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Standard Guide for Greener Cleanups[1]

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ε[1] NOTE—The adjunct order number for the X2. Technical Summary Form in Writable PDF format was editorially corrected (see 2.4) in January 2017.

1. Scope

1.1 Cleaning up *sites* improves environmental and public health conditions and as such can be viewed as "green." However, *cleanup* activities use energy, water, and natural resources. The process of *cleanup* therefore creates its own *environmental footprint*. This *guide* describes a process for evaluating and implementing activities to reduce the *environmental footprint* of a *cleanup* project in the United States while working within the applicable regulatory framework and satisfying all applicable legal requirements.

1.2 This *guide* may also be used as a process for *sites* that are not located in the United States; however, the specific legal references are not applicable.

1.3 This *guide* describes a process for identifying, evaluating, and incorporating *best management practices* (*BMPs*) and, when deemed appropriate, for integrating a *quantitative evaluation* into a *cleanup* to reduce its *environmental footprint*.

1.4 This *guide* is designed to be implemented in conjunction with any *cleanup* framework and should be used with other technical tools, guidance, policy, laws, and regulations to integrate *greener cleanup* practices, processes, and technologies into *cleanup* projects.

1.5 This *guide* provides a process for evaluating and implementing activities to reduce the *environmental footprint* of a *cleanup* and is not designed to instruct *users* on how to clean up contaminated *sites*.

1.6 ASTM also has a *guide* on Integrating Sustainable Objectives into *Cleanup* (E2876). That *guide* provides a broad framework for integrating elements of environmental, economic, and social aspects into *cleanups*. This *guide* may provide assistance with implementing E2876 and other sustainable remediation guidance, such as Holland, et al. (2011)(**1**).

1.7 This *guide* specifically applies to the *cleanup*, not the redevelopment, of a *site*. However, the reasonably anticipated use of a *site*, if known, may influence the *cleanup* goals and scope.

1.8 This *guide* should not be used as a justification to avoid, minimize, or delay implementation of specific *cleanup* activities. Nor should this *guide* be used as a justification for selecting *cleanup* activities that compromise *stakeholder* interests or goals for the *site*.

1.9 This *guide* does not supersede federal, state, or local regulations relating to protection of human health and the environment. No action taken in connection with implementing this *guide* should generate unacceptable risks to human health or the environment.

1.10 This *guide* may be integrated into complementary standards, *site*-specific regulatory documents, guidelines, or contractual agreements relating to sustainable or greener *cleanups*.

1.10.1 If the *cleanup* is governed by a regulatory program, the *user* should discuss with the regulator responsible for the *site* how this *guide* could be incorporated into the *cleanup* and whether the regulator deems it appropriate for the *user* to report the process and results to the regulatory program.

1.10.2 The contractual relationship or legal obligations existing between and among the parties associated with a *site* or *site cleanup* are beyond the scope of this *guide*.

1.11 This *guide* is composed of the following sections: Referenced Documents (Section 2); Terminology (Section 3); Significance and Use (Section 4); Planning and Scoping (Section 5); *BMP Process* (Section 6); *Quantitative Evaluation* (Section 7); Documentation and Reporting (Section 8); and Keywords (Section 9).

1.12 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the*

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responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E1527 Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process

E2091 Guide for Use of Activity and Use Limitations, Including Institutional and Engineering Controls

E2876 Guide for Integrating Sustainable Objectives into Cleanup

2.2 *USEPA Documents:*[3]

USEPA, Life Cycle Assessment: Principles and Practice, EPA/600/R-06/060 (May 2006)

USEPA, Green Remediation: Best Management Practices for Excavation and Surface Restoration, EPA 542-F-08-012 (December 2008)

USEPA, Principles for Greener Cleanups (August 2009a)

USEPA, Green Remediation Best Management Practices: Pump and Treat Technologies, EPA 542-F-09-005 (December 2009b)

USEPA, Green Remediation Best Management Practices: Site Investigation, EPA 542-F-09-004 (December 2009c)

USEPA, Green Remediation Best Management Practices: Bioremediation, EPA 542-F-10-006 (March 2010a)

USEPA, Green Remediation Best Management Practices: Soil Vapor Extraction & Air Sparging, EPA 542-F-10-007 (March 2010b)

USEPA, Green Remediation Best Management Practices: Clean Fuel & Emission Technologies for Site Cleanup, EPA 542-F-10-008 (August 2010c)

USEPA, Green Remediation Best Management Practices: Integrating Renewable Energy into Site Cleanup, EPA 542-F-11-006 (April 2011a)

USEPA, Green Remediation Best Management Practices: Sites with Leaking Underground Storage Tank Systems, EPA 542-F-11-008 (June 2011b)

USEPA, Green Remediation Best Management Practices: Landfill Cover Systems & Energy Production, EPA 542-F-11-024 (December 2011c)

USEPA, Methodology for Understanding and Reducing a Project's Environmental Footprint, EPA 542-R-12-002 (February 2012a)

USEPA, Green Remediation Best Management Practices: Implementing In Situ Thermal Technologies, EPA 542-F-12-029 (October 2012b)

2.3 *Other Documents:*[4]

International Standards Organization —Environmental Management—Life Cycle Assessment—Requirements and Guidelines, ISO 14044:2006 (2006)

2.4 *ASTM Adjuncts:*

X2. Technical Summary Form[5]

X3. *Greener Cleanup BMP* Table[6]

NOTE 1—Appendix X1 of this *guide* lists relevant material available from other government agencies and non-government organizations.

3. Terminology

3.1 *Definitions:*

3.1.1 *activity and use limitations*—legal or physical restrictions or limitations (that is, institutional or engineering controls) on the use of, or access to, a *site* or facility: *(1)* to reduce or eliminate potential exposure to *contaminants* in the environmental media on the property, or *(2)* to prevent activities that could interfere with the effectiveness of a response action in order to ensure maintenance of a condition of no significant risk to public health or the environment. See Guide E2091 for more information on *activity and use limitations*.

3.1.2 *best management practices (BMPs)*—activities that, if applicable to the situation, typically will reduce the *environmental footprint* of a *cleanup* activity.

3.1.3 *BMP categories*—groupings of *BMPs* based on how the *user* would consider each activity during the planning stages of the *cleanup*. *BMP categories* are intended as general guidance for organization and assessment purposes. Some *BMPs* are associated with multiple *BMP categories* in Appendix X3, *Greener Cleanup BMP* Table; therefore, generally the *user* should not eliminate *BMPs* by *BMP category*. The *Greener Cleanup BMP* Table identifies the *BMP category* that best applies to each *BMP*. These *BMPs* are organized into the following *BMP categories*: *(1)* Project Planning and Team Management; *(2)* Sampling and Analysis; *(3)* Materials; *(4)* Vehicles and Equipment; *(5)* Site Preparation and Land Restoration; *(6)* Buildings; *(7)* Power and Fuel; *(8)* Surface and Storm Water; and *(9)* Residual Solid and Liquid Waste.

3.1.4 *BMP process*—a systematic protocol to identify, prioritize, select, implement, and document the use of *BMPs* to reduce the *environmental footprint* of *cleanup* activities.

3.1.5 *cleanup*—the range of activities that may occur to address *releases* of *contaminants* at a *site* from the initiation of *site assessment* activities to achievement of *no further cleanup*. The environmental remediation industry also refers to *cleanup* as remediation or corrective action.

3.1.6 *cleanup phase*—the segments of a *cleanup* project that take place from the initiation of *site assessment* to achievement

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from United States Environmental Protection Agency (EPA), William Jefferson Clinton Federal Building, 1200 Pennsylvania Ave., NW, Washington, DC 20004, http://www.epa.gov.

[4] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, http://www.iso.org.

[5] Appendix X2 for E2893 Technical Summary Form in Writable PDF format available from ASTM International Headquarters. Order Adjunct No. ADJE289301B-E-PDF. Original adjunct produced in 2014. Adjunct last revised in 2016.

[6] Appendix X3 for E2893 BMP Table in Excel Format available from ASTM International Headquarters. Order Adjunct No. ADJE289302A-EA. Original adjunct produced in 2014. Adjunct last revised in 2016.

of *no further cleanup*. This *guide* divides a *cleanup* project into the following five segments: *site assessment*; *remedy selection*; *remedy design/implementation*; *operation, maintenance, and monitoring*; and *remedy optimization*. This terminology is generally consistent with standard industry terminology, but does not conform to every environmental *cleanup* program.

3.1.7 *CERCLA*—the Comprehensive Environmental Response, Compensation, and Liability Act, 42 U.S.C. § 9601 *et seq*., as amended, the primary federal statute that governs the imposition of liability for environmental *cleanups*. *CERCLA* is commonly referred to as Superfund.

3.1.8 *contaminant*—a *hazardous substance*, petroleum product, or other chemical that may pose a threat to human health or the environment when present in environmental media.

3.1.9 *core elements*—for purposes of this *guide*, five factors representing key areas for potentially reducing the *environmental footprint* of a *site cleanup*. These factors are: minimize total energy use and maximize use of renewable energy; minimize air pollutants and *greenhouse gas emissions*; minimize water use and impacts to water resources; reduce, reuse, and recycle materials and waste; and protect land and ecosystems.

3.1.10 *disturbance of vegetation*—removal, cutting, or alteration of plants, bushes, or canopy trees, particularly those that are mature, non-invasive, native species that provide food sources, micro-climates, nesting areas, or refuge supporting indigenous flora and fauna.

3.1.11 *emissions*—the discharge of a *contaminant* to air. However, in the context of *life cycle assessment (LCA)* and *footprint analysis*, this term refers to discharges to air, water, and soil, including *site contaminants* as well as discharges not typically considered *contaminants* in *site cleanup* such as water, nitrogen oxides, and particulate matter.

3.1.12 *environmental footprint*—a qualitative or quantitative estimate of various environmental contributions of a *cleanup phase* or activity to the *core elements*. A quantitative *environmental footprint* may be obtained through either a *footprint analysis* or *LCA*. Appendix X4 provides further clarification on the use of *footprint analysis* and *LCA*.

3.1.13 *environmental law*—any federal, state, or local statute, regulation, or ordinance relating to: the protection of the environment; pollution, investigation, or restoration of the environment or natural resources; or the handling, management, use, presence, transportation, processing, disposal, *release*, or threatened *release* of any *contaminant*. The term *environmental law* in the United States includes, but is not limited to, *CERCLA*, *RCRA*, and *TSCA*.

3.1.14 *final cleanup goals*—the objectives established to address *contaminants* at a *site* by a regulatory agency or through a voluntary *cleanup* program that, when met, protect human health and the environment. Users should review the applicable *cleanup* program for more information on establishing *final cleanup goals* at a particular *site*.

3.1.15 *footprint analysis*—a quantitative estimate of an *environmental footprint* for a *cleanup phase* or activity. The analysis entails the compilation of inputs and outputs to estimate potential contributions (that is, *emissions* or resource use) to the *core elements*. A *footprint analysis* may include raw material acquisition, materials manufacturing, and transportation related to the *cleanup*, in addition to on-site construction, implementation, monitoring, and decommissioning. Results from a *footprint analysis* are typically reported as *emissions* (for example, nitrogen oxides, carbon dioxide equivalents, or total hazardous air pollutants) or resource use (for example, water, energy, or materials use) organized in terms of the five *core elements*.

3.1.15.1 *Discussion*—there are two fundamental differences between *footprint analysis* and *LCA*: *(1)* an *LCA* typically considers the full life cycle of the components of a *cleanup phase* or activity. In contrast, a *footprint analysis* may consider the full life cycle of the components of a *cleanup phase* or activity, but more commonly selects abbreviated boundaries; and *(2)* results from an *LCA* are described in terms of human health and environmental impacts whereas the results from a *footprint analysis* are reported in terms of quantities of *emissions* and resource use, without taking the next step to evaluate the human health and environmental impacts from those *emissions* and resource use.

3.1.16 *greener cleanup*—the incorporation of practices, processes, and technologies into *cleanup* activities with the goal of reducing impacts to the environment through reduced demands on natural resources and decreased *emissions* to the environment. A *greener cleanup* considers the five *core elements*, while protecting human health and the environment. In the environmental remediation industry, this term is used interchangeably with green *cleanup*, green remediation, and greener remediation.

3.1.17 *greenhouse gases*—vaporous constituents of the earth's atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths, including carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

3.1.17.1 *Discussion*—carbon dioxide, methane, and nitrous oxide have been the main focus of *greenhouse gas* emission evaluations within the environmental remediation industry.

3.1.18 *guide*—a compendium of information or series of options that does not recommend a specific course of action. A *guide* increases the awareness of information and approaches in a given subject area.

3.1.19 *habitat*—the physical and natural environment, including niche environments (micro-habitats) that support local indigenous species and related supporting vegetation, food sources, areas for nesting and refuge, soils, and hydrology; and larger environmental features (macro-habitats), such as a bank on a waterway or vegetated, open, wildlife corridors for foraging and natural migration. Areas of *habitat* may be used temporarily by species and timing of a disturbance may minimize impact.

3.1.20 *hazardous substance*—a substance defined as a *hazardous substance* pursuant to *CERCLA*, 42 U.S.C. § 9601(14), as interpreted by EPA regulations.

3.1.21 *impact category*—an *LCA* term representing a compilation of different *emissions* or other metrics, such as resource use, that contribute to a specific environmental or health effect. Examples of *impact categories* are global warming, aquatic acidification, smog formation, and respiratory effects. Some *emissions* and resource use contribute to more than one *impact category*.

3.1.22 *lead environmental professional*—for the purposes of this *guide*, a person possessing sufficient education, training, and experience to: *(1)* meet the requirements set forth in Practice E1527 Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process *(2)* exercise professional judgment regarding the evaluation and implementation of *BMPs* for the *cleanup phases* being addressed by this *guide*, and, if applicable, *(3)* exercise professional judgment in conducting *footprint analyses* or *LCAs*. The person may be the *user*, an independent contractor, or an employee of the *user*.

3.1.23 *life cycle assessment (LCA)*—a quantitative estimate of an *environmental footprint* for a *cleanup phase* or activity. The assessment entails the compilation and evaluation of inputs and outputs to estimate the potential human health and environmental impacts from a *cleanup phase* or activity, from raw material acquisition, materials manufacturing and transportation, to on-site construction, implementation, monitoring, and decommissioning. Results from an *LCA* are reported in *impact categories*, which can be mapped to the five *core elements*. For a description of the differences between *LCA* and *footprint analysis*, see the discussion following 3.1.15, *footprint analysis* and Appendix X4.

3.1.24 *LUST program*—the Leaking Underground Storage Tank Program under *RCRA* that gives EPA and states, under cooperative agreements with EPA, authority to clean up *releases* from regulated underground storage tank systems or require owners and operators to do so (42 U.S.C. § 6991b). EPA's federal underground storage tank regulations require that contaminated *LUST sites* be cleaned up to restore and protect groundwater resources and create a safe environment for those who live or work around these *sites*.

3.1.25 *no further cleanup*—the point in time when *final cleanup goals* are achieved at a *site*, there is no active ongoing *cleanup*, and the *site* is protective of human health and the environment based on the property's *reasonably anticipated future use*. At some *sites*, *activity and use limitations* must be maintained to ensure protection after the *final cleanup goals* are achieved. At *sites* being cleaned up pursuant to a regulatory program, the regulatory agency providing oversight generally issues a determination that the *site* has achieved the *final cleanup goals* and, therefore, *no further cleanup* is required. This includes the term "*site* closure" used in some programs.

3.1.26 *operation, maintenance, and monitoring (OMM)*—the *cleanup phase* following *remedy design/implementation* where the *remedy* is periodically evaluated to ensure that it is operating as intended. Repairs or adjustments may be implemented to maintain or improve progress toward achieving *final cleanup goals*. This *cleanup phase* may include periodic sampling and analysis of environmental media to assist with *remedy* performance evaluation.

3.1.27 *opportunity assessment*—for the purposes of this *guide*, a review of *BMPs*, including those listed in Appendix X3, to determine which *BMPs* apply to the *cleanup phase* being evaluated. This is a screening level assessment. Additional sources of *BMPs*, such as checklists, guidelines, matrices, or industry-recognized tables of *BMPs*, may also be included. During an *opportunity assessment*, all potentially applicable *BMPs* are retained regardless of cost.

3.1.28 *petroleum products*—those substances included within the meaning of the petroleum exclusion to *CERCLA*, 42 U.S.C. § 9601(14), as interpreted by the courts and EPA: "petroleum, including crude oil or any fraction thereof which is not otherwise specifically listed or designated as a *hazardous substance*… the term does not include natural gas, natural gas liquids, liquefied natural gas, or synthetic gas usable for fuel (or mixtures of natural gas and such synthetic gas)."

3.1.29 *project team*—for purposes of this *guide*, the group of individuals and experts brought together to implement the activities identified by this document for a specific *site*. The group typically includes the *lead environmental professional*, the *user*, the state and/or federal regulator, the *site* owner representative, and additional experts, as needed. For some *sites*, the *project team* may include community *stakeholders*. The *lead environmental professional* and *user* can be the same person or work for the same entity.

3.1.30 *quantitative evaluation*—for purposes of this *guide*, the *site*-specific numerical estimate of contributions to the *core elements* for a *cleanup phase* or activity as calculated using *footprint analysis* or *LCA*.

3.1.31 *RCRA*—the Resource Conservation and Recovery Act, 42 U.S.C. § 6901 *et seq*., as amended, sometimes also known as the Solid Waste Disposal Act, the primary federal statute that, *inter alia*, establishes a framework for regulation of solid and hazardous waste and for promoting resource recovery through a federal-state partnership.

3.1.32 *reasonably anticipated future use*—the future use of a *site* that can be predicted with a reasonably high degree of certainty given historical use, current use, and local governmental planning and zoning.

3.1.32.1 *Discussion*—other factors that may be considered in determining *reasonably anticipated future use* include accessibility of the *site* to existing infrastructure, recent development patterns, cultural factors, environmental justice, regional trends, and community preference or acceptance.

3.1.33 *release*—as defined by Section 101(20) of *CERCLA*, 42 U.S.C. § 9601(22), any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment, including abandoning or discarding barrels, containers, and other closed receptacles containing any *contaminant*.

3.1.34 *remedial option*—for the purposes of this *guide*, a technology or activity that removes or controls exposure to *contaminants* present at a *site*. In the environmental remediation industry, this term is also referred to as a remedial alternative.

3.1.35 *remedy*—the technology or *cleanup* activity that is implemented to address *releases* of *contaminants* at a *site*.

3.1.36 *remedy design/implementation*—for the purposes of this *guide*, the *cleanup phase* following *remedy selection* which includes incorporating engineering and geologic studies to develop specifications for the *remedy* as well as the actual construction, to the extent construction is part of the *remedy*.

3.1.37 *remedy optimization*—for the purpose of this *guide*, the *cleanup phase* following *remedy design/implementation* that is implemented at some *sites* to improve *remedy* performance in meeting *final cleanup goals*, reducing its *environmental footprint*, or both. In some situations, *remedy optimization* leads to technology design refinements, such as changes in the type of pumps or the location of groundwater recovery wells. In these cases, *remedy optimization* is analogous to the *remedy design/implementation cleanup phase*. In other situations, *remedy optimization* leads to the selection and implementation of an alternative technology. In those situations, *remedy optimization* is analogous to the *remedy selection cleanup phase*.

3.1.38 *remedy selection*—the *cleanup phase* in which potential *remedial options* are evaluated and compared to one another and the optimum technology(ies) or activity is selected to meet *final cleanup goals* or interim *cleanup* objectives.

3.1.39 *site*—an area defined by the likely physical distribution of *contaminants* from a *release* warranting *cleanup* activities. A *site* can be an entire property or facility, a defined area or portion of a facility or property, or multiple facilities or properties. One facility may contain multiple *sites*. Multiple *sites* at one facility may be addressed individually or as a group.

3.1.40 *site assessment*—the *cleanup phase* in which the *site* is characterized to determine if the concentrations and distribution of *contaminants released* pose a potential risk to human health or the environment. More specifically, this *cleanup phase* involves collecting data on: soil, groundwater, air, surface water, and/or sediment quality; *site* characteristics (for example, subsurface geology, geochemistry, soil properties and structures, hydrology, and surface characteristics); land and resource use; and potential receptors. The *site assessment* generates data to develop a conceptual site model and inform decisions regarding the *cleanup*, if necessary (which may include a risk assessment). Regulatory requirements for *site assessment* may vary by program. In the environmental remediation industry, *site assessment* is also referred to as remedial investigation, *site* investigation, or *site* characterization.

3.1.41 *stakeholders*—for the purposes of this *guide*, individuals, organizations, or entities that directly or indirectly affect, or are affected by, *contaminant releases* or *cleanup* activities. *Stakeholders* are *site*-specific and can include members of the local community (for example, residents, elected officials, regular visitors, nearby businesses, economic development corporations), regulatory agencies, the *site* owner or responsible parties, and future *users* of the property.

3.1.42 *TSCA*—the Toxic Substances Control Act, 15 U.S.C. § 2601 *et seq*., the primary federal statute that, *inter alia*, provides EPA with the regulatory authority to require reporting, recordkeeping, and testing requirements for certain chemicals and mixtures, and to establish restrictions for the manufacture, use, processing, storage, distribution in commerce, and/or disposal of certain chemicals and mixtures.

3.1.43 *user*—the party seeking to use this *guide* to conduct a *greener cleanup*. The *user* can be the *site* owner, responsible party, an employee of these entities, or an agent of the *site* owner or responsible party (for example, a consultant).

4. Significance and Use

4.1 *Purpose*—This *guide* provides a process for identifying, prioritizing, selecting, implementing, documenting, and reporting activities to reduce the *environmental footprint* of a *cleanup* as defined by the following *core elements*.

4.1.1 *Minimize Total Energy Use and Maximize Use of Renewable Energy*—Reducing total energy use while also identifying means to increase the use of renewable energies throughout the *cleanup*. Possible methods may include reducing energy use, using energy efficient equipment, using on-site renewable resources (for example, wind, solar), and purchasing commercial energy from renewable resources.

4.1.2 *Minimize Air Pollutants and Greenhouse Gas Emissions*—Reducing total air *emissions*, including *emissions* of air pollutants and *greenhouse gases*, throughout the *cleanup*. Possible methods may include minimizing the generation and transport of airborne *contaminants* and dust, using efficient emitting equipment (for example, vehicles and heavy equipment), using advanced *emission* controls, and using cleaner fuels or hybrid technologies.

4.1.3 *Minimize Water Use and Impacts to Water Resources*—Minimizing the use of water and impacts to water resources throughout the *cleanup*. Possible methods may include conserving water use in *cleanup* processes, using water efficient products, capturing and reclaiming water for reuse, revegetating with water efficient plants, and employing traditional *BMPs* for storm water, erosion, and sedimentation control.

4.1.4 *Reduce, Reuse, and Recycle Materials and Waste*—Minimizing the use of virgin materials and generation of waste throughout the *cleanup* as well as maximizing the use of recycled materials. Possible methods may include using recycled and locally generated materials, reusing waste materials (for example, concrete made with coal combustion products), diverting construction and demolition debris from disposal by recycling recovered resources, and using rapidly renewable materials or certified wood products.

4.1.5 *Protect Land and Ecosystems*—Reducing impacts to the land and ecosystem services throughout the *cleanup*. Possible methods may include minimizing the area requiring *activity and use limitations* by the removal or destruction of *contaminants*; identifying the presence of and limiting the disturbance of mature, non-invasive, native vegetation, surface hydrology, soils, and *habitats* in the *cleanup* area; and minimizing noise and light disturbance.

4.2 *Professional Experience*—This *guide* requires the skills of a *lead environmental professional* and *project team*, as appropriate, to evaluate and apply *greener cleanup* practices, processes, and technologies to each *cleanup phase* while meeting cleanup program-specific requirements and ensuring protection of human health and the environment. This *guide* presumes the *lead environmental professional* is knowledgeable in *cleanup* practices and experienced in identifying and satisfying applicable statutory or regulatory *cleanup* requirements and expectations.

4.3 *Uncertainty in Greener Cleanups*—Professional judgment, interpretation, and some uncertainty are inherent in the *greener cleanups* process even when decisions are based upon objective scientific principles and accepted industry practices. Although such uncertainties are inevitable, they typically will not detract from the ability of the *user* to achieve meaningful improvements in the *site cleanup*.

4.4 *Regulatory Context*—The *user* is responsible for determining the regulatory context, and associated constraints and obligations for each *site*, and shall comply with all applicable laws and regulations, including *CERCLA*, *RCRA*, *TSCA*, and other *environmental laws*.

4.4.1 The *user* shall comply with health and safety requirements under the Occupational Safety and Health Act and parallel state statutes and regulations.

4.4.2 This *guide* may not be appropriate for certain *cleanups*, such as some emergency response actions, that do not allow sufficient time for its application.

4.4.3 Implementation of this *guide* may involve additional costs or require changes to the *cleanup* schedule; however, its implementation should not unduly delay a *cleanup* or result in the imposition of unreasonable costs.

4.5 *Process Implementation*—This *guide* may be initiated at any time during any *cleanup phase*, including during: *site assessment*; *remedy selection*; *remedy design/implementation*; *operation, maintenance, and monitoring*; and *remedy optimization*.

4.6 *Process Overview*—At initiation, the *user* should review Section 3, Terminology, and then proceed to Section 4, Significance and Use, and Section 5, Planning and Scoping. *Users* who plan to implement the *BMP process* only, should proceed to Section 6. *Users* who plan to employ a *quantitative evaluation* should proceed to Section 7, prior to, or during implementing Section 6. Section 8 describes documentation and reporting.

4.6.1 Section 5, Planning and Scoping, describes information the *user* should collect and consider to assist in making several *site*-specific, *user*-defined decisions for implementing the *guide*.

4.6.2 Section 6, *BMP Process*, describes steps for the *user* to identify, prioritize, select, implement, and document *BMPs*.

4.6.3 Section 7, *Quantitative Evaluation*, describes a process for implementing a *footprint analysis* or *LCA*. Section 7 is not designed to instruct the *user* on how to perform *footprint analysis* or *LCA*. It presumes that a member of the *project team* is knowledgeable in a *quantitative evaluation* approach applicable to the *site*.

4.6.4 Section 8 describes recommended documentation and reporting on the implementation of the *guide*.

4.6.5 Section 9 provides keywords for indexing and searching purposes.

4.6.6 This *guide* includes four appendices.

4.6.6.1 Appendix X1, Supporting Documentation, provides supplemental reference material for the *user* to consider when implementing this *guide*.

4.6.6.2 Appendix X2, Technical Summary Form, is a template of the reporting expectations described in Section 8. This includes general information about the *site* (for example, location), process steps, and *greener cleanup* outcomes from implementing the *guide*. The *user* may employ this template or another applicable format for reporting results from implementing this *guide*. A writeable pdf file of the Technical Summary Form is available as an adjunct.[5]

4.6.6.3 Appendix X3, *Greener Cleanup BMP* Table, supports Section 6 by providing a comprehensive list of *BMPs* to assist the *user*. Standard best management practices for *cleanup* (that is, those related to engineering and technology, but unrelated to reducing *environmental footprints*) are generally not included in the *Greener Cleanup BMP* Table. An Excel-based file of the *Greener Cleanup BMP* Table is available as an adjunct.[6]

4.6.6.4 Appendix X4, Supplemental Information for a *Quantitative Evaluation*, supports Section 7 by providing general information on *footprint analysis* and *LCA*, including their uses, similarities, and differences.

5. Planning and Scoping

5.1 When applying this *guide*, the *user* should perform the following planning and scoping activities: select a *lead environmental professional*; assemble a *project team*; identify the applicable *cleanup* program and project objectives; compile *site* data; identify key *stakeholders*; develop a project budget and schedule; determine which *cleanup phases* to apply the *guide* to and whether to apply the *BMP process* alone or perform a *quantitative evaluation* in conjunction with *BMPs*; and establish a plan for reporting results and for making those results publicly available. The *user* should perform these activities for each *cleanup phase* being evaluated in connection with the use of this *guide*. However, some of the activities will be identical from one *cleanup phase* to the next and should be carried forward and built upon whenever possible as the project progresses.

5.1.1 The *user* should select a *lead environmental professional*. The *lead environmental professional* may be an independent contractor or an employee of the *user*. In addition, the *user* can be the *lead environmental professional*.

5.1.2 The *user* should assemble the appropriate *project team* for the *greener cleanup*, considering factors such as: the technical expertise related to the *cleanup* activities being considered; the *greener cleanup* evaluation and implementation approach (that is, *BMP process* only or a *quantitative evaluation* followed by the *BMP process*); legal requirements; *stakeholder* interests and concerns; project budget; and schedule.

5.1.3 If the *cleanup* is governed by a regulatory program, the *user* should identify: the regulatory program governing the *cleanup*; the goals and requirements for each *cleanup phase* going forward to achieve a determination of *no further cleanup*; applicable *environmental laws*; and the program's *greener cleanup* policies. The *user* should also discuss expectations for greener *cleanups* and how this guide could be incorporated into the cleanup with the regulator responsible for the site, prior to implementing the *guide*.

5.1.4 The *user* should compile *site* data, such as environmental, demographic, and land use characteristics and other factors that influence the *cleanup*.

5.1.4.1 The *user* should identify the *site* size; potential or actual environmental media impacts; the types of *contaminants* present and their distribution, if known; and other *site* characteristics relevant to the use of this *guide*.

5.1.4.2 The *user* should identify the current and *reasonably anticipated future use* (if known) for the *site* and for properties located proximal to the *site*.

5.1.5 The *user* should identify key *stakeholders* and assess their interests and concerns regarding the *cleanup* activities being considered and the potential reuse options for the *site*, if applicable.

5.1.6 The *user* should consider the budget and schedule, as well as any cost constraints or other limitations for the project, and determine how the *BMP process* or *quantitative evaluation* will be integrated into the project in light of those factors.

5.2 The *user* should determine the applicability of the standard to the current *cleanup phase* and future *cleanup phases* to determine which *cleanup phases* to apply the guide as well as whether to employ the *BMP process* alone or the *quantitative evaluation* followed by the *BMP process*. The *BMP process* relies on professional judgment to prioritize and select activities that will likely reduce the *environmental footprint*. The *quantitative evaluation* relies on estimated data inputs to quantify anticipated *environmental footprint* reductions prior to implementing *BMPs*. The *user* should consider the *site* information listed above in 5.1.4 through 5.1.6 and the following information to determine which evaluation is more appropriate for each *cleanup phase* at a *site*.

5.2.1 The *BMP process* and *quantitative evaluation* can be applied to all *cleanup phases*. However, one approach may be better suited relative to the other in certain situations. For example, while a *quantitative evaluation* is applicable to the *site assessment*, in many situations the likely *environmental footprint* reductions may not be sufficient to justify the investment of additional time and effort to conduct the analysis. Similarly, implementation of the *BMP process* is generally not warranted at *remedy selection*; however, evaluating *BMPs* during *remedy selection* may be constructive. More specifically, if two remedies are equally protective and effective, evaluating *BMPs* prospectively through a *quantitative evaluation* can help the *user* identify which *remedy* has greater potential for *environmental footprint* reductions. The *user* should consult Fig. 1 and Table 1 for guidance on the applicability of the *BMP process* or *quantitative evaluation* to the *cleanup phases*.

5.2.2 The *BMP process* is appropriate at any *site*, regardless of its size or complexity, whereas the *quantitative evaluation* followed by the *BMP process* is best suited to relatively large-scale or complex *cleanups* where a range of approaches could be implemented to achieve the objectives for that *cleanup phase*.

5.2.3 The *BMP process* takes less time to complete than a *quantitative evaluation* followed by the *BMP process*. However, a *quantitative evaluation* followed by the *BMP process* may identify more significant *environmental footprint* reductions than the *BMP process* alone.

5.2.4 A *quantitative evaluation* will need an individual on the *project team* who is knowledgeable in *footprint analysis* or *LCA*.

5.3 The *user* should review Section 8 for a discussion about the type of information to document and report, when to document and report it, and suggested options to make the information publicly available.

6. BMP Process

6.1 The goal of the *BMP process* is to enable the *user* to identify, prioritize, select, implement, and document the use of *BMPs* to reduce the *environmental footprint* of *cleanup* activities.

6.2 *Selection of Applicable Cleanup Phases*—The *user* should consider the information collected in the planning and scoping performed under Section 5 to determine the *cleanup phase(s)* that will be assessed when performing the *BMP process*.

6.3 The *BMP process* is applied to one specific *cleanup phase* at a time. If the *user* is implementing the *BMP process* during subsequent phases of a *cleanup*, all steps of the *BMP process* should be followed for each *cleanup phase* in which this *guide* is applied. When considering *BMPs* for subsequent *cleanup phases*, the experience of implementing *BMPs* in prior phases may be useful in determining whether to continue implementing the *BMPs* already selected or to seek different *BMPs*. The *user* should anticipate implementing and building upon the *BMPs* used in earlier phases of the project through the end of the project, if applicable.

6.4 *Greener Cleanup Core Elements*—When evaluating *BMPs*, the *user* should consider the best overall approach for reducing the *environmental footprint* of the planned *cleanup* activities by reviewing the *core elements* defined in Section 4.1.

6.5 The *user* should understand the following about the *BMP process*:

6.5.1 Appendix X3, *Greener Cleanup BMP* Table, provides a list of *greener cleanup BMPs*. These *BMPs* are organized into the following *BMP categories*: *(1)* Project Planning and Team Management; *(2)* Sampling and Analysis; *(3)* Materials; *(4)* Vehicles and Equipment; *(5) Site* Preparation/Land Restoration; *(6)* Buildings; *(7)* Power and Fuel; *(8)* Surface/Storm Water; and *(9)* Residual Solid and Liquid Waste.

6.5.1.1 The *user* is also encouraged to identify or develop and implement *BMPs* not included in Appendix X3 that are consistent with the spirit and intent of the *guide* because they reduce the *environmental footprint* of the *cleanup*.

6.5.2 All *BMPs* that are required by law or regulation should be implemented and documented, as described in Section 8.

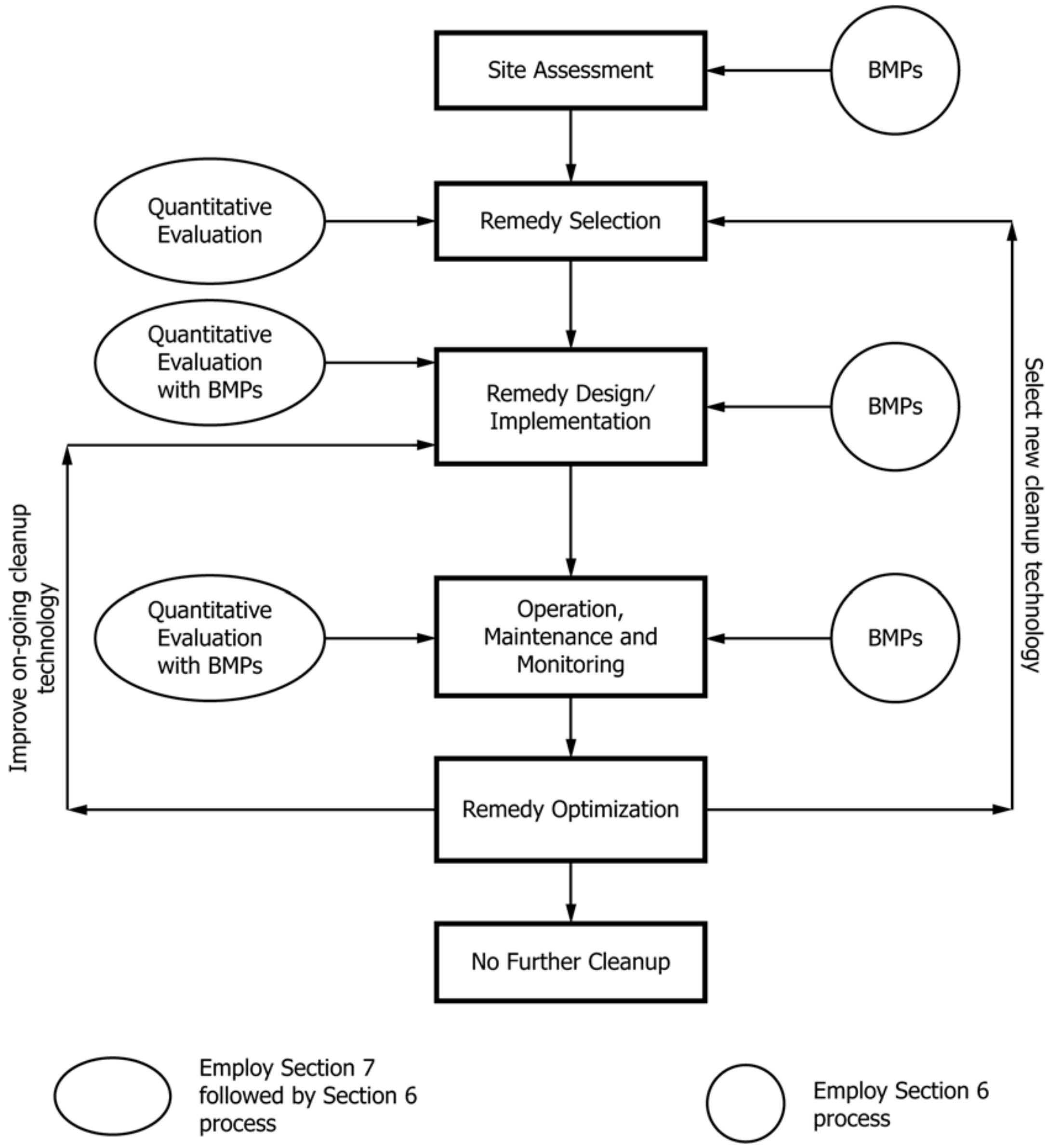

FIG. 1 ASTM Greener Cleanup Overview

6.5.3 As part of the *BMP process*, the *user* may elect to perform a *quantitative evaluation* to optimize performance of a specific *BMP* or to calculate the anticipated numerical *environmental footprint* reduction from implementing the *BMP*. The process of performing a *quantitative evaluation* is described in Section 7.

6.5.4 When evaluating *BMPs*, the *user* may find the following references helpful: Butler, et al., 2011(**2**); Ellis & Hadley, 2009(**3**); ITRC, 2011(**4**); U.S. Army Corp of Engineers, 2010(**5**); and USEPA, 2008, 2009a, 2009b, 2010a, 2010b, 2010c, 2011a, 2011b, 2011c, 2012a, and 2012b.

6.6 *BMP Process*—The *BMP process* involves the following five steps: Step 1: *BMP Opportunity Assessment*; Step 2: *BMP* Prioritization; Step 3: *BMP* Selection; Step 4: *BMP* Implementation; and Step 5: *BMP* Documentation. The *user* should follow all the steps described below and summarized in Fig. 2.

6.6.1 *Step 1: BMP Opportunity Assessment*—This is a screening level assessment. During this step, the *user* identifies all *BMPs* considered potentially applicable to the *site* conditions. Appendix X3 provides a robust list of *BMPs*; however, the *user* is encouraged to identify additional *BMPs* as part of this step, using checklists, guidelines, matrices, or tables and/or

TABLE 1 Timing for Entering and Implementing

Cleanup Phase	Enter	Implement	
		BMP Process	Quantitative Evaluation
Site Assessment	Anytime during the investigation	✓	Generally not warranted
Remedy Selection	When evaluating *cleanup* options	Generally not warranted	✓
Remedy Design/ Implementation	When designing or implementing the remedy	✓	✓
Operation Maintenance and Monitoring (OMM)	Anytime during OMM	✓	✓
Remedy Optimization	Anytime during OMM	✓	✓

relevant literature or trade publications addressing *BMPs* recognized within the environmental remediation industry or within similar industries that utilize environmentally beneficial practices, evaluations, and technologies (see 6.5.4).

6.6.1.1 The *user* should identify and include all *BMPs* that are required by law or regulation.

6.6.1.2 During this step, the *user* should consider only whether each individual *BMP* is potentially applicable to the *cleanup phase* under evaluation, without regard to factors that ultimately will influence the decision to use a particular *BMP*, such as cost, logistics, or the relative benefits of other *BMPs*.

6.6.2 *Step 2: BMP Prioritization*—The *user* reviews the *BMPs* retained in Step 1 and prioritizes the *BMPs* based on the relative ability of each *BMP* to reduce the *environmental footprint* of the *cleanup* activity.

6.6.2.1 The *user* should identify those *BMPs* that are relatively unlikely to result in a significant reduction of the *environmental footprint* and assign them lower priority. The purpose of this designation is to facilitate the elimination of those lower-value *BMPs* in Step 3, in favor of higher-value *BMPs*.

6.6.2.2 The prioritization is based on professional judgment and does not require a detailed analysis.

6.6.2.3 The *user* may deem *BMPs* to be of higher-value based on regional, state, or local considerations, including *stakeholder* concerns. For example, particulate *emissions* may be a priority in an area of non-attainment; water use may be a priority in arid areas; waste generation may be a priority in a community with concerns regarding landfill space; and *greenhouse gas emissions* may be a priority to a municipality or state with *greenhouse gas* reduction goals. Other considerations include the potential for a *BMP* to gain benefits over multiple *core elements*, volumes of material or waste reduced to make a meaningful impact, and limitations in local availability of specific materials.

6.6.2.4 If there are numerous potentially applicable *BMPs*, the *user* may group *BMPs* into categories (for example, high, medium, low) based on the relative anticipated *environmental footprint* reductions.

6.6.2.5 If a *BMP* has potential negative effects on one or more *core elements* but positive effects on others, the *user* should factor in those anticipated outcomes in the prioritization process.

6.6.2.6 As part of this step, the *user* should prepare a prioritized list of *BMPs*.

6.6.3 *Step 3: BMP Selection*—The *user* should review each *BMP* in the prioritized list from Step 2 and select *BMPs* to retain for implementation. This selection should be based on potential *environmental footprint* reductions, relative to other pertinent factors such as implementability, effectiveness, reliability, short-term risks, community concerns, cost, and potential for environmental trade-offs. The *user* should consider the unwanted transfer of *contaminants* from one environmental media to another, or negative effects on one *core element* from implementing a *BMP* with positive effects on another *core element*. The *user* should document the rationale for eliminating *BMPs* identified in Step 2.

6.6.3.1 The *user* should select *BMPs* that reduce or have no effect on the project cost, unless there is a specific reason not to do so (see Section 6.6.3 above for examples of factors). Some *users* may elect to select *BMPs* even if implementation results in an increase in project cost. The cost evaluation may assess the return on investment and other factors such as *environmental footprint* reductions achieved per unit cost and the degree to which the investment is beneficial to the overall project goals.

6.6.4 *Step 4: BMP Implementation*—The *user* should implement the selected *BMPs*.

6.6.4.1 If during implementation of the selected *BMPs*, new information or changed circumstances relevant to the *BMP* or the *site* render a *BMP* selected in Step 3 inapplicable, impracticable to implement, cost-prohibitive, or unacceptable to the public, the *user* may elect not to implement that specific *BMP*. The *user* should document the rationale for not implementing any selected *BMPs* due to challenges that arise during implementation.

6.6.5 *Step 5: BMP Documentation*—The *user* should record Step 2 through Step 4 in a table. This includes a prioritized list of *BMPs* that apply to the *site* conditions, identifying those that are implemented and those that were not implemented, with the associated rationale. If the *BMPs* have not been implemented at the time of report preparation, then the *user* can limit the reporting to Step 2 and Step 3. A single table can be used for this documentation.

6.6.5.1 If a *quantitative evaluation* is to be performed to assist in selecting applicable *BMPs* by providing numerical data to support the *BMP* selection or design, the *user* should follow the steps described in Section 7 for implementing the *quantitative evaluation*.

7. Quantitative Evaluation

7.1 *Selection of Applicable Cleanup Phases*—The *user* should consider the information collected in the planning and scoping performed under Section 5 to determine the *cleanup phases* that will be assessed with a *quantitative evaluation*.

7.2 The *user* should understand the following general considerations:

7.2.1 In the context of this *guide*, a *quantitative evaluation* is inclusive of the following: *emissions*, resource use, and wastes related to the *cleanup*, as estimated using either a *footprint analysis* or *LCA*.

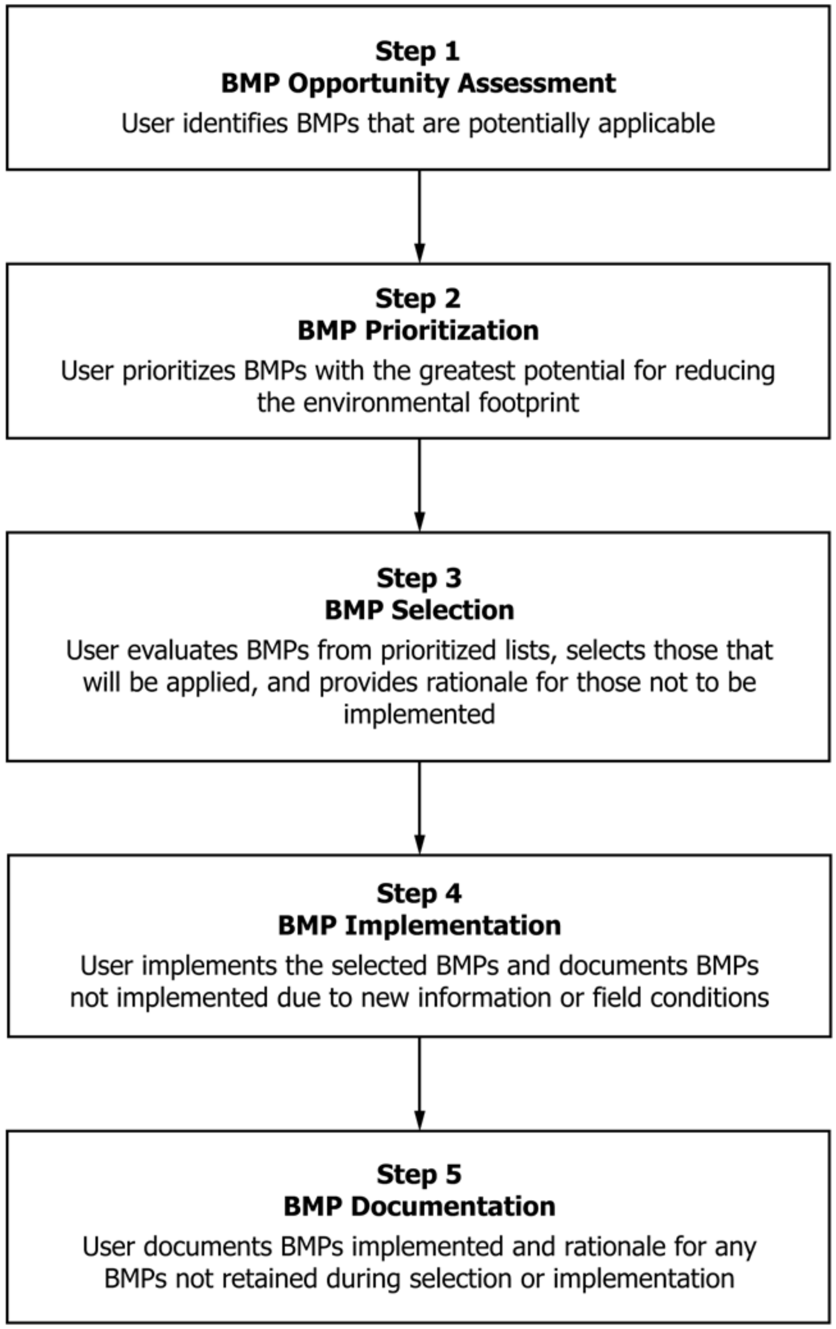

FIG. 2 BMP Process

7.2.2 This *guide* refers to *quantitative evaluations* using *footprint analysis* and *LCA*. Appendix X4 provides an overview and comparison of how a *quantitative evaluation* is completed with these two approaches. This appendix is intended to be instructive to *users* who are not familiar with *footprint analysis* or *LCA*.

7.2.3 The main purpose of a *quantitative evaluation* is to provide information on the most significant contributions to a *cleanup phase* or activity's *environmental footprint* relative to the *core elements*. In addition, a *quantitative evaluation* can facilitate decisions by estimating potential *environmental footprint* reductions achieved by specific *BMPs*.

7.2.4 The *guide* instructs the *user* to follow seven steps for conducting a *quantitative evaluation*. Other stepwise methodologies, such as ISO 14044 (ISO, 2006), SURF Guidance for Footprint Assessments and LCAs (Favara, et al., 2011(6)), USEPA's Life Cycle Assessment: Principles and Practices (USEPA, 2006), and USEPA's Methodology for

Understanding and Reducing a Project's Environmental Footprint (USEPA, 2012) may be used, provided they embody the same steps.

7.3 *Quantitative Evaluation Scope and Application*—The *quantitative evaluation* is most appropriate for three *cleanup phases*: *remedy selection*, *remedy design/implementation*, and *remedy optimization*. However, the *user* is not precluded from applying a *quantitative evaluation* process at any time during a *cleanup*. The *user* should consult Fig. 1 and Table 1 for guidance on performing the *BMP process* or *quantitative evaluation* relative to the *cleanup phases*.

7.3.1 *Quantitative Evaluation for Remedy Selection or Remedy Optimization*—In the evaluation of *remedial options*, new or revisited, the *user* considers how various *remedial options* may contribute to the *environmental footprint*. Conducting a *quantitative evaluation* at this *cleanup phase* provides the *user* with information to help identify *environmental footprint* reduction opportunities for all alternatives that are protective of human health and the environment, comply with applicable environmental regulations and guidance, and meet project objectives.

7.3.1.1 When evaluating several *remedial options* the *user* should endeavor to improve each alternative, to the extent practicable, to reduce the projected *environmental footprint* of the *remedial option* before the *quantitative evaluation* is conducted. These improvements are based on professional judgment, but do not warrant detailed analyses.

7.3.2 *Quantitative Evaluation for Remedy Design/Implementation or Remedy Optimization*—In the evaluation of a single *remedial option*, new or revisited, the *user* assesses several permutations of the *remedial option*. This *quantitative evaluation* may help to identify approaches with a lower *environmental footprint* to incorporate into the design process.

7.3.2.1 In assessing permutations, the *user* first makes a *quantitative evaluation* of the planned *remedy* or, in the situation of *remedy optimization*, the current *remedy*, to determine a baseline *environmental footprint*. Then the *user* evaluates permutations with respect to the baseline. The permutations may include variations such as different treatment reagents, different equipment design or configuration, or different sources of energy. The assessment of permutations will assist the *user* in finding the optimal balance in *remedy design* and *environmental footprint* reductions relative to implementability, effectiveness, cost, and other relevant *cleanup* factors.

7.3.2.2 The *user* should conduct the *quantitative evaluation* as early as possible in the design or optimization process to identify opportunities to reduce the *environmental footprint* of the selected *remedy*.

7.4 *Quantitative Evaluation Process*—When conducting a *quantitative evaluation*, the *user* should follow these steps: Step 1: Goal and Approach; Step 2: Boundary Definition; Step 3: *Core Elements* and Contributors to the *Core Elements*; Step 4: Collection and Organization of Information; Step 5: Calculations for *Quantitative Evaluation*; Step 6: Sensitivity and Uncertainty Analyses; and Step 7: Documentation. The main steps of the process are described below and summarized in Fig. 3.

7.4.1 *Step 1: Goal and Approach*—The *user* should identify the need for a *quantitative evaluation* and document the goal and approach of the *quantitative evaluation*. The goal sets forth the environmental questions to be answered with the *quantitative evaluation* and how the *quantitative evaluation* will be used in decision-making. The approach provides the details of how the *quantitative evaluation* will be conducted (for example, tools, resources), reviewed, and documented.

7.4.1.1 As part of the approach the *user* should decide whether to employ *footprint analysis* or *LCA*. Appendix X4 describes attributes of each of these approaches.

7.4.2 *Step 2: Boundary Definition*—The *user* should determine the activity, geographic, and temporal boundaries of the study. In defining the boundaries, the *user* should take into consideration not only on-site *cleanup* activities but also off-site activities that support the *cleanup*, because the *environmental footprints* of most *cleanups* have significant contributions from off-site activities.

7.4.2.1 The activity boundary establishes which *site* and *cleanup* activities are included in the *quantitative evaluation*. For example, the activity boundary at a *site* may include activities related to groundwater treatment, but not related to source removal.

7.4.2.2 The geographic boundary includes how much of the *cleanup* life cycle (that is, geographic location of the *site* and geographic location of activities, such as manufacturing and waste management, that occur off-site but support the *site cleanup*) is included in the *quantitative evaluation*.

7.4.2.3 The temporal boundary establishes the timeframe for which the *quantitative evaluation* is conducted. The temporal boundary often includes timeframes before or after the site *cleanup*, as well as the timeframe of the cleanup itself. For example, the temporal boundary may include *emissions* from prior manufacturing of products used during the *remedy* or *emissions* that persist in the atmosphere after the end of the *cleanup phase* or activity evaluated.

7.4.3 *Step 3: Core Elements and Contributors to the Core Elements*—The *user* should review each *core element*, determine which *core elements* are likely to be of importance in the *cleanup*, and identify likely contributors to those *core elements*. There may be one or more contributors associated with each *core element*. Examples of how contributors are mapped to *core elements* are presented in Appendix X4.

7.4.3.1 The *user* should evaluate all *core elements* that are expected to be of importance in the *cleanup*. For those *core elements* not evaluated, the *user* should document the reasons why one or more *core elements* were not evaluated.

7.4.3.2 In determining which *core elements* to include in the *quantitative evaluation*, the *user* should consider the potential for environmental tradeoffs across the *core elements*.

7.4.4 *Step 4: Collection and Organization of Information*—The *user* should compile information on the *cleanup* components and inventory datasets associated with the *cleanup* activities to be evaluated. The *user* should document all information collected regarding the *cleanup* components and inventory datasets.

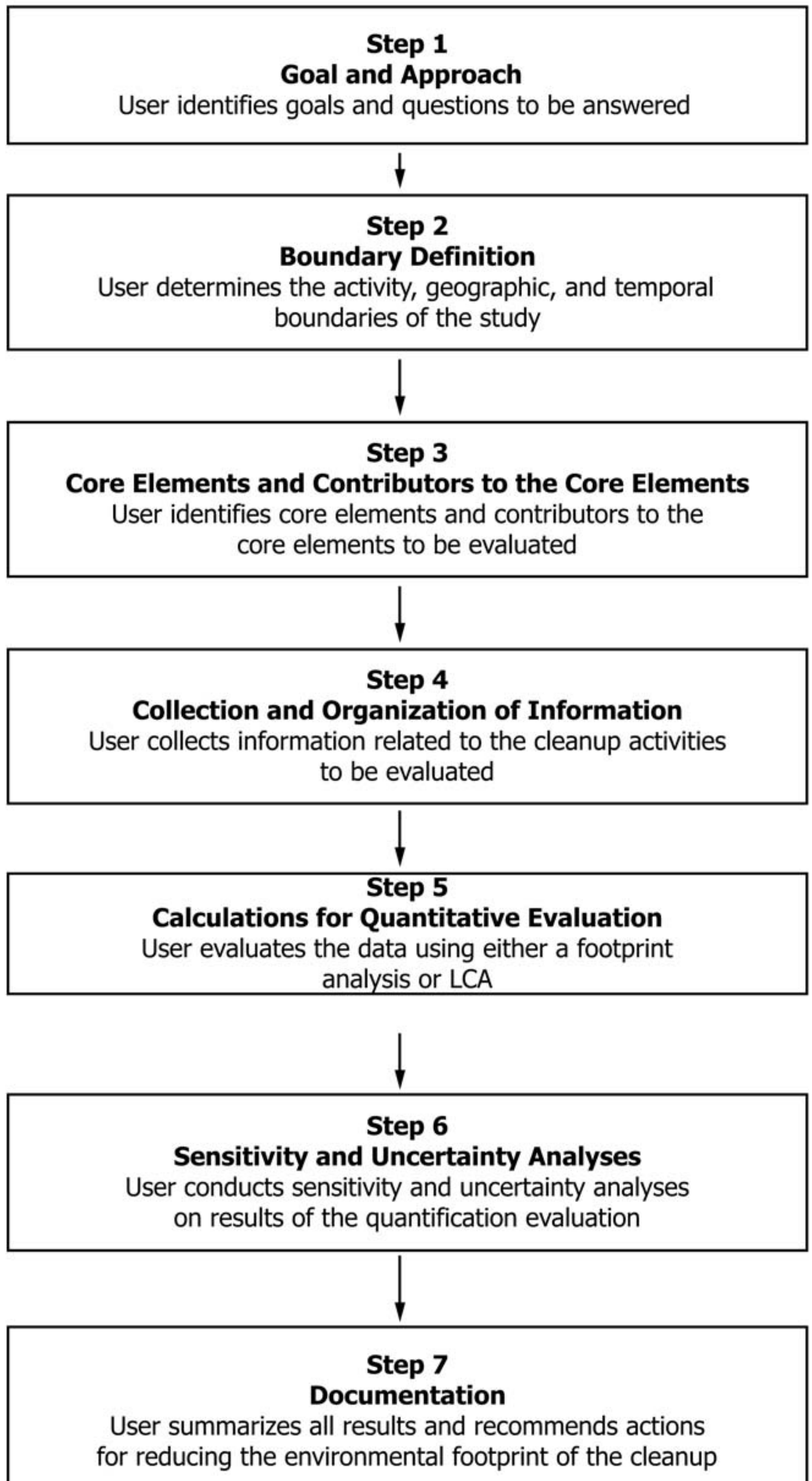

FIG. 3 Quantitative Evaluation

7.4.4.1 In identifying the *cleanup* components, the *user* should consider the following components that may be associated with a *cleanup* activity: materials (for example, pipe, chemicals, cement); energy (for example, electricity, fuel); processes (for example, special processes applied to materials, such as extrusion and molding); transport (for example, trucking, rail); wastes (for example, wastes generated, wastes recycled); and associated off-site activities and services (for example, solid waste management, wastewater treatment, laboratory analyses).

7.4.4.2 After information has been gathered on the *cleanup* components, the *user* should identify inventory datasets relevant to the components. Inventory datasets provide estimates of the *emissions* (for example, nitrogen oxides, carbon dioxide equivalents, total hazardous air pollutants) or resource use (for example, water, energy, materials) associated with each *cleanup* component. The type of inventory dataset used should be consistent with the goal and approach of the *quantitative evaluation*. Refer to Appendix X4 for more information on how to apply inventory datasets in the *quantitative evaluation* process.

7.4.5 *Step 5: Calculations for Quantitative Evaluation*—The *user* should perform the *quantitative evaluation* using either a *footprint analysis* or *LCA*. See Appendix X4 for further information on *footprint analysis* and *LCA*.

7.4.6 *Step 6: Sensitivity and Uncertainty Analyses*—The *user* should conduct sensitivity and uncertainty analyses on the results from the *footprint analysis* or *LCA* to better assess the confidence and uncertainty of the results and to help focus efforts on activities that will likely yield the greatest *environmental footprint* reductions.

7.4.6.1 In the sensitivity analysis, the *user* focuses on secondary information, such as inventory datasets, to assess changes in results due to potential inaccuracies or variability in the information.

7.4.6.2 In the uncertainty analysis, the *user* focuses on adjusting model parameters that may be uncertain in the primary *cleanup* information. Examples of model parameters that may be adjusted include time required to achieve *final cleanup goals* and the size of the target treatment area.

7.4.6.3 In some cases the sensitivity and uncertainty analyses will require the *user* to revisit previous steps of the *quantitative evaluation* process to address inconsistencies or discrepancies of the overall results. These steps should be revisited prior to finalizing the overall conclusions of the *quantitative evaluation* effort.

7.4.7 *Step 7: Documentation*—The *user* presents and summarizes all steps in the *quantitative evaluation* in a transparent and well documented report. This report should present and interpret the results and identify significant contributors relative to the *core elements*, opportunities for *BMPs* to reduce the *environmental footprint* of the *cleanup*, and tradeoffs among the *core elements* as a result of applying *BMPs*. In some cases, the interpretation component of this step may require the *user* to revisit previous steps of the *quantitative evaluation* process to resolve unanswered questions or process new findings that could influence a previous step.

7.4.8 After implementing a *quantitative evaluation*, the *user* should proceed to the *BMP process* described in 6.6. In the *BMP process*, *quantitative evaluation* may be closely intertwined with *BMP* evaluation in order to provide data to assist the *user* in selecting *BMPs*.

8. Documentation and Reporting

8.1 *Documentation and Reporting*—There are two separate steps to the reporting process. Step 1 is to document the process for each *cleanup phase*. Step 2 is to report the documentation to the public along with a technical summary, described in 8.3, and a statement affirming the *user* followed the process outlined in the *guide*. The *user* may opt to combine documentation from multiple *cleanup phases* into a single document for purposes of reporting.

8.2 *Step 1: Documenting the Process*—For each *cleanup phase*, the *user* should create tables to document the *BMP process* as described in 6.6. The *user* should also document *BMPs* that are required by local, state, or federal laws or regulation. If applicable, the *user* should prepare a *quantitative evaluation* report as described in 7.4.

8.3 *Step 2: Reporting the Process*—The *user* should report the documentation in 8.2, along with the following:

8.3.1 A technical summary that includes: general *site* information; *site* status information; application of the *guide* relative to the *cleanup phases*; and anticipated *environmental footprint* reductions across the *core elements*. Appendix X2, Technical Summary Form, provides a template for this information. Alternatively, the *user* can provide the information in an equivalent format. In the Technical Summary Form, it is appropriate to reference reports which contain the information listed in this section instead of repeating the information.

8.3.1.1 General *site* information should include, at a minimum: *user's* name and organization; *lead environmental professional* and organization; property name; *site* location (street address, city, state, zip code); tax parcel ID# or EPA#, state or project ID#; *cleanup* program (for example, *RCRA*, state voluntary *cleanup* program); and lead oversight agency (for example, EPA, state, other).

8.3.1.2 *Site* status information should include the following types of information: current *cleanup phase*; *contaminants* at the *site*; current, historical, and *reasonably anticipated future use(s)* for the *site*, if known; potential human or ecological receptors of contamination; uses of adjacent properties; *stakeholder* involvement in the *site*; past or on-going *cleanup* activities; interim or *final cleanup goals*, if established, and the status in achieving those goals; and *activity and use limitations*.

8.3.1.3 Application of this *guide* should describe: the *cleanup phases* in which the *user* employed the *guide*; whether the *user* employed the *BMP process* or both the *quantitative evaluation* and *BMP process*; and, if the *user* employed a *quantitative evaluation*, whether a *footprint analysis* or *LCA* was performed. The *user* should also state whether the results reported reflect work actually implemented or planned for the future.

8.3.1.4 The *user* should qualitatively or quantitatively describe the anticipated and, if applicable, realized *environmental footprint* reductions across *core elements* from implementation of the *guide*.

8.3.2 *Self-Declaration*—The *user* should include the following statement signed and dated by the *lead environmental professional*,"A *greener cleanup* project was implemented in conformance with the ASTM E2893 Standard Guide for Greener Cleanups for the [*site* name] *site* located at [insert address] by [insert *lead environmental professional*'s name] of [insert name and address of *lead environmental professional*'s organization]."

8.4 *Public Availability*—The *user* should make the documentation described above in 8.2 and 8.3 available to the public. Options for public availability include the following:

8.4.1 The *user* may make the documentation available in a public location, such as a public library, federal or state government office, or municipal administration building.

8.4.2 The *user* may post the documentation on a publicly available website. For example, the user may contact ASTM International to post the results on the ASTM E50 Technical Committee page.

8.4.3 With agreement from a regulator, the *user* may submit the documentation to a regulatory agency where the public can access it through a Freedom of Information Act request.

8.5 *Timing for Reporting*—Timing for reporting should be based on the needs of the *user*; requirements of, or agreements with, a regulatory program; and commitments through contractual agreements or to *stakeholders*, as applicable. For example, at some *sites* it may be appropriate to report after implementation of a *cleanup phase*. At other *sites*, such as a tank removal, it may be more appropriate to report after implementation of all *cleanup phases*.

8.5.1 It is recommended that results be reported after implementation of *cleanup* activities to document that the *greener cleanup* activities selected through use of this *guide* were implemented.

8.5.2 There may be situations where it is appropriate to report process or evaluation results prior to implementation. For example there may be an extended period of time between *remedy selection* and *remedy design/implementation*. In that situation, the *user* should report that the documentation reflects only a *greener cleanup* evaluation and not implementation.

9. Keywords

9.1 *best management practices*; *BMPs*; *core elements*; *environmental footprint*; *environmental footprint analysis*; *footprint analysis*; green cleanup; *greener cleanup*; green remediation; *LCA*; *life cycle assessment*

APPENDIXES

(Nonmandatory Information)

X1. SUPPORTING DOCUMENTATION

X1.1 Government agencies or non-government organizations offer other information resources or tools that may be helpful to *users* of this *guide*. Mention of these materials, as listed below, does not constitute ASTM International's endorsement for the purpose of this *guide*. This list of resources is not exhaustive; *users* may identify additional sources of information or tools relevant to portions of this *guide*.

(1) Battelle Memorial Institute. SiteWise™ GSR Tool. http://www.sustainableremediation.org/library/guidance-tools-and-other-resources/sitewise-version-31

(2) Butler, P. B., Larsen-Hallock, L., Lewis, R., Glenn, C., & Armstead, R., Metrics for Incorporating Sustainability Evaluations into Remediation Projects. Remediation, 21(3), 81–87 (2011)

(3) California Environmental Protection Agency, Department of Toxic Substances Control. Interim Advisory for Green Remediation (December 2009)

(4) Ellis, D. E. & Hadley, P. W., Sustainable Remediation White Paper: Integrating Sustainable Principles, Practices, and Metrics into Remediation Projects, US Sustainable Remediation Forum. Remediation, 19(3), 5-114 (2009)

(5) Illinois Environmental Protection Agency. Greener Cleanups Matrix, Greener Cleanup Strategies Mind Map, LUST Decision Trees

(6) Interstate Technology & Regulatory Council (ITRC), Green and Sustainable Remediation: A Practical Framework, (November 2011)

(7) Massachusetts Department of Environmental Protection, Greener Cleanups Guidance, WSC #14-150 (October 20, 2014)

(8) National Center for Manufacturing Sciences. Construction Industry Compliance Assistance Center. C&D Debris State Resources. http://www.cicacenter.org/solidregs.html

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(19) US Environmental Protection Agency. Methodology for Understanding and Reducing a Project's Environmental Footprint (2012). http://clu-in.org/greenremediation/subtab_b3.cfm

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(21) US Environmental Protection Agency. Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI). http://www.epa.gov/nrmrl/std/traci/traci.html

(22) US General Services Administration. Green Products Compilation. http://www.gsa.gov/portal/content/198257

(23) US Navy, Naval Facilities Engineering Command. Sustainable Environmental Remediation Fact Sheet (2009)

(24) Wisconsin Department of Natural Resources. Green & Sustainable Remediation Manual: A Practical Guide to Remediation in the State of Wisconsin, Pub-RR-911 (January 2012)

NOTE X1.1—The USEPA maintains a website with various references, guidance, and information related to greener *cleanups* that is frequently updated. *Users* are encouraged to research this resource for recent literature updates on the subject of greener *cleanups* (see http://cluin.org/greenremediation/).

X2. TECHNICAL SUMMARY FORM

INTRODUCTION

Instructions: This form[5] is an example template. The *user* may use this Technical Summary Form or another applicable format that contains the same information. The *user* can complete this form to summarize the *BMPs* implemented and *quantitative evaluation* performed, if appropriate. With the exception of Part 4.0, which is only applicable to *users* who performed a *quantitative evaluation*, the *user* should fill out all sections, or attach sheets, and input "NA" for items that are not applicable. If information is included in a report, the *user* only needs to reference the report.

X2.1 *General Information*

X2.1.1 *User's* name and organization:

X2.1.2 *Lead Environmental Professional*'s name and organization:

X2.1.3 Date:

X2.1.4 Property name:

X2.1.5 *Site* location (address, city, state, zip code):

X2.1.6 Tax parcel ID # or EPA, state, project ID #:

X2.1.7 *Cleanup* program (for example, *RCRA*, state voluntary *cleanup* program):

X2.1.8 Lead oversight agency (for example, EPA, state, other):

X2.2 *Site Status Information*

X2.2.1 Current *cleanup phase*:

X2.2.2 *Contaminants* at the *site*:

X2.2.3 Current, historical, and *reasonably anticipated future use(s)* for the *site*, if known:

X2.2.4 Potential human or ecological receptors of contamination:

X2.2.5 Uses of adjacent properties:

X2.2.6 *Stakeholder* involvement in the *site*:

X2.2.7 Past and on-going *cleanup* activities:

X2.2.8 Interim or *final cleanup goals*, if established, and the status in achieving those goals:

X2.2.9 *Activity and use limitations*:

X2.3 *Application of Guide*—See Table X2.1.

X2.4 *Environmental Footprint Reduction*—Describe estimated *environmental footprint* reductions anticipated or resulting from implementing *BMPs* and a *quantitative evaluation*, if applicable, across the *core elements*. The anticipated *environmental footprint* reductions may be described qualitatively (if only the *BMP process* was applied) or quantitatively (if a *quantitative evaluation* was conducted, in addition to the *BMP process*).

X2.5 *BMP Process Summary*—Provide the following for each *cleanup phase* in which the *guide* was implemented.

X2.5.1 Attach table(s) developed according to 6.6:

X2.5.2 Note all *BMPs* that were required by local, state, or federal *environmental laws* or regulations:

X2.6 *Quantitative Evaluation Summary*—For each *cleanup phase* or activity in which a *quantitative evaluation* was implemented, attach sheet(s) or reference the report(s) which includes the information listed in 7.4.7.

TABLE X2.1 Application of Guide (check all that apply)

Cleanup Phase	BMP Evaluation Process	Quantitative Evaluation Process with BMPs		Results Document	
		Footprint Analysis	LCA	Evaluation Only	Evaluation and Implementation
Site Assessment					
Remedy Selection					
Remedy Design/ Implementation					
Operation, Maintenance and Monitoring					
Remedy Optimization					

X3. GREENER CLEANUP BMP TABLE

Acronyms

BACT	best available control technology
BMP	best management practice
CHP	combined heat and power
CPT	cone penetrometer test
ERH	electrical resistance heating
FFD	fuel fluorescence detector
GAC	granular activated carbon
GSA	General Services Administration
HVAC	heating, ventilating, and air conditioning
ISTT	in-situ thermal treatment
LECA	light expanded clay aggregate
LED	light-emitting diode
LIF	laser-induced fluorescence
MACT	maximum achievable control technology
MIP	membrane interface probe
NPDES	National Pollutant Discharge Elimination System
POTW	publicly owned treatment works
PRB	permeable reactive barrier
REC	renewable energy credit
RFP	request for proposal
RFQ	request for quotation
ROST	rapid optical screening tool
SEE	steam enhanced extraction
SVE	soil vapor extraction
TTZ	target treatment zone
VOC	volatile organic compound

TABLE X3.1 Greener Cleanup BMP Table

		Core Element Addressed (at Site Level)					Remediation Technology											
Category	Best Management Practice	Energy	Air	Water	Materials and Waste	Land and Ecosystems	Soil Vapor Extraction	Air Sparging	Pump and Treat	In-situ Chemical Oxidation	Bioremediation/MNA	In-situ Thermal Treatment	Phytotechnology	Subsurface Containment & Treatment Barriers	Excavation and Surface Restoration	Ex-situ Bio/Chemical Oxidation	Landfill Covers and Caps	Vapor Intrusion Mitigation
Buildings	Capture roof runoff for on-site use, as appropriate based on the water quality			X			X	X	X			X				X		
Buildings	Choose water efficient plumbing fixtures (for example, low flow fixtures, tankless water heaters)			X			X	X	X									
Buildings	Install a green roof on buildings to minimize stormwater management and improve energy efficiency	X		X		X	X	X	X									
Buildings	Install energy recovery ventilators in buildings to allow incoming fresh air while capturing energy from outgoing conditioned air	X	X				X	X	X							X		
Buildings	Install roofing with a high solar reflection index	X					X	X	X									
Buildings	Optimize use of natural light through location and orientation of windows	X					X	X	X									
Buildings	Orient new buildings (for example, south facing or with prevailing wind directions) to optimize energy efficient heating and cooling	X					X	X	X									
Buildings	Reuse existing structures for treatment system, storage, sample management, etc	X			X	X	X	X	X									
Buildings	Use energy efficient equipment such as Energy Star verified boilers or heat pumps in buildings or housings	X					X	X	X									
Buildings	Use energy efficient HVAC systems (for example, programmable heating and cooling systems) and/or establish separate heating/cooling zones	X					X	X	X									
Buildings	Use energy efficient lighting systems by incorporating elements such as LED lights or motion sensors				X		X	X	X									
Buildings	Use graywater collection systems at on-site buildings for water during cleanup activities, to minimize freshwater use			X			X	X	X	X	X	X	X	X	X	X	X	
Buildings	Use green insulation materials (for example, spray-on cellulose) when insulating buildings	X			X		X	X	X									
Materials	For ISTT using ERH, co-locate electrodes and recovery wells in the same borehole, particularly in the saturated zone, to minimize the total number of wells and land disturbance	X	X	X	X	X						X						
Materials	For ISTT, when insulating the surface of the TTZ to reduce energy losses, use greener insulation alternatives such as LECA beads (rather than polyurethane foam)	X			X							X						
Materials	For landfill covers and other plant-based systems, use organic material such as compost instead of chemical fertilizers to amend the soil				X	X							X				X	
Materials	For landfill covers, use minimum slope while maintaining proper drainage to reduce the volume of fill material required				X	X									X		X	
Materials	For rubberized asphalt landfill covers, substitute a portion of the hot mix asphalt with rubber from recycled tires				X												X	

TABLE X3.1 *Continued*

		Core Element Addressed (at Site Level)					Remediation Technology											
Category	Best Management Practice	Energy	Air	Water	Materials and Waste	Land and Ecosystems	Soil Vapor Extraction	Air Sparging	Pump and Treat	In-situ Chemical Oxidation	Bioremediation/MNA	In-situ Thermal Treatment	Phytotechnology	Subsurface Containment & Treatment Barriers	Excavation and Surface Restoration	Ex-situ Bio/Chemical Oxidation	Landfill Covers and Caps	Vapor Intrusion Mitigation
Materials	For the reactive component of permeable subsurface treatment barriers, use locally available materials (for example, mulch/compost), by-products (for example, slag, flue gas desulfurization gypsum), or less-refined materials (for example, apatite, natural zeolites) in place of refined chemicals (for example, zero-valent iron, hydrogen reducing compounds) or materials, where possible, without compromising site-specific performance and longevity goals				X									X				
Materials	Implement a flexible network of piping (under and/or aboveground) to allow for shorter piping runs and future modular increases or decreases in the extraction or injection rates and treatment modifications	X	X	X	X	X	X	X	X	X	X	X						X
Materials	Insulate all applicable pipes and equipment to improve energy efficiency with greener insulation material	X			X		X	X	X	X	X	X						
Materials	Link a deconstruction project with a replacement construction project (for example, the same site of the deconstruction project or a local current construction or renovation project) to facilitate reuse of clean salvaged materials				X		X	X	X	X	X	X				X		
Materials	Maximize the reuse of existing wells for sampling, injections, or extractions, where appropriate, and/or design wells for future reuse	X	X		X	X	X	X	X	X	X	X		X		X	X	
Materials	Select oxidants/reagents with a smaller environmental footprint				X	X				X	X				X	X		
Materials	Select piping materials and treatment equipment to facilitate their reuse. For example, carbon steel piping may resist chlorine stress corrosion better than stainless steel				X		X	X	X	X	X	X						X
Materials	Select products that are environmentally preferable (when compared to other products serving the same purpose) with respect to raw materials consumption, manufacturing processes and locations, packaging, distribution, recycled content and recycling capability, maintenance needs, and disposal procedures. Explore the GSA Sustainable Facilities tool at https://sftool.gov/ for a list of greener options				X		X	X	X	X	X	X	X	X	X	X		X
Materials	Steam-clean or use phosphate-free detergents or biodegradable cleaning products instead of organic solvents or acids to decontaminate sampling and other equipment			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

TABLE X3.1 *Continued*

		Core Element Addressed (at Site Level)					Remediation Technology											
Category	Best Management Practice	Energy	Air	Water	Materials and Waste	Land and Ecosystems	Soil Vapor Extraction	Air Sparging	Pump and Treat	In-situ Chemical Oxidation	Bioremediation/MNA	In-situ Thermal Treatment	Phytotechnology	Subsurface Containment & Treatment Barriers	Excavation and Surface Restoration	Ex-situ Bio/Chemical Oxidation	Landfill Covers and Caps	Vapor Intrusion Mitigation
Materials	Use biobased products to reduce petroleum use or enhance degradation of material. For example, use biodegradable seed matting, or erosion control fabrics containing agricultural by-products; use algae-based oils, soybean oil, or waste/by-products from forestries, plant nurseries, or food processing/retail industries as a substrate for bioremediation				X		X	X	X	X	X		X	X	X	X	X	
Materials	Use by-products, waste, or less refined materials in place of refined chemicals or materials (for example, cheese whey, molasses, compost, or off-spec food products for inducing anaerobic conditions; limestone in place of concentrated sodium hydroxide for neutralization; fly ash or slag as a component in concrete)				X				X	X	X		X	X		X		
Materials	Use materials with recycled content (for example, concrete and/or asphalt from recycled crushed concrete and/or asphalt; plastic made from recycled plastic; geotextile fabrics/tarps made with recycled contents)				X		X	X	X	X	X	X	X	X	X	X	X	X
Materials	Use reconstituted reactive media or regenerate ionic adsorption material whenever feasible. For example, use regenerated GAC in carbon treatment beds or canisters rather than virgin GAC				X		X	X	X			X						X
Power and Fuel	Capture on-site waste heat such as treatment plant effluent, excess plant steam, ground-source heat pumps, mobile waste-to-heat generators, and furnaces/air conditioners operating with recycled oil to power cleanup activities. For example, integrate a CHP system powered by natural gas or cleaner diesel to generate electricity while capturing waste heat to be used to condition air inside buildings, for vapor treatment, or for other on-site operations	X	X				X	X	X			X						
Power and Fuel	For ISTT, schedule treatment period when groundwater table is lower to minimize energy requirements	X										X						
Power and Fuel	For ISTT, use an air-water heat exchanger to allow the thermal oxidizer off-gas to serve as a source of heat for pre-heating water prior to its reuse at the electrodes	X										X						
Power and Fuel	For ISTT, use natural gas-fired systems that enable in-well combustion of the contaminants and recovery of associated heat, resulting in a lower energy demand	X	X									X						
Power and Fuel	For SEE, install solar thermal equipment to preheat boiler feed-water and makeup water to reduce the energy needed for raising water temperatures to the target levels	X										X						
Power and Fuel	For SEE, minimize excess air in the steam generation process to reduce the amount of heat lost through the stack	X										X						

TABLE X3.1 *Continued*

		Core Element Addressed (at Site Level)					Remediation Technology											
Category	Best Management Practice	Energy	Air	Water	Materials and Waste	Land and Ecosystems	Soil Vapor Extraction	Air Sparging	Pump and Treat	In-situ Chemical Oxidation	Bioremediation/MNA	In-situ Thermal Treatment	Phytotechnology	Subsurface Containment & Treatment Barriers	Excavation and Surface Restoration	Ex-situ Bio/Chemical Oxidation	Landfill Covers and Caps	Vapor Intrusion Mitigation
Power and Fuel	For SEE, use a natural gas-fired boiler rather than a diesel boiler and preheat water delivered to boiler, if possible, using recycled heat from extracted fluids	X	X									X						
Power and Fuel	Implement a utility provided demand-response program to reduce use of electricity while responding to power grid needs (for example, Smart AC, real-time consumption meter)	X					X	X	X			X						
Power and Fuel	Install amp meters to evaluate electricity consumption rates on a real-time basis and options for off-peak energy usage	X					X	X	X	X	X	X				X		
Power and Fuel	Maintain site energy balance on a regular basis during operation and adjust extraction strategy accordingly to minimize unnecessary operation period	X					X	X	X			X						
Power and Fuel	Purchase renewable energy via local utility and Green Energy Programs or RECs/Green Tags to power cleanup activities	X	X				X	X	X	X	X	X	X	X	X	X	X	X
Power and Fuel	Use a flexible on-site renewable energy system to meet energy demands of multiple activities or consumption needs beyond the lifespan of the cleanup	X	X				X	X	X	X	X	X		X	X	X		X
Power and Fuel	Use biodiesel produced from waste or cellulose-based products to power equipment	X			X		X	X	X	X	X	X	X	X	X	X	X	X
Power and Fuel	Use gravity flow to introduce amendments or chemical oxidants to the subsurface when high-pressure injection is unnecessary	X			X					X	X							
Power and Fuel	Use gravity flow wherever feasible instead of additional pumps to transfer water after subsurface extraction	X			X				X									
Power and Fuel	Use on-site generated renewable energy such as solar photovoltaic, wind turbines, landfill gas, geothermal, and biomass combustion to fully or partially provide power otherwise generated through on-site fuel consumption or use of grid electricity	X	X				X	X	X	X	X	X		X	X	X		X
Power and Fuel	Use passive sub-slab depressurization system to mitigate vapor intrusion, if practicable	X																X
Power and Fuel	Use solar power pack system for low-power system demands (for example, security lighting, system telemetry)	X					X	X	X	X	X	X		X	X	X	X	X
Power and Fuel	When nearing asymptotic conditions and/or when continuous operating is not needed to contain the plume and/or reach clean-up objectives, operate pumping equipment in pulsed mode	X					X	X	X									X
Power and Fuel	When possible, operate remediation system during off-peak hours of electrical demand without compromising cleanup progress	X					X	X	X	X	X	X				X		
Project Planning and Team Management	Buy carbon offset credits (for example, for airline flights) when in person meetings are required		X				X	X	X	X	X	X	X	X	X	X	X	X

TABLE X3.1 *Continued*

		Core Element Addressed (at Site Level)					Remediation Technology											
Category	Best Management Practice	Energy	Air	Water	Materials and Waste	Land and Ecosystems	Soil Vapor Extraction	Air Sparging	Pump and Treat	In-situ Chemical Oxidation	Bioremediation/MNA	In-situ Thermal Treatment	Phytotechnology	Subsurface Containment & Treatment Barriers	Excavation and Surface Restoration	Ex-situ Bio/Chemical Oxidation	Landfill Covers and Caps	Vapor Intrusion Mitigation
Project Planning and Team Management	Choose equipment and product vendors with production and distribution centers near the site to minimize fuel consumption associated with delivery	X	X				X	X	X	X	X	X	X	X	X	X	X	X
Project Planning and Team Management	Choose suppliers that will take back scraps or unused materials				X		X	X	X	X	X	X	X	X	X	X	X	X
Project Planning and Team Management	Contract a laboratory that uses green practices and/or chemicals	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Project Planning and Team Management	Designate collection points for compostable materials and routine recycling of single-use items such as metal, plastic, and glass containers; paper and cardboard; and other items that may be recycled locally	X			X		X	X	X	X	X	X	X	X	X	X	X	X
Project Planning and Team Management	Establish green requirements (for example, greener cleanup BMPs) as evaluation criteria in the selection of contractors and include language in RFPs, RFQs, subcontracts, contracts, etc. For example, procure remediation reagents from vendors with sustainable policies	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Project Planning and Team Management	Select facilities with green policies for worker accommodations and periodic meetings	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
Project Planning and Team Management	Select local waste disposal and recycling facilities to minimize transportation impacts	X	X				X	X	X	X	X	X	X	X	X	X	X	X
Project Planning and Team Management	Use a local laboratory to minimize transportation impacts	X	X				X	X	X	X	X	X	X	X	X	X	X	X
Project Planning and Team Management	Use local staff (including subcontractors) when possible to minimize transportation impacts	X	X				X	X	X	X	X	X	X	X	X	X	X	X
Residual Solid and Liquid Waste	For PRBs, use existing excavation, deep soil mixing, injection or other subsurface infrastructure to minimize volume of excavated soil	X	X		X	X								X				
Residual Solid and Liquid Waste	Recycle or reuse un-used, spent or uncontaminated equipment or infrastructure. For example, recover and recycle or re-use steel electrodes from ISTT thermal treatment using ERH				X		X	X	X			X	X			X		X
Residual Solid and Liquid Waste	Reuse or recycle recovered product (such as resale of captured petroleum products, precipitated metals) and materials (for example, cardboard, plastics, asphalt, concrete)				X		X	X	X	X	X	X			X	X	X	X
Residual Solid and Liquid Waste	Salvage uncontaminated objects/ infrastructure with potential to recycle, re-sell, donate, or re-use				X		X	X	X	X	X	X	X	X	X	X	X	X
Residual Solid and Liquid Waste	Employ closed-loop graywater washing system for decontamination of trucks			X			X	X	X	X	X	X	X	X	X	X	X	

TABLE X3.1 *Continued*

Category	Best Management Practice	Core Element Addressed (at Site Level)					Remediation Technology											
		Energy	Air	Water	Materials and Waste	Land and Ecosystems	Soil Vapor Extraction	Air Sparging	Pump and Treat	In-situ Chemical Oxidation	Bioremediation/MNA	In-situ Thermal Treatment	Phytotechnology	Subsurface Containment & Treatment Barriers	Excavation and Surface Restoration	Ex-situ Bio/Chemical Oxidation	Landfill Covers and Caps	Vapor Intrusion Mitigation
Residual Solid and Liquid Waste	For ISTT, use condensate or treated water as makeup water for the condenser cooling tower (if an unacceptable odor source is not generated) or recycle them into the drip system to maintain moisture at electrodes			X								X						
Residual Solid and Liquid Waste	Reuse or reinject treated or uncontaminated groundwater to the subsurface to recharge an aquifer rather than discharging (for example, NPDES or POTW) as permissible. For example, use water for irrigation, dust control, or to amend wetlands			X					X									
Residual Solid and Liquid Waste	Segregate drilling or excavation waste based on location and composition to reduce the volume of drilling waste disposed off-site; collect needed analytical data to make on-site reuse decisions	X	X		X		X	X	X	X	X	X		X	X		X	
Residual Solid and Liquid Waste	Use filters (for example, baghouse or cartridge filters) that can be backwashed to avoid frequent disposal of filters				X		X	X	X			X						
Sampling and Analysis	Use a multi-port sampling system in monitoring wells to minimize the number of wells needing to be installed				X	X	X	X	X	X	X	X	X	X	X		X	
Sampling and Analysis	Use a passive/no purge groundwater sampling system			X	X			X	X	X	X	X	X	X				
Sampling and Analysis	Use dedicated materials (that is, re-use of sampling equipment and non-use of disposable materials/equipment) when performing multiple rounds of sampling				X		X	X	X	X	X	X	X	X	X	X		X
Sampling and Analysis	Use direct sensing non-invasive technology such as a MIP, X-ray fluorescence, LIF sensor, CPT, ROST, FFD, and/or seismic refraction/reflection	X	X		X	X	X	X	X	X	X	X		X	X	X	X	X
Sampling and Analysis	Use drilling methods which minimize the generation and disposal of cuttings (for example, sonic technology)	X	X		X	X	X	X	X	X	X	X	X	X	X		X	
Sampling and Analysis	Use field test kits for screening analysis of soil and groundwater contaminants such as petroleum, polychlorinated biphenyls, pesticides, explosives, and inorganics to minimize the need for off-site laboratory analysis and associated sample packing and shipping	X	X		X		X	X	X	X	X	X		X	X	X	X	
Sampling and Analysis	Use non-invasive techniques to avoid cover damage when monitoring landfill cover integrity; for example, use open path spectroscopy techniques to periodically confirm no escape of landfill gas				X												X	
Sampling and Analysis	Use on-site mobile lab or other field analysis (for example, portable gas chromatography/mass spectrometry for fuel-related compounds and VOCs) to minimize the need for off-site laboratory analysis and associated sample packing and shipping	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X
Sampling and Analysis	Use tree core sampling as a screening tool to map the source and extent of a contaminant plume	X	X		X	X			X				X	X				

TABLE X3.1 *Continued*

		Core Element Addressed (at Site Level)					Remediation Technology											
Category	Best Management Practice	Energy	Air	Water	Materials and Waste	Land and Ecosystems	Soil Vapor Extraction	Air Sparging	Pump and Treat	In-situ Chemical Oxidation	Bioremediation/MNA	In-situ Thermal Treatment	Phytotechnology	Subsurface Containment & Treatment Barriers	Excavation and Surface Restoration	Ex-situ Bio/Chemical Oxidation	Landfill Covers and Caps	Vapor Intrusion Mitigation
Site Preparation and Land Restoration	Cover filled excavations with biodegradable fabric to control erosion and serve as a substrate for ecosystems			X	X	X								X	X	X	X	
Site Preparation and Land Restoration	For landfill covers, use lower permeability soils than required by regulation when soils are available locally to reduce the amount of leachate generated			X	X												X	
Site Preparation and Land Restoration	For restoration use a suitable mix of trees, shrubs, grasses, and forbs to preserve or improve biodiversity and related ecosystem services			X		X	X	X	X	X	X	X	X	X	X	X	X	
Site Preparation and Land Restoration	If grass is required, use no- or low-mowing species to minimize mowing	X	X										X		X		X	
Site Preparation and Land Restoration	Incorporate wetlands, grassed swales, or grass-lined channels, bioswales, and other types of vegetated areas to enhance gradual infiltration and evapotranspiration, prevent soil and sediment runoff, and promote carbon sequestration		X	X		X							X		X		X	
Site Preparation and Land Restoration	Minimize clearing of trees and other vegetation throughout investigation and cleanup	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Site Preparation and Land Restoration	Minimize dewatering prior to excavation by relying on cold conditions or using ground-freezing technologies, if environmentally beneficial	X	X	X	X									X	X	X		
Site Preparation and Land Restoration	Restore and/or maintain ecosystems in ways that mirror natural conditions			X		X							X		X	X	X	
Site Preparation and Land Restoration	Restrict traffic to confined corridors to minimize soil compaction and land disturbance during site activities			X		X	X	X	X	X	X	X	X	X	X	X	X	
Site Preparation and Land Restoration	Reuse on-site or local clean materials (for example, shredded tires, crushed concrete) rather than importing borrow for fill	X	X		X									X	X		X	
Site Preparation and Land Restoration	Select pre-existing, native and non-invasive vegetation for phytoremediation or restoration activities to minimize use of water and amendments				X	X							X		X			
Site Preparation and Land Restoration	Use an integrated pest management plan or green alternatives (for example, non-chemical solarizing technique) to minimize use of chemical pesticides				X	X							X		X		X	
Site Preparation and Land Restoration	Use biodegradable covers to protect and preserve healthy plants from land disturbing activities			X		X	X	X	X	X	X	X	X	X	X		X	
Site Preparation and Land Restoration	Use crushed concrete as a construction aggregate for road base, pipe bedding, or landscaping				X		X	X	X	X	X	X	X	X	X	X	X	

TABLE X3.1 *Continued*

		Core Element Addressed (at Site Level)					Remediation Technology											
Category	Best Management Practice	Energy	Air	Water	Materials and Waste	Land and Ecosystems	Soil Vapor Extraction	Air Sparging	Pump and Treat	In-situ Chemical Oxidation	Bioremediation/MNA	In-situ Thermal Treatment	Phytotechnology	Subsurface Containment & Treatment Barriers	Excavation and Surface Restoration	Ex-situ Bio/Chemical Oxidation	Landfill Covers and Caps	Vapor Intrusion Mitigation
Site Preparation and Land Restoration	Use excavated areas to serve as retention basins in final storm water control plans	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Site Preparation and Land Restoration	Use pervious surface material such as porous pavement or gravel and separated pervious surfaces, rather than impermeable materials, when installing hardscape (for example, roadway, parking area) to maximize infiltration			X		X	X	X	X	X	X	X	X	X	X	X	X	
Site Preparation and Land Restoration	Use reclaimed asphalt pavement as a granular base for new roads				X		X	X	X	X	X	X	X	X	X	X	X	
Site Preparation and Land Restoration	Use silica-based spent foundry sands from iron, steel, and aluminum foundries in soil-related applications such as manufactured soils and roadway sub-base				X		X	X	X	X	X	X	X	X	X	X	X	
Site Preparation and Land Restoration	Downed trees and snags (standing dead trees) provide habitat for numerous species; do not remove unless required for safety or access and allow leaf litter to remain for natural mulching and weed control			X	X	X							X	X	X			
Surface and Storm Water	Capture rainwater for tasks such as wash water, irrigation, dust control, constructed wetlands, or other uses			X		X	X	X	X	X	X	X	X	X	X	X	X	
Surface and Storm Water	For a landfarm, use a leachate collection and treatment system to fully preserve the quality of downgradient water bodies, soil, and groundwater			X		X									X	X		
Surface and Storm Water	Install a landfarm rain shield (such as a plastic tunnel) with rain barrels or a cistern to capture precipitation for on-site use			X												X		
Surface and Storm Water	Use subsurface/vertical flow wetlands rather than surface flow wetlands when possible to allow use of a greater range of plant species			X		X							X		X			
Vehicles and Equipment	For ISTT with SEE, choose a water-tube boiler rather than a fire-tube boiler wherever feasible; the smaller tubes in water-tube boilers increase boiler efficiency by allowing more heat transfer from exhaust gases	X										X						
Vehicles and Equipment	Install one-way check valves in well casings to promote barometric pumping (passive SVE) as a polishing step once the bulk of contamination has been removed if venting to atmosphere is acceptable	X					X	X										X
Vehicles and Equipment	Use centrifugal blowers, rather than positive displacement blowers and intake air line mufflers, to decrease noise levels					X	X	X										X
Vehicles and Equipment	When using large equipment, employ auxiliary power units to power cab heating and air conditioning when a machine/vehicle is not operating (such as SmartWay generator or plug in outlet) to reduce idling	X	X											X	X	X	X	

TABLE X3.1 *Continued*

Category	Best Management Practice	Core Element Addressed (at Site Level)					Remediation Technology											
		Energy	Air	Water	Materials and Waste	Land and Ecosystems	Soil Vapor Extraction	Air Sparging	Pump and Treat	In-situ Chemical Oxidation	Bioremediation/MNA	In-situ Thermal Treatment	Phytotechnology	Subsurface Containment & Treatment Barriers	Excavation and Surface Restoration	Ex-situ Bio/Chemical Oxidation	Landfill Covers and Caps	Vapor Intrusion Mitigation
Vehicles and Equipment	Implement an idle reduction plan	X	X			X	X	X	X	X	X	X	X	X	X	X	X	
Vehicles and Equipment	Install directional shields on significant lighting sources such as safety beacons used in power distribution systems to minimize visual disturbance to nearby human or animal populations					X	X	X	X			X				X		
Vehicles and Equipment	Soundproof all aboveground equipment housing to minimize noise disturbance to the surrounding environment					X	X	X	X			X						X
Vehicles and Equipment	Use biodegradable hydraulic fluids on hydraulic equipment such as drill rigs				X		X	X	X	X	X	X	X	X	X	X	X	
Vehicles and Equipment	Use electric, hybrid, ethanol, or compressed natural gas vehicles instead of conventional vehicles	X	X				X	X	X	X	X	X	X	X	X	X	X	X
Vehicles and Equipment	Use equipment to increase automation such as electronic pressure transducers, thermo-couples, and water quality monitoring devices coupled with an automatic data logger to optimize operation and minimize transportation of staff to the site	X	X	X			X	X	X	X	X	X	X			X	X	X
Vehicles and Equipment	Use retrofitted engines that use ultra-low, low sulfur diesel, or alternative fuels; or filter/treatment devices to achieve BACT or MACT		X				X	X	X	X	X	X	X	X	X	X	X	
Vehicles and Equipment	Use SmartWay transportation retrofits (for example skirts, air tabs) on tractor-trailers whenever possible	X	X				X	X	X	X	X	X	X	X	X	X	X	
Vehicles and Equipment	Use timers or feedback loops and process controls for dosing chemical injections to minimize transportation of staff to the site	X	X		X				X	X						X		

X4. SUPPLEMENTAL INFORMATION FOR A QUANTITATIVE EVALUATION

X4.1 *Introduction*—Appendix X4 is a supplement to Section 7, *Quantitative Evaluation*, and provides general information on *footprint analysis* and *LCA*. This appendix does not provide sufficient information to support the *user* in conducting a *footprint analysis* or *LCA*, but serves as a primer for those interested in the topic.

X4.1.1 To implement a *quantitative evaluation* in accordance with this *guide*, the *user* should be skilled in *footprint analysis* or *LCA*. References on this subject are provided in Appendix X1 and in Section 2, Referenced Documents.

X4.1.2 The *user* may benefit from the use of tools designed to conduct *footprint analysis* or *LCA*. Examples of *footprint analysis* tools include, but are not limited to: SRT[7], SiteWise[8], and EPA's Spreadsheets for Environmental Footprint Evaluation (SEFA). Examples of *LCA* tools include SimaPro[9] and GaBi[10]. *LCA* tools can also be adapted to replicate the outputs of *footprint analysis* tools.

X4.2 *Overview of the Characteristics of Footprint Analysis and LCA*

X4.2.1 A *footprint analysis* is typically characterized by the attributes listed below:

X4.2.1.1 Considers the full life cycle of the components of a *cleanup phase*, in some cases from cradle to grave, but more commonly selects abbreviated boundaries.

X4.2.1.2 Compiles selected inventory data (for example, certain *emissions* and resource usages) for selected material

[7] SRT is a trademark of Air Force Center for Engineering and the Environment.

[8] SiteWise is a trademark of Battelle, U.S. Navy, Army, and Army Corps of Engineers.

[9] SimaPro is a trademark of SimaPro UK Ltd. (Carshalton, United Kingdom).

[10] GaBi is a trademark of PE INTERNATIONAL Inc. (Boulder, Colorado).

inputs, energy, processes, transportation, and waste scenarios associated with the life cycle of the *cleanup*.

X4.2.1.3 Reports results in terms of inventory data, along with other metrics, mapped to the five *core elements*. Reports inventory data and metrics individually, with the exception of *greenhouse gases*, which are reported as carbon dioxide equivalents based on characterization factors for carbon dioxide, methane, and nitrous oxide.

X4.2.1.4 May use an industry-specific software tool, a commercial software tool, and/or a spreadsheet-based tool developed specifically for the *cleanup* project. A *footprint analysis* may also be conducted in a more informal fashion without use of pre-designed tools.

X4.2.2 An *LCA* is typically characterized by the attributes listed below:

X4.2.2.1 Considers the full life cycle of the components of a *cleanup phase*, in most cases from cradle to grave.

X4.2.2.2 Compiles extensive inventory data (for example, *emissions*, resource usages) for material inputs, energy, processes, transportation, and waste scenarios associated with the life cycle of the *cleanup*.

X4.2.2.3 Compiles and reports results in terms of a diverse range of *impact categories*.

X4.2.2.4 Allows the selection of *impact categories* that are the most meaningful for the goal and approach of the project. The *impact categories* aggregate the effects of the inventory data and can be mapped to the *core elements*.

X4.2.2.5 Generally employs the use of commercial software tools that require specific training and investment. In some limited circumstances, it may be possible to complete an *LCA* without commercial software, depending on the goal and approach defined for the assessment.

X4.3 *Selection and Application of Tools for Footprint Analysis and LCA*

X4.3.1 In applying both *footprint analysis* and *LCA* tools, the *user* starts by identifying the *cleanup* components (that is, the materials, energy, processes, transportation, waste, and off-site activities and services associated with the *cleanup* activities) that are of greatest importance to the *environmental footprint*. Both *footprint analysis* and *LCA* tools contain inventory datasets for a range of *cleanup* components. These inventory datasets provide estimates of the *emissions* (for example, nitrogen oxides, carbon dioxide equivalents, total hazardous air pollutants) or resource use (for example, water, energy, materials use) associated with the *cleanup* component.

X4.3.1.1 One of the main differences between *footprint analysis* and *LCA* tools is that *LCA* tools contain a greater variety of inventory datasets; contain inventory datasets with a greater number of *emissions*, resource usages, and energy types; and consider more environmental media (air, water, soil) to which the *emissions* may be released.

X4.3.1.2 Another main difference between *footprint analysis* and *LCA* tools is how the tools aggregate the inventory data and report the results. *Footprint analysis* tools report *emissions* and resource uses individually, and *LCA* tools aggregate *emissions* and resource use and report the aggregates as *impact categories*.

X4.3.2 It is important that the *user* considers the *core elements* when selecting the tool to be used for the *quantitative evaluation* and verifies that the tool can provide results that are consistent with the goals and approach of the project. Some tools are not able to address all five *core elements* suggested in this *guide*.

X4.3.3 If the user excludes one or more *core elements* from the *footprint analysis*, the *user* may fail to uncover potential impacts, and this may result in transferring impacts from one *core element* to another. For example, if the *user* selects a substrate for in-situ biological treatment because it has lower air *emissions* compared to oxidants, but in the *footprint analysis* does not consider the higher water demands of the substrate, the *user* may not accurately characterize the *environmental footprint* associated with the selection. In this example, the selection of substrate would result in transferring impacts from the "minimize air pollutants and *greenhouse gas emissions*" *core element* to the "minimize water use and impacts to water resources" *core element*.

X4.3.4 For both *footprint analysis* and *LCA*, the *user* should be aware of the features of the specific *footprint analysis* or *LCA* tool to be used (for example, transparency of assumptions, data integrity, applicable boundaries) and the associated inventory datasets, to ensure that the tool can achieve the goal and approach of the assessment as described in 7.4.1.

X4.4 *Additional Information about Footprint Analysis Tools*

X4.4.1 *Footprint analysis* tools typically contain inventory datasets that include information on the following *emissions* and resources for each *cleanup* component: carbon dioxide equivalents (based on carbon dioxide, nitrous oxide, and methane *emissions*), nitrogen oxides, sulfur oxides, particulate matter, hazardous air pollutants, energy, and water.

X4.4.2 Characterization factors are applied to carbon dioxide, nitrous oxide, and methane *emissions*, and the results are summed to represent total carbon dioxide equivalents. All the other *emissions*, along with energy and water, are totaled and reported separately. Once totaled, the outputs from the tool can be mapped to the *core elements*. The first five *emissions* can be mapped to the "minimize air pollutants and *greenhouse gas emissions*" *core element*; energy can be mapped to the "minimize total energy use and maximize renewable energy use" *core element*; and water can be mapped to the "minimize water use and impacts to water resources" *core element*. The various *footprint analysis* tools (for example, SRT, SiteWise, EPA SEFA) contain inventory datasets that may differ from each other regarding the metrics noted above. Also, with regards to *emissions*, the inventory datasets in *footprint analysis* tools typically include only *emissions* to air, and not to water or soil.

X4.4.3 There are other important items that can be tracked with *footprint analysis* tools, such as the quantity of solid and hazardous waste produced. However, since these tools merely track data the *user* enters, discussion of these project components is not included in this section. Fig. X4.1 summarizes the *quantitative evaluation* process of identifying *cleanup* components, converting to *emissions*, energy, and water, and mapping the results to *core elements* for *footprint analysis*.

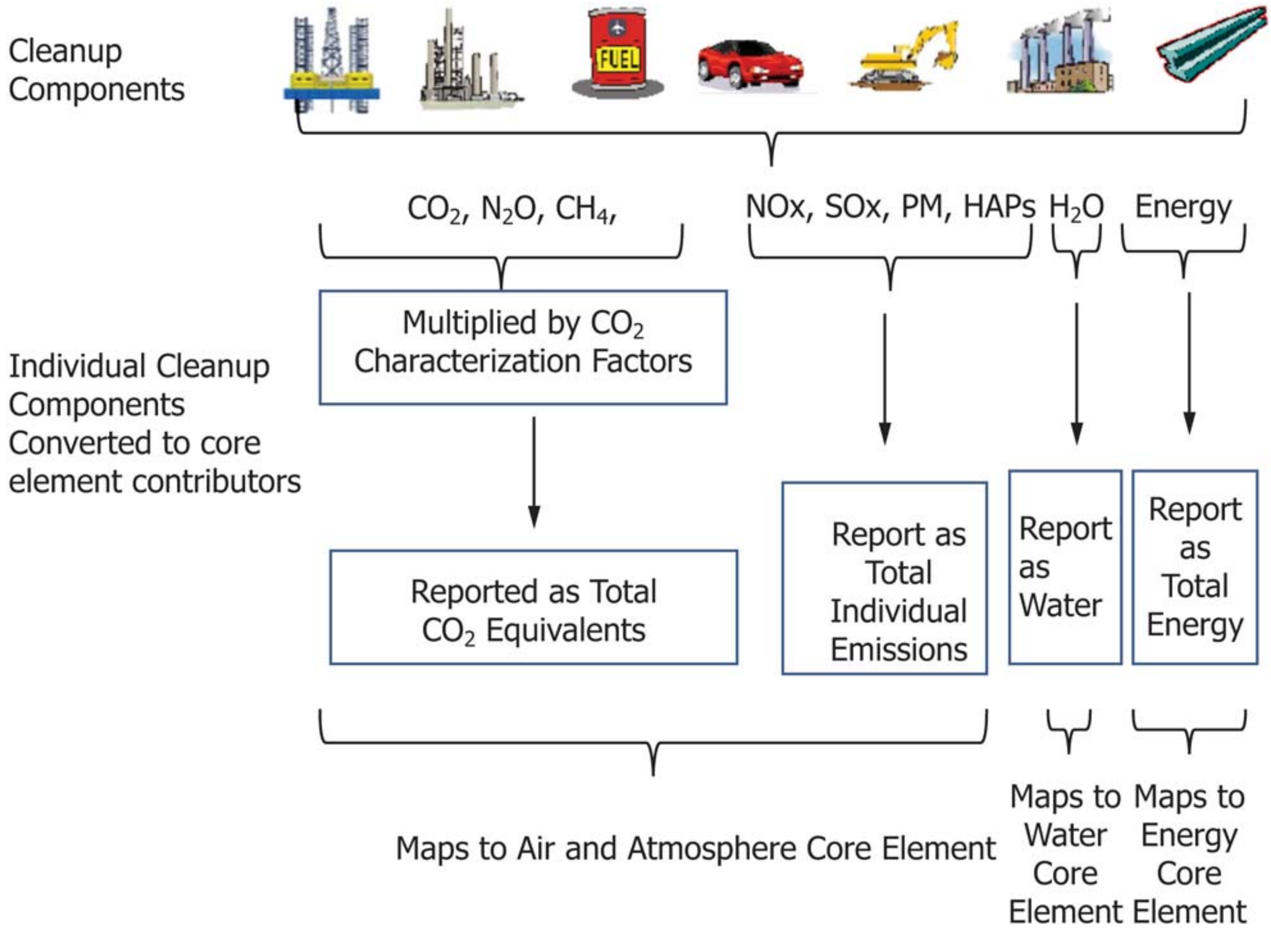

FIG. X4.1 Footprint Analysis—Overview of Approach to Identifying Cleanup Components, Converting to Emissions/Energy/Water, and Mapping Results to Core Elements

X4.5 *Additional Information about LCA Tools*

X4.5.1 *LCA* tools typically contain multiple inventory datasets that include the following: *emissions* resources and activities for each *cleanup* component, *emissions* to air, *emissions* to soil, *emissions* to water, raw materials utilized, all processes and transportation used to convert the raw material to the *cleanup* components, energy inputted, and wastes produced.

X4.5.2 While the number of inventory datasets varies depending on the *LCA* tool employed, the range of *emissions*, resources, and activities in the inventory datasets are typically much greater than those carried by *footprint analysis* tools. Given the greater depth and extent of data typically available in *LCA* inventory datasets as compared to *footprint analysis* tools, *users* have more flexibility in addressing broader project goals and approaches in their assessments. At the same time, in applying an *LCA* tool, the *user* must carefully select the inventory dataset most appropriate for the goal and approach of the project.

X4.5.3 The inventory data compiled in the course of the *LCA* are collectively referred to as the Life Cycle Inventory for the project. Each Life Cycle Inventory parameter is assigned to one or more *impact categories*. The number and type of *impact categories* available to the *user* of the *LCA* tool may vary from tool to tool and depend upon the impact assessment methods contained in the tool. For example, EPA's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), which is an impact assessment method contained in some *LCA* tools, has the following nine *impact categories* (from EPA's TRACI website and Bare, 2011(7)):

X4.5.3.1 *Global Climate Change*—The potential for *greenhouse gases* to change the earth's climate. This *impact category* is reported as carbon dioxide (CO_2) equivalents.

X4.5.3.2 *Acidification*—Processes that increase the acidity of water and soil systems. This *impact category* is reported as sulfur dioxide (SO_2) equivalents.

X4.5.3.3 *Eutrophication*—Addition of nutrients to surface waters that leads to increased growth of aquatic photosynthetic life which can affect both ecosystem quality/diversity and aesthetics. This *impact category* is reported as nitrogen (N) equivalents.

X4.5.3.4 *Ozone Depletion*—Reduction of ozone in the stratosphere caused by the *release* of ozone depleting chemicals. Ozone depletion can allow increased ultraviolet B radiation to reach the earth, which can adversely affect human health (for example, skin cancer, cataracts) and other systems (for example, marine life, agricultural crops, other vegetation). This *impact category* is reported as trichlorofluoromethane (CFC-11) equivalents.

X4.5.3.5 *Photochemical Smog Formation*—Formation of air pollutants (airborne particles, ground-level ozone) from the reaction of nitrogen oxides and volatile organic compounds in the presence of sunlight. When present in the troposphere, smog can lead to negative impacts to ecosystems and human health. This *impact category* is reported as ozone (O_3) equivalents.

X4.5.3.6 *Human Health Particulate*—Characterization of human health effects from inhalation of particulate matter (PM). PM is a collection of small particles in ambient air which have a strong influence on chronic and acute respiratory symptoms and mortality rates. This *impact category* is reported as fine particulate matter (PM 2.5) equivalents.

X4.5.3.7 *Human Health Cancer*—Characterization of human health effects from substances that have the potential to cause cancerous adverse impacts to human health. This *impact category* is reported as comparative toxicity unit cancer (CTU-cancer) equivalents.

X4.5.3.8 *Human Health Noncancer*—Characterization of human health effects from substances that have the potential to cause non-cancerous adverse impacts to human health. This *impact category* is reported as comparative toxicity unit noncancer (CTUnoncancer) equivalents.

X4.5.3.9 *Ecotoxicity*—Characterization of effects from substances that cause negative impacts to ecological receptors, and indirectly to human receptors through the impacts to the ecosystem. This *impact category* is reported as comparative toxicity unit ecotoxicity (CTUeco)–equivalents.

X4.5.4 In addition to the typical *impact categories*, *users* should include an energy *impact category* to represent the energy associated with the *cleanup*. Commercial *LCA* tools often have a range of impact assessment methods from which energy use can be quantified (for example, non-renewable energy, renewable energy, energy from fossil fuels, etc.).

X4.5.5 Each Life Cycle Inventory parameter is multiplied by an appropriate characterization factor to convert the parameter into an indicator parameter that represents the *impact category*. For example, in the *impact category* "Global Climate Change," the parameter "methane" is multiplied by a characterization factor to convert it to the indicator parameter "carbon dioxide." The characterization factors used in TRACI, and other impact assessment methods, are publicly available and typically receive significant review before being released.

X4.5.6 The resulting converted parameters are summed for each *impact category*, and results are presented in terms of indicator equivalents. In the example above, the indicator equivalent for "Global Climate Change" is "carbon dioxide equivalents." Once the *cleanup's* impact assessment is complete and results are presented for each of the *impact categories*, the *impact categories* can be mapped to the *core elements*. Some *impact categories* can be mapped to more than one *core element*. For example, the acidification *impact category* can be mapped to both the "minimized water use and impacts to water resources" *core element* (due to water acidification), and the "protect land and ecosystems" *core element* (due to terrestrial acidification). Fig. X4.2 summarizes the *quantitative evaluation* process of identifying *cleanup* components, converting to *impact categories*, and mapping the results to *core elements* for *LCA*.

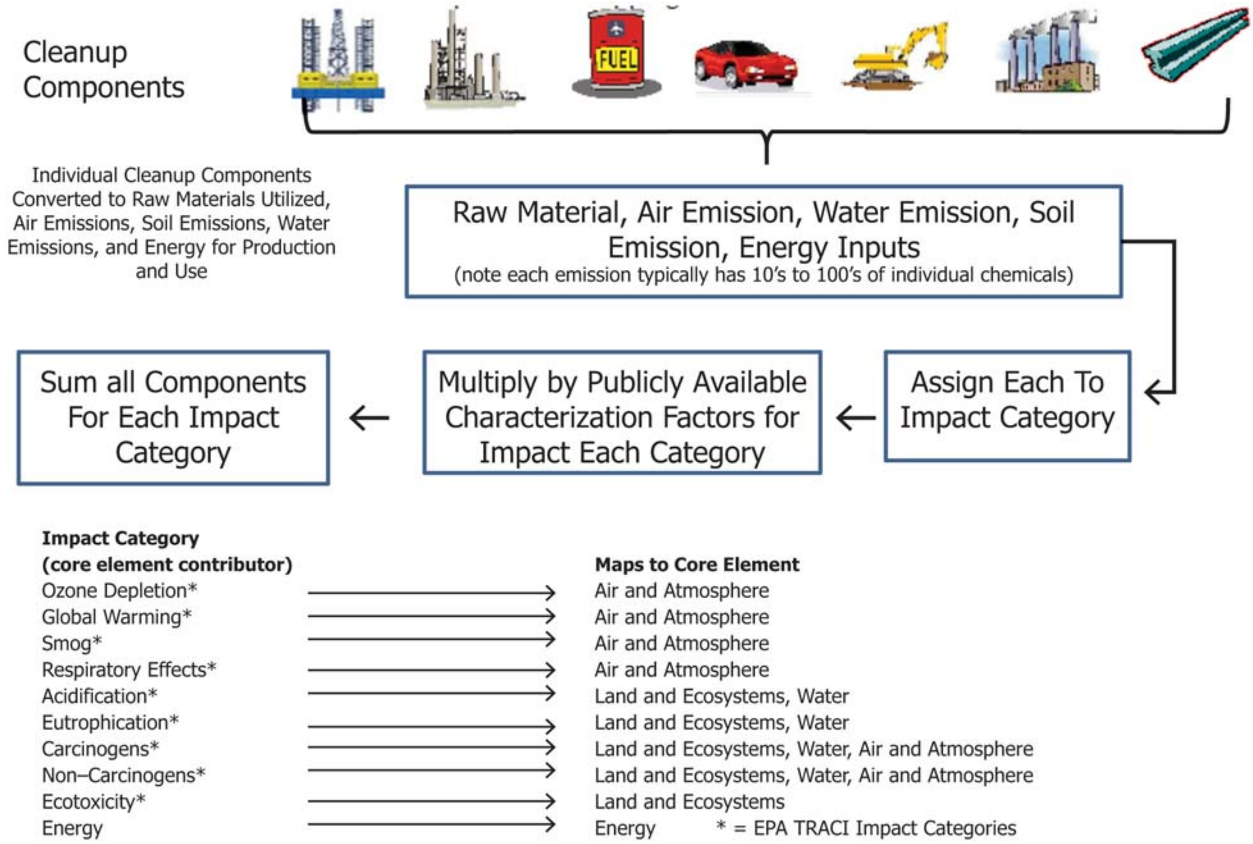

FIG. X4.2 Life Cycle Assessment—Overview of Approach to Identifying Cleanup Components, Converting to Impact Categories, and Mapping Results to Core Elements

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