in Boxes 5-3 and 5-4.

As demonstrated in those two examples, SMM results in increased involvement. Policies that encourage companies to be more engaged with their products or services throughout an entire life have the added benefit of maintaining a manufacturer–customer relationship during product use, maintenance, and return at the end of use. That relationship helps a manufacturer to identify customers' needs, create customer loyalty, and reduce material-supply risk. By maintaining a similar relationship with its supply chain, a manufacturer can respond more quickly to changing demands and reduce supply-chain environmental effects (EPA 2012h).

On the basis of an examination of industry trends, it is possible that life-cycle environmental performance will become as predominant a consideration as safety and quality are today in the design and development of products, technologies, and services.

BOX 5-3 Anvil Knitwear, Inc., Water Footprint Analysis

Anvil Knitwear, Inc., an American apparel company, has taken an active approach to reporting its sustainability initiatives via the Corporate Social Responsibility Reporting and the Global Reporting Initiative (GRI) G3 Sustainability Reporting Guidelines. The company undertook a water footprint analysis for one of its T-shirts to meet the A level GRI reporting standard. By examining water use and consumption throughout the supply chain of the shirt, from cotton growth to textile production and dyeing, the company found that the majority of water consumption for its product occurs in the agricultural processes for growing cotton. Using the results of its water footprint assessment, Anvil developed a fiber diversification and sustainability scorecard that takes into account the effect of water in the company's agricultural supply chain (Anvil 2011).

By taking a life cycle approach in considering its product, Anvil is able to know more about its supply chain and the company's potential effects on important resources, in this case water. That allows Anvil to make choices regarding the sourcing of materials that can benefit the stability of the company's supply chain and the environment.

BOX 5-4 The Aluminum Stewardship Initiative

The Aluminum Stewardship Initiative (ASI) is coordinated by the Global Business and Biodiversity Programme of the International Union for Conservation of Nature. Its goal is to develop principles and criteria for aluminum stewardship to drive responsible environmental, social, and governance performance throughout the aluminum value chain (ASI 2014). The project was founded at the end of 2012 by 14 companies that include primary aluminum producers, aluminum converters, and commercial or consumer-goods producers. By undertaking a transparent approach and involving global stakeholders, the companies are establishing best practices for aluminum use, such as emission reporting and ethical guidelines for companies in the supply chain. They have introduced the concept of an aluminum chain of custody to ensure that best practices are being undertaken throughout the supply chain and to avoid shifting the burden from one life-cycle stage to another. ASI is designed to maximize the value that aluminum generates and minimize its effects in the value chain (Rio Tinto 2012).

EPA should pursue a more harmonized approach with industry regarding sustainability considerations, using life-cycle approaches and other existing efforts as a platform and point of entry. The agency should expand its efforts from voluntary challenges and reporting to encouragement of companies to apply SMM comprehensively, focusing on the entire life cycle of products and service. *(Recommendation 5e)*

Green Infrastructure

In describing its sustainability priorities for FY 2014, EPA highlighted storm-water management as a main focus in the category of green infrastructure. Chapter 4 provides a case study of storm-water management in the context of a combined-sewer overflow project in the Cleveland metropolitan area. This section discusses another aspect of green infrastructure: green buildings.

The General Services Administration (GSA) Public Buildings Service Rocky Mountain Region Denver Federal Center (DFC) houses a 1-mi^2 campus for 28 federal agencies and nearly 7,000 employees. Drivers of sustainability initiatives on the campus include the GSA sustainability policy that sets a goal of zero environmental footprint for all GSA activities; Executive Order 13514, *Federal Leadership in Environmental, Energy, and Economic Performance*; and the DFC master plan and environmental-impact statement.

The DFC sustainability plan identifies strategic goals for a sustainable DFC campus:

- Zero emissions:
  - Storm-water and wastewater reuse.
  - Waste reduction, reuse, and recycling.
  - Chemical-use reduction.
- Improved energy efficiency.
- Carbon neutrality by 2030 (80% by 2020).
- Open space conforming with the master plan.
- Increased use of public transportation.
- Improved GSA–tenant partnership:
  - High-performance building design and improvements.
  - Environmental management and performance.
  - Education and training.
  - Sustained community outreach.

DFC established a Sustainability and Environmental Management System to translate those strategic goals into sustainability objectives, targets, and strategies (management programs) and to measure its progress toward a sustainable DFC.

GSA has incorporated sustainable design and practice into daily operations through the guiding principles (GP) in the 2006 memorandum of understanding *Federal Leadership in High Performance and Sustainable Buildings* and the 2008 *High Performance and Sustainable Buildings Guidance*. GSA is required to achieve full GP compliance for 18% of all owned and leased buildings that are larger than 5,000 gross square feet by FY 2015. To document GP requirements for existing buildings, GSA is using the 2009 version 3 of the Leadership in Energy and Environmental Design (LEED) system for its bulk-volume certification program (GSA 2013a). GSA also recognizes the Green Building Initiative's Green Globes 2010 green-building certification system. The DFC is pursuing GP requirements for 32 buildings by 2015.

In addition to the development of the DFC, GSA conducts research projects to investigate how sustainable technologies and approaches can improve building performance. In 2013, GSA reported on a demonstration project that it conducted in EPA's Region 8 headquarters building. The project provided methods for assessing indoor water use, building thermal performance, and other characteristics (GSA 2013b).

EPA should continue to collaborate with GSA and other organizations in the development of tools and approaches for guiding the design and operation of green buildings. ***(Recommendation 5f)***

Energy Efficiency

Pursuing Energy Efficiency and Setting Appropriate Targets

Siemens is a technology and infrastructure company that operates in many countries. Globally, Siemens operates more than 290 major manufacturing sites, employs more than 350,000 people (60,000 in the United States), and sells technologies in each of its major business sectors: energy, industry, infrastructure and cities, and health care. With such a diverse and global business, Siemens was challenged to develop a program to reduce resource consumption that would be implemented consistently and effectively throughout its operations. By developing and deploying tools for consistent measurement and tracking of resource consumption, including transparent reporting of progress toward resource-efficiency goals, Siemens reduced its resource consumption globally over a 5-year period and developed a new generation of sustainability goals that were based largely on lessons learned in the first 5 years of its sustainability program.

Globally, most Siemens facilities are required to maintain an environmental-management system that is compliant with International Organization for Standardization (ISO) standards, and each new building is expected at least to meet LEED Gold certification requirements where possible. In addition, Siemens tracks the energy consumption (electricity use, primary energy consumption, and district heating) and carbon dioxide emission from production and large-office facilities that the company owns or operates. About 85% of Siemens's total emission and resource consumption is reported to a database; coverage is higher in some cases, such as GHG, of which 95% of direct and indirect emission is reported (Siemens 2011). Siemens calculates its GHG emission, Scope 1, Scope 2, and Scope 3 (travel) on the basis of the guidelines published by the World Resources Institute (WRI) in cooperation with the World Business Council on Sustainable Development (WBCSD). Siemens publishes its energy-consumption data and other natural-resources data, such as its GHG emission, on its global Web site and in its global sustainability report ,which is being integrated into its annual financial reporting. In addition, customers that are evaluating Siemens as a sustainable supplier request information from Siemens about its natural-resources consumption, and Siemens voluntarily discloses some data to such entities as the Carbon Disclosure Project (CDP).

Siemens set global goals in its sustainability program beginning in 2007. Among the goals was a target to achieve, by the end of FY 2011, a global reduction in energy consumption of 20% from a base year of 2006 relative to global revenue (Siemens 2011). The goal was set by the managing board of the company. By the end of FY 2010, Siemens had encountered several uncertainties that affected achievement of its energy-efficiency goal. The company indicated in its annual sustainability report that because of increased business activity in some business divisions and inclusion of new locations in the reporting—and increased use of heating energy in some areas of the world in a severe winter—the efficiency increase for electricity totaled 11% overall. Siemens reported that achievement of its 20% goal by the end of FY 2011 was therefore unlikely. The company reported that it would continue to pursue its energy-efficiency program regardless of economic developments over the prior 2 years, stating that "the base load energy consumption of buildings is, after all, largely independent of economic developments" (Siemens 2011, p. 73). Although power consumption had risen in FY 2010, GHG emission had been reduced because of more favorable emission factors and reductions in the use of sulfur hexafluoride, fuel oil, and liquefied gas. After 2010, those trends continued. By the end of FY 2011, Siemens missed its goal to reduce electricity consumption by 8% but met its other resource goals, including reductions in common air-pollutant emission, GHG emission, primary energy consumption, energy consumption for district heating water consumption, and waste production.

In evaluating the next generation of goals for the company's sustainability program, Siemens identified several categories of improvement that may be important for EPA's consideration, including the need for a detailed implementation plan, with management ownership, to bring about action in individual facilities. To promote individual business ownership of resource-efficiency initiatives and to avoid reliance on a centralized program, the company did not establish a centralized funding source for capital improvements. Some facility managers interpreted a lack of centralized funding as a lack of high-level commitment to the sustainability goals, and it may have been too soon to expect that global sustainability goals would be embedded into individual facility decisions in the absence of specific implementation direction or incentives at the outset. Annual communication (internally and externally) of the goals and progress of the sustainability program and various types of recognition for the program, such as Siemens's leadership in the Dow Jones Sustainability Index, have enhanced awareness of the importance of the sustainability goals throughout the company.

The tools that most contributed to Siemens's success included its centralized database with standardized reporting methods (such as the WRI–WBCSD Greenhouse Gas Protocol), public reporting that enhanced accountability and awareness of the goals (such as the Siemens Web site, which displays progress toward annual goals, its published sustainability report, and voluntary disclosures to such organizations as CDP), the Energy Efficiency Program (created by Siemens and uniformly deployed) used to evaluate potential energy-efficiency improvements at production facilities (see Table 5-1), and published external standards that are now recognized and required by Siemens where possible, such as LEED building certifications and ISO standards. As Siemens's sustainability program has evolved, it has recognized that consistent long-term implementation of tools, such as its Energy Efficiency Program, is essential for achieving long-term goals.

EPA should strive to inform all stakeholders about best sustainability practices and lessons learned by publicizing case studies on its Web site and convening thought-leadership events during which private-sector, government, and NGO participants share their experiences. EPA should emphasize examples of sustainable practices that can be replicated, not only ones that resulted in measurable success. For instance, the examples should underscore the importance of the following practices:

- **Clear leadership from the top of an organization.**
- **Clear implementation plans to accompany sustainability goals.**
- **Clear internal communication of leadership priorities, goals and implementation plans.**
- **Sustained application of consistent methods whether created internally or externally.**
- **Rigorous maintenance of accurate internal data.**
- **Voluntary public disclosure to enhance awareness and accountability.** ***(Recommendation 5g)***

Siemens has also recognized a need for new tools, such as watershed assessment tools for a better understanding of the health of the watersheds in which it has or may have facilities, a recognized method for performing product LCAs in response to increasing customer demand, a recognized method for determining total cost of ownership, and approaches or tools that balance more than one aspect of sustainability (such as, the environmental and economic aspects of sustainability).[5]

[5]In 2011, Siemens launched its Eco-Care Matrix, a decision-support tool that graphically depicts results and brings environmental-impact considerations together with economic factors. The center of the matrix always contains a comparative reference point that is derived from traditional technologies. The y axis shows the new solution's environmental compatibility relative to the reference point. This combined value includes carbon dioxide, sulfur dioxide, nitrogen oxides, dust emissions, water, energy, and natural-resource use. The x axis shows customer benefit expressed as a change in system costs. If a new product or solution is to the right of and above the reference point, the presumed customer benefit is higher and its environmental impact lower.

TABLE 5-1 The Siemens Energy-Efficiency Program

Analysis			**Implementation**
Selection of Location	**Energy Health Check**	**Energy Analysis**	**Performance Contracting**
Focuses on the most promising sites	Evaluates site along comparable star rating system	Details measures and their effects	Applies continuous optimization and best-practices exchange
Applies first internal benchmarks regarding energy consumption	Benchmarks site internally and externally	Develops holistic concept for implementation to achieve savings: • Technology • Production • Infrastructure • People	Integrates training and awareness campaign
	Derives first indication of savings potential and investment requirements		Considers performance Contracting: • Guaranteed return from energy savings • Reduced burden on cash position
	Identifies best practices		

Source: Adapted from Siemens 2011. Reprinted with permission; copyright 2011, Siemens.

EPA can learn about tools developed by stakeholders outside the agency and provide expertise in the development of new tools. EPA should provide assistance in scaling up tools as it did in recognizing the WRI–WBCSD Greenhouse Gas Protocol as an accepted method for use in compliance with the GHG inventory regulation. *(Recommendation 5h)*

Application of an Internal Carbon Tax to Advance Business and Sustainability Objectives

Given its size and prominence as a well-recognized consumer brand, Disney has measured a growing recognition of sustainability issues among its customers. Disney's close brand connection to children and their families makes it especially sensitive—and vulnerable—to any sustainability issue that might affect its reputation.[6] Such issues include GHG emission from cruise ships and other logistical operations; safety, health risks, and emissions associated with its licensing agreements for the manufacture of toys; and menu choices at its lodging and theme park facilities.

Over a period of years, Disney has been migrating along a path of greater sustainability commitments, including changing menus to combat child obesity, achieving a net positive ecosystem impact through the Disney Worldwide Conservation Fund, developing water-conservation plans, setting a goal of zero waste with a 2013 target of solid waste to landfills that is 50% of 2006 levels, informing and mobilizing employees and consumers in sustainability activities, reducing indirect GHG emission from electricity consumption, and setting a net zero direct GHG emission objective. As part of the process, Disney requires the preparation of an environmental assessment for any project that requires a capital authorization request.

In 2009, senior Disney executives instituted an internal price on carbon (externally referred to as a carbon tax). The major motivation for the internal price of carbon was twofold: to increase employee and manager awareness of the company's sustainability challenges and motivate them to greater participation

[6]The Walt Disney Company is a global, diversified company with major businesses in film and television entertainment, parks and resorts, and consumer products. According to Forbes Magazine, it is the 17th most valuable brand in the world; it recorded 2013 sales of $42.84 billion and has a market capitalization of $103.96 billion (April 2014).

in a variety of initiatives and to incentivize individual Disney businesses to minimize carbon emission and to take ownership in finding creative ways to make their individual businesses more sustainable. In designing the levy, Disney assessed several major uncertainties: the newness of the effort and the absence of other mature corporate carbon-tax initiatives to evaluate, instability in the price of carbon in the global and regional marketplaces, and unknowns associated with the future development of government policy frameworks and regulation of carbon (excepting such examples as California's AB 32 legislation and European Union requirements).

The internal carbon tax, based on a range of \$10–20 per metric ton of carbon dioxide–equivalent emission, is calculated on the basis of a business unit's projected carbon emission over a 5-year period. If emission is below the projection, the tax is reduced. Since its implementation, Disney's carbon tax has generated operational changes and innovations, large and small, including

- Changing theme-park trains to be fueled by recycled cooking oil rather than fossil fuels.
- Investing in carbon research and development for waste-heat recovery and conversion to power, biofuels, and other alternatives.
- Altering cruise-ship hull designs and coating formulations, optimizing routes, and installing highly efficient lighting and heating, ventilation, and air conditioning.

Those and other options are subject to continuing evaluation of their costs and performance relative to the company's longer-term objective of achieving zero net GHG emission through a combination of reductions, efficiencies, and offsets.

One of the unique aspects of the design and implementation of the internal carbon tax was the integral role of Disney's financial organization. Disney's environmental and corporate citizenship staffs have responsibility for tracking emission in various source categories, and the financial part of Disney, including the chief financial officer, constructed and measured the financial allocation of the carbon tax among the various business units. That represents a unique collaboration—one that marries highly visible external commitments with internal incentives that shape the bottom-line effect on the operations of Disney's businesses.

Disney's initiative to internalize the cost of carbon has been conducted as part of a growing application of pricing schemes in the private sector, including such companies as DuPont, ExxonMobil, Google, Microsoft, Royal Dutch Shell, and Walmart. Although pricing is at different levels that reflect the relative lifespans of specific assets, the movement toward internal carbon pricing is a major testament to the power of internal transparency to influence business decision-making. Such transparency, in turn, has identified new options for improving business operations and research and development, stimulated further integration of sustainability factors into business strategy, and created new opportunities for innovation, value creation, and collaboration with external stakeholders.

As such agencies as EPA develop their carbon-management policies further, they should strive to learn from an increasingly rich sample of experimentation on how well-designed economic incentives can enhance sustainability objectives. *(Recommendation 5i)*

INNOVATION OPPORTUNITIES FOR THE ENVIRONMENTAL PROTECTION AGENCY

In addition to pursuing the opportunities mentioned above, EPA should use its ability as a convener to assemble individual participants to define and implement value chain-wide goals and performance outcomes. *(Recommendation 5j)*

If EPA serves as the convener, additional precompetitive collaboration opportunities can be identified and concerns over antitrust issues minimized. The convening efforts should include

- Benchmarking against other successful value-chain initiatives that exist in the private sector or between the private sector and NGOs.
- Reviewing existing policy instruments from a value-chain perspective to identify where they complement or contradict each other and trying to reconcile them.

One concept that business and industry have come to understand well is that the fuel of sustainability assessments, programs, and progress is data. No matter what the program, assessment, or tool under scrutiny, it runs on data. The higher the quality of the data, the more contextualized it can be, and the more effective the assessment and program implementation. Many tools in use by the regulated community collect and apply data for sustainability purposes. The data that a company collects to perform LCAs constitute a logical nexus point for EPA to propose collaborative projects. The data and analysis requisite for successful ISO 14001 environmental management systems and ISO 50001 energy management systems certification would make up an excellent dataset and basis for mutually beneficial collaborations between EPA and the regulated community. An examination of leading companies' environmental reports and the data gathered in them can yield surprising new insights and common ground for collaborative projects that EPA may want to pursue. The idea is to pursue mutually beneficial collaborations that are based on data already gathered and processed, many of them already in the public domain.

To the extent practicable under budget constraints, EPA should provide data-analysis capability for synthesizing large quantities of data from the private and public sectors to identify and implement sustainable business practices. *(Recommendation 5k)*

Many firms already engage in a great deal of voluntary reporting on a variety of sustainability indicators, but the full capabilities of mining the data for insights into more sustainable strategies are still evolving. Great insights that could drive value to business, communities, and ecosystems are possible. Much of the regulated community has been studying the concept of sustainability and implementing sustainability processes for years.

Although there is still much that the regulated community can learn from EPA in these matters, the agency has the opportunity to leverage the experience of leaders in the regulated community to strengthen both EPA decision-making and corporate performance more broadly (see Table 5-2).

CONCLUSIONS AND RECOMMENDATIONS

Key Conclusions and Recommendations

Conclusion 5.1: EPA can learn about tools developed by industry and other stakeholders outside the agency and provide expertise in the development of new tools.

Recommendation 5.1: EPA should leverage the sustainability experience of leading companies both to strengthen its decision-making and to incorporate sustainability performance, more broadly. For example, as EPA develops its carbon-management policies further, it should strive to learn from an increasingly rich sample of experimentation on how well-designed economic incentives can enhance sustainability objectives. (See Recommendation 5i)

Conclusion 5.2: EPA was an early pioneer in using collaboration efforts for environmental protection. The ability and credibility needed to convene and manage large-scale collaboration are major assets; no single institution has the knowledge, resources, or other capabilities necessary to solve major problems on a global scale.

TABLE 5-2 Sustainability Drivers for the Private Sector and EPA

Corporate Sustainability Drivers	**Sustainability Drivers Applicable to EPA**
Use of LCA and other approaches to evaluate sustainability effects and risks in a firm's product development and use functions	Application of LCA and other approaches to enhance the understanding of risks of individual products and to strengthen the development of policy frameworks for intrasector and cross-sector regulatory and nonregulatory decisions
Improvement in performance by an individual firm to reduce costs and improve competitive position and brand	Achievement of better performance by firms of all sizes in a sector through regulations, incentives, and voluntary initiatives
Understanding of value-chain footprints and effects to enhance management of business risks and opportunities	Investment in data analysis to understand major trends to guide policy analysis, leverage decision-making on a greater scale (for example, value chains), and provide technical assistance to smaller firms
Alignment of value-chain goals, metrics, and performance commitments for individual firms and their suppliers and downstream customers to integrate enterprise-risk management in businesses engaged in common economic activities	Convening of major value-chain participants in business sectors to develop policy frameworks and regulatory and nonregulatory approaches to improving value-chain performance on specific issues
Integration of sustainability concepts in business models and in individual business units	Integration of sustainability concepts in the core of EPA's strategic plan and within individual programs
Application of materiality assessments to evaluate issues of high importance to stakeholders	Use of innovative methods to consider stakeholder inputs into policy decisions and nonregulatory priorities
Alignment of business decisions to develop approaches to global megatrends through innovative partnerships	Scaling of EPA decision-making through collaboration with national governments, global companies, and NGOs
Investment in technologies and incentives for a lower-carbon economy and reduction in use of natural resources	Designing of policy frameworks to encourage investment in lower-carbon technologies and increased efficiencies in energy and natural-resource consumption

Recommendation 5.2: EPA should use its ability as a convener to assemble non-governmental participants to define and implement value-chain–wide goals and performance outcomes. It should use its convening ability to develop and deploy stakeholder engagement to diagnose and address the most urgent environmental challenges and assist in scaling efforts in the private and public sectors for broad application. (See Recommendations 5a and 5j)

EPA should prioritize collaboration across its offices to develop decisions as an enterprise which balances trade-offs and minimizes unintended consequences. (Recommendation 5b)

Conclusion 5.3: Learning how successful firms have used sustainability tools and approaches can be an important incentive for other companies to do the same.

Recommendation 5.3: EPA should develop nonregulatory tools or guidance on sustainability topics to engage businesses that have not made as much progress in incorporating sustainability concepts into their business model as have generally larger firms that have high-visibility brands. EPA can help to inform these firms and other stakeholders about best sustainability practices and lessons learned by publicizing case studies on its Website and convening thought-leadership events during which private-sector, government, and NGO participants share their experiences to improve the performance of the businesses. To the extent practicable under budget constraints, EPA should provide data-analysis capability for synthesizing large quantities of data from the private and public sectors to identify and implement sustainable business practices. Synthesis capabilities have not kept pace with the great deal of voluntary sustainability reporting. (See Recommendations 5c, 5g, and 5k)

Other Recommendations

As EPA considers life cycle approaches in a sustainability context, it should leverage ongoing work by organizations such as TSC and UNEP-SETAC Life Cycle Initiative. *(Recommendation 5d)*

EPA should continue to collaborate with GSA and other organizations in the development of tools and approaches for guiding the design and operation of green buildings. *(Recommendation 5f)*

EPA should pursue a more harmonized approach with industry regarding sustainability considerations, using life cycle approaches and other existing efforts as a platform and point of entry. The agency should expand its efforts from voluntary challenges and reporting to encouraging companies to apply sustainable material management comprehensively, focusing on the entire life cycle of a product or service. *(Recommendation 5e)*

EPA can learn about tools developed by stakeholders outside of the agency and provide expertise in the development of new tools. EPA should provide assistance in scaling up tools as it did in recognizing the WRI/WBCSD Greenhouse Gas Protocol as an accepted methodology for use in compliance with the greenhouse gas inventory regulation. *(Recommendation 5h)*

6

Identifying and Addressing New Issues

INTRODUCTION

In the 20th century, government agencies, such as the US Environmental Protection Agency (EPA), tracked the emergence of important national and international trends by seeking input from reliable outside and internal experts and businesses that had good reasons to stay ahead of trends and by reading mass-media reports and studies produced by not-for-profit organizations. Federal agencies collected their own data, but often something environmentally important occurred before federal agencies found out by scanning their own data.

In the 21st century, the ability to gather, maintain, analyze, and circulate data has improved markedly. Smaller and less expensive environmental monitors have been developed and deployed, so people in EPA and state environmental agencies (such as California's Emerging Environmental Challenges Program) [1] can quickly scan collected data for notable emerging trends and cross-reference with colleagues anywhere in the world who have similar capabilities.

The ability to identify and understand trends in public preferences and perceptions has also improved markedly. The traditional survey, which uses protocols recommended by the American Association for Public Opinion Research, is one of the best ways to learn about public preferences, perceptions, and values associated with the environment because a representative sample is gathered and confidence limits can be estimated for the results. But it is now feasible to scan data for marked shifts in public perceptions. Joined with standard opinion-poll data and selected longitudinal surveys, social- media data analytics can allow EPA to stay up to date with what the public is thinking; some analytic tools may even assist in predicting public attitudes about specific issues as they emerge. As the 21st century progresses, the United States will probably undergo substantial economic, environmental, and social changes; not only are the expected changes complex, but their occurrence is expected to be rapid. New issues will include substantial uncertainty. The anticipation and prevention of adverse effects, as opposed to detection of and response to them, is growing in its appeal. Earlier recommendations to EPA seem prescient: "that EPA should include among its repertoire of analytical and technical skills, a capability to routinely and systematically study the range of possible environmental futures ahead, and advise the nation on possible actions in response" (EPASAB, 1995). The ability to anticipate, assess, and manage challenges is at the heart of sustainability practices and therefore plays a major role in addressing new issues and evaluating strategies that can minimize potentially deleterious effects.

Regardless of what technologies, tools, methods, or approaches one chooses for assessing and managing emerging issues, data will fuel them (EPA 2013a). Access to high-quality data will be a pivotal determinant of success in applying sustainability approaches to management of new-issues, and it is clear that EPA and other federal agencies have deemed this a signature issue (White House 2014).

This chapter discusses some key considerations regarding the need for EPA to develop science-grounded information more rapidly. It also considers a variety of specific challenges that EPA is likely to face in deciding how to apply sustainability tools and approaches when addressing a new issue.

[1] See OEHHA 2007.

KEY CONSIDERATIONS FOR IDENTIFYING AND ADDRESSING NEW ISSUES

Informing Regulatory Decision-Making

The regulatory implications of new issues can be informed and guided by the early warning of the existence of the issues through a robust EPA surveillance program and by equally robust sustainability assessments and analytics. However, once an emerging issue has been identified, an initial assessment will be necessary to categorize it in such a way as to determine whether regulatory oversight is necessary and, if so, which regulatory agencies should engage. Given that emerging issues, whether proceeding from societal or natural factors, will probably cut across social, economic, technologic, and environmental risk assessment and management, multiple regulatory agencies often will need to engage and collaborate. The discussion on megatrends in Chapter 2 identified several important drivers of new issues that may confront regulatory agencies in the future.

The rate at which challenges are likely to approach and their increased complexity will afford progressively shorter periods in which to assess them and, if necessary, to devise strategies to address them. An increased technical presence within the staffs of regulatory agencies may be required. And screening assessments, tools, and formal sustainability assessments may need to be further automated to meet the rapid throughput that new-issue management will require.

Given the global nature of many existing environmental and sustainability issues and the likelihood that new issues will have international implications, new-issue identification may promote congruent approaches and regulatory convergence among countries that are attempting to address newly identified issues jointly. The sharing of sustainability tools and approaches could foster such congruent approaches.

Rapid Changes in Information Technology and Resulting Opportunities for Input and Stakeholder Engagement

The stunning pace of advances in information technology (IT), data management, and analytics (Chapter 2) presents opportunities for EPA to engage stakeholders better. The considerable computing research already under way in EPA provides an excellent base for improving many sustainability tools and approaches while providing the capacity to create new approaches, tools, and models to support new-issue identification and assessment. *Sustainability and the U.S. EPA*, the so-called Green Book (NRC 2011a) recommended the development of a screening tool to assess an emerging issue rapidly to inform the selection of appropriate sustainability tools and approaches.

Social-media platforms and analytics present new and effective forums to engage stakeholders, allowing for the use of analytic approaches to provide rapid analysis and categorization of stakeholder input and to provide transparency to stakeholders on how the agency uses their input in its decision-making. This approach presents an opportunity to derive a substantial increase in value from stakeholder processes already in place in the agency. Additional value could be created in the use of advanced IT capabilities in:

- Benchmarking the potential effects of newly identified issues in the regulated community and other stakeholders.
- Mapping the effects of newly identified issues in demographic or stakeholder categories.
- Setting priorities of newly identified issues for action in multiple stakeholder categories.
- Identifying the socially influential stakeholders to spearhead the communication of emerging issues to a broader citizenry.
- Assessing stakeholder preferences for sustainable and resilient products and technologies through analysis of social-media data.

EPA should leverage and enhance its advanced IT capabilities to assess emerging issues by involving the regulated community and other stakeholders through social analytic tools. *(Recommendation 6a)*

Incorporating insights from a broad array of stakeholders could markedly improve EPA's understanding of a new issue's importance and of the speed with which it is emerging. The insights could also improve the evidence base for the agency's decision-making process and increase the likelihood of stakeholder acceptance of difficult decisions.

The massive extent to which our world has been instrumented, interconnected, and digitized presents new opportunities to change the way in which decision making is accomplished and government agencies deliver their services. Concepts of e-government, digital government, and digital state include interactions between the government and individuals within a secure, online context. In addition, this new digital age offers opportunities for the government and the governed to conduct a rational and innovative dialog on sustainability. This is especially true when governments are able to discuss sustainability with a focus on what constituents value most, adoption of service design thinking (considering the constituents' perspectives) and building strong levels of trust with public, academic and business sectors. Extensive digital capabilities and assets, such as the ability to assess massive amounts of public-comment through deep analytics, have the potential to deliver answers rapidly to the public via mobile devices and create effective and trustworthy data security and personal privacy through advanced security solutions. In addition, the advent of machine-to-machine learning and cognitive computing portends, not only the democratization of knowledge, but perhaps also the democratization of insights. Shared insights are a powerful cohesive force in consensus building and decision making within sustainability discussions.

If staff reductions and budget cuts continue, EPA may have neither the time nor the resources to devote to expanding and refining its capability to identify and address emerging environmental challenges. The agency could benefit from strategic interaction with industry and academe in a larger collaboration focused on future method development related to sustainability concepts with joint development of assessment tools and approaches. In fact, future development of all existing or new tools and approaches could benefit from a similar strategic collaboration, perhaps occurring in projects under EPA's Design for the Environment program.

Unintended Consequences and Sustainability

The concept of unintended consequences is not a new issue for EPA. For example, the Clean Air Act Amendments of 1990 required that gasoline sold in areas of the nation that have poor air quality have a specified oxygen content to reduce tailpipe pollutant emission. In the 1990s, methyl *tert*-butyl ether (MTBE) was used widely as a gasoline additive to meet that requirement. The now obvious unintended consequence of the widespread use of MTBE was extensive groundwater contamination from leaking underground storage tanks (EPA 1999). Another fuel issue arises from the Renewable Fuel Standard and government support and subsidies for the use of corn-based ethanol as a renewable fuel component of gasoline. As discussed in Chapter 4, increased corn production to meet the demand for corn-based ethanol has raised concern about several sustainability-related consequences, such as hypoxia in the Gulf of Mexico from fertilizer runoff into the Mississippi River and increases in cropland prices (NRC 2011c).

The tools developed by EPA for use in environmental, economic, and social aspects of sustainability practice represent a major investment in sustainability considerations. However, there does not appear to be an overarching capability to integrate the tools in real time in such a way that the outcomes of the combined use of tools or approaches, within or among sustainability considerations, can be assessed and visually represented. Although the futures methods address that need to some extent, it is not a tool set that is able to provide results quickly. Some available cognitive computing systems execute that type of decision analysis in real time. Existing computing capacity (NRC 2012b; EPA 2013a) supplemented with research and development investment to refine sustainability analyses could allow sustainability analysts to run repeated "what if" exercises to reveal aggregate effects in all three pillars of sustainability.

The process of implementing sustainability concepts needs substantial investment in the early discovery of potential unintended consequences because of the concern about optimizing present and future outcomes and intergenerational effects. Unintended consequences are not necessarily unforeseeable; deep analytics technology, which is available, could be applied to this topic. The addition of a formal learning loop would capture additional value from case histories and lessons learned in sustainability projects undertaken by EPA.

> **To enhance postdecision assessment of its activities, EPA should identify, track, and address unintended consequences. The agency should create a searchable database of the lessons learned.** ***(Recommendation 6b)***

Not only would that provide additional evidence-based support capabilities for future decision-making, but the data could feed advanced cognitive analytics that could be used to test proposed decisions against known unintended cause–effect scenarios developed from past decisions.

Tools and Approaches for Identifying and Addressing New Issues

National Research Council work on this topic (NRC 2011a; EPA 2013a) has emphasized the need for a tiered approach to understand what tools should be applied in sustainability assessments and has provided explicit recommendations about investment in screening capabilities. Applying futures methods will inform and guide the use of other sustainability tools as the scenarios developed become more mature and data-stable.

A tiered approach to identifying and addressing emerging challenges includes:

- Applying approaches to identify possible emerging challenges (EPA 2014r):
  - Scanning methods enhanced by deep-analytics tools to provide early detection of even weak signals or patterns.
  - Delphi methods involving subject-matter experts.
  - Trend-analysis methods for quantitative data and additional analytic tools for assessing unstructured data.
  - Future scenarios that use quantitative, qualitative, and unstructured data to fuel real-time and dynamic scenario imaging as data feeds are used to refine and weight potential outcomes.
  - The use of crowd sourcing and analytics to detect and predict emerging challenges, particularly for hazardous natural or human-caused areas of concern.
- Organizing and screening emerging challenges for further review by, for example, applying selected screening-level versions of the mature tools now available in each of the three sustainability pillars (NRC 2011a).
- Analyzing emerging challenges:
  - Screening-level results drive a rank ordering of emerging challenges for further analysis. The most likely scenarios from the futures methods could be subjected to a more detailed set of assessments for each of the three pillars as more refined data become available.
  - Systems-based indicator analysis of likely scenarios from the futures methods could further clarify which projects would benefit most from more refined sustainability assessments.
  - Sustainability-assessment tools and approaches will be informed and guided by emerging related issues that are identified and may include environmental-impact assessments, social-impact assessments, benefit–cost analyses (BCAs), risk assessments, resilience and adaptation assessments, segmentation analyses, and collaborative problem-solving (See Appendix D).
- Communication of findings and recommendations—EPA has and continues to develop powerful communication tools and approaches. In addition to briefings, Internet posting, podcasts, articles and brochures for agency staff, legislative staff, and the public, the use of a broad array of social media can be used to communicate with the public rapidly and effectively.

SPECIFIC CHALLENGES

The remainder of this chapter discusses a wide variety of emerging issues that EPA is likely to face with respect to the application of sustainability tools and approaches.

Sustainable Cities

An important milestone was reached in 2008 when it was recorded that more than half the global population was living in cities and towns. The growth of cities is an important emerging trend in the United States and globally, and this poses many challenges in application of sustainability tools and practices. Cities and their associated problems constitute a strong impetus for innovation; and because the urban centers are massive economic engines, they also provide an important opportunity to develop and test new sustainability tools and approaches that can inform decisions on how cities will be designed, built, and managed in the context of local forces in the future. Urban corridors will provide an important test bed for understanding the effects of increasing population density and other societal megatrends on the vulnerability of infrastructure to natural and human-made disasters and on the factors that create urban resilience.

In many evaluations of increased urbanization, discussion of social-ecological system resilience and sustainability usually focuses substantial attention on the negative effects of human-caused changes to urban social-ecological systems (Tidball and Stedman 2013). Such attention can result in an "assumed negativity" regarding humans and nature. However, others point out the positive actions that humans sometimes take in systems in which they live that contribute to virtuous cycles producing, or enhancing production of, positive social and ecological outcomes, such as in ecosystem services (Bartlett, 2005; Tidball and Krasny, 2008; Krasny, et.al. 2009).

As a consequence of the explosion of enabling technologies, many cities in the United States are investing heavily in infrastructure, including investment in instrumentation and sensoring of locations, utilities, and processes and integration of these data inputs into an architecture that allows continuous real-time status awareness, decision support, and management. Increases in urbanization, climate change, and demographic shifts will change cities. The need to improve quality of life, economic competitiveness, and social equity has driven cities to become more resource-efficient and sustainable.

Technologies are major levers and the basis of further sustainable city development. The challenges that arise from cities and megaregions will probably have at their core an increasing population density that will affect virtually every aspect of their economic, social, and environmental quality. Response to those challenges will be constrained by the limitation of the resources that can be applied to an unlimited set of needs.

Many cities in the United States have recently made important efforts in addressing some combination of interconnected problems of urban air quality, efficient energy production and use, urban transportation systems, and climate change (both mitigation and adaptation) by focusing on development and application of sustainability tools and practices (NRC 2013a, 2014).

In the case of large cities, a combination of megatrends of urbanization, climate change, and a recent and rapidly emerging revolution in application of IT, including social media that promote democratization of knowledge and participation by the general public, has provided a fertile landscape for application of sustainability tools and approaches, including BCA, integrated assessment modeling, collaborative problem-solving, futures methods to evaluate alternative future scenarios, and environmental-justice (EJ) analysis (NRC 2014).

Many cities of different sizes—including Portland, Oregon; Philadelphia, Pennsylvania; Phoenix, Arizona; New York, New York; Charleston, South Carolina; and Ft. Lauderdale, Florida—have developed their versions of sustainability plans. Federal-agency partnerships with communities have also promoted urban sustainability (for example, see the discussion in Chapter 2 of the Sustainable Communities Regional Planning Grant Program).And the application of tools available through social networking can be key to creating sustainable cities because it enables communities to participate in sharing ideas about solutions, such as use of renewable energy, smart transportation choices, and improving air quality through lower per capita energy use. The availability of public portals can inform choices of, for example, transportation modes and provide feedback to the system.

Environmental Justice

President Clinton's (EJ) executive order (EO 12898) was the product of considerable evidence that poor and selected minorities were overburdened by hazards and at higher risk caused by exposure to pollution in air, water, and soil. It required federal agencies to prepare and implement EJ strategies for the administration of environmental rules and guidelines. Raising the profile of the EJ issue has, for example, encouraged private organizations to take demographics into account before siting new facilities and expanding existing ones. EPA has developed Plan EJ 2014 to serve as a roadmap for integrating environmental justice into the agency's programs, policies, and activities. The goals of the plan are to protect health in communities over-burdened by pollution, empower communities to improve their health and environment, and establish partnerships with government organizations to achieve healthy and sustainable communities (EPA 2014s). The plan includes cross-agency focus areas on rulemaking, permitting, compliance and enforcement, community-based programs, and collaborations with other federal agencies. As part of implementing this plan, EPA is developing various assessment tools, including guidelines for cumulative risk assessment, a community-focused exposure and risk screening tool, mapping and analysis tools to elucidate benefits that humans receive from their environment, and a screening tool to identify areas with potential EJ concerns that may warrant further consideration (EPA 2014t).

There is growing awareness of the need to include EJ analysis in a sustainability analytic context. EPA included EJ analysis as one of the tools in its *Sustainability Analytics* report (EPA 2013a) (see Box 6-1). A special panel of EPA's Science Advisory Board is reviewing the agency's draft technical guidance for assessing EJ in regulatory analysis and is considering subjects that are directly and indirectly related to the intersection of EJ and sustainability.[2] Clearly, EJ tools and approaches will be required both in the early identification of new issues and in the later stages of analysis and actionable recommendations. A rapid screening tool that could quickly be applied to a newly identified emerging challenge to allow an initial weighting of potential EJ concerns is especially important. Development of the capability for robust EJ analysis is also important, but the rapid emergence of new challenges requires quick screening capability to ensure that EJ issues are included in sustainability considerations.

BOX 6-1 Strengths and Limitations of EJ Analysis in a Sustainability Context

"Incorporating EJ analysis into the decision-making process promotes sustainability by highlighting the relationships between economy, society, and the environment. However, while scientific and quantitative advancements in EJ analyses have enabled researchers and stakeholders to better grasp disproportionate impacts of environmental stressors and socio-demographic conditions, the complex nature of interactions between these factors is not fully understood. For example, EJ analyses are often required to be performed without the benefit of full-scale epidemiological studies and, hence, while correlations between health impacts and populations may be apparent, analysts should be mindful that the cause and effect may not have been demonstrated."

Source: EPA 2013a (p. 39).

[2]EPA asked the Environmental Justice Technical Guidance Review Panel to provide advice and recommendations on the scientific soundness of the agency's *Draft Technical Guidance for Assessing Environmental Justice in Regulatory Analysis* (EPA 2013g).

Demand for Unsustainable Materials

With increasing population and increasing demand for consumer goods, the need for materials continues to grow. Currently, only 29% of the 70 gigatons (Gt) of materials that the world economy uses annually are recycled (Ashby 2012). Current rates have quadrupled consumption from 50 years ago, creating a demand trend for materials that is unsustainable with current practices. Five key materials make up a substantial fraction of carbon emission into the atmosphere: steel, cement, plastic, paper, and aluminum. Industry accounts for 38% of the total global carbon dioxide emission, and the five key materials listed above account for 56% of industrial carbon emission (IEA 2008). A breakdown of those emissions can be seen in Figure 6-1.

By 2050, the International Energy Agency expects demand for materials to at least double, but the Intergovernmental Panel on Climate Change (IPCC) recommends reducing global emission by 55–85% by that same year (Fisher et al. 2007). Even with an optimistic projection of efficiency, the increased demand makes it impossible to reach the reduced emission targets set by the IPCC (shown in Figure 6-2). Included in the projections are implementation of energy-efficiency measures, future efficiencies in the supply chain, reduction in yield losses, maximum recycling rates, and decarbonization of energy supplies. Substantially increased material efficiency is needed to meet future demand, although much research still needs to be done to balance resource demand with environmental effects and cost.

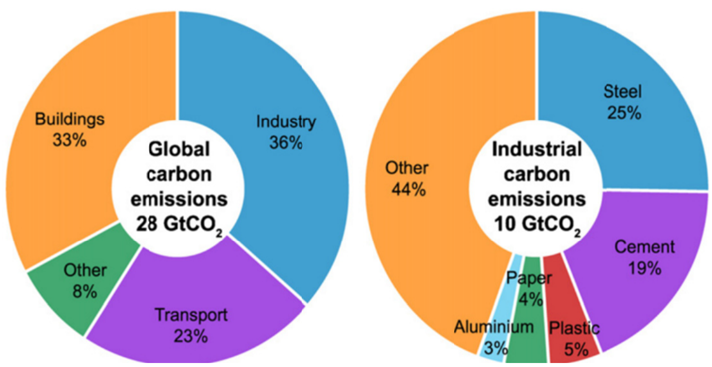

FIGURE 6-1 Global carbon emissions in 2006 and breakdown of the industrial-source sector. Source: Allwood 2011. Reprinted with permission; copyright 2011, *Resources, Conservation and Recycling*.

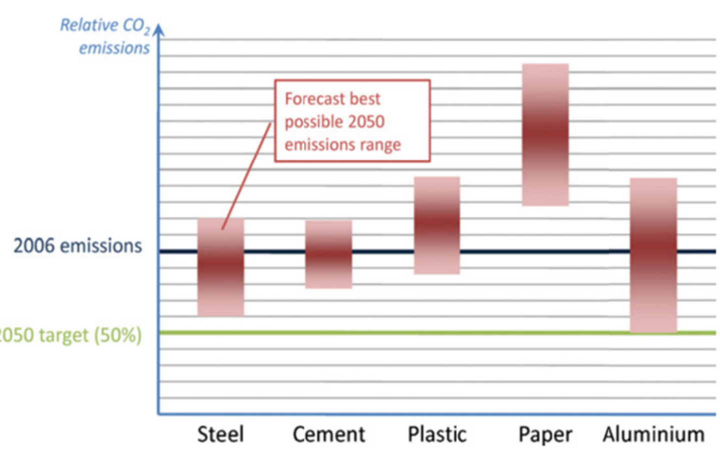

FIGURE 6-2 Optimistic projection of future emissions of five key materials in 2050. None of the materials is expected to reach the 2050 target of a 50% reduction in emission. Source: Allwood et al. 2011. Reprinted with permission; copyright 2011, *Resources, Conservation and Recycling*.

Resource Scarcity

One of the major sustainability challenges is the scarcity of resources, such as raw materials. Historically, shortages of essential materials usually resulted in various kinds of conflicts. Today, resource scarcity continues to be a controversial emerging challenge that engages all three pillars of sustainability. It touches on many aspects of sustainability, such as intergenerational equity, resilience, adaptability, EJ, and social equity. The prospect of future scarcities of vital natural resources is, in many specific cases, underscored by present shortages in water, food, and strategic minerals.

However, from the heightened concern over resource scarcity seen in 2009–2012 (World Economic Forum 2012), a new view of scarcity has turned the emerging issue into an emerging opportunity in the minds of a growing industrial sector. The fundamental premise of the new view of material scarcity is that it will drive yet another industrial revolution (Heck and Rogers 2014) as a result of the convergence of IT, nanoscale materials science, and bioengineering. This view posits that businesses will capitalize on material scarcity by focusing on resource productivity by using five distinct approaches (Heck and Rogers 2014):

- *Substitution*—replacement of expensive or scarce materials with less scarce, less expensive, higher-performing materials.
- *Optimization*—embedding software and IT in resource-intensive industries to improve how the industries produce and use scarce resources.
- *Virtualization*—moving some processes completely from the physical world (such as digitalization of some processes and the use of cognitive computing capabilities).
- *Circularity*—finding value in products after their initial intended use.
- *Waste elimination*—greater efficiency through the redesign of products and services.

Thus, one can imagine that, rather than a spiral of scarcity and rising costs of a shrinking commodity, the challenge that will affect EPA's programs may be the evolution of a host of new materials and material uses. It will probably be a challenge for EPA to provide the inhouse subject-matter expertise needed to address emerging issues in materials development and use.

> **EPA should consider using its convening ability to foster academic, business, and government partnerships to develop scientific and technical understanding to inform agency decision-making**. ***(Recommendation 6c)***

Horizon Materials (Including New Chemicals)

Horizon materials can be defined as advanced next-generation materials that are likely to have a serious effect on our society and economy. Borne of the convergence of advances in IT, industrial technology, materials sciences, and bioengineering, the development of horizon materials often enables new applications in various industry segments.

In light of the growing number of US and global patents and regulations involving materials, the topic of horizon materials should be on the emerging-challenges radar screen. Technical innovations in discrete fields are continuing to overlap, resulting in nanomedicine, nanobiotechnology, genomic-specific therapeutics, systems biology, and bioengineering. The blurred lines here will also demand vigilance in US regulatory agencies.

Nanomaterials

Nanotechnologies are set to transform the global industrial landscape and involve US economic sectors as diverse as agriculture, medicine, engineering, biology, and IT. IOM (2005) and NRC (2013c) emphasized that—despite stunning advances in nanomaterials, environment, health, and safety—research on nanomaterials is not keeping pace with the evolving applications of nanotechnology, and uncertainties in the environmental, health, and safety aspects of this technology persist (see Figure 6-3).

Characterization of the risks posed by engineered nanomaterials and their applications in commercial and consumer products presents substantial challenges to life-cycle assessments, risk analyses, and governance.

Given the rapidly evolving applications (especially biologic) of nanoscale materials, devices, and systems, EPA should work with other organizations to fund research in risk characterization and develop the infrastructure needed to support data-mining and data-sharing. *(Recommendation 6d)*

Although much progress has been made, gaps in knowledge of the environmental, health, and safety (EHS) aspects of nanomaterials remain. Better understanding and integration of EHS data will enhance the effective regulation of these materials.

FIGURE 6-3 The nanotechnology environmental, health, and safety research enterprise. The diagram shows the integrated and interdependent research activities that are driven by the production of engineered nanomaterials (ENMs). The production of ENMs is captured by the orange oval, labeled "materials", which includes reference materials, ENM releases, and inventories. (An inventory is a quantitative estimate of the location and amounts of nanomaterials produced, including the properties of the nanomaterials.) The knowledge commons (red box) is the locus for collaborative development of methods, models, and materials and for archiving and sharing of data. The "laboratory world" and "real world" (green boxes) feed into the knowledge commons. The laboratory world comprises process-based and mechanism-based research that is directed at understanding the physical, chemical, and biologic properties or processes that are most critical for assessing exposures and hazards and hence risk (NRC 2012c, p. 55). The real world includes complex systems research involving observational studies that examine the effects of ENMs on people and ecosystems. The purple boxes capture the range of methods, tools, models, and instruments that support generation of research in the laboratory world, the real world, and the knowledge commons. Source: NRC 2013c, p. 25.

Nanotechnology also offers an archetypal glimpse of the future with regard to the global governance of emerging technologies (Breggin et al. 2009; Falkner and Jaspers 2012). Emerging technologies create unusual, complex, and often fundamental political problems for global governance. Recent international governance coordination mechanisms have been created through the Organisation for Economic Co-operation and Development and the International Organization for Standardization, but the scope of their efforts is limited. Given the lack of harmonization and alignment in global regulatory policies and practices and the great promise inherent in nanotechnology development, the convening nature of sustainability approaches may constitute a logical bridge across the governance divide.

Biospace Advances

Partially obscured by the attention garnered by nanotechnology, a rapidly advancing convergence is occurring in the biospace. Driven by affordable genomics analyses, next-generation genomics marries the advances in sequencing and modifying of genetic materials with the latest big-data and analytics capabilities and enables synthetic biology ("writing" DNA).

An excellent example of the convergence can be seen in a snapshot of emerging medical advances. High-throughput genomic analyses create a pipeline of raw data that are processed by high-end computing and deep analytics into usable information. That information fuels genomic-data integration and analytics platforms to find relationships between genomes and phenotypes, and this leads to the discovery and development of personalized therapies. Such relationships enable not only personalized heath care but decision support for precision medicine.

However convergence of genomics and deep analytics drives a much more rich and complex constellation of capabilities that enables new potentials in three major disciplines: -omics big data and analytics, systems biology (modeling), and bioengineering (synthetic biology). An important example of an emerging new capability in the biospace convergence is metagenomics (Wooley et al. 2010). Metagenomics is the study of the genetic material recovered directly from environmental samples rather than from cultured microbial samples. This approach has revealed that the vast majority of microbial diversity has been missed by cultivation methods (Breitbart et al. 2002). Metagenomics has become an important predictor as well as a tool for use in addressing futures issues in sustainability.

For instance, the research community is beginning to understand that antibiotic resistance may have strong environmental associations. Through the use of metagenomic tools and deep analytics, antibiotic-resistance genes have been shown to accumulate in wastewater-treatment plants (Yang et al. 2013), as contaminants in manures and other agriculture waste products (Zhu et al. 2013), in the water and sediments of rivers (Luo et al. 2010; Kristiansson et al. 2011), and in reclaimed water (Fahrenfeld et al. 2013). One of the most important factors in the development of antibiotic resistance is the remarkable ability of bacteria to share genetic resources via lateral gene transfer (Stokes and Gillings 2011). The use of activated sludges on farmland and the use of reclaimed water in distribution systems and irrigation may accelerate the spread of antibiotic resistance (Fahrenfeld et al. 2013). The World Health Organization has recently released a report on global surveillance of antimicrobial resistance (WHO 2014), which warns of a coming postantibiotic era without global intervention. Given the broad genetic diversity found in metagenomic studies, there is great potential in finding and using gene sequences that could be immediately useful in industrial applications. Bioengineering and industrial biotechnology often are central in sustainability predictions and require the development of novel enzymes, processes, products, and applications. Metagenomics promises to provide insights into new molecules that have diverse functions, but it is the exploitation of the gene-expression systems that are the key to the economic success of the new molecules.

This brief discussion of the biospace convergence should make it apparent that the new insights enable capabilities in diverse sectors of the economy (see Box 6-2).

BOX 6-2 Expected Capabilities Based on Biospace Advances

Health Care and Genomic Medicine
Personalized and preventive health care
Biosensors and bioelectronics
Accelerated drug discovery, development, and manufacturing
Agriculture and Food
Personalized nutrition
Salt-, drought-, and disease-tolerant crops
Food-animal genomics
Energy, Environment, and Natural Resources
Sustainable biofuel production
Rare-earth and precious-metal collection
Carbon capture and bioremediation of air, water, and soil
Chemical, Pharmaceutical, and Consumer Products
Green-chemistry enabling of bioplastics and enzymes
Functional material enhancements, such as spider silk in tires
Cosmetics and personal-care product enhancements

Clearly, this will be a target-rich space for new and emerging issues that will require sustainability assessments and solutions. Sustainability tools, approaches, and assessments may be crucial if the pros and cons of the emerging innovations are to be understood and acted on.

Advanced Manufacturing

Closely aligned with the nanotechnology and biospace discussions are a related set of productivity advances and sustainability practices that arise in the manufacturing space. Collectively, these activities and practices are often referred to as advanced manufacturing, which is defined as "a family of activities that: a) depend upon the use and coordination of information, automation, computation, software, sensing, and networking; and/or b) Make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences (nanotechnology, chemistry, biology)" (PCAST 2011, p. ii). The activities involve new ways to manufacture existing products and advanced technologies to manufacture new products. They affect all five stages of manufacturing: product design, production planning, engineering, production, and service and maintenance.

These capabilities have converged to create a scenario in which an idea can move through design, prototyping, engineering, and production within an hour with 3D computer design, digital prototyping, and additive manufacturing (3D printing that uses polymers or metals). In fact, the ability to model, visualize, and test in the world of virtual-to-real manufacturing is changing the nature of innovation and allowing a new level of efficiency and customization. The United States—with a track record of innovation, software design and development, and university education—is now driving a new era of efficient products by lowering costs and allowing mass customization, extreme scalability, and high speed to market.

The innovative technologies and machinery lead to huge dividends for the environment and economy, such as reductions in material use and waste and in energy use; some manufacturing steps will never again be physical but will remain in the virtual world until translated in final production steps. From this perspective, this represents a major step forward into a more sustainable manufacturing scenario.

It is important to recognize that innovative and disruptive technologies will probably enable the use of new and exotic materials and methods and will enable "manufacturing" to take place not only in modern, clean, tightly controlled facilities but in homes, garages, and schools.

Advanced manufacturing provides new opportunities for material-efficient and energy-efficient processes, but EPA should address this emerging issue as a part of a futures-methods analysis. ***(Recommendation 6e)***

The potential for manufacturing to occur in nonmanufacturing environments might well create new challenges for occupational and environmental regulators. New futures methods will be needed to predict, assess, inform, and guide governance.

Sustainability and Hazardous Events

The scientific consensus is that global climate change is occurring and that weather will trend toward extreme events. Therefore, it is imperative that sustainability factors be considered by planners, engineers, emergency managers, public-health workers, and associated professionals to reduce the vulnerability of people and assets. Sustainability-related activities include removing highly vulnerable land from development and turning it into open space or to less vulnerable uses, siting infrastructure in less vulnerable locations, and prohibiting activities in high-risk areas that have highly vulnerable populations. The activities include retrofitting of structures to be more resistant to hazardous events, providing loans and other inducements to property owners to reduce their vulnerability, and organizing local first responders and community groups that can increase the resilience of a community. Those and many other sustainability activities can be implemented before, during, or after events. It would be prudent to focus on particularly vulnerable populations, such as older people, disabled people, children, and people whose response to hazard events may be hindered by language barriers, lack of transportation options, and other constraints. A great deal of literature is appearing on those subjects in public health, urban planning, and emergency management.

EPA should consider the development of additional futures methods that focus on assessing and predicting vulnerability and resilience of both urban and rural environments. ***(Recommendation 6f)***

More accurate and earlier prediction of emerging issues related to environmental settings would enhance the ability to incorporate resilience strategies into infrastructure design.

Incorporation of resilience in the context of sustainability would have implications for the design and planning of projects, particularly urban infrastructure projects. However, it has been a challenge to accomplish that because no comprehensive tool for quantifying resilience is available. A conceptual tool, the Sustainable and Resilient (SuRe) zone of planning and design, aims to address that issue (see Box 6-3).

BOX 6-3 Simultaneous Consideration of Sustainability and Resilience

Resilience analysis is a tool for evaluating the ability of a system (such as a city's infrastructure, an ecosystem, or a supply chain) to continue functioning after a disruption. Considering options for increasing resilience can be challenging when narrowly targeted sustainability objectives are also being pursued to reduce material and energy investment, motivate the removal of redundancy from systems, and thus undermine their resilience. An approach is being developed to assess sustainability and resilience of urban infrastructure systems simultaneously. It involves use of traditional benefit–cost analysis to assess the costs associated with the building of a more resilient infrastructure and the benefits of avoiding damages through augmented resilience (Pandit et al. in press).

TABLE 6-1 Examples of the Nexus of EPA Focus Areas of Sustainability with New or Emerging Issues

Sustainability Focus Area	New Issue	Tools to Identify or Evaluate Issue
Energy efficiency	Climate change, rapid urbanization, and air quality	Benefit–cost analysis, environmental-justice analysis, futures methods, exposure assessments, risk assessments, health-impact assessments, integrated assessment modeling, resilience assessments, collaborative problem-solving
Sustainable products and purchasing	Advanced manufacturing enabling new products and bioengineered materials	Life-cycle analysis, benefit–cost analysis, green chemistry, green engineering, exposure assessments, health-impact assessments, environmental-footprint analysis, integrated assessment modeling
Green infrastructure	Engineered systems for the reuse of water and activated sludges and rising concentration of antibiotic-resistant microorganisms in urban areas	Benefit–cost analysis, environmental-footprint analysis, green engineering, collaborative problem-solving, life-cycle analysis, exposure assessments, risk assessments, health-impact assessments, environmental-justice analysis, resilience analysis, social-impact analysis
Sustainable materials management	Horizon materials development and use	Benefit–cost analysis, green chemistry, green engineering, risk assessments , chemical-alternatives assessments, life-cycle assessments, environmental-footprint assessments

THE NEXUS OF NEW ISSUES WITH THE ENVIRONMENTAL PROTECTION AGENCY'S FOCUS AREAS OF SUSTAINABILITY

The previous discussions in this chapter reveal a striking relationship: new or emerging issues have substantial intersections with EPA's four focus areas for sustainability and the tools and approaches described in Table 3-1. It should be noted in this context that new issues are likely not to occur in single occurrences (such as climate change) but rather to arise from an aggregation of issues (such as climate change, energy disruptions, food disruptions, and aridity) (NRC 2013a). Table 6-1 provides a few examples to illustrate the nexus by focus area, new issue, and tools for predicting, detecting, or assessing the issues.

The examples in Table 6-1 are not meant to be exhaustive but rather to stimulate thinking about how sustainability focus areas are affected by new issues and how sustainability tools will have the potential both to identify and to evaluate effects of new or emerging issues. The complexity of new issues and their rate of occurrence will probably place even greater demands on even the most automated and robust tools and approaches in the race to prevent new issues from surging to become old unresolved problems.

KEY CONCLUSIONS AND RECOMMENDATIONS

Conclusion 6.1: The rate at which future challenges are likely to approach and their increasing complexity will afford less and less time in which to assess them and, if necessary, to devise strategies to address them. A set of screening tools that can be implemented rapidly is essential. It is important to avoid rapidly approaching challenges from becoming historical events before they can be adequately assessed.

Recommendation 6.1.1: EPA should develop screening tools to assess new issues rapidly to support the selection of appropriate sustainability tools and approaches.

Recommendation 6.1.2: Existing screening approaches, tools, and formal sustainability assessments should be automated further for the rapid analysis that responses to new issues will require.

Conclusion 6.2: The tools developed by EPA for use in environmental, economic, and social areas of sustainability practice represent a major investment in sustainability considerations. However, there does not appear to be an overarching capability to integrate the tools, in real time, in such a way that the results of their combined use can be assessed and visually represented. An integrated "big picture" capability would lead to deeper insights, better pattern recognition, and better decision-making through the avoidance of the overweighting or masking that can be caused by the serial use of tools.

Recommendation 6.2: EPA should leverage and enhance its advanced IT capabilities for integrating sustainability tools so that the outcomes of their combined use approaches can be simulated in a sustainability context in real time. (See Recommendation 6a)

> To enhance post-decision assessment of its activities, EPA should identify, track, and address unintended consequences. The agency should create a searchable database of these valuable lessons learned. (Recommendation 6b)

Conclusion 6.3: The use of a broad array of social media can be used to communicate rapidly and effectively with the public. Private and public organizations are increasingly leveraging the use of structured and unstructured public input to improve prediction of public preferences and to extract valuable insights into public behavior. Public support for regulatory decision-making could be substantially enhanced by using such approaches.

Recommendation 6.3: EPA should consider piloting "electronic jams" that reach out to the public in monitored on-line chat sessions that allow public input to be analyzed and additional value to be derived from it. In addition to the public-comment aspect of this approach, passive "crowd sourcing" can be useful in identifying new issues. (See Recommendation 6a)

> EPA should consider using its convening ability to foster academic, business and government partnerships in this area to develop adequate scientific and technical understanding to inform agency decision making. (See Recommendation 6c)

Other Recommendations

Given the rapidly evolving applications (especially biologic) of nanoscale materials, devices and systems, EPA should work with other organizations to fund research in the area of risk characterization and develop the infrastructure needed to support data-mining and data-sharing. (*Recommendation 6d)*

Advanced manufacturing provides new opportunities for material-efficient and energy-efficient processes, but EPA should address this emerging issue as a part of a futures-methods analysis. *(Recommendation 6e)*

EPA should consider the development of additional futures methods that focus on assessing and predicting vulnerability and resilience of both urban and rural environments. *(Recommendation 6f)*

7

Applying Sustainability Tools and Methods to Strengthen Environmental Protection Agency Decision-Making

In consideration of the various tools and approaches addressed in previous chapters of this report, this chapter discusses the evolving framework for sustainability and EPA decision making, including opportunities to make sustainability the integrating core of the agency's strategic planning process and embedding the use of sustainability tools into its activities.

Throughout the history of the US Environmental Protection Agency (EPA), various major decision-making frameworks have guided policy choices covering a variety of public-health and environmental issues. In the agency's formative years, the frameworks included the application of technology-based standards to restrict emission and effluents from specific sources or source categories; the development of health-based standards to protect drinking-water supplies or ambient-air quality; and the establishment of registration processes and application rates for pesticides and their designated uses. Those and other decision-making frameworks constituted a response to statutory requirements and an expression of the evolution of institutional practices among agencies that preceded the formation of EPA (Portney 1978; Lave 1981).

The publication of the National Research Council's 1983 report *Risk Assessment in the Federal Government: Managing the Process* was another major inflection point in EPA's decision making frameworks. The formalization of risk assessment and risk management processes had been evolving in EPA in the 1970's, but they received more direct and official codification by a series of policy pronouncements issued by several EPA administrators in the 1980s and beyond (NRC 1983).[1] Rather than displacing earlier frameworks however, the risk-assessment–risk-management paradigm added to the scientific tools and approaches used by EPA in implementing its statutory authorities.

Through a combination of statutory changes or through its own initiatives, additional frameworks and approaches continued to supplement EPA's policy toolkit through the 1980s and later years, including:

- The adoption of pollution prevention as a method for examining pollution-reduction opportunities before the point of effluent, emission, or waste generation or discharge.
- The development and implementation of incentive-based offset and "cap and trade" control measures (plant-specific and regional) for such issues as acid-deposition precursors, including nitrogen oxides and sulfur oxides.
- The establishment of an expanded number of voluntary initiatives aimed at accelerating the reduction of toxic emission, expanding energy efficiency, and other objectives.
- The initiation of cross-statutory or multisector initiatives that aspired to identify and manage tradeoffs among statutes to maximize both environmental protection and economic efficiency.

[1]EPA's Science Advisory Board provided further guidance to EPA in using risk-based decision-making in its report *Reducing Risk: Setting Priorities and Strategies for Environmental Protection* (EPASAB 1990).

- The development of more robust initiatives with state and local authorities to address regional air-quality and water-quality problems (such as ozone and fine-particle pollution in the mid-Atlantic and Northeast corridor and regional watershed-management planning for the Great Lakes or Chesapeake Bay).[2]

In recent years, EPA has begun to examine and introduce elements of sustainability-related thinking into research and development, method development, federal procurement guidelines, and strategic planning. For example, EPA's FY 2014–2018 strategic plan incorporates a number of sustainability-relevant initiatives into the agency's five Strategic Goals, Cross-Cutting Fundamental Strategies and Strategic Measurement Framework (EPA 2014a).

EPA's decision making frameworks function in parallel and are in various states of transition, but they are not in integrated relationships with each other. In that respect, EPA's FY 2014–2018 strategic plan mirrors those discontinuous relationships, and it is unclear how the decision making frameworks support each other in executing the agency's mission. Given that each decision making framework has its own set of implementing tools and methods, it is important that EPA achieve greater internal consistency, clarity, and priority-setting among these tools and their applications.

> **EPA should consider the present transition in its decision making approaches as an opportunity to evolve towards making sustainability the integrating principle of its strategic planning process. The committee urges EPA to continue in its efforts to adopt or adapt the sustainability framework presented in *Sustainability and the U.S. EPA*, the so-called Green Book (NRC 2011a). *(Recommendation 7a)***

The advantages of such an evolution include:

- Enabling EPA to achieve greater clarity of purpose in its various regulatory and non-regulatory programs.
- Aligning the agency's sustainability tools and approaches and their implementation with global, regional, and local megatrends; market developments; and stakeholder leader expectations.
- Gaining access to newer tools and methods that have emerged in recent years from private sector and non-government organization (NGO) partnerships, universities, and other stakeholders (examples of some of the tools and methods are cited and illustrated in the present report).
- Building new relationships with thought leaders in multiple institutions to design innovative sustainability tools.
- Providing greater clarity and understanding of EPA's mission and value to the American people at a time of public uncertainty over many public-health and environmental issues and EPA's role in resolving them.

"NUDGING THE FUTURE": THE ENVIRONMENTAL PROTECTION AGENCY'S EVOLVING ROLE IN MANAGING SUSTAINABILITY ISSUES

Numerous government reports, scholarly analyses, and private-company investments attest to the growing importance of mitigation and adaptation strategies necessary to respond to problems as varied as climate change, natural-resource scarcities, public-health protection, and building of more sustainable communities.[3] As the concept of adaptation advances, there are direct implications for how government

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[2]EPA's Common Sense Initiative and Project XL were prominent examples of these types of initiatives in the 1990s.

[3]Examples of such reports include City of New York 2014; IPCC 2014; World Economic Forum 2014.

agencies and private-sector organizations need not only to revise policy frameworks but to recast their own institutional capabilities, resilience, and assessment and implementation tools in a clear and predictable manner that is consistent with their missions and responsibilities.

In EPA's 4.5 decades of existence, there have been many instances in which it has adapted its identification of priorities to recognize new generations of problems (for example, naturally occurring exposures to radon gas and the phaseout of chlorofluorocarbons and successor chemicals to protect the stratospheric ozone layer), modified its implementation strategies to take account of innovative thinking (for example, emission trading and offset initiatives and agreement for testing of high-production-volume chemicals), and developed new tools and approaches for managing public-health and environmental challenges (for example, the formalization of risk-assessment guidelines and the development of a risk-screening model to identify potential risks earlier in the chemical-development process and to encourage substitutions).

> **EPA has a major opportunity to embed sustainability considerations further in its decision-making methods and to communicate and disseminate its application of sustainability tools and approaches outside the agency. EPA should pursue this embedding throughout the agency. *(Recommendation 7b)***

The committee has identified four kinds of major activities (derived from Table 2-1) in which EPA has substantial opportunities to apply sustainability tools and approaches to the extent practicable under budget constraints. Each is consistent with the agency's existing statutory authorities and, in fact, builds on initiatives previously implemented.

Setting and Enforcing Regulatory Standards

Furthering the incorporation of sustainability as a core principle of EPA's mission includes consideration of fundamental public-health and environmental protections related to a suite of air, land, and water issues that are administered at the federal, state, and local levels of government. To ensure effectiveness and accountability, baseline standards and their enforcement are periodically reviewed to account for new scientific information, technologic innovation, and reviews of program effectiveness. Supplemented by such tools as data-quality management, risk assessment, life-cycle assessment (LCA), economic analysis, peer review, management systems, public participation, and other forms of transparency, EPA's standard-setting and enforcement roles provide an important basis of additional efforts in advancing toward more sustainable health, environmental, and economic outcomes. That approach is similar to that used in the private sector, in which sustainability strategies and initiatives have been designed and implemented on the basis of an original structure of environmental, health, and safety policies and management systems.

> **As part of its continuous strategic planning efforts, EPA should consistently review opportunities to insert sustainability concepts, tools, and methods to strengthen evaluations of its existing regulatory policies and simultaneously apply these sustainability approaches to emerging challenges. *(Recommendation 7c)***

In any discussion of standards (regulatory and nonregulatory)—whether they are outgrowths of statutes, outcomes of deliberations of professional bodies (such as those developed by the International Organization for Standardization), or results of obtaining consensus about best practices related to specific issues (such as pollution prevention)—the critical barometer of success is the outcome of application of the standards. Standard-setting is a core role of EPA, not merely through the implementation of its statutory authorities but through collaborative efforts with other organizations to address the suite of sustainability challenges related to its mission.

One of the critical future challenges to both EPA and the private sector will be the need to increase the scale of its environmental and quality-of-life improvements. Individual companies, even when successful, are limited in their scaling potential by the individual markets that they serve.

EPA—in collaboration with the private sector, NGOs, multilateral institutions, and other national governments—should evaluate existing best practices to identify opportunities for increasing the scale of the benefits of sustainability decision-making within the United States and around the world. ***(Recommendation 7d)***

Managing and Synthesizing Data

EPA is responsible for collecting, managing, and interpreting a number of diverse databases for a variety of policy decisions. These efforts range from support of air-quality monitoring stations to evaluate compliance with National Ambient Air Quality Standards in specific air sheds, review of water-discharge data to assess compliance with National Pollutant Discharge Elimination System permits, analysis of data submitted by chemical manufacturers to assess whether to allow new chemicals to enter the marketplace under the Toxic Substances Control Act, and the collection and publication of Superfund Amendments and Reauthorization Act Title III data.

Beyond program-specific data collection and analysis, EPA has for many years performed the role of data manager and synthesizer. The agency's Integrated Risk Information System (IRIS) is an international resource for business, government, and the public to gain access to information on individual chemical profiles as a basis for regulatory policy decisions, discussions of community risks, and risk-management decisions taken by individual companies and consumers. IRIS provides a platform for public discussion and exchange of information; it provides access to scientific tools and enables users to link to related databases. Other agencies have adopted the IRIS concept to implement their missions.

EPA has a major opportunity to build on data initiatives, such as IRIS, by becoming a data manager and synthesizer for a growing number of information-management challenges, including

- ***Synthesizing and interpreting data to aid the investment community***—EPA could assist such organizations as the Sustainability Accounting Standards Board and the Securities and Exchange Commission in collecting and synthesizing general-public comments and provide advice on public-health and environmental issues that are material to the performance and governance of corporations.
- ***Filling information gaps***—EPA could collect and aggregate databases that bear on the materials used in the sourcing, manufacture, distribution, and use in a host of consumer products. There are major gaps in individual companies', government agencies', and consumers' knowledge as to the ultimate disposition of economically valuable materials that can also present health and environmental risks if they are not subject to a cradle-to-cradle system of material recovery and reuse. The development of information-management capability would be a critical step in the advance of infrastructure for sustainable material-management policies.
- ***Monitoring and surveillance to identify problems and trends***—EPA could search for patterns and trends among databases that would yield insights into health and environmental outcomes. As owners and tenants of homes, offices, and other commercial buildings begin to install "smart" information technologies that measure energy and water consumption, for example, their measurement devices will provide data that, when aggregated, can yield important information about emission, natural-resource consumption, and other indicators useful to consumers, businesses and service providers, and public-policy-makers. Another opportunity for pattern recognition and outcomes analysis lies in the synthesis of a growing number of databases that are reporting greenhouse-gas emission. Improved transparency in shale-gas operations, for example, would yield data and trend analysis that can assist operating companies in working collaboratively to design best practices to capture or prevent the release of methane.

Those instances of data management and synthesis represent important opportunities to expand public and stakeholder engagement in decision-making for environmental sustainability. By becoming a greater catalyst for transformational transparency, EPA can unlock new opportunities for innovation in the application of publicly available information and for developing methods applicable to its own and stakeholders' needs. Chapters 4 and 5 of this report provide specific examples of how the private sector and other institutions have made use of these opportunities—and the associated tools that support them—to improve sustainability outcomes.

Convening for Collaboration for System-Level Solutions

A growing number of major sustainability challenges transcend specific environmental media or markets. For example, attempts to reduce or eliminate the disposal of residua in landfills depend increasingly on collaboration among a variety of important economic decision-makers, including providers of raw materials, packaging companies, and producers, retailers, and consumers of manufactured goods. No single institution or group has the capability to design an effective solution to reduce or eliminate the landfilling of such residua. Instead, an empowered convener has the opportunity to leverage the various parties involved in related economic activities for the common good.

There are structural impediments to the private sector's ability to serve in such a convening role. They include antitrust considerations, competitive interests that militate against the direct disclosure of information to rival companies, and periodic public skepticism about the private sector's credibility or motivation.

Such impediments do not exist when the convener is a major government agency that has legal authority to invite major economic actors and their stakeholders into a collaborative, problem-solving process. EPA's history contains many examples of its application of convening authority, including voluntary initiatives with companies to report reductions of high-priority toxic releases, acquisition of data from testing of high-production-volume chemicals, development of test methods for identifying endocrine-disruption potential, and conducting formal regulatory negotiations as a precursor to formal rule-making on such issues as residential wood heaters, equipment leaks from chemical processes, and cleaner fuel development.

Further developing EPA's role as a convener would have several advantages, including

- Obtaining access to scientific and other data generated by less traditional sources that are relevant to EPA decision-making, such as information from private sector and NGO partnerships, initiatives led by NGOs to develop global standards, and newer consortia of private companies, NGOs, and universities (for example, The Sustainability Consortium).
- Gaining valuable experience in applying sustainability tools and methods. Many private companies and NGOs have taken the lead in applying sustainability tools, including LCA, accounting methods for calculating the social cost of carbon, natural-capital valuation, and assessment of tradeoffs at the climate–water–energy–food nexus of issues.
- Initiating a federal interagency process to develop and apply tools, such as LCA, in a sustainability context. EPA is a lead agency in many interagency forums, including science and technology for environment, natural resources, and sustainability in which science and technology priorities, budgets, and programs are assessed and aligned with policy priorities. The process could include assessments of the best practices, research and analytic impediments, data gaps, case studies of federal agencies' tools applications, and approaches that would enable the best use of sustainability tools.
- Applying transregional and global scenarios and trends analysis to problem-solving that is within EPA's specific jurisdiction. The interconnected nature of the global economy requires greater EPA understanding of such scenarios and trends to inform its decision-making on such issues as climate change, recycling opportunities, and green-product development.

- Leveraging existing EPA capabilities to achieve larger-scale outcomes that would greatly exceed the effects of following traditional decision-making approaches. For example, convening the important producers along an entire value chain of the energy market (rather than focusing on emission from the utility sector alone) provides EPA and the public that it serves with the opportunity to use many more tools and options and generate more effective decisions. The cost effectiveness of such an approach is likely to be higher than if single source categories are focused on in isolation.

Expanding EPA's convening role and capabilities would enable the agency to create new decision-making platforms to achieve critical objectives by applying innovative tools and approaches.

Catalyzing Innovation in Decision-Making

An examination of EPA's programs yields many instances of innovation in decision-making frameworks and their applications. EPA made early use of economic-incentive approaches that later found application in the 1990 Clean Air Act Amendments, which codified the use of emission offsets to reduce acid-deposition precursors, such as nitrogen oxides and sulfur oxides, at a small fraction of the previously estimated cost. Similarly, support for pollution-prevention initiatives led a number of companies to examine their business processes to identify less expensive, environmentally effective solutions in their operations.

The committee has identified various assessment approaches that could be used to identify new opportunities for incorporating sustainability concepts into EPA's decision-making.

Developing a Cradle-to-Cradle Approach to Assessing Materials Management[4]

Many of today's most important products—appliances, automobiles, computers, electricity, food, mobile telephones, and synthetic materials—are made and consumed without sufficient understanding of their full life-cycle effects or recognition of their full social costs.[5] As a result, huge volumes of usable materials go unrecovered and unused because current policies (such as water subsidies) encourage overconsumption or make materials recovery or resource efficiencies uneconomical for many products. Given the span of its responsibilities, EPA is well positioned to examine materials management in various business sectors and develop assessment practices that encourage the application of life-cycle approaches and identification of opportunities for innovative design and development of a materials recovery–reuse infrastructure in multiple market sectors.

Evaluating Pollution-Related Risks and Risk-Reduction Opportunities Throughout an Entire Value Chain and Not Only for Individual Sources

In EPA's history, there is precedent for this type of thinking, but it has had little application. A major application of this approach occurred in the aftermath of the 1990 Clean Air Act Amendments. EPA was charged with the responsibility to promulgate regulations by 1995 that would result in cleaner fuels by reducing volatile organic compounds and other air toxics. EPA quickly concluded that such a mandate could not be successfully achieved by focusing on petroleum refiners alone, so it convened a process through which many of the major participants in the fuels value chain contributed scientific data, modeling scenarios, and test results of varied fuel compositions and emission performance of various families of fuels and vehicles. The participants included refining companies, chemical companies that supplied fuel

[4]For a more extensive discussion of the cradle-to-cradle concept and its applications, see McDonough and Braungart 2002.

[5]See, for example, NRC 2010.

components, major automotive manufacturers, engine manufacturers, agricultural interests, state and local government officials, and environmental organizations. The result of their deliberations was encapsulated in a formal agreement among most of the participants. EPA converted the accord into a formal rule-making proposal subject to public notice and comment before a final rule promulgation that was achieved in advance of the statutory deadline.[6]

There are substantial environmental sustainability challenges along a number of important value chains. Examples include reducing packaging in consumer products, such as clothing, electronics, and food; decreasing the carbon and water footprints of the manufacturing and service sectors; and reducing the carbon intensity and fine-particle emission of the nation's energy-production system.

Simultaneously, new value chains are being constructed in ways that have major implications for EPA. The automobile industry, for example, is in the formative stages of a historic transformation away from primary reliance on the internal-combustion engine powered by hydrocarbon-based fuels toward more innovative propulsion by electricity, hydrogen, and other alternatives. In the midst of this transformation, EPA's traditional risk-assessment framework—focused on tailpipe and other evaporative emission from existing fuel combinations—will be less relevant or even rendered obsolete.

EPA should examine various sustainability challenges in collaboration with outside organizations and seek to evaluate risks and optimize decision-making and environmental performance for a number of value chains, both existing and in formation. ***(Recommendation 7e)***

Constructing a Research and Evaluation Template for Sustainable Cities

The historic demographic transition that is under way has already meant that a majority of the US and world population lives in cities. That trend is expected to continue (Portney 2003; Pijawka and Gromulat 2012; Pearson et al. 2014). Providing economic opportunities, infrastructure, and services to the growing urban population poses one of the major challenges to current and future generations. Leading companies, universities, and other thought leaders have initiated plans and programs to prepare for this future and advance the concept of sustainable cities in connection with varied issues, such as commercial and residential buildings; congestion management; health-care delivery systems; optimization of energy, water, and food delivery systems; infrastructure design and investment; and smart technologies

EPA has a number of important responsibilities and leverage points to advance the development of more sustainable cities. They include air and water-quality permitting; remediation practices and requirements; and use of natural systems in addition to human-made infrastructures for combined sewer overflow and storm-water and storm-surge management.

In developing a research and evaluation template for sustainable cities, EPA should explore the application of a broader set of sustainability tools. ***(Recommendation 7f)***

Examples include building on the best practices of cities, such as New York, that have developed widely accepted initiatives for making the energy performance of commercial buildings transparent to architects, engineers, realty companies, building-maintenance and energy-service firms and tenants and creating opportunities for their collaboration to achieve a more efficient use of energy. New York is also a leader in developing plans for mitigation of natural hazards that EPA, in its various authorities, will have a role in reviewing and implementing. Some federal agencies, such as the Department of Defense and Department of Energy, have large land holdings that include small urban centers; these are being man-

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[6]For example, the regulatory negotiations on Reformulated Gasoline under Title II (Section 211) of the 1990 Clean Air Act Amendments.

[7]For an examination of recent coalitions between businesses and NGOs, see Grayson and Nelson 2013.

aged with consideration of sustainability factors as part of the planning process and may provide insights for EPA and other institutions.

MOTIVATIONS FOR LEADERSHIP BY BUSINESS, NONGOVERNMENTAL ORGANIZATIONS, AND GOVERNMENT

As the landscape of the global economy continues to evolve and global megatrends present major new risks and opportunities, institutions in the public, private, and NGO sectors are re-examining their roles and capabilities. For business, these developments are leading to new business models, accounting methods, and accountability processes that recognize the materiality of risks and effects, innovation and market-access opportunities, and a necessity to align value-chain relationships to achieve greater efficiencies and performance improvements.

For NGOs that are reviewing the same macrodevelopments as business, a perceptible shift has evolved in the approach to working with government and business. Concerned about the large-scale effects of climate change, scarcities of natural resources and food, loss of biodiversity, and other planetary-scale effects, many of the leading NGOs have entered into more collaborative relationships with leading global companies. This process of dialogue has reached the point where they are developing common solutions and advocating similar agendas for resolving global, regional, national, and local issues. Beyond the collaboration with business, some NGOs have taken initiatives on various topics, such as developing global standards that would encourage the application of best practices to water management and water-quality protection. NGOs are also increasingly engaged with investors and the financial sector to alter methods of assessing effective governance, expanding transparency, and reconsidering valuations of capital and risk.[7]

RELATIONSHIP OF RISK-ASSESSMENT–RISK-MANAGEMENT DECISION-MAKING TO SUSTAINABILITY TOOLS AND APPROACHES

EPA has decades of experience in applying risk-assessment and risk-management decision tools to a variety of public-health and environmental challenges. As already noted in the present report, the agency has formalized the use of the tools in a formal decision-making framework that it periodically updates (EPA 2014d). In addition, the committee that prepared the Green Book (NRC 2011a) observed that its proposed Sustainability Assessment and Management (SAM) approach can include each of the basic elements of the risk-assessment and risk-management paradigms (see Figure 7-1).[8] The Green Book recommended that EPA include risk assessment as a tool, when appropriate, as a key input into sustainability decision-making.

Risk-assessment and risk-management approaches are dynamic and are continually informed by new scientific information. A similar characteristic is present in sustainability tools and methods, such as LCA, benefit–cost analysis, megatrend analysis, and data analytics.

As discussed in Chapter 3, risk assessment can be used to inform considerations of sustainability concepts by estimating whether and to what extent public health and the environment will be affected if an action is taken. The present committee's evaluation of how best to integrate risk assessment and other sustainability tools and methods is based on a consideration of four major factors:

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[7]For an examination of recent coalitions between businesses and NGOs, see Grayson and Nelson 2013.

[8]In some cases, such as a short timeframe for a decision, the formal four-step risk assessment will not help to discriminate among potential decision options in a sustainability framework. For a decision process in which four-step risk assessment is included, the sustainability framework can be viewed as representing the risk paradigm expanded and adapted to address sustainability goals. See Chapter 5 of NRC 2011a.

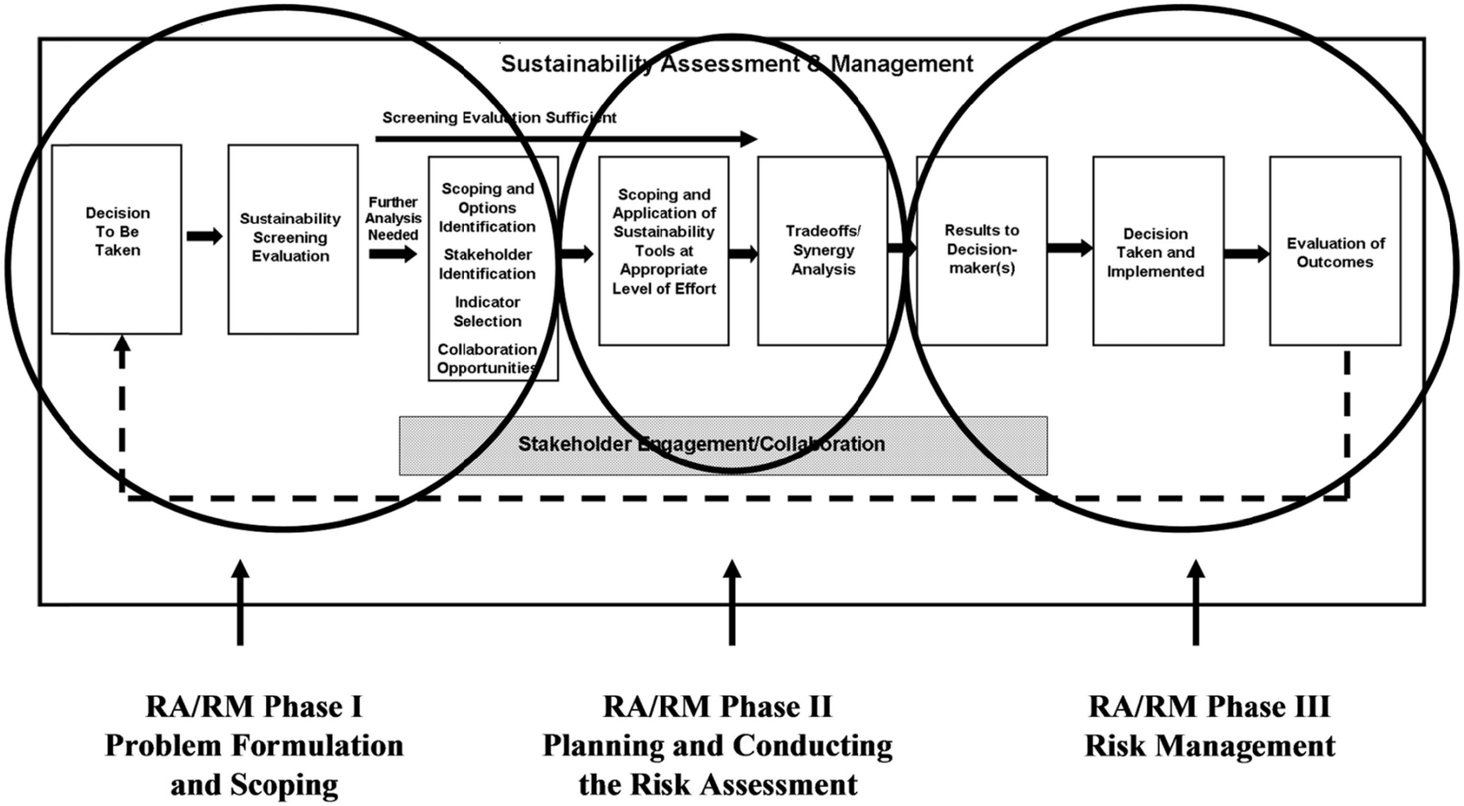

FIGURE 7-1 Correspondence between the components of the sustainability and management approach and the risk-assessment and risk-management frameworks used by EPA. Source: NRC 2011a.

- Planning and scoping that address all major sources of a problem. This would include not only the probabilistic evaluation of health and environmental effects associated with a specific pollutant or pollutant source (the most frequent application of risk assessment in EPA) but an examination of the economic activities in which the pollution originated (for example, the pollution-generating characteristics associated with the source of raw materials burned in a factory).
- Expanding the scope of problem formulation to include not only point and area sources that directly emit or contribute to pollution generation but energy and material flows throughout a value chain of activities that ultimately generate pollution further downstream. Transitioning from a "pollution source" to a "value chain" unit of problem formulation and analysis will provide EPA with important insights into how pollution is created and distributed.
- Many such innovations have emerged through the application of information technology that enables cost-effective analysis of individual problems and their linkage to interconnected systems of problems (for example, climate–water–food challenges) or the application of "traceability" methods that enable the tracking and tracing of pollutants or material flows among multiple participants in the economy (such as suppliers, manufacturers, distributors, and consumers). The application of those and other innovations has led to important insights for decision-makers in public, private, and nongovernment institutions and should be integrated into EPA's decision-making frameworks.
- Using risk assessment and other sustainability tools that are "fit for purpose". That term refers to the utility of an analytic tool that is best suited and adapted to support decision-making (EPA 2014d, p. xii). It applies equally to traditional risk assessment and sustainability methods.

EPA decision-makers need an expanded array of available tools to understand relevant trends emerging from the changing dynamics of the economy (locally, regionally, nationally, and globally). By integrating sustainability tools with an existing suite of risk-assessment methods, EPA would be better informed about the changing nature of risks that it is responsible for reducing and would have a system-level view of key interrelationships in economic–environmental–societal spheres of activities.

The committee agrees with the Green Book recommendation that EPA include risk assessment as a tool, when appropriate, as a key input into sustainability decision-making.

EPA should develop an integrated risk-assessment–sustainability analytic approach for decision-makers that can be applied as part of the SAM process throughout the agency's programs. Such an approach should

- **Identify the appropriate tools and methods for a variety of specific decision-making issues and scenarios.**
- **Articulate how particular sets of risk–sustainability tools and methods can be applied to specific sets of challenges within the scope of EPA's decision-making responsibilities, such as regulatory, technical support and guidance, cross-media and cross-business sector, and international.**
- **Evaluate how EPA can apply risk–sustainability tools to specific value chains.**
- **Conduct a selected number of postdecision evaluations to determine the efficacy and effects of integrated risk–sustainability methods, assess how and whether they would have changed the outcomes achieved, identify risk tradeoffs, and identify new opportunities for solving sustainability challenges.** ***(Recommendation 7g)***

KEY CONCLUSIONS AND RECOMMENDATIONS

Conclusion 7.1: EPA's various decision-making frameworks for the application of analytic tools and approaches function in parallel and are in various states of transition or development. Integrating the frameworks on the basis of sustainability concepts would enhance EPA's decision-making to match the degree and scale of current and future challenges.

Recommendation 7.1: As EPA continues to evaluate and update its current decision-making tools and frameworks, it should strive to use sustainability concepts as an integrating principle for its strategic plan and implementation of its program responsibilities. The committee urges EPA to continue in its efforts to adopt or adapt the sustainability framework recommended in the Green Book (NRC 2011a). (See Recommendation 7a)

Conclusion 7.2: The application of sustainability tools and approaches to EPA's day-to-day operations on a cross-program basis would enhance the agency's execution of its existing activities.

Recommendation 7.2: EPA should embed the application of sustainability tools and approaches in its major activities in a manner that is consistent with its existing statutory authorities and programmatic experience:

- Evaluating existing regulatory policies for public-health and environmental protection and approaches to emerging challenges.
- Extending EPA's role in data management and synthesis to aid the investment community, to fill information gaps in the commercial economy, and to monitor and identify problems and trends, many of which emerge in a nonregulatory context.
- Serving as a convener for collaboration in system-level solutions to leverage knowledge and problem-solving beyond the capability of any single institution or group, to foster cross-business sector collaboration and public–private partnerships, and to design system-level evaluation approaches throughout specific value chains.
- Developing approaches for cradle-to-cradle assessment of materials management, for evaluation of pollution-related risks and risk-reduction opportunities throughout an entire value chain and not only to individual sources or sectors, for integrated assessments of multiple individual risks that apply to cities, and for incorporation of resilience approaches. (See Recommendations 7b-7f)

Conclusion 7.3: Applying an expanded array of risk assessment and other sustainability tools and approaches would enhance EPA decision-makers' understanding of the changing dynamics of the economy and risks associated with the changes.

Recommendation 7.3: EPA should develop an integrated sustainability and risk-assessment–risk-management approach for decision-makers. Such an integrated approach should include an updated set of appropriate tools and methods for specific issues and scenarios, examination of how EPA can apply risk assessment and other sustainability tools throughout specific value chains, and selected postdecision evaluations to identify lessons learned and new opportunities to inform future decision-making. (See Recommendation 7g)

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Appendix A

Statement of Task

The Board on Environmental Studies and Toxicology (BEST) will convene an ad hoc committee to examine applications of numerous scientific tools and approaches for incorporating sustainability concepts into assessments used to support EPA decision making. Using specific case studies it develops (e.g., environmental media and sector-based), the committee will consider the application of analytic and scientific tools, methods, and approaches in the Sustainability Assessment and Management (SAM) process presented in the 2011 NRC report *Sustainability and the U.S. EPA*. The recommended process is intended to assess options for optimizing environmental, social (including health), and economic outcomes in EPA decisions. The committee will focus on analytic and scientific tools, methods, and approaches and will not recommend specific policy choices.

In carrying out its task, the committee will consider key aspects of advancing sustainability such as the following:

- Currently available and emerging tools, methods, and approaches most appropriate for assessing and/or evaluating potential economic, social and environmental outcomes within an EPA decision context.
- Data needs, major assumptions, strengths, and limitations associated with currently available and emerging analytic and scientific tools, methods, approaches, and practices for incorporating sustainability concepts into assessments supporting EPA decision making.
- Analytical and scientific tools, methods, metrics and approaches to assess and/or evaluate potential environmental, social, and economic effects of EPA actions (compared to pre-existing conditions) across geographic locations (including international), population subgroups, material lifecycles, environmental media, and future generations.
- Scientific and analytic approaches for initial screening to evaluate whether or not more in-depth analyses are warranted.
- Uncertainty in scientific results obtained from the application of analytical and scientific tools, methods, and approaches within environmental, economic, and social (including health) contexts.
- Post-decision evaluation of outcomes on dimensions of sustainability.
- Key research and development needs for improving the scientific and technical capabilities of current and emerging tools, methods, and approaches and assessing synergies and tradeoffs in order to incorporate sustainability concepts into assessments supporting EPA decision making.

Appendix B

Biographic Information on the Committee on Scientific Tools and Approaches for Sustainability

Michael C. Kavanaugh (NAE) is a senior principal of Geosyntec Consultants, Inc., an international engineering and consulting firm. His research interests have included hazardous-waste management, soil and groundwater remediation, process engineering, industrial-waste treatment, technology evaluations, strategic environmental management, compliance and due-diligence auditing, water quality, water and wastewater treatment, and water reuse. Dr. Kavanaugh serves as a member of the National Research Council Roundtable on Science and Technology for Sustainability. He served as chair of the National Research Council Board on Radioactive Waste Management and of the Water Science and Technology Board. He served as a member of the Committee on Incorporating Sustainability in the US Environmental Protection Agency. Dr. Kavanaugh is a registered chemical engineer in California, a Board-Certified Environmental Engineer of the American Academy of Environmental Engineers and Scientists, and a member of the National Academy of Engineering (elected in 1998). He received a PhD in civil/environmental engineering from the University of California, Berkeley.

Sherburne (Shere) B. Abbott is vice president for sustainability initiatives and University Professor of Sustainability Science and Policy at Syracuse University, and she oversees the Syracuse Center of Excellence for Environmental and Energy Systems. Before that appointment in 2011, she was a senior adviser to President Obama, serving as the Senate-confirmed associate director for environment of the Office of Science and Technology Policy in the Executive Office of the President, where she oversaw the roughly $5 billion federal portfolio of research and development related to the environment and natural resources. Previously, Ms. Abbott was a faculty member of the University of Texas at Austin and served as the director of the Center for Science and Practice of Sustainability in the Office of the Executive Vice President and Provost. From 2003 to 2005, she served as chief international officer of the American Association for the Advancement of Science, where she was responsible for the International Office and where she established and directed the Center for Science, Innovation and Sustainable Development. Earlier, she had consulted on environmental science and sustainable development for various organizations. Until 2001, Ms. Abbott worked at the National Research Council over a 17-year period, serving in several capacities, including as director of the Board on Sustainable Development. She also served as assistant scientific program director of the US Marine Mammal Commission. Ms. Abbott earned a master's degree in environmental science and natural resource policy from Yale University, where she was a Dodge Fellow in Human–Animal Ecology.

David T. Allen is Melvin H. Gertz Regents Professor in Chemical Engineering at the University of Texas at Austin and director of the university's Center for Energy and Environmental Resources. Dr. Allen serves as chair of the US Environmental Protection Agency Science Advisory Board. He is editor-in-chief of the American Chemical Society journal *Sustainable Chemistry & Engineering*. His research focuses on urban air quality and the engineering of sustainable systems, and he has been lead investigator of multiple air-quality studies, which have had a substantial impact on the direction of air-quality policies. Dr. Allen has served on several National Research Council committees and on the Board on Environmental Studies and Toxicology. He holds a PhD in chemical engineering from the California Institute of Technology.

Praveen K. Amar is an independent consultant based in Boston, who works in the areas of energy, environment, and climate strategies. Previously, he was senior advisor to the Clean Air Task Force (CATF), an environmental organization with a focus on environmental protection through research, advocacy, collaboration, and innovation. At CATF, he investigated environmental effects of Marcellus shale gas development in Pennsylvania, and with industry participation, developed air, climate, and water related performance standards for unconventional gas development. Dr. Amar serves on the science advisory committee for the New York State Energy Research and Development Authority's (NYSERDA) environmental research program. He was director of science and policy at Northeast States for Coordinated Air Use Management (NESCAUM), a nonprofit association of states air-quality agencies in the Northeast, where he focused on monetizing the public-health benefits of controlling mercury emissions from coal-fired power plants in the United States and evaluating potential future effects of global climate change on regional ground-level air quality. He is a member of the US Environmental Protection Agency (EPA) Advisory Council on Clean Air Compliance Analysis. He is currently serving on the National Research Council's Board on Environmental Studies and Toxicology. He served as a member of EPA's Clean Air Scientific Advisory Committee panel on review of secondary national ambient air quality standards for sulfur dioxide and nitrogen oxides. He is a licensed professional engineer in California and received a PhD in engineering from the University of California, Los Angeles.

Bradford Brooks is an IBM Fellow in recognition of his sustained achievement and leadership regarding IBM's involvement with complex materials that are used in the electronics and information-technology industries. Dr. Brooks's work focuses on manufacturing processes in the information-technology industry, toxicology risk assessments for information-technology products, technologies and materials that are newly emerging for industrial use, environmental risk management, industrial chemical security, and chemical-management laws and regulations. He received a PhD in immunology from Montana State University–Bozeman.

Ingrid C. Burke is director of the Haub School of Environment and Natural Resources of the University of Wyoming and of its Ruckelshaus Institute. She also is a professor and holds a Wyoming Excellence Chair in the Department of Botany and the Department of Ecosystem Science and Management. She is a former professor and University Distinguished Teaching Scholar in the Warner College of Natural Resources of Colorado State University. Dr. Burke is an ecosystem scientist and has particular expertise in carbon and nitrogen cycling of semiarid ecosystems. She directed the Shortgrass Steppe Long Term Ecological Research team for 6 years and other large interdisciplinary research teams funded by the National Science Foundation, the Environmental Protection Agency, the National Aeronautics and Space Administration, and the National Institutes of Health. She was designated a US Presidential Faculty Fellow, has served on the National Research Council Board on Environmental Studies and Toxicology, and was a member of the National Research Council's Committee on a New Biology for the 21st Century: Ensuring That the United States Leads the Coming Biology Revolution. She served as cochair of the Committee on Economic and Environmental Impacts of Increasing Biofuels Production. She was recently elected a Fellow of the American Association for the Advancement of Science. Dr. Burke received a PhD in botany from the University of Wyoming.

John C. Crittenden is a professor and director of the Brook Byers Institute for Sustainable Systems of the Georgia Institute of Technology. He is a Georgia Research Alliance Eminent Scholar in Sustainable Systems and occupies the Hightower Chair for Environmental Technologies. His research includes pollution prevention, physical–chemical processes, nanotechnology, air and water treatment, mass transfer, and numerical methods. With insight gained into how these processes connect with each other and with people, markets, and nature, he develops tools and educational programs that connect social decision-making, regional development, material flows, energy use, and local, regional, and global environmental effects. He served on the Environmental Protection Agency Science Advisory Board and the Engineering Advisory Board of the National Science Foundation. Dr. Crittenden was elected to the National Academy of Engineering in 2002. He received a PhD in civil engineering from the University of Michigan.

James Fava is senior director of PE International and cofounder of Five Winds International. He was previously a vice president of Weston Solutions, Inc., and Battelle. He specializes in the integration of life-cycle–based environmental and social aspects into core business and government policies and practices. He has directed and managed hundreds of projects to help to solve and prevent environmental, health, safety, and resource-productivity problems. He is founder of the Society of Environmental Toxicology and Chemistry (SETAC) Life Cycle Assessment (LCA) Advisory Group and headed the US delegation in the development of the International Organization for Standardization LCA standards. He is cochair of the UN Environment Programme–SETAC Life Cycle Initiative and served on the World Resources Institute–World Business Council for Sustainable Development Steering Committee for the Scope 3 and Product GHG Protocol efforts. He founded and for nearly 20 years has directed the Product Sustainability Roundtable. He received a PhD in environmental toxicology and fisheries biology from the University of Maryland, College Park.

Paul Gilman is senior vice president and chief sustainability officer of Covanta Energy Corporation. Previously, he served as director of the Oak Ridge Center for Advanced Studies and as assistant administrator of the Environmental Protection Agency (EPA) Office of Research and Development. He also worked in the Office of Management and Budget, where he had oversight responsibilities for the Department of Energy (DOE), EPA, and all other science agencies. In DOE, he advised the secretary of energy on scientific and technical matters. From 1993 to 1998, Dr. Gilman was the executive director of the National Research Council Commission on Life Sciences and director of its Board on Agriculture and Natural Resources. He has served on numerous National Research Council committees. Dr. Gilman received a PhD in ecology and evolutionary biology from Johns Hopkins University.

Michael R. Greenberg is a distinguished professor and associate dean of the faculty of the Edward J. Bloustein School of Planning and Public Policy of Rutgers, the State University of New Jersey. He is also director of the school's Environmental Assessment and Communication Group. Dr. Greenberg's research includes urban redevelopment, risk analysis, and environmental health policy. He has written more than 300 articles and 30 books, including *Urbanization and Cancer Mortality* (1983), *Hazardous Waste Sites: The Credibility Gap* (1984), *Public Health and the Environment* (1987), *Environmental Risk and the Press* (1987), *Environmentally Devastated Neighborhoods in the United States* (1996), *The Reporter's Environmental Handbook* (2003), *Environmental Policy Analysis and Practice* (2008), *The Environmental Impact Statement After Two Generations: Managing Environmental Power* (2011), and *Nuclear Waste Management, Nuclear Power and Energy Choices: Public Preferences, Perceptions and Trust* (2012). He has been a member of National Research Council committees that focused on setting priorities for chemical-waste site remediation, destruction of the US chemical-weapons stockpile and nuclear weapons, and degradation of the US government physical infrastructure. He received awards for research from the Environmental Protection Agency, the Society of Professional Journalists, the Public Health Association, the Association of American Geographers, and the Society for Risk Analysis. He served as area editor for social sciences and then editor-in-chief of *Risk Analysis: An International Journal* during the period 2002–2103, and he continues as associate editor for environmental health for the *American Journal of Public Health*. Dr. Greenberg holds a PhD from Columbia University in environmental and medical geography.

Andrew M. Hutson is director of Global Value Chain Initiatives at the Environmental Defense Fund (EDF) and leads the development and implementation of value-chain strategies to reduce the effects of trade and commerce on ecosystems. This includes using private-sector leverage to craft deforestation-free supply chains in the Amazon and improve the energy efficiency of Chinese factories. Before joining EDF, he helped launch the Manufacturing Leadership Board, a program for senior-most manufacturing executives; served as a consultant to business and nonprofit organizations in developing and industrialized countries; and worked as a business-process analyst for Accenture. His interest in the global environment was sparked during his volunteer service with the RARE Conservation in Honduras in the late 1990s. He was named a Graduate Fellow of the American Academy of Political and Social Science in 2006. Dr. Hutson holds a PhD in public policy from the University of North Carolina at Chapel Hill.

Catherine Kling is Charles F. Curtiss Distinguished Professor of Economics and director of the Center for Agricultural and Rural Development of Iowa State University. She is a Fellow of the Agricultural and Applied Economics Association and past president of the Association of Environmental and Resource Economists. Dr. Kling leads an interdisciplinary research group that focuses on water quality and agricultural practices; has published over 60 journal articles and refereed book chapters; has received seven awards from professional associations for her research; has been principal investigator or coprincipal investigator on over $7 million of grants, including grants from the National Science Foundation, the Environmental Protection Agency (EPA), the US Department of Agriculture, and state agencies; and has held editorial positions with seven economics journals. Dr. Kling's engagement in the policy process includes over 10 years of service as a member of EPA's Science Advisory Board and as a member of five National Research Council committees. She holds a PhD in economics from the University of Maryland.

H. Scott Matthews is a professor of civil and environmental engineering and of engineering and public policy at Carnegie Mellon University. He is research director for the Green Design Institute, an interdisciplinary research consortium that focuses on identifying and assessing the environmental effects of environmental systems and on helping businesses to manage their use of resources and toxic materials. His research focuses on creating data-rich corporate and policy decision-support tools in sustainable engineering, environmental life-cycle assessment, life-cycle management of physical and digital infrastructure systems, and carbon footprinting. He is a member of the National Research Council Board on Environmental Studies and Toxicology and previously served on the Committee on Hidden Costs of Energy (2010). He is associate editor of the *Journal of Industrial Ecology* and has coedited issues on sustainable infrastructure in the American Society of Civil Engineers *Journal of Infrastructure Systems*. He received the Laudise Prize from the International Society for Industrial Ecology and numerous AT&T Faculty Fellow in Industrial Ecology awards. He received a PhD in economics from Carnegie Mellon University.

Erik Petrovskis is director of Environmental Compliance and Sustainability at Meijer, Inc. Previously, he was a principal environmental engineer for Geosyntec Consultants. His work focuses on environmental-management plans for large, complex manufacturing and service facilities and the remediation and closure of industrial properties affected by chlorinated solvents, metals, and petroleum hydrocarbons with a specialization in the development and implementation of innovative in situ groundwater-remediation technologies. Dr. Petrovskis's research is in bioaugmentation and surfactant-enhanced aquifer remediation and the use of molecular biologic tools at chlorinated solvent sites. Dr. Petrovskis works on ISO 14001 Environmental Management System implementation, auditing, and training. He provided project management and technical direction on projects for the General Services Administration that were recognized as award-winning examples of environmentally sustainable real-property management. He sits on the Interstate Technology and Regulatory Council and the Huron River Watershed Council Board and previously served on the Sustainable Remediation Forum Framework Team. Dr. Petrovskis is an adjunct professor at the University of Michigan–Ann Arbor, where he teaches water–wastewater treatment design and sustainability engineering principles. He holds a PhD in environmental engineering from the University of Michigan–Ann Arbor.

Helen H. Suh is an associate professor in the Department of Health Sciences of Northeastern University. She is also Senior Fellow of the National Opinion Research Center at the University of Chicago and an adjunct faculty member of the Harvard School of Public Health. Her research focuses on assessing multipollutant effects on human health, the development of GIS-based spatiotemporal modeling tools for epidemiologic research, and examination of the individual and joint effects of pollution and lifestyle on health. Dr. Suh has performed advisory work in environmental health for numerous international, national, and local organizations. She is a member of the Environmental Protection Agency Clean Air Scientific Advisory Committee. Dr. Suh received an ScD in environmental health sciences from the Harvard School of Public Health.

Alison Taylor is vice president for sustainability-Americas at Siemens Corporation. In that position, she is responsible for driving the sustainability program for the Americas and acting as a resource for sustainability initiatives among Siemens's business sectors. In her previous role as director of government affairs, Ms. Taylor represented Siemens's position on environmental issues with Congress and the executive branch. Before joining Siemens, she was chief counsel for the US Senate Committee on Environment and Public Works and counsel to the US House Committee on Energy and Commerce. She received a BA in biology from Duke University and a JD from the University of Denver.

Terry F. Yosie is president and CEO of the World Environment Center, a nonprofit, nonadvocacy organization whose mission is to advance sustainable development through the private sector in partnership with government, nongovernment organization, academic, and other stakeholders. He has 35 years of professional experience in managing and analyzing the use of scientific information in the setting of environmental standards. He was the first executive director of the Environmental Protection Agency (EPA) Clean Air Scientific Advisory Committee. He served as director of EPA's Science Advisory Board from 1981 to 1988 and instituted policies and procedures for enhancing the use of scientific information in regulatory decision-making. Dr. Yosie was vice president for health and environment at the American Petroleum Institute and executive vice president of Ruder Finn consultancy, where he was responsible for the firm's environmental-management practice. From 2001 through 2005, he served as the American Chemistry Council's vice president for the Responsible Care initiatives, a performance program that includes environmental, health, and safety management; product stewardship; security; and other aspects of the business value chain. He has served on a number of National Research Council bodies, including the Committee to Review the Structure and Performance of the Health Effects Institute, the Committee on Research Priorities for Airborne Particulate Matter, and the Board on Environmental Studies and Toxicology. He is the author of over 70 publications on the use of scientific information in the development of public-health and environmental policies and strategies to advance sustainable development. He earned a doctorate from the Dietrich College of Humanities and Social Sciences of Carnegie Mellon University. He is the 2013 recipient of that Universities Alumni Achievement Award.

Appendix C

The Sustainability Assessment and Management Approach

Sustainability and the U.S. EPA (NRC 2011), known also as the Green Book, was prepared in response to a request from EPA for an NRC study committee to help the agency strengthen the analytic and scientific basis for sustainability.[1] Specifically, the following questions were posed to the NRC Committee on Incorporating Sustainability in the U.S. Environmental Protection Agency:

- What should be the operational framework for sustainability for EPA?
- How can the EPA decision-making process rooted in the risk assessment/risk management (RA/RM) paradigm be integrated into this new Sustainability Framework?
- What scientific and analytical tools are needed to support the framework?
- What expertise is needed to support the framework? (NRC, 2011, p. 133)

EPA had already begun sustainability initiatives and featured sustainability in its 2011-2015 strategic plan prior to its request to the NRC, but it sought "an operational framework to integrate sustainability as one of the key drivers within its regulatory responsibilities" (NRC, 2011, p. 1). A framework would provide a means by which to institutionalize sustainability in agency decision-making and effectively use the concept as a process and as a goal.

The Green Book committee relied upon the definition of sustainability provided in Executive Order 13514: "to create and maintain conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations." It presented the Sustainability Framework and the Sustainability Assessment and Management approach to guide and support EPA in its use and incorporation of sustainability (Figure 1-1 in Chapter 1). In developing the framework, the Green Book committee sought to ensure that it would need to lead to measurable goals and objectives that can be publicly reported, be flexible for use with new developments in science, technology, and the economy, work within the current RA/RM paradigm, and facilitate decision making supportive of EPA's mission to protect human health and the environment (NRC, 2011).

The framework is organized into a two-level process. The Sustainability Framework is described in the Green Book as Level 1 (Figure 1-1). At this level, the framework begins with a paradigm, principles, and responsibilities. The Green Book committee recommended that EPA select the three-pillar approach (social, environmental, and economic) as its sustainability paradigm and that it highlight in particular the inclusion of human health as a component of the social pillar. The Green Book committee also suggested that EPA develop, adopt, and publish EPA Sustainability Principles to "guide the agency's implementation of regulatory mandates and discretionary programs in ways to optimize benefits" related to sustainability (NRC, 2011, p. 41). Such principles could include transparency, accountability, and effectiveness, and the Green Book placed emphasis on principles related to justice, intergenerational and intragenerational equity, and a holistic systems approach to solving environmental problems. Finally, the Green Book noted that EPA would benefit from integrating sustainability into its implementation of regulatory authorities and objectives.

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[1]NRC (National Research Council). 2011. Sustainability and the U.S. EPA. Washington, DC: National Academies Press.

The next step in Level 1 of the framework is the development of an EPA Sustainability Vision to guide employees in the use of sustainability as a process and as a goal. With this vision set, EPA can then establish objectives, goals, indicators, and metrics to achieve sustainable outcomes and to reinforce to employees the agency's commitment to integrating sustainability into its operations. In terms of organization and culture, the Green Book committee emphasized the need to incorporate sustainability into the culture of EPA, which has already begun in some parts of the agency. Another key recommendation of the Green Book is that "EPA should incorporate upfront consideration of sustainability options and analyses that cover the three sustainability pillars, as well as trade-off considerations into its decision making" (NRC, 2011, p. 49). The penultimate step of Level 1 is the Sustainability Assessment and Management approach, which addresses day-to-day activities and comprises Level 2 of the framework. The framework concludes with periodic evaluation and public reporting of accomplishments toward objectives and goals.

Level 2, or the Sustainability Assessment and Management (SAM) approach, is designed to help sustainability inform decision-making (Figure 1-2). It is a multi-step process geared towards major decisions that could affect more than one pillar of the sustainability paradigm. However, it could be scaled down to address more minor or routine decisions. Therefore, the first step in SAM is to evaluate the level of depth of analysis needed for the decision at hand.

To do this, screening tools must be used. One example included in the Green Book is a quick scan process to assess whether a project affects more than one pillar of sustainability and what the magnitude of potential impacts will be. EPA could also make use of check lists and impact matrices to evaluate a program initiative against economic, environmental, and social criteria to determine if there will be moderate impacts to and potential conflicts between the pillars. If so, EPA could decide that further analysis is needed. Regardless of what screening tools EPA selects, it needs to formalize a screening procedure to be used at the start of its decision-making process.

If further analysis is needed, then EPA has to define the scope of the problem and identify alternative decisions that could be made with respect to the problem. Once alternative options have been identified, EPA can begin to assess the extent and timing of stakeholder engagement. It can also develop indicators and metrics to help them evaluate outcomes and success.

When the problem has been scoped, stakeholders and collaborators identified, and metrics for success developed, then EPA needs to select and implement assessment tools to quantify the impacts of decisions on sustainability criteria. The Green Book highlighted many sustainability assessment tools that have been developed but emphasized that the list is not exhaustive and that EPA will need to keep abreast of the latest developments in sustainability assessment tools and possibly develop new tools itself as assessment capabilities progress.

The Green Book presented six principles in the application of tools:

- No single tool is likely to be comprehensive; a comprehensive analysis will probably require application of a suite of tools to analyze impacts on social, environmental, and economic pillars of sustainability.
- The suite of tools should include dynamic analysis that analyzes the consequences of alternative options through time (intergenerational component).
- Tools should be capable of delivering quantitative assessments of impacts to the greatest extent feasible.
- It is desirable to have relatively transparent methods that can be easily explained and where the results of the analysis can be effectively communicated to decision makers.
- Data availability will, in part, determine the necessary tool.
- Uncertainty and sensitivity analysis will be required (NRC, 2011, pp. 59-60).

However, the Green Book committee did not make prescriptive recommendations about what tools to use in particular situations. Rather, the framework was designed to provide EPA with a way to assess how sustainability can be incorporated into a decision and how to select tools to use to achieve sustainable outcomes in the myriad types of decisions that EPA makes. However, the Green Book did not illustrate how to apply sustainability tools and methods in the SAM approach. The report noted that EPA will have to continue to adapt and improve tools to inform sustainability analysis.

Following the application of appropriate sustainability tools, the SAM approach includes trade-off and synergy analysis, which seeks to maximize all three pillars of sustainability in a decision while minimizing the adverse effects that occur when sustainability goals amongst the three pillars are in conflict with one another. The Green Book stressed that EPA will need to develop a systematic way to assess trade-offs "because improperly managed trade-offs can compromise environmental protection, public health, or other key aspects of sustainability" (NRC, 2011 p. 66).

The SAM approach also emphasized the need to clearly communicate results of the screening procedure, sustainability assessment tools, and trade-off and synergy analysis to decision-makers. This communication is essential to helping a decision-maker process the results before deciding which course of action to take. It also may help illuminate whether any further analysis needs to be undertaken before a decision is made.

The end of the SAM approach includes an evaluation of outcomes. This may start with a comparison between the observed outcome and the one projected in the original options identification. Differences that exist may point out weaknesses in the assessment tools or the data used to inform the process. It is also important to assess whether the outcome was within the predicted range of uncertainty. The results of such evaluations should be published to keep stakeholders engaged and to provide lessons learned about incorporating sustainability.

An important Green Book recommendation for a SAM approach is that EPA needs to develop a "sustainability toolbox" to use with this approach. In addition to analyzing the consequences of different decisions in the context of the sustainability paradigm, the tools should be used in a way that can address situations ranging from simple to complex and that "have the capability for showing distributional impacts of alternative options with particular reference to vulnerable or disadvantaged groups or ecosystems" (NRC, 2001, p. 72).

While EPA has made efforts to incorporate sustainability as a priority in its work, the Green Book noted that there was no formalized approach to conducting the analyses called for in the SAM approach. Therefore, the report recommended EPA create and adopt a formalized process for using the SAM approach when making decisions. The full set of findings and recommendations from the Green Book on the SAM approach are presented below.

FINDINGS AND RECOMMENDATIONS ON THE SUSTAINABILITY ASSESSMENT AND MANAGEMENT APPROACH[2]

4.1. Key Finding: The Sustainability Assessment and Management approach "requires application of a suite of tools capable of analyzing the full set of current and future social, environmental, and economic consequences of alternative options". Many tools already exist, and much activity is under way in the United States and globally to develop such tools. Some tools will need modification or expansion to be appropriate and some new tools will need to be developed (pp.60-65).

4.1. Key Recommendation: EPA should develop a "sustainability toolbox" that includes a suite of tools for use in the Sustainability Assessment and Management approach. Collectively, the suite of tools should have the ability to analyze present and future consequences of alternative decision options on the full range of social, environmental, and economic indicators. Application of these tools, ranging from simple to complex, should have the capability for showing distributional impacts of alternative options with particular reference to vulnerable or disadvantaged groups and ecosystems.

4.2. Finding: An important step in the Sustainability Assessment and Management approach is an evaluation of present and future conditions to show that present decisions and actions are not compromising future human and ecologic health and well-being. Therefore, a requirement is to be able to forecast

[2]The findings and recommendations are excerpted from pages 72–74 of NRC (2011).

potential future conditions as a function of the decision option chosen, although there will always be some degree of uncertainty attached to the forecast (pp.64-65).

4.2. Recommendation: EPA should identify potential future environmental problems, consider a range of options to address problems, and develop alternative projections of environmental conditions and problems.

4.3. Finding: The culture change being proposed here will require EPA to conduct an expanding number of assessments. Although EPA has been involved in state-of-the-environment and environmental assessments, it currently does not have a formalized approach to conducting or participating in the analyses required in the Sustainability Assessment and Management approach. Thus, such assessments could readily miss sustainability concerns not typically considered in past environmental assessments, including social and economic issues and environmental justice (pp.58-59).

4.3. Recommendation: The agency should develop a tiered formalized process, with guidelines, for undertaking the Sustainability Assessment and Management approach to maximize benefits across the three pillars and to ensure further intergenerational social, environmental, and economic benefits that address environmental justice.

4.4. Finding: Screening is often used in other OECD countries prior to undertaking full sustainability assessments; criteria examined include the magnitude of the activity and potential short-term and long-term conflicts between at least two dimensions of sustainability (p.56).

4.4. Recommendation: EPA should formalize a screening procedure for implementing the Sustainability Framework recommended by the committee.

4.5. Finding: Economic benefit-cost analysis as commonly applied to environmental issues often does not adequately account for the full range of ecosystem benefits, take intergenerational considerations into account sufficiently, or take into account the distribution of benefits and costs among population groups (p.61).

4.5. Recommendation: EPA should continue to adapt its current method of cost benefit analysis for sustainability by, among other things, improving its estimates of the value of ecosystem services, extending its boundaries by incorporating life-cycle analysis, and better addressing intergenerational and environmental justice considerations.

4.6. Finding: Risk analysis as commonly applied to environmental issues often does not adequately account for the full range of human health and ecosystem risks, including cumulative risks, intergenerational considerations, and the distribution of risks among population groups. In addition, better methods are needed to support consideration of health and environmental effects for the green chemistry goal of safer products and more sustainable chemical usage (p.60).

4.6. Recommendation: EPA should develop a range of risk assessment methods to better address cumulative risk and intergenerational and environmental justice considerations and to support comparisons of chemicals as part of an alternatives analysis for green chemistry applications.

4.7. Finding: EPA and other organizations have developed and continue to develop environmental indicators; however, appropriately addressing sustainability in the decision-making process will require additional attention to economic and social issues, including environmental justice (p.69).

4.7. Recommendation: EPA should expand its environmental indicators to address economic and social issues in collaboration with other federal agencies to address economic and social issues, and consider adopting them and developing appropriate metrics to inform sustainability considerations for state and local actors. Where relevant, these indicators should allow for international comparisons and the rapid adoption and adaptation of best practices from other countries responding to the challenges of sustainability.

Appendix D

Glossary of Sustainability Tools and Approaches

The definitions provided in this appendix are from the U.S. Environmental Protection Agency report, *Sustainability Analytics: Assessment Tools & Approaches* (EPA 2013).

Benefit-Cost Analysis (p. 20)[1]

Benefit-cost analysis (BCA) (also known as cost-benefit analysis) is a widely used, well-documented tool for assessing the net economic effects of policies. BCA provides a systematic process for calculating, monetizing, and comparing the economic benefits and costs of a particular action, process, regulation, or project by putting benefits and costs in a common metric. The results of a BCA can be used in two key ways: to provide insight into whether a project or policy provides a net economic benefit or cost to a company or society; and, to compare the outcomes of different project or policy alternatives.

BCA is based on economic theory and techniques. Specifically, BCA draws on peer-reviewed economic literature both to identify and define categories of benefits and costs and to help estimate benefits and costs that are not directly bought and sold in markets. BCA has been an important component of regulatory analysis at the EPA for over three decades. Documentation of the EPA's use of BCA to assess the economic impact of federal policies and programs is extensive. EPA's 2010 *Guidelines for Preparing Economic Analyses* provides detailed guidance on the proper use of BCA (and other forms of economic analyses) to assess regulations and policies (EPA 2010a).

Chemical Alternatives Assessment (p. 54)

The premise behind chemical alternatives assessment (CAA) is that because risk is a function of hazard and exposure, focusing on hazard reduction is an effective way to mitigate risk. By assessing chemicals of potential concern and their functional alternatives with respect to their effects on the environment and human health, CAA enables the substitution of safer chemicals (Lavoie et al. 2010)] Information gained through CAA can be used by decision-makers in combination with analyses of cost, performance, and other factors to select safer chemical and material alternatives.

CAA compares alternative chemicals within the same functional-use group across a consistent and comprehensive set of hazard endpoints. CAAs may also consider intrinsic properties of chemical substitutes that affect exposure potential, including absorption potential, persistence, and bioaccumulation. This approach to alternatives assessment orients chemical evaluations within a given product type and functionality. Factors related to exposure scenarios, such as physical form and route of exposure are generally constant within a given functional use group and would fall out of the comparison. Thus, the health and environmental profiles in the alternatives assessments become the key variable and source of distinguishing characteristics.

[1]Page numbers cited immediately after the names of the tools and approaches refer to EPA (2013).

Collaborative Problem-Solving (p. 33)

Collaborative problem-solving (CPS) is a tool that allows various stakeholders to work together to address a particular issue or concern. Stakeholders often have to reconcile divergent interests in order to address complex and interrelated environmental, public health, economic, and social problems in local communities. Many of these problems are deeply rooted and difficult to resolve without the concerted effort and active participation of all the stakeholders. When multiple stakeholders work together, they create a collective vision that reflects mutually beneficial goals for all parties. Such collaboration fosters the conditions that enable the parties to mobilize the resources necessary to realize stronger, more enduring solutions.

CPS involves proactive, strategic, and visionary community-based processes that bring together multiple parties from various stakeholder groups (e.g., community groups, all levels of government, industry, and academia) to develop solutions to address local environmental and/or public health issues. Partnerships and negotiations are required to achieve such solutions. Partnerships refer to arrangements through which different stakeholders work together to achieve a common goal. These partnerships can range from informal working relationships to very structured arrangements in which goals, membership, ground rules, and operating principles are clearly defined. Negotiations refer to processes, ranging from informal to formal, through which different stakeholders agree to come together and resolve disagreements.

Design Charrettes (pp. 35-36)

The National Charrette Institute defines a charrette as "a collaborative design and planning workshop held on-site and inclusive of all affected stakeholders." (Lennertz et al. 2008). Charrettes enable community organizations, public agencies, developers, and other stakeholders to work together towards solving contentious or complex situations. They are frequently applied in the context of land use planning to support revitalization efforts, including brownfield assessment, cleanup, and reuse. Often facilitated by architects and planners, the goal of design charrettes is to come up with a mutually agreed-upon vision for future development that is both effective and sustainable (EPA 2010b).

Eco-Efficiency Analysis (pp. 23-24)

Eco-efficiency analysis (EEA) is a tool for quantifying the relationship between economic value creation and environmental impacts, throughout the entire lifecycle of a product or service (Brattebø 2005; Moller and Schaltegger 2005; MBDC 2010; NACFAM 2010; BASF 2011 The term 'eco-efficiency' evolved from the work of the World Business Council for Sustainable Development (WBCSD) in response to the first United Nations Earth Summit. The WBCSD defines eco-efficiency as "the delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle." (Lehni and Pepper 2000). In other words, to be eco-efficient is to add more value to a good or service while simultaneously decreasing adverse environmental impacts. EEA evaluates products and services by examining their environmental impact in proportion to their cost-effectiveness. BASF Chemical Corp. was one of the first companies to establish an EEA methodology in the early 1990s with the goal of reducing the environmental impact and costs of its products and processes. BASF's EEA tool quantifies the sustainability of products or processes throughout their entire life-cycle, beginning with the extraction of raw materials through the end of life disposal or recycling of the product. It compares two or more products analyzed from the end-use perspective to obtain comprehensive data on the total cost of ownership and the impact on the environment (BASF 2012).

EEA differs from benefit-cost analysis (see discussion on page 20) in that it does not seek to monetize environmental benefits or costs and compare them to non-environmental benefits or costs (Bohne et al. 2008). Whereas BCA typically seeks to evaluate the net social benefits of a policy or program compared to a baseline without the policy or program, EEA calculates the ratio of the total value of goods and services produced (output) to the sum of the environmental pressures created by the production of those goods and services (input). More sustainable alternatives have a higher output to input ratio, or eco-efficiency ratio (UNESCAP 2010).

Ecosystem Service Valuation (p. 26)

EPA defines the term ecosystem as the "dynamic complex of plant, animal, and microorganism communities and their non-living environment." (EPA 2009) The contributions of ecosystems to human well-being—or ecosystem services—are measured in terms of human values, and can be thought of as the direct and indirect economic, social, and environmental services provided to human populations and reflects the complex interactions between and among living organisms and their natural environment (EPA 2009).

Ecosystem services may be divided into four categories: provisioning services (e.g., food, fibers, drinking water); regulating services (e.g., flood protection, pest control); cultural services (e.g., cultural, spiritual, aesthetic); and, supporting services (e.g., soil formation, primary productivity) (Millennium Ecosystem Assessment 2005). The objective of ecosystem service valuation is to assess the consequences of altering ecosystems or using ecosystem services for human well-being (Millennium Ecosystem Assessment 2005).

For example, one third of our food comes from plants pollinated by birds, bats and insects. The value of these pollination services in the United States is estimated at $6 billion a year. If we destroy populations of pollinators with pesticides, loss of habitat, or other stressors we would be forced to either forgo many fruits, vegetables, and grains we enjoy or replace pollination services with potentially costly alternatives. Thus, pollination is an essential and valuable service provided free in natural functioning ecosystems, and its loss has obvious and direct implications on the economic, social, and environmental systems.

Environmental Footprint Analysis (p. 58)

Environmental footprint analysis is an accounting tool that measures human demand on ecosystem services required to support a certain level and type of consumption by an individual, product, or population. Footprint methodologies estimate life-cycle environmental impacts from a narrower viewpoint than traditional life-cycle assessment (see discussion on page 75). The environmental footprint methods described below can be classified into two broad categories of analyses: streamlined life-cycle assessments that use a single-unit indicator (e.g., carbon dioxide equivalents) and location-specific analyses (e.g., ecological footprint of a city).

A single-unit indicator does not mean that only one source or one piece of data is used. Typically, many different data are used but are converted to a single common unit, such as carbon or nitrogen. In this manner, single-indicator environmental footprint analyses are similar to economic tools that use currency as their single-unit indicator. Ecological, materials, carbon, nitrogen, and water footprint analyses are common methods available for calculating environmental footprints.

Environmental Justice Analysis (pp. 37-38)

Environmental justice (EJ) is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies (EPA 2010c). Recognizing that some populations experience higher levels of risk, Executive Order 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations," directs federal agencies to identify and address disproportionately high adverse human health or environmental effects on minority and low-income populations that may result from their programs, policies, and activities (Clinton 1994). The development of the environmental justice movement has precipitated a great deal of research on the racial and socioeconomic disparities in exposure to environmental health risks (Cole and Foster 2001; Ringquist 2005; Brulle and Pellow 2006). These studies, often referred to as EJ analyses, evaluate risks and may also attempt to address them using other sustainability tools, such as collaborative problem-solving (see discussion on page 33), and design charrettes (see discussion on page 35), among others (NRC 2011).

Exposure Assessment (p. 62)

Exposure refers to a measurable contact of an agent with a target or receptor for a specific duration of time (IPCS 2000; Zartarian et al. 2005). In the broadest terms, agents can be biological, physical, chemical, social, or psychological, and can produce both adverse and beneficial impacts to the target. EPA has historically focused on minimizing negative impacts, but in a sustainability context assessing exposures that result in positive impacts is also relevant to evaluating tradeoffs. For human exposures, receptors can be individuals, populations, subpopulations, or life-stages of interest. For ecological systems, receptors can be individuals, populations, species communities, or ecosystems that include both wildlife and vegetation. For exposure to occur, the agent and the receptor must intersect in both space and time.

Exposure assessments characterize and predict this intersection by estimating the magnitude, frequency, and duration of exposure (EPA 1992). Exposure assessments also describe the number and characteristics of the population exposed (e.g., vulnerable communities, ecosystems, or endangered species). They describe the sources, routes, pathways, and uncertainty in the assessment. Exposure assessments describe the environment as well as characterize and link the processes that impact the transport and transformation of agents from their source through contact with human or ecological receptors. These assessments are a central component in understanding environmental systems and how they change when intended or unintended perturbations occur.

Futures Methods (pp. 41-42)

Futures methods seek to help decision-makers anticipate conditions and events that have not yet fully developed so they can influence or better respond to the ultimate outcome. Futures methods attempt to look "beyond the horizon" to provide insight into future trends that can be used to inform strategic planning. The following four basic techniques are widely used futures methods, each drawing on a different body of knowledge and serving a distinct purpose (EPA 1995, 2007):

- Scanning methods are systematic and broad-based reviews of information gleaned from journal articles, newspapers, websites, books and other sources to identify relevant "weak signals," early indications of trends that are just beginning to emerge. Scanning methods results typically require further analysis and can provide input for other futures methods.
- Delphi methods use a structured series of interviews to learn from the observations and judgments of experts. Interview questions may explore the probability, timing, and impact of emerging opportunities and challenges.
- Trend analysis methods examine quantitative data for trends and patterns, and use mathematical projections to extrapolate into the future. A complete analysis also requires identifying potential counter trends, exploring possible implications, and identifying options for a response.
- Future scenario analyses construct detailed qualitative or quantitative snapshots of alternative scenarios that serve as plausible images of the future rather than predictions or forecasts and are used to investigate how individual elements might interact under certain conditions (Schoemaker 1995; Swart et al. 2004). This method can provide a context for a diverse group of stakeholders to examine how changes occur in complex systems, and explore how best to achieve positive outcomes given the range of potential changes.

Many variations on these basic techniques have been developed (Glenn, and Gordon 2009).

Green Accounting (p. 30)

Green accounting (also known as environmental accounting) seeks to better measure sustainability by expanding gross measures of national welfare (product, investment, etc.) to include non-market values, in particular ones associated with environmental goods and services (Vincent 2000). In addition, green accounting seeks to incorporate costs and benefits of environmental protection and depletion of natural capital – two measurements not typically included in national accounting systems such as gross domestic product (Hecht 1999). While opinions vary on how to perform green accounting, the technique is used worldwide and is well-established in the United States.

Green Chemistry (p. 65)

Green chemistry is the science and practice of designing chemicals, products and processes in order to reduce or eliminate the generation and use of hazardous substances. Like the related field of green engineering, green chemistry seeks to protect human health and the environment by applying sustainability principles at the design phase of a process or a product, where they can have the greatest impact and be most cost-effective (EPA 2011a).

Green chemistry is a transdisciplinary field encompassing elements of chemistry, engineering, biology, toxicology and environmental science. This nexus across disciplines is essential for focusing on the complex questions associated with sustainability and for providing the tools needed to answer those questions. Green chemistry is guided by a set of principles that encourage the creation of safer, more efficient, and more sustainable designs for chemical products, feedstocks, and processes (EPA 2011b).

Green Engineering (p. 70)

Green engineering is the design and use of economically feasible products and processes that: 1) reduce the generation of pollution at the source, and 2) minimize the risks posed to human health and the environment. Green engineering incorporates environmental science along with sound engineering design principles to minimize the overall environmental impact of products and services during manufacture, processing, use, and disposal. Like the related field of green chemistry (described on page 65), green engineering operationalizes the philosophy that decisions to protect human health and the environment have the greatest impact and cost effectiveness when applied early in the design phase of a process or product (EPA 2011a).

Health Impact Assessment (p. 45)

Health Impact Assessment (HIA) is defined as "a combination of procedures, methods, and tools by which a policy, program, or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population." (WHO 1999) This tool is used to systematically identify how new projects or policies might affect public health. HIAs consider determinants of human health stemming from all of the three pillars of sustainability – social, environmental, or economic (Quigley et al. 2006). For example, HIA takes into consideration factors such as employment, education, and climate change.

The two main objectives of HIA are: (1) to predict the human health impacts of program- or project-related actions, and (2) to provide stakeholders and decision-makers with information to consider when assessing and prioritizing strategies for addressing health risk and preventing adverse health outcomes over the life of a program or project (IFC 2009). HIA is designed to address negative and positive, intended and unintended, and single and cumulative health impacts across entire populations, taking into account the fact that not all subgroups will be affected equally Quigley et al. 2006).

Integrated Assessment Modeling (pp. 72-73)

Integrated assessment modeling (IAM) is a tool that integrates knowledge from two or more domains into a single framework. In general, IAM brings a systems-based approach to decision-making that takes into account the three pillars of sustainability. Integration can occur at many different levels: some integrative models are limited to water quality or hydrology while other models integrate two or more environmental components (e.g., soil and water or water and biology). For example, the Framework for Risk Analysis in Multimedia Environmental Systems (FRAMES) represents a series of fate and transport models, which are integrated such that the outputs of one model feed seamlessly as inputs into one or more models in the framework. Still other IAMs integrate multiple decision criteria, which can permit stakeholders to consider all economic, social, and environmental criteria they can identify and obtain data for decision analysis. The integration of fate and transport (environmental) models with social and economic models and then the integration of these three components in multi-criteria decision approaches is yet another example of integration. The overarching goal of IAM is to ensure that policy decisions are informed by a thorough understanding of the interdependencies and interactions within a system's economic, environmental and social spheres. Through IAM, policymakers and stakeholders can gain better insight into the suite of impacts of policy interventions, which is expected to lead to more sustainable outcomes. In a broader context, EPA defines integrated modeling as: (EPA 2008a) "…a systems analysis-based approach to environmental assessment. It includes a set of interdependent science based components (models, data, and assessment methods) that together form the basis for constructing an appropriate modeling system. The constructed modeling system is capable of simulating the environmental stressor-response relationships relevant to a well specified problem statement."

Life-Cycle Assessment (p. 76)

Life-cycle assessment (LCA) is a systems-based approach to quantifying the human health and environmental impacts associated with a product's life from "cradle to grave." A full LCA addresses all stages of the product life-cycle and should take into account alternative uses as well as associated waste streams, raw material extraction, material transport and processing, product manufacturing, distribution and use, repair and maintenance, and wastes or emissions associated with a product, process, or service as well as end-of-life disposal, reuse, or recycling. In some cases, LCA is applied with restricted boundaries, such as "cradle to [loading] gate." Environmental footprint analysis (see discussion on page 58) is a type of bounded LCA (EPA 2006).

LCA typically return two specific types of information:

- A comprehensive life-cycle inventory of relevant energy and material inputs and environmental releases throughout the system (EPA 2006).
- Estimates of the resulting impacts for a wide range of impact categories including global climate change, natural resource depletion, ozone depletion, acidification, eutrophication, human health, and ecotoxicity (Bare et al. 2000).

This information allows an analyst to consider multiple parts of a system and multiple environmental endpoints in developing effective policies.

Resilience Analysis (p. 80)

Resilience analysis investigates the ability of a system (e.g., a human community, a supply chain, or an ecosystem) to continue functioning in the face of disruptions. Generally, resilience can be defined as "the capacity for a system to survive, adapt, and flourish in the face of turbulent change" (Fiksel 2006). Examples of resilience metrics include the magnitude of disruption that is required to move a system out of equilibrium and the cost (or effort) required to restore a system to equilibrium after a disruption has occurred (Carpenter et al. 2001; Vugrin et al, 2009). Resilience analysis studies the adaptive cycles in a system in order to understand its vulnerabilities and its capacity for resilience (Gunderson and Holling 2002). Once these patterns are understood, a system's resilience can be enhanced through designs and processes that promote diversity, variation, distributed functions, effective feedback loops, and freedom for innovation and adaptation (Walker and Salt 2006).

The resilience of any system depends on the interconnectedness and functional diversity of multiple subsystems. For example, in decentralized systems, functions are distributed so that a malfunction or disturbance in one area does not necessarily have a critical impact on other system components. More resilient systems are able to absorb larger shocks without changing in fundamental ways (Fiksel 2003). While natural systems tend to be inherently resilient, poorly designed human systems are often brittle and vulnerable to a variety of disruptions.

Risk Assessment (p. 83)

Risk assessment adds an important contribution to advancing sustainability. In a risk assessment, risk is understood to be the possibility of adverse consequences from an event or activity. A risk assessment, therefore, is a process for evaluating the likelihood and/or magnitude of such consequences. Risk assessment should be viewed as a tool for evaluating the relative merits of various options for managing risk (NRC 2009). This includes carefully posing the risk management questions and evaluating the options available to manage the environmental problems at hand. There are a number of context-specific types of risk assessment that can be useful in understanding aspects of sustainability in complex, real-world situations. Four of these are described below (Bahr 1997; Stewart and Melchers 1997; Landoll 2006; Hiles 2011).

Human Health Risk Assessment (p. 83)

Human health risk assessment (HHRA) is the process used to estimate the nature and probability of adverse health effects for humans who may be exposed to environmental stressors (chemical, non-chemical, or both), now or in the future. HHRA can help inform solutions to a broad range of problems related to human health risk.

Children's Environmental Health Assessment (pp. 83-84)

Children are a subpopulation that may be more susceptible to harm caused by environmental stressors because of various physiological and behavioral factors (EPA 2008b):

- their bodily systems are still developing;
- they eat more, drink more, and breathe more in proportion to their body size; and,
- their behavior such as crawling on the ground and hand-to-mouth activity can higher exposures to chemicals and organisms.

Cumulative Risk Assessment (pp. 84-85)

There are multiple definitions of cumulative risk assessments. The Food Quality Protection Act (FQPA) defines cumulative risk as the risk from the total exposure to multiple stressors (usually chemical) that cause one or more common toxic effects to human health by the same, or similar, sequence of major biochemical events. The EPA's Cumulative Risk Framework provides a considerably broader definition that includes combined risks from aggregate exposures to multiple agents or stressors, where agents or stressors may be chemical, biological, social, or physical (e.g., noise, nutritional status) (EPA 2003). EPA's cumulative risk assessment process focuses on populations and consideration of population variability; it has been used in many of the EPA's programs, including: Research and Development, Superfund, Air, Water, and cross-program endeavors like the Community Action for a Renewed Environment program.

Ecological Risk Assessment (pp. 85-86)

An ecological risk assessment (EPA 1998)] is the process for evaluating how likely it is that the environment may be impacted as a result of exposure to one or more environmental stressors such as chemicals, land change, disease, invasive species and climate change. Ecological risk assessments can be used to predict the likelihood of future effects (prospective) or evaluate the likelihood that effects are caused by past exposure to stressors (retrospective). Information from ecological risk assessment is then used by risk managers for follow-up such as communicating to interested parties and the general public, limiting activities related to the ecological stressor, limiting use of a given chemical, or developing a monitoring plan to determine if risks have been reduced or whether an ecosystem is recovering.

Segmentation Analysis (pp. 47-48)

Segmentation analysis (also known as market segmentation or audience segmentation) is a process of dividing a larger population into smaller subpopulations or segments in order to identify psychological and socio-demographic correlates of target behaviors or values. Members of subpopulations are statistically more similar to one another than they are to members of other subpopulations (Grunig 1989). Common segment factors include demographic, psychological, and behavioral variables, such as income, age, attitude, race, sexual orientation, education, consumption, and leisure pursuits. Segmentation analysis combines these data into bundles of closely correlated attributes in order to define specific segments of the population.

Social Impact Assessment (p. 49)

Social impact assessment (IA) is a tool used to assess the social impacts—both positive and negative--resulting from planned interventions (such as policies, programs, projects or actions), as well as any social change invoked by those interventions. The goal of social IA is to help decision-makers produce more socially, economically, and environmentally sustainable results. Social IA draws on knowledge gained through collaborative, community-based tools, and is therefore complementary to many other sustainability tools discussed in this document (ICGPSIA 1994; Vanclay 2003).

Social Network Analysis (p. 52)

Social Network Analysis (SNA) refers to a systematic process of analyzing groups (nodes) and relationships among groups (Wellman 1988). The groups and ties comprising the social network can be visually mapped as a scatter plot: interpretation of the social network draws on scientific disciplines focused on understanding interpersonal relations and social structures (e.g., anthropology, psychology, and sociology) (Borgatti et al. 2009). One of the most important uses for SNA is in mapping communications and knowledge flows among groups (Reagans and McEvily 2003). Understanding such knowledge flows has many benefits, including identifying new opportunities for strategic collaboration, identifying communication bottlenecks, streamlining the flow of information across departmental or organizational boundaries, identifying trusted sources of knowledge within the network, and targeting specific stakeholders where key messages will have the greatest impact. Understanding such dynamic network interactions is possible through SNA because the emphasis is not on the attributes of individual groups, but on how the structure of relationships among groups affects how individual groups behave when they are plugged into the network. Thus, the overall shape and connectedness of the social network is an important determinant of what the groups within it do and how effectively the network operates to transmit information or ideas (Granovetter 1973).

Sustainability Impact Assessment (pp. 89-90)

Sustainability impact assessment (IA) is a combination of procedures, methods, and tools by which a policy, program, or project may be judged as to its potential impacts on the sustainability of a system and the distribution of those impacts within and among the economic, social, and environmental dimensions.

Sustainability impact assessments are most commonly applied through a multi-criteria decision analytic approach, which helps stakeholders investigate the combined economic, environmental and social impacts of proposed policies. This approach can be used to guide stakeholder and decision-maker engagement and collaboration throughout the entire planning process (OECD 2010). The purpose for conducting a sustainability impact assessment is twofold: inform policy development by explicitly considering impacts within and among the economic, social, and environmental systems; and, assess potential economic, social, and environmental impacts resulting from a proposed policy (OECD 2010). Explicit in a sustainability impact assessment is the integration of all three sustainability pillars; consideration of both spatial and temporal impacts; stakeholder involvement; transparency; accountability; and, match between the level of detail in the assessment and the impacts (OECD 2010).

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Appendix E

Application of General Evaluation Criteria

Table E-1 was developed by the committee to illustrate the presentation of results from a ratings approach that uses a set of general evaluation criteria (see Chapter 3). The rows list the various tools presented in the US Environmental Protection Agency (EPA) 2013 report *Sustainability Analytics: Assessment Tools and Approaches*,[1] and the columns list seven evaluation criteria. The table's cells contain color-coded (red, yellow, or green) entries representing members' opinions about the tools with respect to each criterion. Generally, a red entry in a cell suggests the rating of a tool is "low", a yellow entry suggests "moderate", and a green entry suggests "high".

The ratings should be interpreted carefully. A tool with many red ("low") entries is not intended to be designated as inappropriate for use in sustainability analyses, nor does it mean that a tool is not important. Instead, these low entries might suggest areas where additional investments would be valuable for further development (such as, to improve data or documentation for use). Ecosystem services valuation, for example, is seen as a critical and emerging tool in support of sustainability considerations, but has had relatively modest work and support to date. Likewise, tools with many green entries are not presumed by the committee to be most appropriate or most important for use in sustainability analyses. These tools, however, in our opinion, may be most ready to be used "off the shelf" in support of analyses.

It is important to note that the table is only an illustration of the kind of ongoing assessment that would be useful in developing and refining a full suite of sustainability assessment tools. The results in the table should not be considered as evaluative findings because they may have been influenced by the extent of the committee's familiarity with the development and use of some of the tools.

[1]EPA 2013. Sustainability Analytics: Assessment Tools and Approaches. U.S. Environmental Protection Agency, Washington, DC [online]. Available: http://www.epa.gov/sustainability/analytics/docs/sustainability-analytics.pdf [accessed April 16, 2014].

TABLE E-1 Illustration of Using a Consistent Set of Evaluation Criteria*,±

Tool	Documentation	Accepted Use	Maturity	Software	Screening	Data	Extent of Usage
Benefit-cost analysis	◆	◆	◆	◆	◆	◆	◆
Eco-efficiency analysis	●	●	■	■	■	●	■
Ecosystem services valuation	■	●	●	■	●	●	●
Green accounting	■	■	■	■	●	■	●
Collaborative problem-solving	■	■	■	●	■	●	■
Design charrettes	■	■	■	■	●	●	●
Environmental justice analysis	■	■	■	●	■	■	■
Futures Methods	■	■	■	■	●	■	●
Health impact assessment	◆	◆	◆	■	◆	◆	■
Segmentation analysis	■	■	■	●	●	●	●
Social impact assessment	●	●	●	●	●	■	●
Social network analysis	●	●	●	●	●	■	●
Chemical alternatives assessment	■	■	■	■	■	■	■
Environmental footprint analysis	■	■	■	◆	■	■	■
Exposure assessment	◆	◆	◆	◆	◆	◆	◆
Green chemistry	■	■	■	■	◆	■	■
Green engineering	■	■	●	■	●	●	■
Integrated assessment modeling	■	■	■	■	●	■	■
Life cycle assessment	■	■	■	◆	◆	■	■
Resilience Analysis	■	■	●	●	■	●	■
Risk Assessment	◆	◆	◆	◆	◆	◆	◆
Sustainability Impact Assessment	●	●	●	●	●	●	●

***Legend**: ● = low, ■ = medium, ◆ = high.

±The results in the table should not be considered as evaluative findings because they may have been influenced by the extent of the committee's familiarity with the development and use of some of the tools.