Greener Cleanups

United States Environmental Protection Agency

Methodology for Understanding and Reducing a Project's Environmental Footprint

Draft for Public Input

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www.cluin.org/greenremediation/methodology

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For additional information about EPA's footprint assessment methodology or strategies for conducting greener cleanups, interested parties may contact Carlos Pachon (OSRTI) at: 703-603-9904 or pachon.carlos@epa.gov. Other technical assistance can be obtained from the Engineering Forum at: http://www.epa.gov/tio/tsp/engforum.htm.

An electronic version of this document can be downloaded from OSRTI's websites at:

http://cluin.org/greenremediation/methodology and http://www.epa.gov/superfund/greenremediation/.

Disclaimer

This document presents EPA's draft methodology to reduce negative environmental effects that might occur during hazardous waste site assessment, site remediation, or non-time critical removal actions and to consequently maximize the environmental outcome of cleanup projects. It presents technical information based on EPA's current understanding of the link between cleanup activities and potential risks to human health and the environment, and contains information designed to be useful for interested stakeholders including governments, the public, and the regulated community. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. This document was subjected to the Agency's administrative and expert review and was approved for release as an EPA document for the purpose of gathering public input.

This document provides topical introductory information rather than guidance and does not impose legally binding requirements, nor does it confer legal rights, impose legal obligations, implement any statutory or regulatory provisions, or change or substitute for any statutory or regulatory provisions. EPA recommends that users refer to applicable regulations, policies, and guidance documents regarding selection of cleanup remedies and implementation of cleanup actions; selected references and additional resources are provided herein. The Agency notes that this is a living document that may be revised periodically without public notice. EPA welcomes public comments on this document at any time and will consider those comments in any future revisions of this document.

Abbreviations & Acronyms

BMP	best management practice
CO_2e	carbon dioxide equivalent
EPA	U.S. Environmental Protection Agency
GAC	granular activated carbon
GHG	greenhouse gas
HAP	hazardous air pollutant
LCA	life-cycle assessment
NOx	nitrogen oxides
OSRTI	Office of Superfund Remediation and Technology Innovation
P&T	pump-and-treat
PM	particulate matter
REC	renewable energy certificate
SOx	sulfur oxides
SVE	soil vapor extraction
WRI	World Resources Institute

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1.0 Introduction

1.1 Background

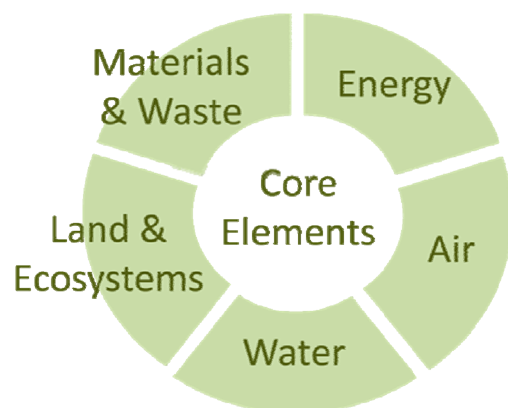
U.S. EPA defines green remediation as the practice of considering all environmental effects of remedy implementation and incorporating options to minimize the environmental footprint of cleanup actions. To this end, green remediation involves quantifying the footprint of the cleanup action on the environment and then taking steps to reduce that footprint, while meeting regulatory requirements.

Two concepts are central to quantifying the environmental footprint of a cleanup. The first is to establish those parameters (or metrics) that are to be quantified, and the second is to establish a straightforward methodology for quantifying those metrics. The term "footprint", which is commonly applied to quantifying the emissions of carbon dioxide (i.e., "carbon footprint") refers to the quantification or measure of a specific metric that has been assigned some meaning. For example, the carbon footprint is the quantification or measure of carbon dioxide (and other greenhouse gases (GHGs)) emitted by a particular activity, facility, individual, or remedy. This quantification has been established because emissions of carbon dioxide (and other greenhouse gases) have been linked to global warming and climate change. The term "footprint" can be expanded to other environmental metrics such as energy use, water use, land use, and air emissions to represent the effects a remedy may have on the environment.

This document presents green remediation metrics associated with environmental cleanups and a methodology for quantifying those metrics. The organization of this document and the metrics presented are consistent with EPA's five core elements of green remediation described at www.cluin.org/greenremediation and depicted in Figure 1.1. The document is organized as follows:

- Introduction
- Definition of green remediation metrics
- Four-step process to quantify the metrics
    - Step 1 – Gather and organize remedy information
    - Step 2 - Quantify materials & waste metrics
    - Step 3 - Quantify water metrics
    - Step 4 - Quantify energy & air metrics
- Considerations for analyzing and utilizing footprint results
- Approaches to reducing footprints.

Figure 1.1. Green Remediation Core Elements



Appendix A provides useful exhibits to augment the text, Appendix B provides suggested formats for documenting green remediation metrics, and Appendix C provides illustrative case studies.

The methodology briefly discusses the land & ecosystem core element but does not provide metrics or a means of evaluating the land & ecosystem core element. It is expected that the approach to considering the land & ecosystem core element will be described in a separate document.

The information needed and the process of obtaining the information for this methodology are the same used while developing remedy alternatives, designing a remedy, or optimizing a remedy. For this reason, it is highly suggested that the footprint analysis be conducted in concert with one or more of these other activities.

1.2 Purpose

EPA recognizes that there are many factors involved in quantifying the environmental footprint of a remedy. This document acknowledges some of these factors and presents a methodology and supporting information that is flexible, straightforward, and not overly burdensome relative to the other components of the remedial process. The methodology utilizes publicly available information, can be implemented using standard spreadsheet software, accounts for the primary contributors to the footprints, and provides meaningful information for making decisions regarding a remedy.

This document is intended to serve the following purposes:

- It is intended to supplement the green remediation primer (EPA 542-R-08-002) by providing a methodology to quantify a set of materials & waste, water, and energy & air metrics that are representative of the environmental footprint of an environmental cleanup (e.g., a soil, groundwater, or sediment remedy). The metrics are intentionally designed to reflect parameters that a remedy project team has a relatively direct ability to change.
- It is intended to encourage (not require) quantification of these metrics for remedial activities. It is a general framework to help site teams understand the remedy components that have the greatest influence on the remedy's environmental footprint. Quantification of the green remediation metrics can serve as an initial step in reducing the remedy footprint, and the quantification process allows those involved in the remedial process to analyze a remedy from another perspective, potentially yielding viable and effective improvements that may not have been identified otherwise.
- It is intended to provide suggestions on how to reduce the footprint of a remedy.
- It conveys, as technology transfer, EPA's lessons learned about footprint analysis of environmental cleanups that are a result of conducting footprint analyses at many remediation sites nationwide.
- It is intended for footprint analyses conducted on behalf of EPA and for use by EPA in evaluating footprint analyses submitted by other parties in any cleanup program.

1.3 Limitations

This methodology is not intended to be a detailed life-cycle assessment (LCA). The methodology presents and helps quantify green remediation metrics that most site teams could reduce through application of best management practices (BMPs) and optimization. Documents presenting green remediation BMPs are available at www.cluin.org/greenremediation. Unlike an LCA, it does not attempt to accurately detail all natural resource inputs and all environmental outputs, and it does not include an "impact analysis" that converts emissions and metrics into environmental effects such as acidification, increased incidence of respiratory illness, human toxicity, or ecotoxicity. Remediation practitioners are not discouraged from using LCA, but EPA has found suitable benefit from the methodology presented here for application in most green remediation efforts where quantification of an environmental footprint or footprint reductions are sought.

This methodology considers the mandates of Executive Order 13514 *Federal Leadership in Environmental, Energy, and Economic Performance* and EPA guidance on resource conservation and waste minimization, and it is intended to be applied in a manner consistent with EPA's Principles for Greener Cleanups, the Superfund Green Remediation Strategy, and EPA Regional green remediation policies, all of which are available at www.cluin.org/greenremediation. The methodology is not intended to be applied to non-remediation projects or to be submitted to other organizations or programs that have their own established methodologies for footprint analysis, greenhouse gas inventories, or similar efforts.

Finally, this methodology and the results from evaluations that follow this methodology are intended to support the remedial process and not to derail, delay, or otherwise reduce the protectiveness of an environmental cleanup. This document does not constitute a requirement to conduct footprint analyses; therefore, in the absence of other policies that would require this type of analysis, the remedial process can and should move forward without the described footprint analyses if the analysis is an obstacle to the cleanup process.

1.4 The Value of Footprint Analysis

Green remediation can be achieved through the application of BMPs without quantifying a remedy footprint or footprint reductions. EPA supports the application of BMPs and provides guidance in the application of BMPs (see www.cluin.org/greenremediation).

However, conducting a footprint analysis has a number of benefits, including the following:

- Allows quantification of the footprint reductions that might be achieved from making improvements in a remedy
- Can highlight those aspects of a remedy that dominate the footprint, allowing the site team and stakeholders to more specifically target those aspects during remedy design and implementation
- Provides a different perspective in analyzing or evaluating a selected remedy, which may lead to not only footprint reduction, but also improvements in remedy effectiveness and efficiency that may not have been identified by a more traditional evaluation.

Determining the footprint of a remedy can be a complex process depending on the level of detail and accuracy sought from the analysis. The decision of whether or not to conduct a footprint analysis, the structure and detail of the analysis, and the level of effort to conduct the analysis depend on several factors, including the following:

- The intended use of the footprint results – Will the results be used to assist with determining the footprint for an entire organization or a portfolio of sites within the organization? Will the footprint be used to help document or quantify footprint reductions?
- The complexity of a site cleanup – Is the cleanup likely to be dominated by one or two items such that footprinting is not necessary in order to determine the largest footprint contributors? Without undertaking calculations, is it apparent that the cleanup will have a very small footprint relative to other cleanups within an organization's portfolio? Is the cleanup very complex with many on-site and off-site components to the footprint or is it comparatively simple?

This document does not dictate those circumstances in which remedy footprint quantification should be conducted. The reader is encouraged to use professional judgment and consultation with other environmental professionals to determine the usefulness of footprint analysis in a given set of circumstances.

The level of effort to conduct a footprint analysis will vary depending on the cleanup project complexity and the availability of information. Most of the information used in a footprint analysis is generated during typical site activities and is documented in site reports. Coordinating a footprint analysis with these other activities such as the remedial design or optimization of a remedy can help minimize the level of effort involved in the conducting the footprint analysis.

1.5 Level of Effort and Cost

The application of the methodology is expected to add a negligible amount to the level of effort and cost associated with overall remediation and a fraction of any particular remedial activity such as an optimization evaluation. For example, footprint analysis is expected to add approximately 10% to the level of effort or cost of an optimization evaluation or less than 5% to the level of effort or cost of a remedial design. The level of effort and cost will vary depending on the site complexity, experience in conducting footprint analyses, and the level of detail of the analysis.

The methodology focuses on the green remediation metrics and therefore does not include quantification of remedy cost. It is expected that the cost of implementing BMPs or other footprint reduction measures will be considered separately by a project team and evaluated on a project-by-project basis. Because remedy cost is directly related to many of the green remediation core elements (e.g., energy usage, materials usage, and waste disposal), it is expected that many footprint reduction strategies will result in cost savings over the life of a remedy.

2.0 Green Remediation Metrics

Green remediation metrics have been chosen to intentionally reflect parameters that a remedy project team may have the ability to change. The green remediation metrics defined in this methodology are summarized in Table 2.1 and discussed below. Table 2.1 can be used to report the estimated environmental footprint of a remedy, accompanied by supporting documentation as outlined in this methodology. A more detailed breakdown of the metrics noted in Table 2.1 may be developed based on intermediate calculations in the footprint analysis, and may be reported in addition to these metrics.

Table 2.1. Summary of Green Remediation Metrics

Core Element	Metric	Unit of Measure	Value
Materials & Waste	Refined materials used on-site	Tons	
	% of refined materials from recycled or waste material	%	
	Unrefined materials used on-site	Tons	
	% of unrefined materials from recycled or waste material	%	
	On-site hazardous waste disposed of off-site	Tons	
	On-site non-hazardous waste disposed of off-site	Tons	
	% of total potential waste recycled or reused	%	
Water	On-site water used (by source)	Millions of gallons	
Energy	Total energy used	MMBtu	
	% of total energy use from renewable resources	%	
Air	On-site NOx, SOx, and PM emissions	Pounds	
	On-site HAP emissions	Pounds	
	Total NOx, SOx, and PM emissions	Pounds	
	Total HAP emissions	Pounds	
	Total greenhouse gas emissions	Pounds CO_2e	
Land & Ecosystems	No metrics. Qualitative analysis to be discussed in a future document.		

2.1 Materials and Waste Metrics

2.1.1 Materials Metrics

The materials metrics consider the total amount of materials used and the percentage of those materials that are produced from recycled material, reused material, or waste material. The following materials metrics are defined for this footprint methodology:

Refined materials used – This metric is reported in tons and refers to the mass of manufactured or significantly processed materials that are used on-site and come from off-site sources. Examples include chemicals, nutrients, food grade amendments, metals, plastics, and cement.

% of refined materials from recycled or waste material – This metric refers to the portion of the "refined materials" that is produced using recycled or reused materials or is otherwise a waste product of a manufacturing process. Examples include the portion of steel that is from recycled content, off-specification food grade amendments that are otherwise waste and which can be used as in-situ bioremediation reagents, and regenerated (not virgin) granular activated carbon (GAC) or ion exchange resin.

Unrefined materials used – This metric is reported in tons and refers to the mass of materials that are used on-site, come from off-site sources, and generally have not undergone significant processing or refinement. Examples include clean fill, sand and gravel, clay, limestone, bentonite, and the aggregate portion of concrete or asphalt. The term “unrefined materials” does not refer to raw materials that are the feedstock of a “refined material” as defined above.

% of unrefined materials from recycled or waste material – This metric refers to the portion of “unrefined materials” obtained from recycled or reused materials or is otherwise a waste product. An example includes crushed concrete that is brought from off-site sources and used as on-site fill.

2.1.2 On-Site Waste Metrics

The waste metrics consider the total amount of waste generated on-site and the percentage of total potential waste that is recycled or reused. The following water metrics are defined for this footprint methodology:

On-site hazardous waste generated – This metric is reported in tons and refers to the mass of hazardous waste generated on-site and disposed at an off-site hazardous waste facility or in a regulated on-site disposal unit.

On-site non-hazardous waste generated – This metric is reported in tons and refers to the mass of non-hazardous waste that is generated on-site and disposed off-site or in a regulated on-site disposal unit.

% of total potential on-site waste that is recycled or reused – This metric reflects the total potential waste (hazardous or non-hazardous) generated on-site that is recycled or reused on-site or off-site. Examples of wastes that are considered recycled or reused are as follows:

- Treated soil or crushed concrete from the remedy that is used as fill on-site or off-site
- Cleared vegetation that is chipped, shredded, or composted and used on-site or off-site for mulch or compost
- GAC or ion exchange resin that is sent off-site for regeneration instead of disposal
- Recovered product from remedial activities that is recycled or reused.

Consistent *with Clarification on Counting Waste-to-Energy in Waste Diversion Goals As per Executive Order 13423 and Implementing Instructions, January 14, 2008*, waste of high heat content that is used for energy recovery is not considered recycled or reused.

2.1.3 Off-Site Waste

A remedy team may have the ability to reduce waste that is generated as part of on-site activities through BMPs, but does not have much control over the waste generation, reusing, recycling, and disposal practices of material manufacturing or other off-site activities. For most remedy project teams, efforts to reduce off-site waste will therefore likely rely on reduced use of materials or reduced use of off-site activities that generate waste. In addition, quantifying waste generated off-site and determining the fate of that waste is complex. For these two reasons, an off-site waste metric is not included in this methodology. Although this methodology does not include an off-site waste metric, site teams are not discouraged from evaluating waste that is generated elsewhere in support of a remedy.

2.2 Water Metrics

2.2.1 On-Site Water Metrics

The on-site water metrics consider source and amount of water used on-site, as well as the fate of the water after use. Site-specific factors are discussed further in Section 2.2.2. The following water metrics are defined for this footprint methodology:

On-site water use – This metric is reported in millions of gallons of each type of water that is used on-site, including brief descriptions of the sources, uses, and fates of the various types of water used. Water types considered in this metric include but are not limited to the following:

- Water from the public potable water supply
- Extracted groundwater from each local aquifer
- Surface water
- Reclaimed water
- Collected or diverted storm water.

The use of the water includes but is not limited to the following:

- Equipment decontamination
- Extraction and treatment
- Chemical blending.

Potential fates of the used water include but are not limited to the following:

- Reuse in a public or domestic water supply
- Use as industrial process water
- Discharge to groundwater (specify the aquifer)
- Discharge to fresh surface water
- Use for crop irrigation
- Discharges to brackish or saline water
- Discharge to the atmosphere (i.e., as water vapor)
- Discharge to the sanitary sewer.

2.2.2 Site-Specific Consideration for the On-Site Water Footprint

Water is typically a local or regional resource that may be plentiful or scarce. In addition, there may be several types of local water resources available, and after use, the water may lose its original quality, retain its original quality, or improve in quality. These concepts are discussed further below.

Water is typically a local or regional resource. The same water footprint calculated for two similar sites in two different parts of the country may be interpreted differently by local site stakeholders. For example, groundwater extraction, treatment, and discharge to surface water in Kansas may be seen as use of a valuable, potential source of local drinking water. However, groundwater extraction, treatment, and discharge in another part of the United States may not be of concern for water use if the groundwater in that particular location is of relatively low quality and surface water is the primary source of drinking water for that location.

Various types of water with varying water quality may be used in association with cleanup activities. For example, potable water provided by a water supply utility is a refined water resource that likely involves extraction, treatment, and/or distribution prior to use. Groundwater and surface water, depending on the aquifer or source, may be of drinking water quality without treatment, may be of drinking water quality with some limited treatment, or may not practicably be used for drinking water or other beneficial purposes. Groundwater and surface water may also be used in industrial processes or for irrigation without prior treatment.

The on-site use of water can affect how it is discharged and how it can be reused. Water use can include groundwater extraction and treatment, which typically improves water quality (in addition to removing contamination). Therefore, extracted and treated groundwater may potentially have more uses than other uncontaminated water from the same aquifer. Water used for heating or cooling purposes may have a change in temperature that does not significantly affect its potential use for other purposes. Public water used for blending chemicals that are injected into an aquifer or into a water treatment process will typically involve decreasing the quality of the water given that public water is of high quality.

Water may be returned to the environment in the same, improved, or reduced quality as a result of cleanup activities. For example, discharge of treated groundwater from a pump-and-treat (P&T) system to the subsurface may involve returning that water to its original aquifer and therefore maintain the original groundwater resource. By contrast, the treated groundwater might be discharged to brackish surface water that is not of suitable quality for drinking, irrigation, or industrial uses, and therefore, the extracted groundwater would no longer be available as a fresh water resource.

2.2.3 Off-Site Water Use

Off-site water use refers to the quantity of water that is used off-site for activities such as electricity generation at a power plant and materials manufacturing. Unlike on-site water use, off-site water is used for many purposes and may occur in a variety of geographical locations. Information may not be readily available regarding the source of the water, the specific use of the water, the fate of the used water, and the scarcity/availability of water resources in the areas it is being used. Due to these sources of uncertainty and the level of effort that would be required to better understand off-site water use, an off-site water metric is not included in this methodology. It is noted, however, that off-site water use will generally decrease when other green remediation metrics (e.g., energy use and materials use) decrease. Although this methodology does not include an off-site water metric, site teams are not discouraged from evaluating water that is used elsewhere in support of a remedy.

2.3 Energy Metrics

The energy metrics consider the total amount of energy used by the remedy (including on-site and off-site activities), and the percentage of energy coming from renewable resources. The following energy metrics are defined for this footprint methodology:

Total energy use – This metric refers to the total amount of energy used by the remedy for on-site and off-site activities including electricity generation, transportation, materials manufacturing, and other off-site activities that support the remedy.

Percentage of total energy use from renewable resources – This metric is calculated by dividing the energy derived from renewable resources by the "total energy use." Energy from renewable resources includes energy from on-site renewable energy systems, energy from the use of renewable biofuels, renewable energy purchased from an electricity provider, and electricity bundled with purchased renewable energy certificates

(RECs). See Exhibit 2.1 (in Appendix A) for a discussion regarding renewable energy as it pertains to this methodology, and see Exhibit 2.2 for a discussion regarding RECs as it pertains to this methodology.

2.4 Air Metrics

The air metrics consider emissions of greenhouse gases, nitrogen oxides (NOx), sulfur oxides (SOx), particulate matter (PM), and Hazardous Air Pollutants (HAPs). For the purpose of this document, NOx, SOx, and PM are combined into a single group to streamline footprint reporting. HAPs refer to the 188 toxic air pollutants defined by the Clean Air Act. Additional information related to greenhouse gases can be found at www.epa.gov/climatechange, and additional information related to NOx, SOx, PM, and HAPs can be found at www.epa.gov/oar. The following air metrics are defined for this methodology:

2.4.1 On-Site Air Metrics

On-site NOx, SOx, and PM Emissions – This metric refers to the sum of the on-site emissions for NOx, SOx and PM measured in pounds. On-site emissions are distinguished from off-site emissions because of the local or regional health and air quality issues that arise from emission of these pollutants.

On-site HAP Emissions – This metric refers to on-site HAP emissions measured in pounds. On-site emissions are distinguished from off-site emissions because of the local or regional health and air quality issues that arise from HAP emissions.

2.4.2 Total Air Metrics

Total NOx, SOx, and PM Emissions – This metric refers to the total on-site and off-site NOx, SOx, and PM emissions measured in pounds. Total emissions are included in the methodology in addition to on-site emissions because these pollutants can also have broad regional effects on air quality.

Total HAP Emissions – This metric refers to the total on-site and off-site HAP emissions measured in pounds. Total emissions are included in the methodology in addition to on-site emissions because these pollutants can also have broad regional effects on air quality.

Greenhouse gas emissions – This metric refers to greenhouse gas emissions and is measured in pounds of carbon dioxide equivalent (CO_2e) of global warming potential. The metric refers to the total on-site and off-site greenhouse gas emissions associated with remedy activities. On-site emissions are not distinguished from off-site emissions because greenhouse gases result in global, not local or regional, effects. Greenhouse gases, global warming potential, and CO_2e are discussed in more detail in Exhibit 2.3 (Appendix A).

2.4.3 Further Categorization of Air Metrics

In estimating the on-site and total air metrics presented above and in Table 2.1, this methodology uses a structure based on three "scopes" for air emissions. This structure provides additional insights into air emissions from the remedy, and is in general agreement with the approach recommended by the World Resources Institute (WRI) Greenhouse Gas Protocol. The approach based on "scopes" is also reflected by a number of regulatory, non-profit, and other organizations, such as the EPA Climate Leaders Program, the Climate Registry, the Chicago Climate Exchange, various greenhouse gas inventories, and Executive Order 13514. The specific calculations and backup documentation for air emission metrics used in this methodology are described below.

On-site (Scope 1) – This scope of air emissions occurs from within the site boundaries. This is generally consistent with the WRI Scope 1 emissions. WRI defines Scope 1 emissions as emissions derived from equipment "owned" by the facility, even if these emissions occur off-property. However, unlike a manufacturing facility or institution that may participate in a greenhouse gas inventory, very few remediation projects actually "own" equipment. Therefore, the definition of Scope 1 emissions has been modified for the purpose of this methodology to include only those emissions from on-site activities. Examples of Scope 1 emissions include emissions associated with fuel combusted on-site in heavy equipment.

Electricity generation (Scope 2) – This scope of emissions results from off-site generation of electricity used by the project. These emissions can be offset by renewable energy purchased from an electricity provider or purchased as qualified RECs. (See Exhibit 2.1 for a discussion regarding renewable energy as it pertains to this methodology.) This scope of air emissions does not include air emissions associated with the transmission of electricity from the power station to the site through the electricity grid.

Off-site (Scope 3) – This scope of air emissions results from remedy-related emissions not covered by the "on-site" or "electricity generation" categories. For this methodology, off-site air emissions are further subdivided as follows:

- *Transportation* air emissions are those associated with off-site transportation of personnel, equipment, and materials.
- *Other off-site* air emissions are those associated with off-site activities such as materials manufacturing, off-site services (e.g., laboratory analysis), transmission of electricity through the electricity grid, and resource extraction for fuels used in electricity generation.

Purchased emissions offsets that do not result from RECs are subtracted from the Scope 3 emissions.

Because energy and air emissions are closely linked, these categories also apply to calculations and backup documentation for energy use. For example, the electricity used on-site (e.g., electricity as measured by remedy's utility meter) would be considered "*on-site*" energy use. The waste energy at the off-site electricity power plant would be "*electricity generation*" energy use. The energy lost in transmitting the electricity to the site would be "*other off-site*" energy use.

3.0 Footprint Methodology

As illustrated in Figure 3.1, this methodology is a six-step process that begins with gathering and organizing information about the remedy to be footprinted. This information is then used to estimate the materials and waste metrics and the on-site water metrics. The materials, waste, and on-site water information, plus other remedy information already gathered, is then used to estimate the energy metrics and the air metrics. After the metrics have been calculated, ecosystem services that are affected during remedy implementation are described qualitatively. The process ends with reporting the results in a manner similar to that illustrated in Table 2.1. After the results are reported, the results can be analyzed to evaluate opportunities for footprint reduction.

EPA recognizes that there are many factors involved in quantifying the environmental footprint of a remedy. This document acknowledges some of these complicating factors and presents a methodology and supporting information that is flexible, straightforward, and not overly burdensome relative to the other components of the remedial process. The methodology utilizes publicly available information, can be implemented using standard spreadsheet software, accounts for the primary contributors to the footprints, and provides meaningful information for making decisions regarding a remedy.

Figure 3.1. Overview of Footprint Methodology

Step 1:	**Gather Remedy Information**
Step 2:	**Estimate Materials & Waste Metrics**
Step 3:	**Estimate On-Site Water Metrics**
Step 4:	**Estimate Energy and Air Metrics**
Step 5:	**Qualitatively Describe Affected Ecosystem Services**
Step 6:	**Report Results**

3.1 Step 1: Gather Remedy Information

Step 1

This initial step of the footprint methodology involves collecting information about remedy design, construction, and operation. The information includes design parameters, activities conducted, and types of materials used. Exhibit 3.1 (in Appendix A) provides examples of this type of information for several common remedies.

The quality of the information depends on the stage of the remedy when the footprint methodology is conducted. The information will likely be relatively uncertain during the early design stage but will increase in certainty as the design stage proceeds and as the remedy is implemented. The degree of uncertainty in the remedy information used in the footprint analysis should be documented as the analysis proceeds, along with the likely effects of the uncertainty on the results of the analysis.

The outcome of the information gathering step is a bulleted list of remedy information. The case studies presented in Appendix C illustrate the level of detail that is expected for this step of the process. Although the case studies provide examples for data gathering, professional judgment is used on a site-specific basis to determine the appropriate level of detail to meet the objectives of the footprint analysis.

Some of the information to be gathered in this initial stage and in the next stages of the footprint process is generally available from existing documents and the site consultant. Moreover, the information needed and the process of obtaining the information is similar to the information and process used while preparing design documents, remedial action progress reports, or conducting remedy optimization evaluations. For this reason, it is highly suggested that the footprint analysis be conducted in concert with one or more of these other activities. Depending on the information available, some technical remediation expertise may be required to translate some aspects of the remedy into useable information. For example, the level of effort and type and size of equipment needed to excavate a given volume of contaminated soil may be estimated to provide information for the footprint analysis, or the amount of GAC to treat process water may be estimated for a specified flow rate and contaminant load. This document cannot provide all of the technical details and expertise needed to complete this step, but does provide exhibits (Appendix A) and examples (Appendix B) to convey fundamental information.

The level of detail achieved in the footprint analysis is heavily dependent on the information gathering step because the information gathered will determine the information that is included in the analysis and the information that is omitted from the analysis. A tradeoff arises between the level of detail achieved in the analysis and the level of effort for conducting the analysis. This methodology suggests setting and documenting the following two types of limits to select the activities or materials included in the analysis.

- ***A limit based on a specified percentage of the maximum contributor to a particular metric***
- ***A limit based on a specified magnitude for a particular metric***.

The limits and the reasoning for selecting them should be clearly documented. Based on professional judgment, an item or activity that is expected to contribute less than either of the limits can be omitted from the analysis with an appropriate level of documentation. Both types of limits should be applied to each of the green remediation metrics or grouping of metrics because an item that is a negligible contributor for one metric may be a significant contributor for another metric. Exhibit 3.2 (Appendix A) presents a screening approach that can be used and an example application of it.

3.2 Step 2: Estimate Materials & Waste Metrics

Step 2

The methodology involves quantification of materials from off site that are used on site and waste that is generated on site. This quantification is an accounting of the significant materials used, the recycled content of those materials, various wastes generated, and portion of that waste that is recycled or reused. The primary challenges associated with this step include 1) understanding what to include and what not to include, 2) converting the various quantities of materials and wastes into common units for each of the metrics, 3) recognizing recycling and reuse when it occurs, and 4) documenting information in a clear concise manner.

3.2.1 Content of a Materials Footprint Analysis

To assist with identifying materials used on-site, Table 3.1 provides the materials typically involved in several remedy components or activities. The majority of materials listed are "refined" materials as defined in this methodology. The list also includes a few "unrefined" materials. Where materials are a known combination of refined and unrefined materials, it is appropriate to distinguish between the refined and unrefined portions. For example, concrete is approximately 15% refined materials and 79% unrefined material (see Section 3.2.3 for more information). The use of one ton of concrete is therefore considered 0.15 tons of refined material and 0.79 tons of unrefined material.

Materials that exceed the limits discussed in Section 3.1 and Exhibit 3.2 are included in the calculation of the footprint. Materials that fall below these limits are not included in the calculation of the footprint. Examples of materials that are not included are documented and may still be addressed by green remediation BMPs.

Appendix B includes an example format for organizing a materials footprint analysis. Examples of completed tables are presented in the case studies provided in Appendix C.

3.2.2 Items not Included in the Materials Footprint Analysis

The methodology does not include in the materials metric the raw materials used in manufacturing processes or materials used in other off-site activities that support the remedy. Similarly, it does not consider waste generation associated with materials manufacturing or other off-site activities that support the remedy. Emphasis is placed on reducing on-site materials usage, increasing the recycled content in the materials that are used, reducing on-site waste generation, and recycling or reusing materials that have served their purpose.

Although water is a "material" in a broad sense, this methodology considers water a separate core element of green remediation with its own metrics for footprint analysis. Therefore, water used at a cleanup site is not included in the materials metric, and water discharged to an off-site treatment plant is not considered in the waste metric.

Equipment that is used only temporarily for a remedy is not considered in the materials metric when it is brought on site and is not considered recycled or reused in the waste metric when it is removed from the site. Equipment that is not included in the materials or waste metrics includes contractor equipment used at other sites (e.g., heavy equipment, mixing tanks, and hoses) and rental equipment (e.g., portable generators or air compressors for sampling). Equipment that is dedicated to the cleanup remedy, such as well extraction pumps or tanks for treatment of extracted groundwater, should be included in the materials and waste metrics when they are used and decommissioned, depending on the level of detailed desired in the footprint analysis.

The production and use of fuels such as gasoline and diesel are considered thoroughly in the energy & air metrics. Because fuels are adequately covered in those aspects of the environmental footprint, fuels are not considered materials for the purpose of materials and waste footprinting.

Table 3.1. Potential On-Site Use of Materials

The majority of materials listed here are "refined" materials as defined by this methodology. Unrefined materials are marked with an asterisk (*).

- Wells
  - Grout
  - Well casing (PVC or steel)
  - Sand/gravel/bentonite*
- Piping
  - Steel
  - Plastic (PVC, HPDE, other)
- Buildings and foundations
  - Concrete**
  - Steel
- Cutoff walls
  - Sheet pile (PVC, steel)
  - Slurry (bentonite, grout, fill)**
- Geomembranes/liners/caps
  - PVC, HDPE
  - Clay*
  - Asphalt**
- Treatment chemicals/materials
  - GAC
  - Oxidants (e.g., hydrogen peroxide)
  - Acids (e.g., sulfuric acid)
  - Bases (e.g., sodium hydroxide)
  - Flocculants (e.g., ferric chloride)
  - Polymer
  - Well rehabilitation chemicals
- Injection reagents
  - Oxidants (e.g., permanganate)
  - Acid (e.g., sulfuric acid)
  - Catalysts (e.g., ferrous sulfate)
  - Zero-valent iron
  - Nutrients
  - Electron donors (e.g., vegetable oil)
- Other
  - Fertilizers
  - Mulch/compost*
  - Process equipment (PVC, HDPE, steel)

** Unrefined material*

***combination of refined and unrefined materials*

3.2.3 Rules of Thumb and General Assistance for Quantifying Materials Use

Quantifying materials use in tons can be challenging during any phase of a remedy because many materials are ordered or described in different units, such as feet of pipe, square feet of plastic membrane, or gallons of chemical reagents. Some materials use can also be difficult to quantify if many small components are used (e.g., treatment system valves, fittings, and piping). In addition, some commonly used construction materials (e.g., steel) include significant recycled content but the recycled content is not necessarily communicated to the purchaser. For this reason, rules of thumb are useful for simplifying the materials inventory process when more site-specific information is not readily available. Exhibits 3.3 through 3.8 (Appendix A) provide general information and rules of thumb for this purpose.

- Exhibit 3.3 provides densities of common materials
- Exhibit 3.4 provides the approximate materials content of commonly used aqueous chemical solutions
- Exhibit 3.5 provides estimated materials usage for piping and wiring runs
- Exhibit 3.6 provides estimated materials usage for well installation
- Exhibit 3.7 provides estimated materials usage for process equipment and building construction
- Exhibit 3.8 provides reasonable assumptions for recycled content of steel, concrete, and asphalt, which are construction materials with a significant percentage of recycled content.

3.2.4 Content of a Waste Footprint Analysis

The following is a list of common on-site waste streams associated with remediation that can be used to help identify significant contributors to on-site waste generation.

- Drill cuttings and used drilling mud
- Excavated soil for off-site disposal
- Construction debris
- Treatment plant residue
- Spent GAC.

The following waste streams are also commonly associated with remediation but are likely too small to merit inclusion in the waste footprint.

- Used packaging
- Used personal-protective equipment that is disposable.

Waste streams that exceed the limits discussed in Section 3.1 and Exhibit 3.2 are included in the calculation of the footprint. Waste streams that fall below these limits are not included in the calculation of the footprint. Examples of waste streams that are not included are documented, and recycling and reuse of these waste streams (where appropriate) can still be applied as BMPs.

Quantifying waste generation is generally straightforward during remedy design and remedy implementation because waste streams are regulated and because when waste generation is significant, it is a significant cost driver and is suitably analyzed and documented. For this reason, general information and rules of thumb for waste generation are not provided as they have been for materials use.

Appendix B includes an example format for organizing a waste footprint analysis. Examples of completed tables are presented in the case studies provided in Appendix C.

3.3 Step 3: Estimate On-Site Water Metrics

Step 3

The methodology involves quantification of water that is used on-site. Emphasis is placed on reducing on-site water usage, and returning water of high quality to productive use. In quantifying on-site water use, the methodology recommends the following:

- Distinguishing among various local and on-site water sources
- Identifying the quality of the water used from each source
- Quantifying the amount of water used from each source
- Identifying the use of the water from each source
- Distinguishing among various fates of the water from each source after use.

The following section discusses each of these items in more detail.

3.3.1 Content of On-Site Water Footprint Analysis

Water Resources – Common sources of water that may be used on-site in association with a remedy include potable water from a public water supply system, multiple potential groundwater resources, multiple surface water resources, captured stormwater, and reclaimed water. Multiple groundwater and surface water resources are possible because the water quality may depend on the aquifer from which groundwater is extracted or the location from which surface water is extracted.

Water Quality – The quality of the water used is an important aspect of the water footprint because the potential beneficial uses of the water by the local community, economy, and environment are directly related to the water quality. Indicating the source of water does not necessarily describe the quality of the water. For example, if water is extracted from a shallow aquifer that is classified as a potential source of drinking water by the state but actually has naturally inadequate water quality for this purpose (perhaps due to high levels of naturally occurring dissolved iron or dissolved solids), then the water quality might be indicated as "potential potable water resource that likely requires treatment before use." For water that is contaminated by site-related contamination, the description should be of the natural water quality of that groundwater with a note that it is contaminated by site-related contamination.

Volume Used – The amount of water used from the indicated water resource refers to the volume that is used or diverted from that resource over the life-cycle of a remedy. For example, the use of impermeable surfaces results in diversion of stormwater to surface water rather than allowing it to infiltrate into the subsurface. The units chosen for this analysis are millions of gallons.

Potential Water Uses – The uses of the water vary from remedy to remedy. Common uses of water resources associated with remediation include the following:

- Extraction for treatment (e.g., in a groundwater P&T system)
- Extraction for testing (e.g., for long-term pumping tests)
- Blending and injecting reagents for in-situ bioremediation
- Blending and injecting reagents for in-situ chemical oxidation
- Blending of chemicals for treatment plant operation
- Make-up or backwash water for treatment plant
- Mixing grout or slurry
- Evapotranspiration from phytoremediation
- Purge water from sampling
- Equipment decontamination
- Dust control
- General construction.

Potential Fates of Used Water – The fate of the used water is an important part of the water footprint because the potential beneficial uses of the "used" water by the local community, economy, and environment directly depend on where the water is discharged and the quality of the water once it is discharged. Although water may be used as described above, the use and the fate of the used water does not necessarily result in a net effect on the on-site water resource. The fate of on-site water refers to the location the water is discharged, the water quality that the discharged water inherits, and affect of the discharged water on the receiving water body. For example, discharge of treated water from a P&T system to brackish or saline water inherits the brackish or saline quality such that its potential uses may be limited. In addition, it may also reduce the salinity of the brackish or saline water in localized areas. In some cases, the water may be reinjected into the same aquifer from which it was extracted. In this case, the amount used is equal to the amount extracted. The amount of reinjected water fully offsets the amount of extracted water and there is a marginal effect on the water resource. In some cases, however, where the natural quality of the extracted water is substantially improved by treatment, it may be appropriate to indicate the amount of water that is extracted and reinjected because reinjecting the treated water may be a lost opportunity for beneficially using the improved resource. Common fates of water after water use during remediation include the following:

- Discharge to public water supply

- Discharge for use as industrial process water
- Discharge to groundwater
- Discharge to surface water
- Discharge for use as irrigation
- Discharge to a brackish or saline water body
- Discharge to the atmosphere through evapotranspiration or vaporization.

An on-site water metric is established for each combination of a water source and water fate. For example, if extracted groundwater from a specified aquifer is used for two purposes and has two different fates, this results in two on-site water metrics. Water use from each major water resource that exceeds the limits discussed in Section 3.1 and Exhibit 3.2 are included in the calculation of the water footprint. Water uses from the various sources that fall below these limits are not included in the calculation of the footprint. Examples of water uses that are not included are documented and may still be addressed by green remediation BMPs.

Appendix B includes an example format for organizing a water footprint analysis. Examples of completed tables are presented in the case studies provided in Appendix C.

3.3.2 Rules of Thumb and General Assistance for Quantifying On-Site Use

Quantifying on-site water use is generally straightforward during remedy implementation and remedy optimization when actual data is available. It is also generally straightforward during the design process because engineering estimates made at that point can be converted into water usage. For example, engineering estimates are typically available for the extraction rate for a P&T system or the amount of water that will be used for injecting nutrients or reagents into the subsurface for an in-situ remedy. These types of engineering estimates should be used where available. General assistance is provided below to elaborate on some categories of water use and how to quantify that water use.

Storm Water Diversion - Significant diversions of storm water can also be considered a "use" because it results in transferring (using) water from one resource and adding (discharging) it to another. For example, a large cap might divert storm water to a local surface water body rather than allowing it to recharge an aquifer. This diversion has two effects. First, it reduces the recharge to the aquifer. The significance of this effect will vary from site to site. If the site is in the recharge area of a drinking water aquifer, then diversion of precipitation would divert a potential drinking water resource. By contrast, a site might be located along a creek such that infiltrating water would migrate only a short distance in the subsurface before discharging to the creek. Preventing the water from recharging the aquifer in this latter case will not significantly affect the local groundwater resource. Second, diversion of storm water results in higher peak flows in the receiving stream. This may have an effect on soil erosion or local ecosystems, potentially affecting one of the other core elements of green remediation. It could also increase loading to a storm sewer or combined sewer infrastructure. The significance of storm water diversion can be conveyed by describing the quantity and quality of the water diverted and the fate of the water. The quality of the water diverted is considered the same quality as if it had naturally infiltrated and recharged the aquifer.

Diverted storm water does not necessarily need to be discharged to surface water. Depending on the facility, the surrounding environment, and the local land uses, the diverted storm water may be collected and used for beneficial purposes such as irrigation. The use of collected storm water could then displace the need to use other potentially valuable local water resources for these purposes. The collected storm water could also be allowed to infiltrate into a different area of the same aquifer.

Calculating the amount of storm water diverted depends on the percentage of precipitation water that typically infiltrates, and this is dependent on the surface soil, vegetation, slope, and other factors. Unless site-specific calculations have been made to estimate changes in infiltration, the maximum amount of water diverted can be used. This conservative approach assumes that all water naturally infiltrates into the subsurface and the cap or remedy involves diversion of all of this water. Using these conditions, the amount of water diverted annually is the average precipitation multiplied by the area of water diverted according to the following equation:

Annual water diverted (gallons/year)	=	*Annual precipitation (inches/year)*	×	*Area (acres)*	×	*27,157 (gallons/acre-inches)*

Total water diverted as a result of the remedy would be the annual water diverted multiplied by the number of years diversion would occur.

Chemical Solutions – Chemical solutions brought to the site from a chemical vendor can contain a significant amount of water. Absent other information, it is appropriate to consider content of the solution's public potable water that is used on-site. Relevant information for many common aqueous solutions used in remediation is available in Exhibit 3.4.

3.4 Step 4: Estimate Energy & Air Metrics

Step 4

The energy and air metrics as calculated by the methodology attempt to account for as much of the life-cycle of the material or activity as practical. For example, the energy and emissions associated with electricity use includes resource extraction for fuel, use of the fuels, and transmission and distribution losses. In addition, regarding gasoline and diesel used on-site or for transportation, the energy and emissions for extracting crude oil and refining the oil into the gasoline and diesel are included, in addition to combustion of the fuels in equipment and during transportation.

The methodology purposefully does not include energy usage and air emissions resulting from the following aspects of the remedy:

- The manufacturing of rental or temporary equipment for the site (e.g., the manufacturing of an excavator that is used for removing contaminated soil)
- Office-related work and other off-site personnel activities (other than transportation between the site and the office)
- Items or activities that are non-additional (i.e., would have occurred in the absence of site remediation)
- Items or activities external to the remediation process associated with redeveloping a property.

This methodology recommends including off-site energy usage and air emissions because for some sites the off-site energy usage and emissions may represent the majority of the remedy footprint.

Step 4 is divided into the following three parts to facilitate organizing, presenting, and calculating the energy and emission footprints:

Part 1 – Inventory Remedy Transportation, Equipment Use, Materials, Public Water Use, and Off-site Services
Part 2 – Inventory Remedy Energy Use
Part 3 – Convert the Remedy Inventory into Energy and Air Metrics.

Each of these parts is discussed in the following sections.

3.4.1 Part 1 - Inventory Remedy Transportation, Equipment Use, Materials, Public Water Use, and Off-Site Services

The first step in quantifying the energy & air metrics is to make an inventory of the transportation, equipment use, materials, public water use, and off-site services required for the remedy. Much of the information required for this inventory is based on the information previously gathered for the materials, waste, and water footprints. Additional information is gathered on transportation, equipment use, and off-site services required for the remedy. As noted earlier for the materials, waste, and water footprints, the quality of the inventory information gathered in this step depends on the phase of the remedy when the footprint methodology is conducted, with greater certainty associated with later phases of the remedial process.

The type information collected varies by remedy technology and by remedy phase. Exhibits 3.9A and 3.9B provide checklists as a reminder of the types of information to be gathered. Exhibit 3.9A provides a checklist for the remedy construction phase, and Exhibit 3.9B provides a checklist for the remedy operation phase.

In an effort to streamline the footprint analysis process, it is appropriate to screen the information to be included in the analysis. The materials use, waste disposal, and public water use described in Steps 2 and 3 can be included directly. The transportation, equipment use, and other off-site services are screened against the limits discussed in Section 3.1 and Exhibit 3.2. Items and activities that exceed the limits are included, and items and activities that fall below the limits are excluded. Examples of items and activities that are not included are documented and may still be addressed by green remediation BMPs.

The outcome of this step is a reference to the previously documented materials, waste, and public water from Steps 2 and 3 along with a bulleted list of types and quantities of transportation, equipment use, and off-site services that are involved in the remedy.

3.4.2 Part 2 – Inventory Remedy Energy Use

The second step in estimating the energy and air metrics is to organize and refine the inventory information that was developed in Step 1 and to use that information to determine the amount of energy involved.

This step is divided into the following parts:

- Determining fuel use
    - Converting personnel transportation into fuel use
    - Converting on-site equipment use into fuel use
    - Converting transportation of equipment, materials, and waste into fuel use
    - Gathering information about actual fuel use (when such information is available).
- Determining electricity use
    - Converting electrical equipment and power requirements into electricity use
    - Gathering information about actual electricity use (when such information is available).

Determining Fuel Use

Converting Personnel Transportation into Fuel Use

Fuel use associated with personnel transportation is a function of the type of vehicle, the type of fuel, and the distance traveled. During remedy construction or remedy operation, this information may be readily available, and in some cases, actual fuel use may be tracked. If fuel usage has been tracked for some or all of the remedy, it should be used directly and/or used to estimate other fuel usage. However, in most cases, particularly during remedy design, it may be necessary to make some assumptions regarding fuel use. Exhibit 3.10A provides assistance with quantifying fuel use for personnel transportation.

Fuel use associated with relatively routine personnel travel is considered in the footprint calculations. However, it may not be necessary to include fuel use for non-routine or one-time travel because it likely falls below the established screening limits. For example, it is typically appropriate to include daily or weekly travel of a site operator to the site, whereas it may not be necessary to include travel by multiple parties for a kickoff planning meeting. Carpooling can be assumed where appropriate (e.g., two sampling technicians traveling together to conduct a monitoring event). The process of estimating fuel use for personnel transportation is illustrated in the case studies presented in Appendix C.

Converting On-Site Equipment Use into Fuel Use

Equipment operation typically involves the use of a diesel or gasoline engine that may or may not have been modified to operate on biodiesel or fuel blends. Fuel use associated with equipment operation is a function of the following:

- Horsepower rating of the equipment
- Type of fuel
- Engine efficiency
- Load on the engine
- Hours of operation.

Although the horsepower rating and fuel type may be known, the load on the engine, the engine efficiency (which varies with load), and the hours of operation may not be known. During remedy construction or operation, it may be feasible to track fuel usage or contact equipment owners/operators about estimated fuel use. However, during remedy design, this may not be practical and a means of approximating fuel use is needed. Exhibit 3.10B provides assistance with quantifying fuel use for operation of heavy equipment. The process of estimating fuel use associated with heavy equipment operation is illustrated in the case studies presented in Appendix C.

Converting Transportation of Equipment, Materials, and Waste into Fuel Use

Fuel use associated with transportation of equipment, materials, and waste is a function of the type of vehicle, the type of fuel, the weight of the cargo, the presence of other cargo, the distance traveled, and whether or not the vehicle makes an empty return trip. During remedy construction or remedy operation, this information may be readily available. In some cases, actual fuel use may have been tracked or can be estimated by freight carriers. If fuel usage has been tracked for some or all of the remedy, it should be used directly and/or used to estimate other fuel usage. In most cases, however, particularly during remedy design, it may be necessary to make some assumptions regarding fuel use. Exhibit 3.10C provides assistance with quantifying fuel use for equipment, materials, and waste transportation.

Fuel use for materials and waste transportation should be estimated for the materials and wastes quantified in Steps 2 and 3 and for the equipment transportation that meets the screening limits described in Section 3.1 and Exhibit 3.2. The following addition considerations are noted:

- Empty return trips for trucks should be considered in most cases (e.g., when items are transported directly to the site from the supplier or when waste is transported to a disposal facility).
- Consideration should be given to how a specific item is transported. For example, large quantities of materials and waste are typically carried in bulk, whereas equipment is typically transported via specialty freight (i.e., with no other cargo on board).

- In general, fuel requirements for transportation from the manufacturer to the vendor and then to the site should be considered where practical.
- It is common for heavy equipment such as drill rigs to remain at the site throughout the project, reducing the amount of equipment mobilizations. This can be assumed unless site-specific information suggests otherwise.

The process of estimating fuel use for equipment, materials, and waste transportation is illustrated in the case studies presented in Appendix C.

Converting Electrical Equipment and Power Requirements into Electricity Use

Electricity use associated with a remedy typically results from one of the following types of equipment:

- Electric motors for pumps, blowers, air compressors, and mixers
- Specialized treatment equipment such as ozone generators or ultraviolet oxidation units
- Subsurface electric resistive heating for in-situ thermal remedies
- Electric resistive heating for building heat
- Building lighting
- Process controls (typically with negligible electrical usage compared to the equipment that is controlled).

Electricity provided by an on-site generator should not be included in estimating electricity use. Rather, the fuel used to power the generator should be included when converting equipment use into fuel use, as noted above.

Electricity obtained from a utility is easily tracked through past bills. When the footprint analysis is conducted on an operating remedy and past electricity use is representative of future electricity use, the electricity use from the electric bills should be used in the energy footprint. During the remedy design and remedy construction phases, utility bills are not available, and assumptions regarding electricity use are made. In either case, an attempt should be made to document the individual demands for electricity from various pieces of equipment because this information is useful for identifying areas for reducing electricity usage during interpretation of the results. Exhibit 3.11 provides equations for estimating equipment power ratings based on remedy information, and Exhibit 3.12 provides equations for estimating electricity use given the equipment power rating. The process of estimating electricity use is illustrated in the case studies presented in Appendix C.

Like other forms of energy use, electricity generated from on-site renewable energy contributes to the metric of total energy use. On-site renewable energy is also an important component of the metric for the percentage of energy from renewable resources and for off-setting the emissions typically associated with grid electricity. On-site renewable energy systems commonly include meters to track electricity generated, and this direct information can be used for footprint analysis when it is available. During the feasibility study and design stage of a renewable energy system, engineering estimates of electricity generation are often available and can be used for footprint analysis. It is important to note that utility bills do not include the renewable electricity generated on-site. Therefore, when using utility bills to quantify electricity usage, the electricity generated from the on-site renewable energy system also is considered but tracked separately so that conversion factors for grid electricity are not applied to the electricity generated from the renewable energy system. When electricity usage is estimated by considering electrical demand of individual pieces of equipment, it is similarly important to subtract from this estimate the amount of electricity generated by the on-site renewable energy system so that the conversion factors for grid electricity are not applied to the electricity generated from the renewable energy system.

3.4.3 Part 3 – Convert the Remedy Inventory into Energy and Air Metrics

The third part of Step 4 is to convert the fuel, electricity, materials, and off-site services involved in the remedy into energy & air metrics. Footprint conversion factors are used for this purpose. Each item noted above (i.e., each type of fuel, each source of electricity, each material, and each off-site service) has its own set of conversion factors related to the production, manufacturing, or provisioning of that item or service. In addition, fuels such as diesel, gasoline, and natural gas each have an additional set of conversion factors related to the combustion of the fuels. For example, for a fuel such as diesel, conversion factors are used to calculate metrics for energy, greenhouse gases, NOx, SOx, PM, and HAPs associated with the production of the fuel and the combustion. The application of the conversion factors for one of the metrics (greenhouse gases measured as CO_2e) is illustrated in the following example for diesel fuel. First, the CO_2e conversion factor for off-site production of a gallon of diesel from the well field through the refinery (which is distinct from using a gallon of diesel) is applied.

Diesel used (gallons)	×	*Footprint conversion factor for converting production of a gallon of diesel to pounds of CO_2e*	=	***CO_2e footprint from diesel production (pounds of CO_2e)***

Second, the CO_2e conversion factor for diesel use (combustion) is applied.

Diesel used (gallons)	×	*Footprint conversion factor for converting a gallon of diesel used to pounds of CO_2e*	=	***CO_2e footprint from diesel use (pounds of CO_2e)***

Footprint conversion factors are applied in a similar manner to calculate the other metrics (energy use and emissions of NOx, SOx, PM, and HAPs) for use and production of diesel fuel. In addition, unique conversion factors are applied in a similar manner to the use and production to all the other fuels, to the generation and use of electricity, and to the manufacturing or provision of materials and services used for the remedy. The results are then compiled, distinguishing among the four categories mentioned in Section 2.4.3 (on-site, electricity generation, transportation, and other off-site activities) when summing and reporting the results. Example tables for applying the conversion factors and reporting the results are presented in the Appendix B and in the case studies in Appendix C.

One of the challenges of conducting a footprint analysis is establishing accurate conversion factors for the fuels, electricity, materials, and services used in a the remedy. Exhibit 3.13 (Appendix A) provides suggested default footprint conversion factors to use in footprint analyses of environmental cleanups. Most of these conversion factors are obtained from publicly available life-cycle inventory databases. Others represent reasonable approximations based on analysis of a compilation of conversion factors. The values presented in life-cycle inventory databases are generic or industry-wide averages that may not be accurate for specific manufacturing facilities. There is therefore a degree of uncertainty associated with using these values for footprinting specific remedies. These conversion factors are made available in Exhibit 3.13 to provide a means for estimating the green remediation metrics specified in this methodology and are not intended to guide procurement decisions or to suggest that one material should be used in place of another. In some cases, a site team may identify more specific footprint conversion factors that are based on site-specific or vendor-specific information. Site-specific conversion factors can be used for footprint analyses but the source of the conversion factor should be documented as part of the footprint analysis. For example, a site team that uses a vendor who provides "carbon neutral" solid waste disposal (if properly documented by the vendor) would choose a CO_2e conversion factor of zero for solid waste disposal rather than the "default" conversion factor, and documentation for choosing the site-specific conversion factor should be referenced as part of the footprint analysis.

Other on-site sources of emissions may be identified for cleanup activities, particularly for the greenhouse gas and air toxics footprints. For example, greenhouse gases or HAPs may be emitted in the off-gas of an air stripper, the exhaust of a soil vapor extraction (SVE) system, by evaporation from exposed contaminated soil or groundwater, landfill gas emissions, or perhaps other site-specific activities. In addition, on-site activities may result in carbon storage or other reductions of the greenhouse gas footprint (e.g., combusting landfill gas or carbon storage in tree biomass). Exhibit 3.14 provides a method of calculating HAP air emissions from common site activities given limited site-specific information. Exhibit 3.15 provides a method of calculating carbon stored in the biomass of trees that have been planted as part of remedial activities.

Conversion factors for energy and emissions from off-site electricity generation are dependent on the specific grid mix supplied to the site and are determined on a site by site basis. The type of information used to determine the conversion factors is generally available from the individual electric service providers. If it is not, the information can be obtained for the state where the site is located from www.eia.gov or for a region defined by eGRID (www.epa.gov/egrid). Exhibit 3.16 illustrates how to use the information from these sources to obtain the footprint conversion factors and renewable energy metrics for this methodology.

The footprint conversion factors suggested in Exhibit 3.13 and calculated according to Exhibit 3.12 or discussed above are not intended for use by site owners or regulatory agencies in submittals of footprint information to other organizations such as climate registries. Rather, they are intended to provide a sufficient level of information to allow a site team to make educated decisions regarding energy use and pollutant emissions associated with the cleanup. It is expected that updates or refinements to these emission and offset factors will be provided as more information becomes available.

Appendix B provides example tables for applying conversion factors and reporting results, and the case studies presented in Appendix C provide examples of calculating and presenting the energy & air metrics.

3.5 Step 5: Qualitatively Describe Affected Ecosystem Services

Step 5

It is expected that the approach to considering the land & ecosystem core element will be described in a separate document.

3.6 Step 6: Report Results

Step 6

A suggested format for reporting results of each step is presented in Appendix B. In addition to this information, documentation in a footprint analysis should be provided for the screening process, analytical assumptions, and possible areas of uncertainty.

4.0 Considerations for Interpreting Footprint Results

Interpreting the results of a footprint analysis is influenced by a number of considerations, including the original goal of the footprint analysis and the quality of the data used in the analysis. In addition, trade-offs among footprint metrics and the magnitude of the footprint are taken into consideration when interpreting the results of a footprint analysis. The following sections discuss each of these four considerations, and the case studies provided in Appendix C demonstrate how they are considered.

4.1 Goals of Footprint Analysis

One of the main considerations in interpreting the results of a footprint analysis is the goal of the analysis. The goal of the analysis varies with the remedial stage and with other site-specific factors. The following table summarizes likely goals of the footprint quantification based on remedy stage. It should be noted that the quality of the information changes significantly depending on the available remedy information, and the confidence in the footprint results increases with later remedy stages as more robust remedy information becomes available.

Table 4.1. Goals of Footprint Quantification

Remedy Phase	Typical Goal of Footprint Quantification
Development of remedy alternatives	• Identify components of various remedies that are large contributors to footprints
Remedial Design and Remedy Optimization	• See remedy from different perspective to identify opportunities for improvement • Identify: o Design components that are large contributors to footprints during construction or during remedy operation o Refinements or data gaps in the conceptual site model that, if addressed, might help reduce footprints (e.g., improved characterization that refines the known contamination source area) o Potential opportunities for footprint reductions
Other	• Quantify and document emissions

* *Results of a footprint analysis during the development of remedy alternatives may be subject to substantial uncertainty due to limited specific remedy information available and the absence of actual data or engineering design estimates.*

4.2 Data Quality

There are three main factors that influence data quality:

- The first influence is the quality of the remedy information input into the footprint analysis. Variations in remedy information, such as the volume of soil to be treated or the groundwater extraction rate, can result in significant variations in the footprint results. This influence affects all green remediation metrics. The quality of the data input is generally lowest during the development of remedy alternatives when design studies have not been conducted and design-level engineering estimates have not been made. By contrast, the quality of data input is generally highest during remedy operation when actual data is available and the site has been thoroughly studied. The data quality during the design stage generally has benefited from several design studies and engineering estimates but does not have the benefit of actual data for input into the footprint analysis.

- The second influence is the accuracy or appropriateness of the formulas for estimating electricity, fuel, water, materials, and off-site services involved in a specific remedy. Although formulas are provided in this methodology to help reasonably estimate these quantities, they are not robust and do not necessarily apply accurately to each site or scenario. This influence primarily affects the energy & air metrics, but can also affect the other metrics to some degree. Example #1 (at the end of this section provides an example of how assumptions regarding materials transport can greatly affect the footprint results.

- The third influence is the accuracy of the conversion factors used to convert the remedy inventory into green remediation parameters. Although this methodology includes conversion factors to use for this purpose, the conversion factors are general in nature and cannot account for differences that might occur from one manufacturing facility to another. Even the footprint conversion factors associated with converting electricity generation to emissions can impart significant variation in the footprint results. Example #2 (at the end of this section) provides an example of this influence and demonstrates that footprint conversion factors could vary by as much as one order of magnitude. This third influence also predominantly affects the energy & air metrics. Based on the above discussion, it is apparent that the energy & air metrics may have the largest amount of uncertainty relative to the other green remediation metrics because the energy & air metrics are affected by all three data quality influences and the other metrics are primarily affected by the first data quality influence.

4.3 Tradeoffs between Metrics

This methodology helps quantify metrics for 15 different parameters in four different green remediation core elements. Some of the parameters are local in nature (e.g., on-site HAP emissions or local water use), and others are more regional (e.g., NOx/SOx/PM emissions) or global in nature (e.g., total greenhouse gas emissions). A potential modification to an existing remedy may increase the values for some metrics and decrease the values for others.

For example, a bioremediation remedy using water from the public supply results in significant use of public water but relatively minimal on-site emissions of NOx, SOx, and PM because a generator or other equipment is not needed to provided power for extracting groundwater. Potentially modifying the remedy to use extracted groundwater will decrease or eliminate the use of public water but may increase the on-site NOx, SOx, and PM emissions from a generator that provides the power for groundwater extraction. Different site teams and different stakeholders may favor one option over another depending on their prioritization of green remediation parameters, cost, and other factors. When such tradeoffs exist, it is helpful to know the metrics or parameters that are more important to site stakeholders as well as the influence of parameters relative to regulatory requirements.

4.4 Footprint Magnitude

Two main questions regarding the magnitude of a footprint may arise when interpreting the results of a footprint analysis:

- "What is considered a large footprint or footprint reduction?" When seeking to reduce a footprint, it is helpful to understand the significance of the magnitude of the potential reduction and the appropriate level of resources (e.g., time, materials, and money) that could be reasonably invested to achieve the reduction. A small percentage decrease in a footprint of a remedy with a large footprint may be greater in magnitude and more cost-effective to achieve than a large percentage decrease in the footprint of another remedy with a relatively small footprint.

- "What is considered a significant difference between footprints of two or more potential modifications that are under consideration?" The data quality influences noted above are crucial elements in determining if there is a significant difference between the footprints of two potential modifications to a remedy, and comparisons of footprints should be interpreted with a degree of caution that is commensurate with the degree of uncertainty in the input data.

Example 1. Data Quality - Transportation

Consider the following example of carrying 1.5 tons of emulsified vegetable oil (equivalent to approximately 400 gallons) 500 miles via specialty freight and common freight. The fuel economies used are from Exhibit 3.10C.

Specialty freight (includes empty return trip)

Delivery trip:	500 miles	÷	6 miles per gallon	=	83 gallons
Empty return trip:	500 miles	÷	6 miles per gallon	=	83 gallons
				Total:	166 gallons

Specialty freight (excludes empty return trip)

500 miles	÷	6 miles per gallon	=	83 gallons

Common freight "heavy load" (i.e., truck is fully loaded, including freight not related to the site)

1.5 tons	×	500 miles	×	0.029 gallons per ton-mile	=	22 gallons

The fuel use differs by 750% depending on the mode of transportation assumed. This example also assumes that the distance transported is known and correct. In many cases, especially during the remedy design stages, the transport distance or mode of transportation may not be known, introducing additional data quality concerns.

Example 2. Data Quality – Electricity Generation

Consider the following example of estimating the greenhouse gas emissions (measured in CO_2e) from a P&T system in Tacoma, WA, where electricity usage is 100,000 kWh per year and represents the large majority of the greenhouse gas footprint for the remedy. Various sources of information on the fuel blend or generation mix for grid electricity supplied to the site may be found on-line or may be obtained from electricity providers. The sources include the 2007 generation mix for the eGRID (www.epa.gov/egrid) Northwest Power Pool (NWPP) subregion (where Washington is located), the 2009 generation mix for the NWPP from the Washington State Department of Commerce ("Commerce"), the 2007 Washington State generation mix from eGRID, the 2009 Washington State generation mix from Commerce, and the 2009 generation mix for Tacoma Power (local utility) provided by Commerce.

	NWPP (eGRID 2007)	NWPP (Commerce 2009)	WA (eGRID 2007)	WA (Commerce 2009)	Tacoma Power (Commerce 2009)
Generation Mix					
Coal	31.96	44.29	8.00	17	3.83
Hydropower	48.37	34.76	73.72	64	87.64
Natural Gas	12.78	17.46	6.81	13	1.51
Nuclear	3.0	1.41	7.58	4	6.68
Other	3.89	2.08	3.89	2	0.34
Total	100%	100%	100%	100%	100%
CO_2e emissions generation (lbs/kWh)	0.87	1.20	0.26	0.54	0.10
CO_2e footprint (lbs) for 100,000 kWh of electricity usage	87,000	120,000	26,000	54,000	10,000

Notes:

- *"Commerce" = Washington State Dept. of Commerce http://www.commerce.wa.gov/site/539/default.aspx)*
- *Coal, natural gas, and nuclear CO_2e emissions for "Commerce" generation mixes are based on data from the National Renewable Energy Laboratory Lifecycle Inventory (NREL, www.nrel.gov/lci). Hydropower CO_2e emissions are assumed to be 0 lbs/kWh. "Other" fuels are assigned CO_2e emissions of 0 lbs/kWh in calculating conversion factors for each fuel blend, which may slightly underestimate emission factors for these generation mixes. The footprint for extracting and transporting fuels is not included.*

It is apparent from the above table that the generation mixes vary considerably among the various sources of information. For example, the percentage of electricity generated from coal varies from 8% to 44%. The variation in the generation mix results in a variation in the footprint from 10,000 to 120,000 lbs of CO_2e per year, which is more than one order of magnitude. The conversion factor even varies by over 35% for the NWPP subregion depending on the year and/or entity compiling the data. The method for calculating the conversion factors for electricity generation therefore has a significant influence on the footprint results. The conversion factors for electricity are relatively straightforward to calculate compared to the conversion factors for other items associated with a remedy, and it is reasonable to expect that the conversion factors for manufactured goods also vary significantly based on factory location and several other factors.

5.0 Approaches to Reducing Footprints

The largest footprint reductions for any one metric likely result from modifications to those aspects of the remedy that are the largest contributors to the parameter footprint. For example, if electricity usage is the largest contributor to the energy footprint for a remedy, the largest footprint reductions will likely come from reducing electricity usage. Furthermore, the largest reductions in electricity usage will likely come from modifying those remedy components that use the most electricity. The process of conducting a footprint analysis and the results can help identify the largest contributors and potential approaches to reducing those contributions.

U.S. EPA's experience to date in case studies posted on www.cluin.org/greenremediation suggests that the largest footprint reductions come from optimization of the remedy from a technical perspective or from the application of renewable or alternative energy sources. The optimization of a remedy could include changes in the conceptual site model or data interpretation that results in changes to the remedy. Optimization could also include changes in various remedy components to more cost-effectively and efficiently achieve its purpose. Example #3 (at the end of this section) illustrates footprint reductions that occur from optimizing the remedy and from applying renewable energy. The footprint methodology can help quantify the footprint reductions associated with optimization, and optimization can benefit from the additional perspective provided by conducting a footprint analysis. For this reason, it is often beneficial to conduct a footprint analysis during remedy optimization or to include an optimization component during a footprint analysis.

The use of BMPs can result in direct footprint reductions and can enhance optimization efforts. For example, the BMP of carpooling can reduce energy use and air emissions and reduce travel costs. The BMP to evaluate plume capture and optimize groundwater extraction rates can result in substantial energy and emission footprint reduction and cost reduction if current levels of extraction are higher than necessary. Other best management practices can be applied to reduce water materials usage. EPA has compiled the following documents that include BMPs for specific remedial technologies as well as issues common to many sites (www.cluin.org/greenremediation):

- Excavation and Surface Restoration, EPA 542-F-08-012, December 2008
- Site Investigation, EPA 542-F-09-004, December 2009
- Pump and Treat Technologies, EPA 542-F-09-005, December 2009
- Bioremediation, EPA 542-F-10-006, March 2010
- Soil Vapor Extraction & Air Sparging, EPA 542-F-10-007, March 2010
- Clean Fuel & Emission Technologies for Site Cleanup, EPA 542-F-10-008, August 2010
- Integrating Renewable Energy into Site Cleanup, EPA 542-F-11-006, April 2011
- Sites with Leaking Underground Storage Tank Systems, EPA 542-F-11-008, June 2011.

A few key ideas related to footprint reduction for a few example remedy types are presented in the following sections. Footprint analysis can help quantify footprint reductions from implementing BMPs.

5.1 Approaches to Reducing Materials & Waste Footprints

P&T remedies: The largest contributors to the materials and waste footprints for a P&T remedy are typically system construction, chemicals usage, and waste disposal. All of these items are directly tied to the extraction rate and water quality, so the optimal extraction program would be a key focus for footprint reduction of P&T systems. Consider the GCL Tie & Treating Superfund Site in Sydney, NY. Potassium permanganate use and waste generation associated with removal of manganese (a nuisance parameter for treatment at this site but not a contaminant of concern) is directly tied to manganese loading (flow rate multiplied by influent concentration). Optimizing the extraction network can reduce the flow rate and manganese loading, resulting in a reduction of both potassium permanganate use and waste generation. Another key focus for footprint reduction of P&T systems is the beneficial reuse of the treated water. Also consider the P&T system at the 10th Street Superfund Site in Columbus, NE. A dispersant is added to the water to reduce fouling of the air stripper. However, the treated water is distributed for public consumption, and the dispersant addition is required by the water provider to prevent scaling in distribution piping and fixtures and piping in residential and commercial buildings. Because the dispersant is required for public distribution of the water, the dispersant use is not an "additional" item contributed by the remedy and need not be considered part of the materials footprint for the remedy.

In-situ chemical oxidation and bioremediation: The largest contributors to the materials footprint associated with these in-situ remedies is the amount of reagents used/injected and the construction of permanent injection locations. Optimizing the number of injection locations and the reagent demand could lead to significant footprint reductions. In some cases, using existing wells as injection points can reduce the number of additional wells needed. Optimizing the area to be treated (perhaps with more characterization) could reduce both the number of injection locations and the demand for reagents. Creating recirculation cells by using extracted groundwater for reagent blending and injection could help distribute the reagents in the subsurface, potentially reducing the number of injection points. The use of direct-push technology to deliver reagents instead of permanent injection wells may reduce materials use but increase energy use, presenting a potential tradeoff for site stakeholders.

Excavation remedies: The largest contributions to materials use and waste generation for excavation remedies is the disposal of excavated material in a landfill and the use of clean fill for backfill. Consideration could be given to conducting on-site treatment of impacted soils followed by reuse of the treated soil on-site, using clean soil from the excavation to partially backfill the excavation, and/or locating crushed concrete or other reusable materials for fill. Consideration could also be given to in-situ remediation via contaminant removal/destruction or soil stabilization. These alternative approaches may reduce waste generation but might also affect the materials use or energy and air footprints, presenting a potential tradeoff for the site team.

5.2 Approaches to Reducing Water Footprints

P&T remedies: The most important factor in estimating the water footprints for many P&T remedies is the change in water quality through the extraction, treatment, and discharge process. Extracted and treated groundwater may be a valuable resource, but if the treated water is discharged to relatively low quality surface water (e.g., water with high dissolved or suspended solids), the higher quality of the treated water is lost. Finding beneficial use of the treated water (e.g., potable water, industrial process water, or irrigation) is preferred if appropriate and if the water has been thoroughly tested because it displaces demand on other water supplies and offsets the energy and footprint of obtaining that other water resource. If a beneficial use is not available, discharging the water to an aquifer or surface water body of equal quality and availability is another means of reducing the water footprint. Focus should also be placed on optimizing the groundwater extraction rate.

In-situ chemical oxidation and bioremediation: The largest contributors to the water footprint associated with these in-situ remedies is the reagent dilution, injection, and dispersal. Optimizing the number of injection locations, reagent demand, and delivery concentration could help reduce overall water use. In addition, the type of water used can be a factor. Using extracted groundwater in place of water from the public supply would be favorable because extracted groundwater is a less refined water resource than public supply water. In addition, use of extracted groundwater may help disperse the reagents in the subsurface.

Excavation remedies: Large contributions to the water footprint for excavation and other earth moving remedies could include water used for dust control or water from dewatering. Water used for dust control could be reduced by planning work for the appropriate season or weather condition. Water use could also be reduced through use of chemicals, but this would result in an increase in the materials footprint. With respect to dewatering, excavations below the water table can result in substantial dewatering efforts to lower the water table below the planned extent of the excavation. Cutoff walls or other engineering controls could help reduce the extraction rates for dewatering. Polymers or bentonite slurry may also help prevent trenches beneath the water table from collapsing and help avoid or reduce the need for dewatering.

5.3 Approaches to Reducing Energy & Air Footprints

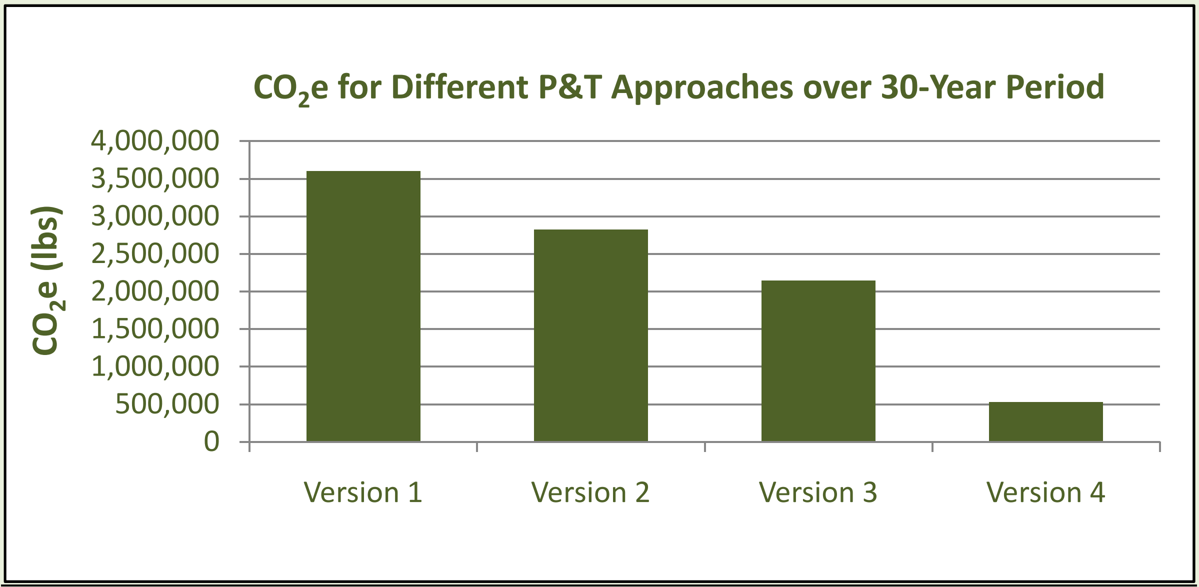
P&T remedies: The largest contributors to the energy & air footprints are typically electricity, chemicals usage, process sampling, and waste disposal. Electricity, chemical usage, and waste disposal are directly tied to the extraction rate, so establishing the optimal extraction rate would be a key focus for footprint reduction of P&T systems. The intensive electricity usage of P&T systems also makes them excellent candidates for the application of renewable energy. The renewable energy may be generated on-site (e.g., by a photovoltaic system, wind turbine, or system for converting landfill gas to energy), purchased from the utility provider, or purchased as RECs. Significant energy is used to lift ground water from the water table to the surface and to treat it. As a result, substantial footprint reduction can occur if the treated water can be put to an appropriate beneficial use (after thorough testing), effectively offsetting the energy and emissions associated with the water supply that has been displaced. Process sampling can also be a large contributor to the energy and air footprints. For that reason, optimizing the process sampling program and utilizing surrogate parameters such as pressure drop, oxidation-reduction potential, pH, turbidity, and other parameters may help streamline the process sampling program.

In-situ chemical oxidation and bioremediation: The largest contributors to energy & air footprints are typically the production and transport of the reagents to be injected. Therefore, optimizing the amount of reagent to be added would be a key focus for footprint reduction for in-situ remedies that involve reagent injection. It may be appropriate to work in phases, beginning with the best estimate of reagent use and modifying or increasing reagent doses for future injection events rather than injecting too much reagent in the first event. Increased characterization of the treatment area may also help reduce the treatment volume and the reagent use. Selection of the reagent type can be a factor. Although most reagents for chemical oxidation are refined chemicals that are unlikely to be a manufacturing waste or byproduct, the reagents for in-situ bioremediation may be food or agricultural waste products. Mulch, off-specification soft-drink syrup, low-grade molasses, and other waste products may be appropriate reagents for in-situ bioremediation of chlorinated solvents. Because these items are waste products, the footprint for producing them would not be attributed to the remedy. Attention could also be given to the provider's location. Preference could be given to local providers to avoid long transport distances. Where multiple injections are required or the subsurface formations are relatively tight, it may be preferable to use permanent injection wells to avoid the repeated mobilization of heavy equipment (e.g., direct push rigs) that would operate throughout the injection events.

Excavation remedies: The largest contributions to energy & air footprints for excavation remedies is the transport of the excavated material or backfill material from one location to another. The transport may be from one portion of the site to another portion via dump truck, loader, or dozer. It may also be from the site to an off-site location for disposal or reuse. As a result, minimizing this horizontal transport distance would be a key focus in reducing the footprints of excavation remedies. Consideration could be given to using on-site treatment of impacted soils followed by reuse of the treated soil on-site, using clean soil from the excavation to partially backfill the excavation, locating local sources for fill, and minimizing the distance to disposal locations. If soil or material requires substantial transport on-site, footprint reductions may be best achieved by loading dump trucks rather than carrying loads long distances in front loader buckets or transporting long distances with a dozer. The use of renewable fuels (e.g., biodiesel) could increase the percentage of energy from renewable resources. It could also reduce the greenhouse gas footprint for the remedy. Although there may be a greenhouse gas footprint for on-site soil treatment, there is also a footprint associated with landfill activities that could partially or completely offset the footprint of the on-site treatment.

Example 3. Footprint Reductions from Optimization and Application of Renewable Energy

The chart below presents the greenhouse gas emissions for several competing versions of a P&T system that treats approximately 50 gpm of extracted water with a trichloroethene (TCE) concentration of approximately 500 µg/L. The chart illustrates the footprint reductions associated with optimized versions of the P&T system plus the effect of purchasing RECs to convert all electricity obtained through the grid into electricity from renewable resources. Although other parameters of are of importance, the greenhouse gas (CO_2e) footprint is used as an example parameter.



Version 1 *– Treatment provided by air stripping with treatment of air stripper off-gas*
Version 2 *– Air stripping with off-gas treatment – but use of variable frequency drives on motors*
Version 3 *– Treatment provided by liquid phase GAC instead of air stripping*
Version 4 *– Version 1 with all electricity usage offset with purchase of RECs*

The example illustrates that the footprint can be reduced by energy efficiency efforts (e.g., variable frequency drives), potential changes to the treatment system components (e.g., GAC instead of air stripping), and application of renewable energy.

6.0 References

Council on Environmental Quality, Guidance for Federal Greenhouse Gas Accounting and Inventories
http://www.whitehouse.gov/administration/eop/ceq/sustainability/fed-ghg

European Commission – Joint Research Center, LCA Tools, Services and Data
http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm

Executive Order 13514, *Federal Leadership in Environmental, Energy, and Economic Performance*, October 5, 2009
http://www.fedcenter.gov/programs/eo13514/

National Renewable Energy Laboratory, U.S. Life Cycle Inventory Database
www.nrel.gov/lci

U.S. Environmental Protection Agency, Clean Energy
http://www.epa.gov/cleanenergy

U.S. Environmental Protection Agency, Climate Change
http://www.epa.gov/climatechange/emissions/

U.S. Environmental Protection Agency, Climate Leaders
http://www.epa.gov/climateleaders/

U.S. Environmental Protection Agency, Green Power and Renewable Energy
http://www.epa.gov/oaintrnt/greenpower/index.htm

U.S. Environmental Protection Agency, Green Remediation
http://www.cluin.org/greenremediation

U.S. Environmental Protection Agency, National Clean Diesel Campaign, Tools & Resources
http://www.epa.gov/cleandiesel/tools/

U.S. Environmental Protection Agency, Wastes – Resource Conservation
http://www.epa.gov/osw/conserve/rrr/

U.S. Environmental Protection Agency, Water Conservation
http://www.epa.gov/oaintrnt/water/

Appendix A: Exhibits

EXHIBIT 2.1 – ACCOUNTING FOR RENEWABLE ENERGY

There are four main ways in which renewable energy can be applied to site remediation:

- On-site renewable energy systems
- Renewable energy provided to the site as part of grid electricity
- Renewable energy purchased from an electricity provider or purchased as renewable energy certificates (RECs)
- Use of renewable fuels in equipment and vehicles

The following table provides a list of conventional (non-renewable) energy sources and a list of renewable energy sources. These lists are generally consistent with EPA's definition of green remediation including that used in the Re-Powering America's Land Initiative (http://www.epa.gov/renewableenergyland) and that used in the Greening EPA Green Power Basics description (www.epa.gov/greeningepa).

Conventional (non-renewable) Energy Sources	Renewable Energy Sources
Diesel Gasoline Natural gas Electricity from coal, natural gas, oil, nuclear	Biodiesel Landfill gas Solar thermal energy systems Electricity from wind, geothermal, hydroelectric, solar, biomass

Note: The low-emission footprint for nuclear power is considered when calculating the emissions for electricity usage. Nuclear, however, is not considered a "renewable energy resource" for this methodology.

The electricity portions of the above table is used for distinguishing between conventional and renewable energy resources when calculating the metric for percentage of energy from renewable resources. When renewable fuels are blended with conventional fuels, use the percentages of renewable and conventional fuels to determine the amount of each type of fuel (e.g., B20 fuel is 20% biodiesel and 80% diesel, 100 gallons of B20 would be equivalent to 20 gallons of biodiesel and 80 gallons of diesel).

Purchased Electricity from Renewable Resources

The proceeds of purchased electricity (e.g., green pricing programs and RECs) are used by energy providers financially to justify or partially fund renewable energy projects. For this reason, purchased renewable electricity follows stricter standards and definitions. For this methodology, the definition of renewable electricity as it applies to purchased electricity from renewable resources should meet the definition of "green power" used by the *U.S. EPA Green Power Partnership, Partnership Requirements, Appendix A* as follows:

- Solar photovoltaic
- Wind
- Geothermal (not to be confused with the use of geothermal heat pumps)
- Eligible biomass
- Eligible hydropower

The reader is directed to the above reference for definitions of "eligible" biomass and hydropower.

EXHIBIT 2.2 – RENEWABLE ENERGY CERTIFICATES (RECs)

What is a renewable energy certificate (REC)?

The Guide to Purchasing Green Power (Office of Air (6202J), EPA430-K-04-015, March 2010) developed by U.S. EPA, the Department of Energy, the World Resources Institute, and Center for Resource Solutions defines a REC as follows:

> *A REC is a certificate that represents the generation of one megawatt-hour (MWh) of electricity from an eligible source of renewable energy. Each REC denotes the underlying generation energy source, location of the generation, and year of generation (a.k.a. "vintage"), environmental emissions, and other characteristics associated with the generator. RECs represent a claim to the environmental attributes associated with renewable energy generation, but purchasers should nevertheless ensure that their contracts are explicit about which environmental attributes are conveyed to them.*

U.S. EPA and many other institutions choose to purchase RECs to reduce the environmental impacts associated with purchased electricity use (www.epa.gov/greenpower). The EPA Climate Leaders Program endorsed use of RECs to offset greenhouse gas emissions, and the Council on Environmental Quality Federal Greenhouse Gas Accounting and Reporting Guidance, October 6, 2010 also discusses the use of RECs by the federal government to offset emissions from electricity use. The use of RECs for offsetting greenhouse gas or other emissions is a topic of ongoing debate, but for the purpose of this methodology, the use of RECs is intended to be consistent with the above programs and guidance.

How do RECs apply to this footprint methodology?

RECs can be applied in t his footprint methodology as follows:

- RECs can be purchased and "bundled" with electricity purchased from the grid to allow the project to claim that electricity as "renewable" and to offset emissions consistent with the REC product label. If the footprint analysis is considering a prospective REC purchase, the emissions offsets can be obtained from the non-baseload emissions reported in the most recent version of eGRID (www.epa.gov/egrid) for the eGRID region in which the RECs will be purchased.

- RECs should be purchased in the same region of the country as the remedy (as defined by eGRID, www.epa.gov/egrid) to represent renewable energy generated.

- The amount of RECs purchased cannot exceed the amount of grid electricity used for the remedy and cannot result in negative "electricity generation" emissions.

- RECs used for this purpose are to be verified by a qualified third-party to confirm that the proceeds of the purchase were integral in the business decision to install a renewable energy system.

More information about RECs, purchasing renewable energy, and eligibility of purchased renewable energy is provided at www.epa.gov/greenpower.

An example application of RECs is presented on the following page.

EXHIBIT 2.2 – RENEWABLE ENERGY CERTIFICATES (RECs) (continued)

The emission factors used to calculate reductions in "electricity generation" emissions from purchased renewable electricity are obtained from the most recent version of eGRID (www.epa.gov/egrid), reflect the region in which the renewable generator is located, and represent the non-baseload output emissions rates for that region. The amount of RECs purchased cannot exceed the amount of grid electricity used for the remedy and cannot result in negative "electricity generation" emissions. Consider the following example:

A remedy in California uses 100,000 kWh (100 MWh) of electricity per year. Based on the generation mix from the local electricity provider, the emission factors and annual emissions are as follows:

Parameter	"Electricity Generation" Emission Factor (lbs/MWh)	"Electricity Generation" Annual Emissions (lbs)
CO_2e	1300	130,000
NOx	1.1	110
SOx	0.0066	0.66
PM	0.08	8
HAPs	0.025	2.5

RECs are purchased from the CAMX eGRID subregion (eGRID subregion that includes California) to offset 100 MWh of electricity use. The following table presents non-baseload emission factors from the CAMX subregion, the annual emission offsets from the purchased RECs, the annual emission from the conventional electricity use, and the net annual emissions.

Parameter	CAMX eGRID Subregion Non-Baseload Emission Factor (lbs/MWh)	"Electricity Generation" Annual Emission Offsets from REC Purchase (lbs)	"Electricity Generation" Annual Emissions (see above) (lbs)	"Electricity Generation" Net Emissions for Methodology (lbs)
CO_2e	1047.6	104,760	130,000	25,240
NOx	0.3481	34.81	110	75.19
SOx	0.1699	16.99	0.66	0
PM	N/A	N/A	8	4**
HAPs	N/A	N/A	2.5	1.25**

** net emissions for SOx are recorded as 0 lbs to prevent a negative net emission value. The purchase of RECs is not intended to allow a remedy to offset more than its air pollutant footprint.*
*** eGRID does not provide emission factors for PM and HAPs. Absent other information, assume that the purchase of RECs offsets 50% of PM and HAP emissions from conventional use.*

As is apparent in the above example, the purchase of 100 MWh of RECs is not sufficient to completely offset the "electricity generation" CO_2e emissions, and more than 100 MWh of RECs cannot be purchased because each REC is to be bundled with conventional electricity use. In addition, it is apparent that the net SOx emissions are reported as 0 (zero) rather than the mathematical difference between the annual emissions and the offsets. The purchase of RECs is not intended to allow a remedy to offset more than its air pollutant footprint. Although not shown in the above example, REC purchases are assumed to offset energy and emissions associated with extracting fuels for electricity generation and electricity transmission losses, which are covered in "off-site emissions." Refer to Energy & Emission Case Study #2 in Appendix A for an example.

EXHIBIT 2.3 – DEFINING GLOBAL WARMING POTENTIAL

Different greenhouse gases have different residence times and different effectiveness in absorbing and emitting back to earth the infrared radiation that results in temperature increases. The concept of global warming potential (GWP) accounts for these differences and quantifies the contribution of a particular greenhouse gas to global warming in terms of a reference gas. Carbon dioxide is typically chosen as the reference gas, and GWP is measured in carbon dioxide equivalents (CO_2e). The GWP of common greenhouse gases used for this methodology are as follows:

Greenhouse Gas	GWP (pounds of CO_2e)
Carbon dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous oxide (N_2O)	310
Carbon tetrachloride (CCl_4)	1,400
1,1,1-Trichloroethane (CH_3CCl_3, methyl chloroform)	146
Bromomethane (CH_3Br)	5
Chloromethane (CH_3Cl)	13
Methylene chloride (CH_2Cl_2)	8.7
CFC-11 (CCl_3F, Freon-11)	3,800

Intergovernmental Panel on Climate Change Assessment Report 4, Chapter 2, Changes in Atmospheric Constituents and in Radiative Forcing (www.ipcc.ch), which is referenced by U.S. EPA at www.epa.gov/climatechange.

Example: the emission of 1 pound of methane has an equivalent warming effectiveness as the emission of 21 pounds of carbon dioxide.

Many other compounds, particularly chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), and other perfluorinated compounds, are strong greenhouse gases but are not typically associated with environmental cleanups. If these compounds are indentified in the soil, groundwater, or sediments of a site, it may be important to include air emissions of the compounds in the greenhouse gas metric. Information pertaining to their global warming potential can be found in the Intergovernmental Panel on Climate Change Assessment Report 4, Chapter 2, *Changes in Atmospheric Constituents and in Radiative Forcing* (www.ipcc.ch).

EXHIBIT 3.1 – EXAMPLE REMEDY INFORMATION TO GATHER FOR STEP 1

Excavation and Disposal

- Volume of soil to be excavated
- Percentages disposed of as hazardous waste and non-hazardous waste
- Methods of transportation available
- Facilities for disposal
- Associated sampling and analysis
- Material used for backfill
- Need for dewatering and discharge point for water

Pump and Treat and Soil Vapor Extraction

- Number of wells, trenches, etc. and distance to process area
- Extraction rates
- Expected influent concentrations
- Treatment processes
- Discharge location (for pump and treat)
- Frequency of operator visits

In-situ Remedies Involving Nutrient or Reagent Injections

- Method of injection (direct push, injection wells, delivery trenches)
- Aquifer volume to be treated
- Number of injection points
- Number of injections
- Nutrient demand for calculating mass of injected materials

Phytoremediation

- Number and types of trees
- Method of planting
- Fertilizer, pesticide, watering, and fencing needs

In-situ Thermal Remediation

- Method of heating
- Volume of treatment area
- Type of contaminant and required heating temperature
- Size of vapor control system
- Method of treating off-gas
- Pounds of contaminants to be removed

Soil Amendments

- Amendment material
- Volume of soil to be treated
- Method of adding amendment
- Amendment demand

Monitoring for Various Remedy Types

- Process monitoring
- Long-term monitoring
- Performance monitoring

EXHIBIT 3.2 – SCREENING APPROACH

The screening approach utilizes two limits to determine items and activities that are included in the footprint analysis:

- Limit based on a specified percentage of the maximum contributor to a particular metric
- Limit based on a specified magnitude for a particular metric

Based on professional judgment, an item or activity that is expected to contribute less than either of the limits can be omitted from the analysis with an appropriate level of documentation. These limits, and the selection of the applicable unit, are applied to the following categories:

- Refined materials
- Unrefined materials
- Non-hazardous waste
- Hazardous waste
- Each significant on-site water resource
- On-site NOx, SOx, PM emissions
- On-site HAP emissions
- Total energy use*

** The total energy use category is generally representative of the total emissions for CO_2e and other air pollutants.*

Comparing materials use, waste generation, and water use relative to the limits may be reasonably straightforward based on professional judgment.

The NOx, SOx, and PM emissions are generally linked to on-site fuel combustion; therefore, determining the largest contributor and gauging other contributions relative to the set limits is based on usage of various fuels. The table to the right shows the approximate amounts of fuel that will result in generally equivalent NOx, SOx, and PM emissions. For purposes of this screening process, assume that combustion of the volumes of fuel noted in the table to the right results in emissions of 0.2 pounds of NOx + SOx + PM. However, do not use this assumption for final footprint reporting.

Approximate Equivalencies for NOx, SOx, and PM from On-Site Fuel Combustion	
Diesel combustion	1 gallon
Gasoline combustion	1 gallon
Natural gas combustion	10 ccf

ccf = 100 cubic feet, which contains a similar amount of energy as 1 therm
Note: The sum of the NOx, SOx, and PM emissions from the combustion of the indicated amounts of the fuels are generally comparable. This table is not intended to suggest that they are equal. This table is based on the information provided elsewhere in this document.

FOR SCREENING COMPARISON PURPOSES ONLY
DO NOT USE THESE APPROXIMATE EQUIVALENCIES FOR FINAL FOOTPRINT REPORTING

EXHIBIT 3.2 – SCREENING APPROACH (continued)

The total energy use contributions are based on a wide variety of factors, including electricity use, fuel combustion, and materials manufacturing. The following table shows approximate amounts of energy-related items, materials, or services that result in generally equivalent amounts of energy use. The table also defines an "energy screening unit" to help compare various forms of energy use.

Item	Physical Unit	Number of Physical Units in One Screening Unit	Number of Screening Units for each Physical Unit
Electricity use	kWh	1	1
Continuous electric motor operation	HP-hr	1	1
Natural gas use	Ccf or therm	0.1	10
Diesel or gasoline use	Gallon	0.1	10
On-site heavy equipment use	HP-hr	2	0.5
Excavation	Cubic yard	5	0.2
Trenching and pipe installation	Linear foot	10	0.1
Well installation (including drill rig)	Vertical foot	0.02	50
Personnel transport	Mile	2	0.5
Materials or waste transportation	Mile	0.5	2
Materials or waste transportation	Ton-mile	3	0.33
Refined materials use	Pound	1	1
Unrefined materials use	Ton	1	1
Water discharged to the sanitary sewer	1,000 gallons	1	1
Waste disposal (drums)	Drum	10	0.1
Waste disposal (bulk)	Ton	0.1	10
Laboratory analysis	$	1	1

Note: The total energy usages associated with a screening unit is generally between 0.01 and 0.02 MMbtus (with some exceptions) and is only intended to be used to assist with screening. Do not use these approximations for final footprint reporting. The values in this table are based on information provided elsewhere in this document.

Example: A remedy involves the following:

Item	Number of Screening Units
10,000 pounds of materials	10,000 × **1** = 10,000
5,000 ton-miles of materials	5,000 × **0.33** = 1,650
300,000 kWh of electricity	300,000 × **1** = 300,000

The numbers in bold in the table to the left are taken from the right-hand column of the above table. The use of a screening unit facilitates comparison between various items that involve energy use. For example, 1,650 is a small fraction of 300,000 (<1%), indicating that materials transport can be omitted from the footprint analysis.

EXHIBIT 3.2 – SCREENING APPROACH (continued)

The following table demonstrates the development and general application of screening limits for the footprint screening categories presented at the beginning of this exhibit. Items in each screening category would then be compared to the “applicable screening limits” for that category, and items in each category that are expected to be less than the limit area omitted from the analysis. A simplified in-situ bioremediation remedy is used for example purposes in this table.

Category	Unit	Largest Contributor	Largest Contribution	Selected % of Largest Contributor	% - based Limit	Magnitude-based Limit	Applicable Screening Limit
Refined Materials	Tons	Vegetable oil	150	1%	1.5	0.5	**1.5**
Unrefined Materials	Tons	Sand for sand pack	1.5	1%	0.015	0.5	**0.5**
Non-hazardous Waste	Tons	Drill cuttings	6	1%	0.06	0.5	**0.5**
Hazardous Waste	Tons	None	0	1%	0	0.5	**0.5**
Public water	Gallons	Water for drilling	500	1%	0.05	1,000	**1,000**
Shallow groundwater (off-site disposal)	Gallons	Pump test	1,000,000	1%	10,000	1,000	**10,000**
Shallow groundwater (reinjection)	Gallons	Nutrient blending & injection	3,000,000	1%	30,000	1,000	**30,000**
On-site NOx, SOx, PM emissions	Pounds	Drill rig	120	1%	1.2	1	**1.2**
On-site HAP emissions	Pounds	Drilling	<1	1%	0.01	1	**1**
Total Energy use	Screening Units*	Vegetable oil	300,000	1%	3,000	1	**3,000**

Notes: The “selected % of largest contributor” and the “magnitude-based limit” for each category is chosen by the project team based on the level of detail and accuracy sought in the footprint analysis.

** Energy screening units defined above.*

EXHIBIT 3.3 – DENSITIES OF COMMON MATERIALS

Material	Density
Refined	
Cement	94 lbs/ft^3
GAC	30 lbs/ft^3
HDPE	59.6 lbs/ft^3
Lime (hydrated)	30 lbs/ft^3
PVC	87.36 lbs/ft^3
Steel	490 lbs/ft^3
Unrefined	
Asphalt	1.95 tons/cy
Concrete	1.95 tons/cy
Compacted clay	1.5 tons/cy
Mulch/compost	0.4 tons/cy
Sand, gravel, soil	1.5 tons/cy

REFERENCES*:*
Cement – Portland Cement Association (www.cement.org)
GAC – consistent with various GAC vendor specifications
HDPE –consistent with HDPE pipe made to ASTM standards
Lime – consistent with National Lime Association fact sheet values for hydrated lime
PVC – consistent with PVC pipe made to ASTM standards
Steel – various materials handbooks (specific gravity of 7.8)
Asphalt – Nation Asphalt Pavement Association
Concrete – Portland Cement Association (www.cement.org)
Compacted clay, sand, gravel & soil – generally accepted engineering assumption
Mulch/compost – generally consistent with purchased bagged mulch

Example conversion from volume to mass

$$10 \text{ cubic yards of concrete} \times 1.95 \text{ tons per cubic yard} = 19.5 \text{ tons of concrete}$$

EXHIBIT 3.4 – APPROXIMATE MATERIAL CONTENT OF AQUEOUS CHEMICAL SOLUTIONS

Environmental remedies commonly involve the use of chemical solutions, and in some cases a substantial portion of the solution may be water, which is not considered in this methodology to be part of the materials and waste footprint but is part of the water footprint. In general, for chemical solutions, the weight of the chemical itself (not the full solution) is used for determining the weight of the refined material. Table 5.2 lists common chemical solutions, the specific gravity of the solution, the solution density, and the weight of the chemical per gallon of solution. The water used

Chemical Solution	Specific Gravity	Density of Solution (lbs/gal)	Weight of Chemical per Gallon of Solution (lbs/gal)	Volume of Water per Gallon of Solution (gal/gal)
Hydrochloric acid (37%)	1.19	9.92	3.67	0.75
Sulfuric acid (98%)	1.84	15.3	15.0	0.04
Sodium hydroxide (20%)	1.22	10.2	2.03	0.98
Sodium hydroxide (50%)	1.53	12.8	6.40	0.77
Hydrogen peroxide (30%)	1.11	9.26	2.78	0.78
Hydrogen peroxide (50%)	1.19	9.92	4.96	0.59
Ferric chloride (37%)	1.4	11.7	4.33	0.88
Sequestering agent (assume 40% solution)	1.2	10.0	4.00	0.72

Information obtained from Material Data Safety Sheets for these chemical solutions

Example conversion from gallons of solution to pounds of chemical

4,000 *gallons of* 20% *NAOH solution* × 2.04 *lbs per gallon* = ~800 *pounds of NaOH*

NaOH = sodium hydroxide

Equation for determining water content of an aqueous solution

$$\text{Water content (gallons)} = \text{Volume of solution (gallons)} \times \text{Specific gravity (unitless)} \times \text{(100 - \% concentration) (\%)}$$

Example: 10,000 gallons of 20% Sodium Hydroxide (Specific gravity = 1.22)

$$9{,}760 \text{ gallons} = 10{,}000 \text{ gallons} \times 1.22 \times 80\%$$

EXHIBIT 3.5 – APPROXIMATE MATERIALS USAGE FOR PIPING AND WIRING RUNS

Some remedies include long runs of piping and wiring to connect extraction wells to a treatment system. The following table can be used to estimate the weight of refined materials involved in long runs of plastic piping and wiring/conduit based on an approximate flow rate carried in the pipes. Values for PVC or HDPE pipe are provided.

Pipe Diameter	Approx. Flow (gpm)	SDR 11 HDPE Pipe (lbs per ft)	SCH 80 PVC Pipe (lbs per ft)	Estimated Wire and Conduit (lbs per foot)
1-inch	5	0.196	0.405	N/A
2-inch	25	0.639	0.936	1
3-inch	50	1.387	1.911	1.5
4-inch	90	2.294	2.793	2
6-inch	200	4.971	5.327	2.5
8-inch	350	8.425	8.089	3

REFERENCES/METHODOLOGY:

Pipe size is based on approximate flow velocity of 2 to 2.5 feet per second. Pipe weight is based on pipe made to ASTM standards. Conduit values are general estimates based on one PVC or HDPE power cable conduit and one PVC or HDPE control cable conduit that are sized appropriately for the necessary cable/wire conductors. Wire values are general estimates based on with four conductors (including a ground) appropriately sized to provide power to a submersible pump providing the specified flow and the associated control cables.

Example Application

1,000 *feet of* 6-*inch HDPE pipe* × 4.971 *lbs per foot* = ~5,000 *pounds of HDPE*

EXHIBIT 3.6 – APPROXIMATE MATERIALS USAGE FOR WELL INSTALLATION

Wells are a common element of groundwater remedies and can be complex from a materials inventory perspective. Table 5.4 lists approximate materials usage for well construction on a per foot basis of well depth.

	Pounds per Foot of Well Depth				
Well Diameter	**SCH 40 PVC Casing**	**Steel Casing**	**Stainless Steel Screen**	**Grout for Annulus**	**Sand for Annulus***
2-inch	0.681	3.65	1.5	13	19
4-inch	2.012	10.79	2.9	19	29
6-inch	3.537	18.97	4.8	25	39
8-inch	5.323	28.55	7.0	32	48

REFERENCES/METHODOLOGY: *Grout and sand usage assumes annulus around casing has a diameter that is 4 inches larger than the casing. Grout values are for neat cement assuming 6 gallons of water is mixed with 94 lbs of neat cement (generally typical of engineering specifications). Pipe and screen values based on typical of pipe specifications made to ASTM standards. Actual values for grout or well screen may vary depending on the specific application.*

** The "Sand for Annulus" values can also be used to estimate the mass of drill cuttings that would be generated per linear foot of well depth.*

EXHIBIT 3.7 – APPROXIMATE MATERIALS USAGE FOR PROCESS EQUIPMENT AND BUILDING CONSTRUCTION

Process Equipment and Controls

Permanent process equipment, piping, valves, and controls at a site can be comprised of many different types of materials, and so can be complex from a materials inventory perspective. For simplicity, this methodology suggests using the weight of the primary components (for example, the weight of steel in an air stripper) and adding 25% to this weight as a general rule of thumb to obtain a reasonable approximation of the refined materials associated with the piping, pumps, and controls for an overall system. The weight of process equipment is typically readily available from a vendor web site.

Building Construction

Building construction is another type of materials use that can be difficult to inventory, especially during the design stage if building vendors have not been contacted. Absent other information, the following general rules of thumb can be used for estimating materials usage associated with steel building construction.

- Approximately 1 pound of steel per cubic foot of building space
- Approximately 1.3 pounds of steel per square foot of 6-inch slab
- Approximately 72.5 pounds of concrete per square foot of 6-inch slab

EXHIBIT 3.8 – APPROXIMATE CONTENT OF CONCRETE, ASPHALT, AND STEEL

Concrete, asphalt, and steel are construction materials that are commonly used in environmental cleanups and can represent a substantial portion of the materials used. General information about these materials that is relevant to the footprint methodology, such as the typical proportions of the components in concrete and asphalt, and the typical recycled content in steel, is provided in the following table and discussed below. *Note that if specific information is available from the manufacturer on the content of the material used, the specific information should be used instead of the information provided here.*

Material	Density (lbs/ft^3)	Per Cubic Foot of Material			
		Refined Material		Unrefined Material	
		Total	Recycled/Reused Content	Total	Recycled/Reused Content
Concrete	145	22	0	115	0
Fly ash concrete	145	22	4	115	0
Asphalt	145	7	1.4	138	28
Steel	490	490	270	0	0

Concrete – Mixed concrete (by volume) is typically 0.5 parts water, 1 part cement (a refined material), and 4.5 parts aggregate (an unrefined material). Water is covered separately under the water footprint and is not considered a material in this methodology. Using the densities in Exhibit 3.3, concrete is 15% refined material and 79% unrefined material by weight, with the remaining 6% attributed to the water. The density of concrete is approximately 145 lbs per cubic feet. Therefore, for every cubic foot of concrete, approximately 22 lbs is refined material and 115 lbs is unrefined material. For many applications, fly ash can be used as an admixture to replace up to 20% of the cement component. Therefore, for fly ash concrete, 20% of the refined material (4 lbs) can be considered recycled/reused.

REFERENCES: Values for proportions by volume obtained from Portland Cement Association (www.cement.org) and converted to mass using densities provided from same source. Information on fly ash from the Federal Highways Administration Materials Group: http://www.fhwa.dot.gov/infrastructure/materialsgrp/flyash.htm.

Asphalt – Asphalt is approximately 5% asphalt cement (a refined material) and 95% aggregate (unrefined) by weight. Therefore, for the purpose of this methodology, asphalt is assumed to be 5% refined material and 95% unrefined material. Asphalt has an approximate compacted density of 145 lbs per cubic foot. Therefore, for every cubic foot of asphalt, approximately 7 lbs is refined material and 138 lbs is unrefined material. Asphalt pavement typically contains up to as much as 20% recycled material. For the purpose of this methodology, this recycled content is assumed to be evenly distributed among the refined and unrefined portions. Therefore, for one cubic foot of compacted asphalt, approximately 1.4 lbs of the refined material is from recycled material and approximately 28 lbs of the unrefined material is from recycled material.

REFERENCES: National Asphalt Pavement Association (www.hotmix.org).

Steel – Recycling is an inherent part of the steel industry, and the recycled content of steel varies depending on the furnace technology, which is somewhat specific to the type of product produced. The recycled content for steel produced from a blast oxygen furnace is approximately 30% and the recycled content for steel produced from an electric arc furnace is approximately 80%. For the purpose of this methodology, the recycled content of steel is assumed to be the average (approximately 55%).

REFERENCES: Steel Takes LEED® with Recycled Content, American Iron and Steel Institute, November 2009

EXHIBIT 3.9A – GENERAL CHECKLIST FOR TYPICAL ITEMS TO CONSIDER IN A FOOTPRINT ASSOCIATED WITH CONSTRUCTION OF A REMEDY

This exhibit applies to the construction of remedies such as P&T, AS/SVE, multi-phase extraction, or other remedies that involve installing wells, laying pipe, erecting a building, and site grading (e.g., in-situ bioremediation remedies that involve permanent water supply wells and/or injection wells). This checklist is intended to serve as an aid in identifying relevant components and is not necessarily an exhaustive list. Other items related to the remedy, but not included below, should also be included if they are believed to contribute significantly to the remedy footprint.

Transportation	Equipment Use	Quantities of Materials & Off-Site Services
• Distance between site and… - Office of primary consultant - Offices of primary contractors - Manufacturers of various construction materials - Non-hazardous waste landfill - Hazardous waste landfill • Types of vehicles or modes of transportation for personnel, equipment, material, and waste transport • Quantity of material or waste transported per trip • Type of fuel used in vehicles • Material or waste transport that requires an empty return trip after delivery	• Equipment type, horsepower rating, and total hours of operation for… - Drilling wells - Laying extraction and injection network piping - Trenching - Clearing/grubbing - Excavation and backfilling - Grading - Dredging - Erecting buildings - Dewatering - On-site electricity generation - Providing compressed air • Major electrical equipment not running off of generators - Pumps - Blowers - Mixers	• Materials* • Services - Waste disposal* - Off-site water treatment** - Laboratory analysis ** SEE MATERIALS & WASTE SECTION* *** SEE WATER SECTION*

EXHIBIT 3.9B – GENERAL CHECKLIST FOR TYPICAL ITEMS TO CONSIDER IN A FOOTPRINT ASSOCIATED WITH REMEDY OPERATION

This exhibit applies to the operation of remedies such as P&T, AS/SVE, multi-phase extraction, or other remedies that involve long-term operation (e.g., in-situ bioremediation or monitored natural attenuation). This checklist is intended to serve as an aid in identifying relevant components and is not necessarily an exhaustive list. Other items related to the remedy, but not specified below, should also be included if they are believed to contribute significantly to the remedy footprint.

Transportation	Equipment Type, Power Rating, &Hours of Operation	Quantities of Materials & Services
• Distance between site and… - Office of primary consultant - Office of primary contractors - Manufacturers of various construction materials - Non-hazardous waste landfill - Hazardous waste landfill • Types of vehicles or modes of transportation for personnel, equipment, material, and waste transport • Quantity of material or waste transported per trip • Type of fuel used in vehicles • Material or waste transport that requires an empty return trip after delivery	• Electrical equipment - Extraction pumps - Transfer pumps - Chemical feed pumps - Blowers - Air compressors for pneumatic equipment and air sparging - GAC pre-heaters - Mixers - Ozone generators - Subsurface electric heating - Electric building heat - Building lighting - Building ventilation - Catalytic oxidizers • Gasoline, diesel, and biofuel equipment - Direct-push rigs for chemical injection - Other heavy equipment - Generators - Fuel-powered pumps and compressors - Subsurface heating - Major landscaping - Vehicles for on-site transportation • Natural gas equipment - Building heat - Process heaters - Generators - Thermal oxidizers - Subsurface steam heating - Boilers	• Materials* • Services - Waste disposal* - Off-site water treatment** - Laboratory analysis ** SEE MATERIALS & WASTE SECTION* *** SEE WATER SECTION* **On-Site Emissions and Offsets** • Landfill gas emissions • Air stripper or SVE off-gas • Emissions from large open excavations • Planted trees and biomass

EXHIBIT 3.10A – QUANTIFYING FUEL USE FOR PERSONNEL TRANSPORTATION

The following table can be used to organize and calculate fuel use for personnel transportation. Two different calculation options are provided in decreasing order of known information. It is preferable to use the calculation Option 1 where possible. Option 2 can be used if the information is not available for Option 1.

Activity	**Input #1**		**Input #2**		**Fuel Usage**
Option 1 – Known Number of Events and Known Fuel Use per Trip					
	# of events	×	**Fuel use per event**	=	**Fuel Usage (gallons)**
Option 2 – Known Distance and Vehicle Type					
	Distance traveled	÷	**Fuel efficiency (mpg or pmpg)**	=	**Fuel Usage (gallons)**

Notes:
"Event" can refer to a specific trip, time period, or broader activity for which fuel usage is known.
"mpg" = miles per gallon "pmpg" = passenger miles per gallon

If the distance of travel is not known, it should be estimated based on professional judgment (e.g., the approximate distance to the nearest suburban or metropolitan area where a consultant or contractor may be located). If the vehicle type is not known, it can be assumed based on professional judgment and applying the fuel efficiencies from the following table.

Vehicle Type	**Fuel Efficiency (mpg or pmpg)**	
	Gasoline	**Diesel or B20**
Airplane (pmpg)	N/A	45
Bus (pmpg)	N/A	96
Passenger car (mpg)	24	28
Light-duty truck (mpg)	17	20
Light-duty truck with trailer or heavy load (mpg)	N/A	6
Train (pmpg)	N/A	59

- *Airplane/jet fuel calculated as diesel for simplicity and due to similarities between kerosene and diesel*
- *Gasoline car and truck efficiencies and diesel car, truck, airplane, bus, and train efficiencies from converting average CO2 emissions Climate Leaders from Commuting, Business Travel and Product Transport to diesel usage assuming Climate Leaders value of 22.3 lbs of CO2 per gallon of diesel.*

EXHIBIT 3.10B – QUANTIFYING FUEL USE FOR HEAVY EQUIPMENT USE

The following table can be used to organize and calculate fuel use associated with heavy equipment use. Two different calculation options are provided in decreasing order of known information. It is preferable to use the calculation Option 1 where possible. Option 2 can be used if the information is not available for Option 1.

Activity	Input #1				Input #2				Fuel Usage
Option 1 – Known Fuel Use or Equipment Owner Estimated Fuel Use									
	Event			×	**Fuel use per event**			=	**Fuel Usage (gallons)**
Option 2 – Known or Estimated Horsepower Rating, Fuel Type, and Hours of Operation									
	HP	×	**Hours**	×	**BSFC**	×	**PLF**	=	**Fuel Usage (gallons)**

Notes:
Option 1 – "Event" can refer to a specific task, time period, or entire scope of work. Fuel use per event is assumed to be a reasonable estimate by the equipment owner based on fuel use for a similar, but previously executed event.
Option 2 – "HP" = horsepower rating of equipment   "Hours" = hours of operation
"BSFC" brake-specific fuel capacity   "PLF"= partial load factor

The assumed BSFC for diesel and biodiesel is 0.050 gallons per HP-hr.
The assumed BSFC for gasoline is 0.056 gallons per HP-hr.

BSFC values are consistent with 7,000 Btu/HP-hr (as used by EPA AP-42, Compilation of Air Pollutant Emission Factors, Chapter 3) and fuel higher heating values of 139,000 Btus for diesel and 124,000 Btus for gasoline (as used by Climate Leaders).

The following table provides HP and PLF values for common types of equipment.

Equipment Type	HP	PLF	Production Rate
Medium/large excavator (2 CY bucket)	175	0.75	720 CY/day
Medium loader (3 CY bucket)	200	0.75	1200 CY/day
Medium dozer, 100+ foot haul	200	0.75	500 CY/day
Direct-push rig for soil sampling	60	0.75	250 ft/day
Hollow-stem auger for well installation	150	0.75	100 ft/day
Air or mud rotary for well installation	500	0.75	200 ft/day

Production rates and equipment sizes are generally consistent with production rates reported RS Means Building Construction Cost Data. Absent other information a PLF of 0.75 is a reasonable estimate for heavy equipment. The PLF may decrease if work is inefficient for a variety of reasons. Many of the same inefficiencies would also reduce the production rate. Therefore, if the assumed production rate is lower, it is appropriate for the PLF to be lowered by a commensurate amount.

EXHIBIT 3.10C – QUANTIFYING FUEL USE FOR EQUIPMENT, MATERIALS, AND WASTE TRANSPORTATION

The following table can be used to organize and calculate fuel use for equipment, materials, and waste transportation. Two different calculation options are provided in decreasing order of known information. It is preferable to use Option 1. Option 2 can be used if information is not available for Option 1.

Activity	**Input #1**				**Input #2**		**Fuel Usage**
Option 1 – Known Number of Events and Known Fuel Use per Trip							
	# of events			×	**Fuel use per event**	=	**Fuel Usage (gallons)**
Option 2a – Common Freight - Known Distance, Cargo Weight, and Vehicle Type							
	Distance traveled	×	**Weight (tons)**	×	**Fuel efficiency (gptm)**	=	**Fuel Usage (gallons)**
Option 2b – Specialty Freight Load or Empty Load by Truck – Known Distance							
	Distance			×	**Fuel efficiency (mpg)**	=	**Fuel Usage (gallons)**

Notes:
"Event" can refer to a specific trip, time period, or broader activity for which fuel usage is known.
"gptm" = gallons per ton-mile *"mpg" = miles per gallon*

The distance for materials transport should be from the manufacturer, not just from the local distributor. If the distance of travel is not known, it should be estimated based on professional judgment considering the following examples: 1,000 miles for specialty items and hazardous waste transport, 500 miles for most materials, and 25 miles for borrow, fill, sand/gravel, asphalt, concrete, and non-hazardous waste transport. Empty return trips should be considered as appropriate. For common freight, a reasonable approximation to accommodate an empty return trip is to double the fuel usage rate used for transport. The following table provides appropriate estimated fuel efficiencies (excluding an empty return trip):

Vehicle Type	**Fuel Efficiency**	
	Units	**Value**
Truck	mpg	6
Truck Common Freight	gptm	0.029
Train	gptm	0.0025
Barge	gptm	0.0047
Aircraft	gptm	0.15

- *Airplane/jet fuel calculated as diesel for simplicity and due to similarities between kerosene and diesel*
- *Fuel efficiencies are obtained by from converting average CO_2 emissions reported in Climate Leaders: Commuting, Business Travel and Product Transport (EPA430-R-08-006) to diesel usage.*

EXHIBIT 3.11 – ESTIMATING SIZES OF ELECTRICAL EQUIPMENT

Estimating Pump Size Based on Expected Flow Parameters

$$HP = \frac{QH}{3956} \times \frac{1}{\eta}$$

HP = horsepower
Q= flowrate (gpm)
H=total dynamic head (feet of water)
η=pump efficiency (absent other information, assume (70%)
3956 = conversion factor from ft-gpm to HP

Round HP to the next highest value of (0.5, 0.75, 1, 1.5, 2, 3, 5, 7.5, 10, 15, 20, 30, 40, 50,…) to determine motor size

Estimating Blower Size Based on Expected Air Flow Requirements

$$HP = \frac{QH}{527} \times \frac{1}{\eta}$$

HP = horsepower
Q= flowrate (cfm)
H=total dynamic head (inches of water)
η=blower efficiency (absent other information, assume (55%)
527 = conversion factor from cfm-inches of water to HP

Round HP to the next highest value of (0.5, 0.75, 1, 1.5, 2, 3, 5, 7.5, 10, 15, 20, 30, 40, 50,…) to determine motor size

Estimating Compressor Size Based on Compressed Air Requirements

Absent more specific information, based on a general rule of thumb, at 100 psi, assume approximately 3.6 standard cubic feet per minute (scfm) per HP.

$$HP = \frac{scfm}{3.6}$$

Off-gas Preheating

Absent more specific information, based on a general rule of thumb, assume approximately 0.003 kW of electricity demand per cfm of air flow.

$$kW = 0.003 \times cfm$$

Note: The above formulas are intended to provide approximate values for the purpose of estimating an energy footprint and are not intended to provide accurate estimates for design purposes or financial forecasting. If more specific information is available, it should be used in place of these formulas.

EXHIBIT 3.12 – ESTIMATING ELECTRICITY USAGE FOR TYPICAL REMEDIATION COMPONENTS

During operation, electricity usage can typically be determined by referring to electrical bills; however, during the early remedy design stages, estimating electrical usage is not as straightforward. In addition, even if electrical bills are available during operation, it is helpful to estimate electricity usage from all major remedial components. This exhibit provides general rules of thumb for estimating electricity power requirements.

Item	Calculation for Estimating Electricity Usage
Small motors (< 1 HP) (e.g., for pumps, blowers, mixers)	$kWh = \frac{HP \times L_M}{\eta} \times 0.746 \times hours$ $(\eta = 0.65, L = 80\%)$
Large motors (≥ 1HP) (e.g., for pumps, blowers, mixers)	$kWh = \frac{HP \times L_M}{\eta} \times 0.746 \times hours$ $(\eta = 0.75, L = 80\%)$
Items with known electrical ratings (e.g., kW)	$kWh = kW \times hours$
Interpreting VFD settings	$kWh = \frac{HP \times {L_V}^3}{\eta_m \times \eta_v} \times 0.746 \times hours$

kW = kilowatts of electric power
kWh = kilowatt-hours of electricity
HP = horsepower
L_M *= % of motor full load*
L_V *= % of VFD full load (or speed in Hertz divided by 60 Hertz)*
η_m *= motor efficiency (typically 60% for less than 1 HP to 85% for 15 HP or greater)*
η_v *= VFD efficiency (typically 75% for less 50% load to 93% for more than 90% load)*
hours = hours of operation over time frame of project
0.746 = conversion of HP to kW
VFD = variable frequency drive

Note: The above formulas are intended to provide approximate values for the purpose of energy footprinting and are not intended to provide accurate estimates for design purposes or financial forecasting. If more specific information is available, it should be used in place of these formulas.

EXHIBIT 3.13 – SUGGESTED CONVERSION FACTORS

Suggested conversion factor values are provided to help convert various forms of fuel use, materials manufacturing, and off-site services into energy use and air pollution emissions. The conversion factors presented here are from a variety of sources, most of which are publicly available life-cycle inventory databases, and there is an inherent degree of uncertainty in the values. First, the life-cycle inventory data may not be able to accurately represent complex processes involved in manufacturing or off-site services. Second, the life-cycle inventory data represent overall averages of a particular industry rather than the specific processes or resources used at a particular facility that may produce the majority of a particular material used in a project. Third, there are many materials or services that may be used in a remedy that are not included in the publicly available databases. More robust proprietary life-cycle inventory databases exist and were consulted as part of developing this methodology, but proprietary conversion factors are not presented in the tables below due to restrictions in database licensing agreements. Project teams are not discouraged from using other well-documented and referenced sources for conversion factors if more specific information is available to the project team and the additional level of effort and level of detail is preferred. The data quality and the sources of alternative conversion factors, whether obtained from life-cycle inventory databases or developed independently by the project team, should be well documented as part of the footprint analysis.

			Suggested Conversion Factors						
			Parameters Used, Extracted, Emitted, or Generated						
Item or Service			**Energy**	**CO_2e**	**NOx**	**SOx**	**PM**	**HAPs**	**Reference**
			Used	**Emitted**	**Emitted**	**Emitted**	**Emitted**	**Emitted**	
		Unit	**MMBtu**	**Lbs**	**lbs**	**lbs**	**lbs**	**lbs**	
Fuel Combustion									
Biodiesel use		gal	0.127	22.3	0.20	0	0.00099	NP	1
Diesel use		gal	0.139	22.5	0.17	0.0054	0.0034	5.2E-06	2
Gasoline use		gal	0.124	19.6	0.11	0.0045	0.00054	3.9E-05	3
Natural gas use		ccf	0.103	13.1	0.01	0.0000063	0.00076	8.4E-06	4

NP = not provided
See notes on last page of this exhibit for references.

EXHIBIT 3.13 – SUGGESTED CONVERSION FACTORS (continued)

Item or Service Used		Suggested Conversion Factors — Parameters Used, Extracted, Emitted, or Generated: Energy	CO_2e	NOx	SOx	PM	HAPs	Reference
		Used	Emitted	Emitted	Emitted	Emitted	Emitted	
	Unit	MMBtu	Lbs	Lbs	lbs	lbs	lbs	
Construction Materials								
Cement	dry-lb	0.0021	0.9	0.0018	0.00105	0.0000032	2.9E-05	5
Concrete	lb	0.0004	0.14	0.00029	0.00017	0.0000022	0.0000044	6
Gravel/sand/clay	lb	0.000028	0.0034	0.000017	0.000015	0.0000020	2.1E-10	7
HDPE	lb	0.031	1.9	0.0032	0.0041	0.00064	3.4E-06	8
Photovoltaic system (installed)	W	0.034	4.5	0.015	0.032	0.00063	2.9E-06	9
PVC	lbs	0.022	2.6	0.0048	0.0076	0.0012	4.7E-04	10
Stainless Steel	lbs	0.012	3.4	0.0075	0.012	0.0044	1.4E-04	11
Steel	lbs	0.0044	1.1	0.0014	0.0017	0.00056	6.7E-05	12
Other refined construction materials	lbs	0.014	1.98	0.0037	0.0053	0.0014	1.4E-04	13
Other unrefined construction materials	lbs	0.000028	0.00335	0.000017	0.000015	0.000002	2.1E-10	14

See notes on last page of this exhibit for references.

EXHIBIT 3.13 – SUGGESTED CONVERSION FACTORS (continued)

Item or Service Used	Unit	Energy Used MMBtu	CO_2e Emitted Lbs	NO x Emitted lbs	SO x Emitted lbs	PM Emitted lbs	HAPs Emitted lbs	Reference
Treatment Materials & Chemicals								
Cheese Whey	lbs	0.0025	0.031	0.000062	0.000033	0.000002	NP	15
Emulsified vegetable oil	lbs	0.0077	3.44	0.0066	0.0019	0.000033	NP	16
Molasses	lbs	0.0044	0.48	0.0011	0.00024	0.0000041	NP	17
Treatment materials & chemicals	lbs	0.015	1.7	0.003	0.0065	0.00061	1.6E-05	18
Virgin GAC (coal based)	lbs	0.015	5.8	0.014	0.034	0.00078	1.2E-03	19
Fuel Processing								
Biodiesel Produced	gal	0.029	-16.8	0.018	0.033	0.00082	NP	1
Diesel Produced	gal	0.019	2.7	0.0064	0.013	0.00034	1.2E-04	20
Gasoline Produced	gal	0.021	4.4	0.008	0.019	0.00052	1.6E-04	21
Natural Gas Produced	ccf	0.0052	2.2	0.0037	0.0046	0.000072	6.1E-06	22
Public water	gal x 1000	0.0092	5	0.0097	0.0059	0.016	1.50E-05	23

NP = not provided
See notes on last page of this exhibit for references.

EXHIBIT 3.13 – SUGGESTED CONVERSION FACTORS (continued)

Item or Service Used	Unit	Energy Used MMBtu	CO_2e Emitted lbs	NOx Emitted lbs	SOx Emitted lbs	PM Emitted lbs	HAPs Emitted lbs	Reference
		Suggested Conversion Factors — Parameters Used, Extracted, Emitted, or Generated						
Off-Site Services								
Off-site waste water treatment	gal x 1000	0.015	4.4	0.016	0.015	NP	NP	24
Off-site Solid Waste Disposal	ton	0.16	25	0.14	0.075	0.4	1.40E-03	25
Off-site Haz. Waste Disposal	ton	0.18	27.5	0.154	0.0825	0.44	1.54E-03	26
Off-site Laboratory Analysis	$	0.0065	1	0.0048	0.0036	0.0004	1.30E-04	27
Electricity Generation	See Exhibit 3.16							
Resource Extraction for Electricity								
Coal extraction and processing	MWh	3.1	0.18	0.00077	0.00015	0.000018	NP	28
Natural gas extraction and processing	MWh	1.6	0.27	0.00018	0.013	0.0000071	NP	29
Nuclear fuel extraction and processing	MWh	0.16	0.025	0.00015	0.0005	0.0000015	NP	30
Oil extraction and processing	MWh	2.3	0.27	0.0017	0.000069	0.000042	NP	31
Electricity Transmission	10% of electricity generation footprint for each parameter							32

NP = not provided
See notes on last page of this exhibit for references.

EXHIBIT 3.13 – SUGGESTED CONVERSION FACTORS (continued)

REFERENCES:

1. *Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus, NREL/SR-580-24089 UC Category 1503, U.S. Department of Agriculture and U.S. Department of Energy, May 1998*
2. *Multiple sources*
    a. *Energy and CO_2e emissions from Direct Emissions from Mobile Combustion Sources, EPA430-K-08-004, U.S. EPA, May 2008.*
    b. *NOx, SOx, PM, and HAPs from NREL: SS_Transport, single unit truck, diesel powered.xls*
3. *Multiple sources*
    a. *Energy and CO_2e emissions from Direct Emissions from Mobile Combustion Sources, EPA430-K-08-004, U.S. EPA, May 2008.*
    b. *NOx, SOx, PM, and HAPs from NREL: SS_Transport, single unit truck, gasoline powered.xls*
4. *Multiple sources*
    a. *Energy and CO_2e emissions for compressed natural gas in heavy vehicles from Direct Emissions from Mobile Combustion Sources, EPA430-K-08-004, U.S. EPA, May 2008.*
    b. *NOx, SOx, PM, and HAPs from NREL: SS_Natural gas, combusted in industrial boiler.xls*
5. *EUROPA – Portland cement*
6. *Calculated from presented emission factors for public water, cement, and gravel/sand/clay by assuming typical concrete proportions by weight of 0.45:1:4 of water, cement, and sand/gravel*
7. *EUROPA – Gravel 2/32*
8. *EUROPA – Polyethylene high density granulate (PE-HD)*
9. *Life-Cycle Assessment of the 33 kW Photovoltaic System on the Dana Building at the University of Michigan Thin Film Laminates, Multi-Crystalline Modules, and Balance of System Components Sergio Pacca, Deepak Sivaraman and Gregory A. Keoleian Center for Sustainable Systems, University of Michigan Report No. CSS05-09, June 1, 2006*
10. *EUROPA - Suspension Polymerisation PVC*
11. *EUROPA – Stainless steel*
12. *EUROPA – Average of Steel hot rolled section, Steel hot rolled coil, Steel rebar*
13. *Averages of conversion factors for cement, HDPE, PVC, stainless steel, and steel*
14. *Same as conversion factors for gravel/sand/clay*
15. *Offset values for cheese whey obtained from the module for yellow cheese from Nielsen PH, Nielsen AM, Weidema BP, Dalgaard R and Halberg N (2003). LCA food data base. www.lcafood.dk, Andersen M and Jensen JD (2003). Marginale producenter af udvalgte basislevnedsmidler (in Danish) Udkast d. 5. februar 2003.*
16. *Values for rapeseed oil from Nielsen PH, Nielsen AM, Weidema BP, Dalgaard R and Halberg N (2003). LCA food data base. www.lcafood.dk. Landbrugets rådgivningscenter (2000). Tal fra Fodermiddeltabellen, Raport nr. 91. In Danish. Weidema BP (1999). System expansions to handle co-products of renewable materials. Presentation Summaries of the 7th LCA Case Studies Symposium SETAC-Europe, 1999. Pp. 45-48. pdf. Weidema B (2003). Market information in life cycle assessments. Technical report, Danish Environmental Protection Agency (Environmental Project no. 863).*
17. *Offset values for molasses obtained from the module for sugar from Nielsen PH, Nielsen AM, Weidema BP, Dalgaard R and Halberg N (2003). LCA food data base. www.lcafood.dk, Sugar Production based on Danisco Sugar Author: Per H. Nielsen July 2003*

EXHIBIT 3.13 – SUGGESTED CONVERSION FACTORS (continued)

18. *Intended for any common treatment chemical in pure form including chemical oxidants and regenerated granular activated carbon. For chemical solutions, use only the mass of the chemical portion of the solution. Conversion factor is based on average value of conversion factors for the following seven common treatment chemicals as reported by Ecoinvent v2.1 from the Ecoinvent Centre for Life-Cycle Inventories, http://www.ecoinvent.ch/*
    - *Hydrochloric Acid (30%) – normalized to pure hydrochloric acid by dividing by database results by 0.3.*
    - *Sodium hydroxide (50%) – normalized to pure sodium hydroxide by dividing database results by 0.5.*
    - *Ferric chloride (iron III chloride)*
    - *Potassium permanganate*
    - *Sodium persulfate*
    - *Chlorine gas*
    - *Hydrogen peroxide (50%) – normalized to pure hydrogen peroxide by dividing database result by 0.5.*

    This averaging approach adds an additional layer of uncertainty to the conversion factors provided. For example, the range for energy is approximately 0.007 MMBtu to 0.025 MMBtu. The average (0.015 MMBtu) may over estimate the energy use value for some of the chemicals below by more than 100% and underestimate the energy us value for other chemicals by 40%. Additionally, some common treatment chemicals (e.g., sulfuric acid and ferrous sulfate) have energy footprints that are substantially outside the presented range and would not be accurately represented by these values. If an additional level of accuracy is preferred, readers of this methodology are encouraged to seek and document well referenced conversion factors as part of footprint analysis submittals.
19. *Based on "treatment materials & chemicals" above plus the result of combusting 1.86 pounds of bituminous coal. The additional coal combustion represents the coal that is combusted in the activation process. The 1.86 pounds of bituminous coal assumes that the activated carbon yield is approximately 35% of the coal used as a feedstock (e.g., 2.86 pounds of coal yields 1 pound of granular activated carbon), which is consistent with values reported in Pore Develop of Activated Carbon Prepared by Steam Activate Process, Kim SC and Hong, IK, Journal of Industrial and Engineering Chemistry, Vol. 4, No. 3, September 1998, 177-184.*
20. *EUROPA – diesel at refinery*
21. *EUROPA – gasoline at refinery*
22. *EUROPA – natural gas at consumer*
23. *EUROPA - Drinking water from surface water and drinking water from groundwater*
24. *Calculated based on Life-Cycle Energy and Emissions for Municipal Water and Wastewater Services: Case-Studies of Treatment Plants in US Malavika Tripathi, Center for Sustainable Systems, University of Michigan Report No. CSS07-06, April 17, 2007*
25. *EUROPA – Inert waste disposal*
26. *Values from EUROPA inert waste disposal plus an arbitrary additional 10% to account additional practices required of a hazardous waste disposal facility*
27. *Based on U.S. CARBON DIOXIDE EMISSIONS AND INTENSITIES OVER TIME: A DETAILED ACCOUNTING OF INDUSTRIES, GOVERNMENT AND HOUSEHOLDS, APRIL 2010. Approximatley 1 lb of CO2 is emitted per dollar of gross domestic product. In the absence of other information, it is assumed that the laboratory also has an emission profile of approximately 1 lb of CO2 emitted per dollar of sample cost. Conversion factor estimates assume that 50% of this 1 lb of CO2 per dollar of sample cost results from electricity use (U.S. average fuel blend) and 50% is due to diesel use. A dollar of sample cost can then be converted into electricity and diesel usage. The conversion factors result from this electricity and diesel usage using the average electricity fuel blend for the United States and the diesel conversion factors provided here.*

EXHIBIT 3.13 – SUGGESTED CONVERSION FACTORS (continued)

28. *NREL – life-cycle of electricity from bituminous coal minus the emissions from combusting coal*
29. *NREL – life-cycle of electricity from natural gas minus the emissions from combusting natural gas*
30. *NREL – life-cycle of electricity from nuclear*
31. *NREL – life-cycle of electricity from residual oil minus the emissions from combusting residua oil*
32. *U.S. Dept. of Energy (GridWorks: Overview of the Electric Grid http://sites.energetics.com/gridworks/grid.html).*

NREL = National Renewable Energy Laboratory, Lifecycle Inventory, provided by the National Renewable Energy Laboratory and operated by Alliance for Sustainable Energy, LLC under contract to the U.S. Department of Energy. www.nrel.gov/lci

EUROPA = European Reference Life Cycle Database (ELCD core database), version II compiled under contract on behalf of the European Commission - DG Joint Research Centre - Institute for Environment and Sustainability with technical and scientific support by JRC-IES from early 2008 to early 2009. (http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm)

EXHIBIT 3.14 – ESTIMATING AIR POLLUTANT EMISSIONS FROM ON-SITE SOURCES

Some treatment processes (such as air strippers used in P&T systems) and some remedies (such as SVE systems) involve discharge of process air to the atmosphere. It is common to include off-gas treatment to mitigate discharge of pollutants to the atmosphere, but in some cases off-gas treatment is not provided. The following equations provide assistance in calculating the emission rate in pounds per year from air strippers and SVE systems.

Estimating Air Emissions from Air Stripper Off-Gas

$$E = \frac{Q \times C \times 3.785 \times 1440 \times 365 \times 2.2 \times \eta_s \times (1 - \eta_t)}{10^9}$$

E = Emission rate (pounds per year)
Q = process water flow rate (gpm)
C = concentration (µg/L)
η_s = air stripper efficiency (assume 100%)
η_t = off-gas treatment efficiency (varies)
3.785 = liters per gallon
1440 = minutes per day
365 = days per year
2.2 = pounds per kilogram

Estimating Air Emissions from SVE Systems

$$E = \frac{Q \times C \times 0.0283 \times 1440 \times 365 \times 2.2 \times (1 - \eta_t)}{10^9}$$

E = Emission rate (pounds per year)
Q = process water flow rate (cfm)
C = concentration (µg/m^3)
0.0283 = cubic meters per cubic feet
1440 = minutes per day
365 = days per year
2.2 = pounds per kilogram
η_t = off-gas treatment efficiency (varies)

EXHIBIT 3.15 – ESTIMATING CARBON STORED IN PLANTED TREES

<u>*Carbon Stored in Planted Trees*</u>

$$C_S = e^{-2.2+2.4\ln(bhd)} \times (1 + e^{(-1.63+.0.74/bhd)}) \times 0.46 \times 1.69$$

C_s = carbon dioxide stored

bhd = breast-height diameter of tree in (cm), assume 1 cm/yr growth rate for up to 40 years and a slower rate thereafter

Values represent average parameters for willow, poplar, oak, birch, and cypress trees

REFERENCES:

Biomass calculated based on equations from Jenkins, Jennifer C.; Chojnacky, David C.; Heath, Linda S.; Birdsey, Richard A., National scale biomass estimators for United States tree species, Forest Science. 49: 12-35, 2003

Willow - http://na.fs.fed.us/pubs/silvics_manual/volume_2/salix/nigra.htm species group (aa) according to Jenkins 2003

Bald Cypress - http://na.fs.fed.us/pubs/silvics_manual/Volume_1/taxodium/distichum.htm species group (cl) according to Jenkins 2003

Poplar - http://na.fs.fed.us/pubs/silvics_manual/volume_2/liriodendron/tulipifera.htm species group (aa) according to Jenkins 2003

River Birch - http://na.fs.fed.us/pubs/silvics_manual/volume_2/betula/nigra.htm species group (mb) according to Jenkins 2003

Water Oak - http://na.fs.fed.us/pubs/silvics_manual/volume_2/quercus/nigra.htm species group (mo) according to Jenkins 2003

EXHIBIT 3.16 – USING DATA FROM ELECTRIC SERVICE PROVIDERS TO DETERMINE FOOTPRINT CONVERSION FACTORS

The methodology involves the use of footprint conversion factors to convert electricity usage into energy use and CO_2e, NOx, SOx, PM, and HAP emissions. In addition, the methodology involves distinguishing between energy from conventional resources and energy from renewable resources. When possible, the fuel blend from the electric service provider should be used to determine this information because it is likely more specific to the site and has likely been updated more recently than eGRID. This fuel blend may be referred to as a "generation mix" or provided on a "Power Content Label". If this information is not available, then the data for the state where the site is located can be obtained from the most recent year indicated in Table 5 of the state electricity profile from obtained from www.eia.gov. Note that information for electricity service providers is available through eGRID (www.epa.gov/egrid) but should not be used for this methodology unless the information is consistent with that obtained directly from the electric service provider.

Example Power Content from Electric Service Provider

Energy Source	**Percentage of Power Mix Delivered to Customers**
Natural gas	39%
Nuclear	
Renewable (30% total)	
- Geothermal (16%)	4.75%
- Biomass/waste (15%)	4.5%
- Hydroelectric (63%)	18.8%
- Wind (6.5%)	1.95%
- Solar (<1%)	<1%
Coal	8%
Other	1%

22%

Converting Resource Mix to Footprint Conversion Factors and Portion of Energy Derived from Renewable Resources

Type	**% of Total Used**	**Energy (MMbtu/MWh)**		**CO_2e (lbs/MWh)**		**NOx (lbs/MWh)**		**SOx (lbs/MWh)**		**PM (lbs/MWh)**		**HAPs (lbs/MWh)**	
		Full Load	**Adj. by %**	**Full Load**	**Adj. by %**	**Full Load**	**Adj. by %**	**Full Load**	**Adj. by %**	**Full Load**	**Adj. by %**	**Full Load**	**Adj. by %**
Conventional Energy													
Coal		6.9		2200		6		15		.092		0.66	
Natural Gas		6.9		1300		1.1		0.0066		0.08		0.025	
Oil		6.9		1800		2.2		2.8		0.13		0.066	
Nuclear		6.9		0									
Subtotal Conventional													
Renewable Energy					0		0		0		0		
Biomass		6.9		0	0	1.4		0.65		0.084		5.3E-6	0
Geothermal		6.9		0	0	0	0	0	0	0	0	0	0
Hydro		6.9		0	0	0	0	0	0	0	0	0	0
Solar		6.9		0	0	0	0	0	0	0	0	0	0
Wind		6.9		0	0	0	0	0	0	0	0	0	0
Subtotal Renewable													
Total													

Full load emission values for each fuel type obtained from www.nrel.gov/lci.
All values do not include energy and emissions for resource extraction or for transmission losses, which are accounted for in Scope 3.
Energy conversion factors exclude the energy contained in the MWh of electricity used by the remedy to avoid double counting of Scope 1 energy use.
For simplicity, energy conversion factors are assumed to be 6.9 MMBtu per MWh (equivalent to 33% efficiency) for all energy sources, which is typical for thermoelectric facilities but may under or over estimate the energy footprint from other sources.

Appendix B:
Suggested Formats for Documenting the Footprint Analysis

SUGGESTED FORMAT FOR REPORTING MATERIALS METRICS

SUGGESTED FORMAT FOR REPORTING WASTE METRICS

SUGGESTED FORMAT FOR REPORTING ON-SITE WATER METRICS

SUGGESTED FORMAT FOR CALCULATING AND DOCUMENTING ON-SITE (SCOPE 1) ENERGY AND AIR METRICS

SUGGESTED FORMAT FOR CALCULATING AND PRESENTING ELECTRICITY GENERATION (SCOPE 2) ENERGY AND AIR METRICS

SUGGESTED FORMAT FOR CALCULATING AND PRESENTING TRANSPORTATION ENERGY & AIR METRICS

SUGGESTED FORMAT FOR CALCULATING AND PRESENTING OFF-SITE (SCOPE 3) ENERGY AND AIR METRICS

SUGGESTED FORMAT FOR SUMMARZING ENERGY AND AIR METRICS

SUGGESTED FORMAT FOR SUMMARIZING AND DOCUMENTING THE ENVIRONMENTAL FOOTPRINT ANALYSIS RESULTS

SUGGESTED FORMAT FOR REPORTING MATERIALS METRICS

Material and Use	Quantity	Conversion Factor to Lbs	% Recycled or Reused Content	Quantity	
				Virgin	Recycled
Refined Materials (lbs)					
Refined Materials Total (tons = lbs/2000):					
% of Refined Materials that is Recycled or Reused Content					
Unrefined Materials (tons)					
Bentonite					
Clay					
Clean soil					
Mulch					
Sand and gravel					
Other #1					
Other #2					
Other #3					
Other #4					
Other #5					
Unrefined Materials Total (tons):					
% of Unrefined Materials that is Recycled or Reused Content					

SUGGESTED FORMAT FOR REPORTING WASTE METRICS

Waste or Spent Material	Quantity	% of Total Potential Waste
Recycled/Reused Waste (tons)		
Used On-Site		
Used On-Site Subtotal:		
Recycled or Reused Off-Site		
Recycled/Reused Off-Site Subtotal:		
Recycled/Reused Waste Total:		
Waste Disposal (tons)		
Hazardous Waste		
Hazardous Waste Subtotal:		
Non-Hazardous Waste		
Non-Hazardous Waste Subtotal:		
Waste Disposal Total:		
Total Potential Waste*:		**100%**

** Includes waste that is recycled or reused as well as waste that is disposed of in landfills, incinerators, or other forms of disposal that do not allow for recycling or reuse.*

SUGGESTED FORMAT FOR REPORTING ON-SITE WATER METRICS

Water Resource	Description of Quality of Water Used	Volume Used (1000 gallons)	Uses	Fate of Used Water
Public water supply				
Extracted groundwater #1 Location: Aquifer:				
Extracted groundwater #2 Location: Aquifer:				
Extracted groundwater #3 Location: Aquifer:				
Surface water #1 Intake Location:				
Surface water #2 Intake Location:				
Reclaimed water Source:				
Collected/diverted storm water				
Other resource #1				
Other resource #2				

SUGGESTED FORMAT FOR CALCULATING AND DOCUMENTING ON-SITE (SCOPE 1) ENERGY AND AIR METRICS

			Energy		Greenhouse Gas		NOx		SOx		PM		HAPs	
Contributors to Footprints	**Units**	**Usage**	**Conv. Factor**	**MMBtus**	**Conv. Factor**	**lbs CO_2e**	**Conv. Factor**	**lbs**	**Conv. Factor**		**Conv. Factor**		**Conv. Factor**	**lbs**
On-Site Renewable Energy														
Elec. generated on-site by renewable resources	MWh		3.413						**lbs**		**lbs**			
Grid electricity from renewable resources	MWh		3.413											
Grid electricity offset by purchased renewable electricity	MWh		3.413											
Landfill gas combusted on-site	ccf CH_4													
Biodiesel used on-site	Gal													
Other forms of on-site renewable energy use	TBD													
On-Site Renewable Energy Subtotals														
On-Site Conventional Energy														
Grid electricity from conventional resources	MWh		3.413											
Grid electricity offset by purchased renewable energy	MWh		(3.413)											
On-site diesel use	Gal													
On-site gasoline use	Gal													
On-site natural gas use	Ccf													
Other forms of on-site conventional energy use	TBD													
On-Site Conventional Energy Subtotals														
Other On-Site Contributions														
On-site HAP process emissions	Lbs													
On-site GHG emissions	Lbs													
On-site carbon storage	Lbs				(1)									
GHG offset by combusting on-site landfill methane	Lbs				(20)									
Other on-site contributions	TBD													
Other On-Site Subtotals														
				1										
On-Site Totals														

TBD = to be determined *Values in parentheses are negative values. Energy for electricity is only that energy of that electricity and not the energy required to generate the electricity.*

ccf CH_4 = 100 cubic feet of methane. Obtained by multiplying total volume of landfill gas in 100 ccf by the percentage of the gas that is methane.

If fuel is a blend of conventional fuel and renewable resource fuel, enter the amount of fuel from conventional sources into appropriate conventional fuel categories and enter amount of fuel from renewable resources into appropriate renewable fuel categories (e.g., for 100 gallons of B20 biodiesel blend, 20 gallons would be entered under biodiesel and 80 gallons would be entered under diesel).

Usage × Conversion factor = Footprint

1. Enter usages into blue cells in "Usage" column in indicated units.
2. Convert usages into indicated units of each parameter by multiplying usage by the indicated conversion factors. Enter result into blue cells in parameter columns.
3. Sum On-Site Renewable Energy results for each parameter and enter in green "On-Site Renewable Energy Subtotals" cells.
4. Sum On-Site Conventional Energy results for each parameter and enter in green "On-Site Conventional Energy Subtotals" cells. Be sure to subtract the energy from electricity offset by purchased renewable energy (e.g., renewable energy certificates).
5. Sum Other On-Site Contributions results for each parameter and enter in green "Other On-Site Subtotals" cells.
6. Sum green cells for each parameter and enter result in green "On-Site Totals" cells.

SUGGESTED FORMAT FOR CALCULATING AND PRESENTING ELECTRICITY GENERATION (SCOPE 2) ENERGY AND AIR METRICS

Contributors to Footprints	Units	Usage	Energy		Greenhouse Gas		NOx		SOx		PM		HAPs	
			Conv. Factor	MMBtus	Conv. Factor	lbs CO_2e	Conv. Factor	lbs	Conv. Factor	lbs	Conv. Factor	lbs	Conv. Factor	lbs
Grid Electricity from Renewable Resources	MWh													
Grid Electricity from Conventional Resources	MWh													
Total Grid Electricity	MWh													
Offsets from Purchased Renewable Energy Certificates	MWh													
Net Energy from Conventional Resources														
Total Energy from Renewable Resources														
Electricity Generation Net Emissions														

Grid electricity from Renewable Resources includes renewable energy purchased from green pricing programs from the electric service provider.

See Exhibit 3.16 for how to determine the percentage of grid electricity that is from renewable resources and then multiply this percentage by the total grid electricity usage to obtain the grid electricity from renewable resources.
See Exhibit 3.16 for how to determine the percentage of grid electricity from conventional resources and then multiply this percentage by the total grid electricity usage to obtain the grid electricity from conventional resources.
Use the information from the "product content label" from the Renewable Energy Certificate vendor to determine the emission conversion factors for GWP, NOx, SOx, and PM, if available.
If the "product content label" for renewable energy certificates does not provide conversion factors for all parameters use the renewable energy portion of the table in Exhibit 3.16 to determine those conversion factors.

Total Energy from Renewable Resources = Energy Associated with Grid Electricity from Renewable Resources + Energy Associated with Purchased Renewable Energy Certificates

Net Energy from Conventional Resources = Energy Associated with Grid Electricity from Conventional Resources – Energy Associated with Purchased Renewable Energy Certificates

Electricity Generation Net Emissions = Emissions Associated with Total Grid Electricity – Emissions Associated with Purchased Renewable Energy Certificates

SUGGESTED FORMAT FOR CALCULATING AND PRESENTING TRANSPORTATION ENERGY & AIR METRICS

Category	Units	Usage	Energy		Greenhouse Gas		NOx		SOx		PM		HAPs	
			Conv. Factor	**MMBtus**	**Conv. Factor**	**lbs CO_2**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**
Conventional Energy														
Diesel use	gal	7,250	0.139	1008	22.5	163125	0.17	1233	0.0054	39	0.0034	25	5E-06	0.038
Gasoline use	gal	1,410	0.124	175	19.6	27636	0.11	155	0.0045	6	0.00054	1	3.9E-05	0.055
Natural gas use	ccf		0.103	0	13.1	0	0.01	0	0.0000063	0	0.00076	0	8.4E-06	0.000
Subtotal				**1,183**		**190,761**		**1,388**		**45**		**25**		**0.093**
Renewable Energy														
Biodiesel use	gal	0	0.127	0	22.3	0	0.20	0	0	0	0.00099	0	NP	
Transportation Totals				**1,183**		**190,761**		**1,388**		**45**		**25**		**0**

1. *Enter usages of each material or service into "Usage" column in indicated units.*
2. *Convert usages into indicated units of each parameter by multiplying usage by the indicated conversion factor. Enter result into blue cells in parameter columns.*

SUGGESTED FORMAT FOR CALCULATING AND PRESENTING OFF-SITE (SCOPE 3) ENERGY AND AIR METRICS

			Energy		Greenhouse Gas		NOx		SOx		PM		HAPs	
Category	**Units**	**Usage**	**Conv. Factor**	**MMBtus**	**Conv. Factor**	**lbs CO_2**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**
Construction Materials														
Cement	dry-lbs													
Concrete	Lbs													
Gravel/sand/clay	Lbs													
HDPE	Lbs													
Photovoltaic system (installed)	W													
PVC	Lbs													
Stainless Steel	Lbs													
Steel	Lbs													
Other refined construction materials	Lbs													
Other unrefined construction materials	Lbs													
Treatment Materials & Chemicals														
Cheese Whey	Lbs													
Emulsified vegetable oil	Lbs													
Molasses	Lbs													
Treatment materials & chemicals*	Lbs													
Virgin GAC (coal based)	Lbs													
Fuel Processing														
Biodiesel Produced	Gal													
Diesel Produced	Gal													
Gasoline Produced	Gal													
Natural Gas Produced	Ccf													
Public water	gal x 1000													
Off-Site Services														
Off-site waste water treatment	gal x 1000													
Off-site Solid Waste Disposal	Ton													
Off-site Haz. Waste Disposal	Ton													
Off-site Laboratory Analysis	$													

SUGGESTED FORMAT FOR CALCULATING AND PRESENTING OFF-SITE (SCOPE 3) ENERGY AND AIR METRICS (continued)

Category	Units	Usage	Energy		Greenhouse Gas		NOx		SOx		PM		HAPs	
			Conv. Factor	MMBtus	Conv. Factor	lbs CO_2	Conv. Factor	lbs	Conv. Factor	lbs	Conv. Factor	lbs	Conv. Factor	lbs
Resource Extraction for Electricity														
Coal extraction and processing	MWh													
Natural gas extraction and processing	MWh													
Nuclear fuel extraction and processing	MWh													
Oil extraction and processing	MWh													
Grid renewable energy	MWh													
Purchased renewable energy	MWh													
Electricity Transmission	MWh													
Conventional energy	MWh													
Renewable energy	MWh													
Total Off-Site Conventional														
Total Off-Site Renewable														

1. *Enter usages of each material or service into "Usage" column in indicated units.*
2. *Convert usages into indicated units of each parameter by multiplying usage by the indicated conversion factor. Enter result into blue cells in parameter columns.*
3. *Fuel processing refers to all fuel used, including that for on-site equipment use and transportation.*
4. *Electricity from various resources is obtained from generation mix that is used in Exhibit 3.16 and the resource extraction conversion factors from Exhibit 3.13.*
5. *For electricity transmission, enter 10% of the grid electricity used for calculating energy and emission from electricity generation. The conversion factors are the same as those used for electricity generation. The energy conversion factor also includes the 3.413 MMbtus embodied in the actual electricity that is used.*
6. *Resource extraction conversion factors are calculated using values in Exhibit 3.13 and the specified fuel blend for electricity generation.*
7. *RECs, if purchased, are assumed to 1) offset emissions associated with transmission losses and resource extraction, 2) eliminate the energy associated with resource extraction, and 3) convert the energy associated with transmission losses to renewable energy.*

SUGGESTED FORMAT FOR SUMMARZING ENERGY AND AIR METRICS

Category	Energy from Renewable Resources	Energy from Conventional Resources	Total Energy	Greenhouse Gas	NOx	SOx	PM	NOx + SOx + PM	HAPs
	MMbtus	MMbtus	MMbtus	lbs CO_2e	lbs	lbs	lbs	Lbs	lbs
On-site (Scope 1)									
Electricity Generation (Scope 2)									
Transportation (Scope 3)									
Other Off-Site (Scope 3)									
Off-site (Scope 2 + Scope 3)									
Remedy Totals									
% of Total Energy from Renewable Resources									

Values in green cells represent the summation of values presented in other cells in this table.
Summary level metrics are provided in outlined cells. All other cells and values are provided for transparency and analysis purposes only.

SUGGESTED FORMAT FOR SUMMARIZING AND DOCUMENTING THE ENVIRONMENTAL FOOTPRINT ANALYSIS RESULTS

Core Element	Metric	Unit of Measure	Value
Materials & Waste	Refined materials used on-site	Tons	
	% of refined materials from recycled or waste material	%	
	Unrefined materials used on-site	Tons	
	% of unrefined materials from recycled or waste material	%	
	On-site hazardous waste disposed of off-site	Tons	
	On-site non-hazardous waste disposed of off-site	Tons	
	% of total potential waste recycled or reused	%	
Water	On-site water used (by source)	Millions of gallons	
Energy	Total energy used	MMBtu	
	% of total energy use from renewable resources	%	
Air	On-site NOx, SOx, and PM emissions	Pounds	
	On-site HAP emissions	Pounds	
	Total greenhouse gas emissions	Pounds CO_2e	
	Total NOx, SOx, and PM emissions	Pounds	
	Total HAP emissions	Pounds	
Land & Ecosystems	No metrics. Qualitative analysis		

Appendix C:
Case Studies

The case studies presented in this appendix are categorized according to:

- **Materials & Waste**
- **Water**
- **Energy & Air**

The case studies have been separated into these categories for illustrative purposes, and the same site conditions or scenarios are not necessarily common among the three categories.

Case studies are provided for illustrative purposes only and do not constitute a recommendation by EPA.

Case Studies:
Materials & Waste

MATERIALS & WASTE CASE STUDY #1

MATERIALS & WASTE CASE STUDY #2

MATERIALS & WASTE CASE STUDY #3

MATERIALS & WASTE CASE STUDY #1

Case Study Background:

A P&T system is under design to treat arsenic through co-precipitation. The 50% design extraction rate is 700 gpm, and the system is anticipated to operate for 30 years. The process water is oxidized with hydrogen peroxide. Ferric chloride is added to provide iron to adsorb the arsenic, and sodium hydroxide is added to neutralize the water. Polymer is added to assist with flocculation. Precipitated metals are dewatered and disposed of off-site as listed hazardous waste. No other significant waste streams are associated with site.

The following items will be constructed:

- 10 6-inch extraction wells, each to 60 feet deep with 20-foot screens
- 3,000 feet of 6-inch HDPE piping with electrical conduit and wiring
- 80-foot x100-foot building that is 30 feet high
- 200-foot x 200-foot reinforced fly-ash concrete pad and containment area (20,000 ft^3 of concrete)
- 50,000 pounds of primary treatment equipment

Screening:

The largest contributor to refined materials is expected to be the sodium hydroxide (over 6,000,000 lbs of pure sodium hydroxide) over a 30-year period. The largest contributor for unrefined materials is expected to be the aggregate in the concrete for the building foundation (about 1,200 tons). No specific appreciable non-hazardous waste streams have been identified. The dewatered sludge from metals removal is expected to be 2,600 tons. The project team has chosen a %-based screening limit of 1% for refined and unrefined materials and magnitude based limits of 1,000 lbs for refined materials and 1 ton for unrefined materials and wastes. The limits are therefore as follows:

Category	Largest Contributor	Largest Contribution	Selected % of Largest Contributor	% - based Limit	Magnitude-based Limit	Applicable Limit
Refined materials	Sodium hydroxide	6,000,000 lbs	1%	60,000 lbs	1,000 lbs	**60,000 lbs**
Unrefined materials	Concrete aggregate	1,200 tons	1%	12 tons	1 tons	**12 tons**
Non-hazardous Waste	General waste	Unknown	1%	Unknown	1 ton	**1 ton**
Hazardous Waste	Dewatered sludge	2,600 tons	1%	26 tons	1 ton	**26 tons**

The data quality for the remedy information is considered poor to moderate. The extraction rate is subject to change due to additional modeling and capture zone evaluation during startup. The chemical dosing is highly dependent on actual influent chemical loading, and the remedy duration was loosely estimated for cost estimating purposes. The footprint results are expected to be highly sensitive to these relatively uncertain parameters. Because the metrics are direct reporting of expected materials use and waste, there is little or no added uncertainty associated with converting remedy information and engineering estimates into the metrics as there would be for energy & air metrics.

Estimated Materials Footprint over 30-Year Operation Period

Material and Use	Quantity	Conversion Factor	% Recycled or Reused Content	Quantity: Virgin	Quantity: Recycled
Refined Materials (lbs)					
Wells – PVC casing and grout	Expected to be less than screening limit				
Wells – screen	Expected to be less than screening limit				
Piping and conduit	3,000 ft	7.5 lbs/ft		22,500*	
Building steel	240,000 ft^3	1 lbs/ft^3	55%	108,000	132,000
Concrete reinforcing steel	40,000 ft^2	1.3 lbs/ft^2	55%	23,400*	28,600*
Cement portion of concrete	20,000 ft^3	22 lbs/ft^3	20%	352,000	88,000
Process equipment (plus controls)	Expected to be less than screening limit				
Process controls	Expected to be less than screening limit				
Hydrogen peroxide (50%)	295,650 gal	4.96 lbs/gal	0%	1,467,000	0
Ferric chloride (37%)	1,368,750 gal	4.33 lbs/gal	0%	5,928,000	0
Sodium hydroxide (20%)	3,011,250 gal	2.04 lbs/gal	0%	6,144,000	0
Polymer (specific gravity = 1.04)	120,450 gal	8.7 lbs/gal	0%	1,047,000	0
Refined Materials Total (tons = lbs / 2000):				**7,550**	**124.3**
% of Refined Materials that is Recycled or Reused Content				**<2%**	
Unrefined Materials (tons)					
Wells –sand pack	Expected to be less than screening				
Aggregate for concrete	20,000 ft^3	115 lbs/ft^3		1,150	
		2000 lbs/ton			
Unrefined Materials Total (tons):				**1,150**	**0**
% of Unrefined Materials that is Recycled or Reused Content				**0%**	

NOTE: polymer quantity includes unknown water content of aqueous solution

** values for piping/conduit and concrete reinforcing steel are shown in the above table because the project team determined that professional judgment alone was not sufficient to assume they were below the screening limit. Because the project team invested the time and resources to estimate the values for the screening process, the contributions from these items are retained in the analysis.*

Values provided in the "Quantity" Column are obtained from engineering estimates during design.

Conversion factors in above tables obtained from Exhibit 3.3 through Exhibit 3.8.

Estimated Waste Footprint

Waste or Used Material	Quantity	% of Total Potential Waste
Recycled/Reused Waste (tons)		
Used On-Site		
None.		
Used On-Site Subtotal:	**0**	**0%**
Recycled or Reused Off-Site		
None.		
Recycled/Reused Off-Site Subtotal:	**0**	**0%**
Recycled/Reused Waste Total:	**0**	**0%**
Waste Disposal (tons)		
Hazardous Waste		
2,600 tons of dewatered precipitated metals sludge	2,600	100%
Hazardous Waste Subtotal:	**2,600**	**100%**
Non-Hazardous Waste		
None.		
Non-Hazardous Waste Subtotal:	**0**	**0%**
Waste Disposal Total:	**2,600**	**100%**
Total Potential Waste*:	**2,600**	**100%**

** Includes waste that is recycled or reused as well as waste that is disposed of in landfills, incinerators, or other forms of disposal that do not allow for recycling or reuse.*

Findings:

Overall materials usage is dominated by the treatment chemicals. Efforts for footprint reduction can be focused on identifying a potential waste stream of iron hydroxides that may help reduce some of the sodium hydroxide and ferric chloride use. Use of this waste stream would also increase the percentage of materials from recycling/reuse. The waste footprint is dominated by the precipitated sludge. The waste is not characteristically hazardous. Delisting the waste may allow for non-hazardous waste disposal, which would lower the hazardous waste footprint and increase the non-hazardous waste footprint. Effort will also be placed on optimizing the extraction rate because the extraction rate directly influences treatment chemical use and waste disposal.

MATERIALS & WASTE CASE STUDY #2

Case Study Background:

A biobarrier that involves routine injections of emulsified vegetable oil is designed to control groundwater plume migration. A total of 20 permanent injection wells each with 20-foot screen intervals will be used. Of the 20 wells, 10 will be 60 feet deep and 10 will be 40 feet deep. The wells will be constructed with 2-inch PVC casing. A total of 400,000 lbs of emulsified vegetable oil will be injected over events spanning 10 years. Drill cuttings (approximately 9 tons) are disposed of off-site at a landfill as non-hazardous waste.

Screening:

The largest contributor to refined materials is expected to be the emulsified vegetable oil. The largest contributor for unrefined materials is expected to be the sand (about 4 tons) for the sand packs of the injection wells. The drill cuttings are the only anticipated waste stream. The project team has chosen a %-based screening limit of 1% for refined and unrefined materials and magnitude based limits of 1,000 lbs for refined materials and 1 ton for unrefined materials and wastes. The limits are therefore as follows:

Category	Largest Contributor	Largest Contribution	Selected % of Largest Contributor	% - based Limit	Magnitude-based Limit	Applicable Limit
Refined materials	Emulsified vegetable oil	400,000 lbs	1%	4,000 lbs	1,000 lbs	**4,000 lbs**
Unrefined materials	Sand	4 tons	1%	0.04 tons	1 ton	**1 ton**
Non-hazardous Waste	Drill cuttings	9 tons	1%	0.09 tons	1 ton	**1 ton**
Hazardous Waste	None expected					

The data quality for the remedy information is considered moderate. The design for the injection well network is finalized and is conservative. No additional wells are expected. The amount of emulsified vegetable oil to be added in the first event has also been determined, but the frequency of maintenance injections and the amount of oil to be injected in each maintenance injection event are estimates to be refined during remedy implementation. The footprint results are expected to be highly sensitive to parameters of the reinjection events. Because the metrics are direct reporting of expected materials use and waste, there is little or no added uncertainty associated with converting remedy information and engineering estimates into the metrics as there would be for energy & air metrics.

Estimated Materials Footprint

Material and Use	Quantity	Conversion Factor	% Recycled or Reused Content	Quantity	
				Virgin	Recycled
Refined Materials (lbs)					
Injection wells - PVC casing & screen	Expected to be less than screening limit				
Injection well grout	800 ft	13 lbs/ft	0%	10,400	0
Emulsified vegetable oil	400,000	1	0%	400,000	0
Other items	Expected to be less than screening limit				
Refined Materials Total (tons = lbs/2000):				**205**	**0**
% of Refined Materials that is Recycled or Reused Content				**0%**	
Unrefined Materials (tons)					
Injection wells – sand pack	400 feet	0.01 tons/ft	0%	4	0
Unrefined Materials Total (tons):				**4**	**0**
% of Unrefined Materials that is Recycled or Reused Content				**0%**	

Values provided in the "Quantity" Column are obtained from engineering estimates during design.

Conversion factors in above tables obtained from Exhibit 3.3 through Exhibit 3.8.

Estimated Waste Footprint

Waste or Used Material	Quantity	% of Total Potential Waste
Recycled/Reused Waste (tons)		
Used On-Site		
None.		
Used On-Site Subtotal:	**0**	**0%**
Recycled or Reused Off-Site		
None.		
Recycled/Reused Off-Site Subtotal:	**0**	**0%**
Recycled/Reused Waste Total:	**0**	**0%**
Waste Disposal (tons)		
Hazardous Waste		
None.	0	0%
Hazardous Waste Subtotal:	**0**	0%
Non-Hazardous Waste		
Drill cuttings	9	100%
Non-Hazardous Waste Subtotal:	**9**	**100%**
Waste Disposal Total:	**9**	**100%**
Total Potential Waste*:	**9**	**100%**

** Includes waste that is recycled or reused as well as waste that is disposed of in landfills, incinerators, or other forms of disposal that do not allow for recycling or reuse.*

MATERIALS & WASTE CASE STUDY #2 *(continued)*

Findings:

Overall materials usage is dominated by the emulsified vegetable oil. Efforts for footprint reduction can be focused on identifying a potential off-spec food grade amendment that will otherwise be considered a waste product. This may modify the total amount of materials used but will also increase the percentage of materials from recycled/reused material. Performance monitoring data will be reviewed closely to evaluate quantity and frequency of maintenance injections so that remedy protectiveness is maintained without using much more vegetable oil than expected. The drill cuttings are not hazardous, and it may be possible to use them as fill elsewhere on site to reduce the quantity of waste for off-site disposal and increase the total potential waste that is recycled/reused.

MATERIALS & WASTE CASE STUDY #3

Case Study Background:

Contaminated soil is being consolidated on-site and covered with a RCRA Subtitle C cap. The total cap surface area is approximately 100,000 square feet. No waste is being transported off-site for disposal, so there is no waste footprint. The cap components are as follows:

- 24 inches of earthen material (200,000 ft^3 or 7,400 cy = 9,000 tons)
- 12 inches of sand (100,000 ft^3or 3,700 cy = 5,600 tons)
- 40-mil HDPE membrane (40 mils = 0.040 inches, total volume = 333 ft^3 =19,900 lbs)
- 24 inches of compacted clay (200,000 ft^3or 7,400 cy = 11,100 tons)
- 12 inches of native soil/sand as a foundation for the cap (100,000 ft^3or 3,700 cy = 5,600 tons)

The 12 inches of native soil/sand are used from an on-site borrow pit that will be converted to a required storm water retention basin. The 24-inch thick layer of earthen material will be a combination of on-site soil (75%) and mulch/compost (25%) generated from on-site vegetation. The 12-inches of sand for the drainage layer, the 24-inches of clay, and the HDPE are brought in from off-site. The design has been finalized, and little change is expected in these parameters.

Screening:

The largest contributor to refined materials is expected to be the HDPE liner. The largest contributor for unrefined materials is the clay. The native soil is considered a reused product because the excavated area will be converted to a storm water retention basin. The mulch/compost is also considered a reused or recycled material because it is generated from cleared vegetation that would otherwise need to be hauled off-site. No waste streams have been identified. The project team has chosen a %-based screening limit of 1% for refined and unrefined materials and magnitude based limits of 1,000 lbs for refined materials and 1 ton for unrefined materials and wastes. The limits are therefore as follows:

Category	Largest Contributor	Largest Contribution	Selected % of Largest Contributor	% - based Limit	Magnitude-based Limit	Applicable Limit
Refined materials	HDPE	19,900 lbs	1%	190 lbs	1,000 lbs	**1,000 lbs**
Unrefined materials	Clay	11,100 tons	1%	110 tons	1 ton	**1 ton**
Non-hazardous Waste		None expected				
Hazardous Waste		None expected				

The data quality for the remedy information is considered good. The design has been completed and construction is underway. No significant changes in materials usage are anticipated. Because the metrics are direct reporting of expected materials use and waste, there is little or no added uncertainty associated with converting remedy information and engineering estimates into the metrics as there would be for energy & air metrics.

Estimated Materials Footprint

Material and Use	Quantity	Conversion Factor	% Recycled or Reused Content	Quantity	
				Virgin	Recycled
Refined Materials (lbs)					
HDPE – 40 mil thickness (40 mil = 0.040 inches)	333 ft^3	59.6 lbs/ft	0%	19,900	0
Refined Materials Total (tons = lbs/2000):				**9.95**	**0**
% of Refined Materials that is Recycled or Reused Content				**0%**	
Unrefined Materials (tons)					
Clay	7,400	1.5 tons/cy	0%	11,100	0
Soil for 12-inch layer	3,700	1.5 tons/cy	100%	0	5,600
Soil for 75% of 24-inch layer	5,550	1.5 tons/cy	100%	0	8,300
Mulch/compost for 25% of 24-inch layer	1,850	0.4 tons/cy	100%	0	700
Sand	3,700	1.5 tons/cy	0%	5,600	
Unrefined Materials Total (tons):				**16,700**	**14,600**
% of Unrefined Materials that is Recycled or Reused Content				**47%**	

Values provided in the "Quantity" Column are obtained from engineering estimates during design.

Conversion factors in above tables obtained from Exhibit 3.3 through Exhibit 3.8.

Waste Footprint
NONE

Findings:

The materials metrics and waste metrics are the result of careful planning during design to use materials for multiple purposes (e.g., excavated areas for retention basins and cleared vegetation for mulch). No other materials and waste footprint reduction opportunities are expected to be identified for this remedy.

Case Studies:
Water

WATER CASE STUDY #1

WATER CASE STUDY #2

WATER CASE STUDY #3

WATER CASE STUDY #1

Case Study Background:

A P&T system at a site in the Eastern United States with non-aqueous phase liquid extracts 50 gpm from a shallow aquifer to contain a continuing source of groundwater contamination and prevent the contamination from discharging to a local creek. The aquifer from which water is extracted is considered a potential source of drinking water by the State, but given the water quality, treatment would be required prior to use. Treatment would include removal of dissolved iron and potentially other forms of treatment. There are no current local users of the aquifer. Public water supply in the area is provided either by surface water or by deeper, uncontaminated wells. Water treated by the P&T system is discharged to the creek that is protected by the remedy. The P&T system is expected to operate for more than 30 years.

An optimization evaluation team suggested constructing a slurry wall and impermeable cap around the contaminant source to reduce the required pumping rate to 10 gpm from 50 gpm. The slurry wall would be 3,000 feet long, with an average depth of 30 feet, and a minimum width of 3 feet. Construction of the slurry wall requires approximately 2 million gallons of extracted groundwater to prepare the slurry. Treated water would be discharged to the same creek. The storm water diverted by the cap (approximately 1 million gallons per year) eventually discharges to the creek.

Screening:

Given the extraction rates and remedy duration for the existing and optimized remedy configurations, extracted groundwater for treatment is expected to range between 157 million gallons and 800 million gallons. The amount of extracted groundwater required for slurry wall construction (2 million gallons) is considered negligible. No appreciable public water is used for the remedy.

Estimated On-Site Water Footprint:

See tables on following pages.

Findings:

The existing remedy configuration has the largest total water footprint, but the majority of the water usage is from the extraction and treatment of shallow groundwater that would otherwise discharge to a local creek. The extracted water is treated and discharged to the same creek such that local water resources are not significantly affected. The existing remedy and optimization configurations both have marginal effects on local water resources, but other green remediation metrics may be substantially affected. The diverted stormwater could be used to help construct wetlands to increase ecosystem services in the area.

WATER CASE STUDY #1 – Existing Remedy Configuration - On-Site Water Footprint Analysis

Water Resource	Description of Quality of Water Used	Volume Used (1000 gallons)	Uses	Fate of Used Water
Public water supply				
Extracted groundwater #1 Location: **within 100 feet of creek** Aquifer: **shallow**	Shallow groundwater that discharges to creek in relatively short distance. Groundwater classified as drinking water by State. Requires treatment prior to use. Other water resources available	790,000	Extracted for treatment	Discharged to creek
Surface water #1 Intake Location: **not applicable**				
Collected/diverted storm water				

WATER CASE STUDY #1 – Optimization Consideration (Slurry Wall) Water Footprint Analysis

Water Resource	Description of Quality of Water Used	Volume Used (1000 gallons)	Uses	Fate of Used Water
Public water supply				
Extracted groundwater #1 Location: **within 100 feet of creek** Aquifer: **shallow**	Shallow groundwater that discharges to creek in relatively short distance. Groundwater classified as drinking water by State. Requires treatment prior to use. Other water resources available	160,000	Extracted for treatment	Discharged to creek
Surface water #1 Intake Location: **not applicable**				
Collected/diverted storm water	Rain water quality	30,000	Prevented from recharging shallow groundwater near creek	Eventually discharged to nearby creek.

For the above tables, orange indicates areas of potential improvement in the water footprint. Yellow indicates no net affect on the water footprint. Green indicates examples of water best management practices.

WATER CASE STUDY #2

Case Study Background:

Note that this case study purposely includes similar features to Case Study #1 with the exception of the quality and local use of groundwater that is extracted and treated as part of the remedy. The footprint of the extracted groundwater differs significantly based on the quality of the water and its local use.

A P&T system in the Midwestern United States with non-aqueous phase liquid extracts 200 gpm from an aquifer used as a local potable water supply. Water treated by the P&T system is discharged to surface water. The P&T system is expected to operate for more than 30 years.

An optimization team has suggested two potential modifications to the existing remedy that are not mutually exclusive:

> **Slurry wall** – A slurry wall and impermeable cap could be constructed around the contaminant source to reduce the required pumping rate to 40 gpm from 200 gpm. The slurry wall would be 3,000 feet long, with an average depth of 30 feet, and a minimum width of 3 feet. Construction of the slurry wall will require approximately 2 million gallons of water to prepare the slurry. Water treated by the P&T system is discharged to surface water. The P&T system is expected to operate for more than 30 years. The storm water diverted by the cap (approximately 1 million gallons per year) is directed to a nearby infiltration basin.
>
> **Beneficial reuse** – The treated water can be used for irrigation during the growing season. Approximately 40% of the extracted water could therefore be used beneficially.

Screening:

Given the extraction rates and remedy duration for the existing and optimized remedy configurations, extracted groundwater for treatment is expected to range between 630 million gallons and over 3 billion gallons. The amount of extracted groundwater for slurry wall construction (2 million gallons) is considered negligible. No appreciable public water is used for the remedy.

Estimated On-Site Water Footprint:

See tables on following pages.

Findings:

The existing remedy configuration has the largest total on-site water footprint. The two optimization suggestions both improve the on-site water footprint, and the two suggestions implemented together improve the footprint further. The substantial volume of extracted water may also serve a beneficial purpose if it can be used for heat transfer in a geothermal heat pump application. Water that is not used for a beneficial purpose can be reinjected to maintain the water resource.

WATER CASE STUDY #2 – Existing Remedy Configuration – Water Footprint Analysis

Water Resource	Description of Quality of Water Used	Volume Used (1000 gallons)	Uses	Fate of Used Water
Extracted groundwater #1 Location: **on-site** Aquifer: **water supply aquifer**	Groundwater used for local potable water supply. Limited alternative potable water resources available	3,200,000	Extracted for treatment	Discharged to surface water (not reusable)
Collected/diverted storm water				

WATER CASE STUDY #2 – Optimization Suggestion (Slurry Wall) – Water Footprint Analysis

Water Resource	Description of Quality of Water Used	Volume Used (1000 gallons)	Uses	Fate of Used Water
Extracted groundwater #1 Location: **on-site** Aquifer: **water supply aquifer**	Groundwater used for local potable water supply. Limited alternative potable water resources available	630,000	Extracted for treatment	Discharged to surface water (not reusable)
Collected/diverted storm water	Rain water quality	30,000	Diverted from source area	Allowed to recharge aquifer in unimpacted area.

WATER CASE STUDY #2 – Optimization Suggestion (Beneficial Reuse) – Water Footprint Analysis

Water Resource	Description of Quality of Water Used	Volume Used (1000 gallons)	Uses	Fate of Used Water
Extracted groundwater #1 Location: **on-site** Aquifer: **water supply aquifer**	Groundwater used for local potable water supply. Limited alternative potable water resources available	1,920,000	Extracted for treatment	Discharged to surface water (not reusable)
Extracted groundwater #1 Location: **on-site** Aquifer: **water supply aquifer**	Groundwater used for local potable water supply. Limited alternative potable water resources available	1,280,000	Extracted for treatment	Used beneficially. No net loss of water resource due to groundwater extraction and treatment.
Collected/diverted storm water				

WATER CASE STUDY #2 – Optimization Suggestion (Slurry Wall & Beneficial Reuse) – Water Footprint Analysis

Water Resource	Description of Quality of Water Used	Volume Used (1000 gallons)	Uses	Fate of Used Water
Extracted groundwater #1 Location: **on-site** Aquifer: **water supply aquifer**	Groundwater used for local potable water supply. Limited alternative potable water resources available	378,000	Extracted for treatment	Discharged to surface water (not reusable)
Extracted groundwater #1 Location: **on-site** Aquifer: **water supply aquifer**	Groundwater used for local potable water supply. Limited alternative potable water resources available	252,000	Extracted for treatment	Used beneficially. No net loss of water resource due to groundwater extraction and treatment.
Collected/diverted storm water	Rain water quality	30,000	Diverted from source area	Allowed to recharge aquifer in unimpacted area.

For the above tables, orange indicates areas of potential improvement in the water footprint. Yellow indicates no net affect on the water footprint. Green indicates examples of water best management practices.

WATER CASE STUDY #3

Case Study Background:

This case study compares two similar remedies considered at two different sites to illustrate how location and local water resources affect the on-site water footprint.

Scenario #1 - A soil remedy for a site in the arid Western United States involves the excavation, land farming, and backfill of treated soil. Up to 40 acres is expected to be disturbed by heavy equipment. The underlying aquifer is a crucial local water resource for potable water and irrigation. No other viable sources of potable water are available in the area. Over 2 million gallons of extracted groundwater is anticipated to be used for dust control over the duration of the remedy. Over 4 million gallons of extracted groundwater is anticipated to be used to foster degradation of contaminants during landfarming over the duration of the remedy.

Scenario #2 - A soil remedy for a site in the Northern Central United States involves the excavation, land farming, and backfill of treated soil. Up to 40 acres is expected to be disturbed by heavy equipment. The underlying aquifer is not used for potable water or irrigation. Surface water resources are the predominant sources of water in the area. No water is anticipated to be needed for dust control over the duration of the remedy. Approximately 750,000 gallons of extracted groundwater and 250,000 gallons of collected storm water, which would otherwise discharge to surface water downgradient of the local reservoir, are anticipated to be used to foster degradation of contaminants during landfarming over the duration of the remedy.

Screening:

There are no other appreciable water resource uses other than those specified.

Estimated On-Site Water Footprint:

See tables on following pages.

Findings:

Water usage for a the same soil remedy is substantially higher in the arid Western United States than it is the Northern Central United States due to the need for dust control and the high evaporation potential in west. In addition, the water resource in the Western United States is of greater local value due to it use and the absence of other potential sources of water. Timing some of the work associated for Scenario #1 with or following precipitation events may help reduce the amount of water that needs to be extracted for dust control. However, this could adversely affect schedule. Groundwater use for Scenario #2 is lower for the same remedy as Scenario #1. In addition, groundwater is the not the primary water resource used in the area and storm water is an available resource.

WATER CASE STUDY #3 – Scenario #1 - Water Footprint Analysis

Water Resource	Description of Quality of Water Used	Volume Used (1000 gallons)	Uses	Fate of Used Water
Public water supply				
Extracted groundwater #1 Location: **on-site** Aquifer: **water supply aquifer**	Groundwater used for local potable water supply and irrigation. Limited alternative potable water resources available	2,000	Dust control	Evaporated to atmosphere
Extracted groundwater #1 Location: **on-site** Aquifer: **water supply aquifer**	Groundwater used for local potable water supply and irrigation. Limited alternative potable water resources available	4,000	Landfarming	Evaporated to atmosphere or microbial metabolism
Surface water #1 Intake Location: **not applicable**				
Collected/diverted storm water				

WATER CASE STUDY #3 – Scenario #2 - Water Footprint Analysis

Water Resource	Description of Quality of Water Used	Volume Used (1000 gallons)	Uses	Fate of Used Water
Public water supply				
Extracted groundwater #1 Location: **on-site** Aquifer: **water supply aquifer**	Groundwater not used for local potable water supply or irrigation.	750	Landfarming	Evaporated to atmosphere or microbial metabolism
Surface water #1 Intake Location: **not applicable**				
Collected/diverted storm water	Storm water that would otherwise discharge to local creek	250	Landfarming	Evaporated to atmosphere or microbial metabolism

For the above tables, orange indicates areas of potential improvement in the water footprint. Yellow indicates no net affect on the water footprint. Green indicates examples of water best management practices.

Case Studies:
Energy & Air

ENERGY & AIR CASE STUDY #1

ENERGY & AIR CASE STUDY #2

ENERGY & AIR CASE STUDY #1

Case Study Background:

Design of an in-situ bioremediation remedy for chlorinated volatile organic compounds is underway.

Remedy information is as follows:

- Restoration of 200-foot x 200-foot area of shallow aquifer (25 feet to 50 feet deep)
- Construction of 80 permanent 2-inch PVC wells, 50 feet deep with 20-foot screen intervals
- Drill cuttings left at well locations
- Injection of 500,000 pounds of emulsified vegetable oil (5% solution) over three injection rounds
- Extracted groundwater used for chemical blending and injection
- Quarterly sampling at 30 points for 5 years, semi-annual sampling at 30 points for additional 5 years, annual sampling at 30 points for 10 additional years
- All samples analyzed for VOCs only
- Purge water disposed to ground surface

Screening:

The step identifies the largest contributors to the energy and on-site air metrics and develops screening limits for use in identifying important potential contributors to the footprint and providing the rationale for excluding minor contributors.

On-Site NOx+SOx+PM Emission Screening

The only sources of on-site emissions are expected to be the drill rig operation and the low-flow sampling equipment. Both are expected to be above the screening limits.

On-Site HAP Emission Screening

No additional sources beyond those accounted for in the NOx+SOx+PM screening.

Total Energy Screening

The screening limit is based on the higher of a magnitude based limit of 100 screening units or a percentage-based limit equal to 1% of the largest contributor to the total energy footprint. Because no appreciable renewable energy is used, it is assumed that the total energy screening process reasonably screens items/activities for the total air emissions metrics. Based on professional judgment, the two most likely candidates for the largest total energy contributor are the 500,000 pounds of emulsified vegetable oil and the well installation. Based on Exhibit 3.2, the 500,000 pounds of emulsified vegetable oil equates to 500,000 screening units (500,000 × 1), and the well installation equates to 200,000 screening units (4,000 × 50). The emulsified vegetable oil is the largest contributor. Therefore, the percentage based screening unit is 5,000 (500,000 × 1%). Items or activities associated with the remedy that would equate to less than 5,000 screening units will be omitted.

The following table presents the primary items/activities associated with the remedy and preliminary engineering estimates regarding the quantities of those items/activities. Screening unit conversions from Exhibit 3.2 are applied to calculate the number of screening units, and a decision to include or exclude each item/activity is stated. Items exceeding the screening limit of 5,000 will be quantified more accurately during footprint calculation. Some items that are available from the materials or waste footprint or for the on-site emissions footprint are included even if the values are below the screening limit because the information is already available.

Item	Quantity	Screening Units	Limit = 5,000 Decision
Vegetable oil	500,000 lbs	500,000	Include
Drill rig operation	Used for on-site NOx+SOx+PM footprint		Include
PVC & Grout & Steel for wells	Available from materials footprint		Include
Sand for wells	Available from materials footprint		Include
Concrete for wells	Available from materials footprint		Include
Drill rig transport	<1,000 miles	<2,000	Exclude
Oversight transport	<1,000 miles	<500	Exclude
Well materials transport	<10,000 ton-miles	<3,300	Exclude
Veg. oil transport	>100,000 ton-miles	>33,000	Include
Lab analysis	>$100,000	>100,000	Include
Electricity	>5,000 kWh	>5,000	Include
Injection team travel	>10,000 miles	>5,000	Include
Sampling travel	~10,000 miles	~5,000	Include
Sampling equip.	Used for on-site NOx+SOx+PM footprint		Include
Sampling materials	<5,000 lbs	<5,000	Exclude

Footprint Calculation:

Part 1: Inventory Remedy Travel, Equipment Use, Materials, and Off-site Services

The following are construction materials are available from the materials footprint (not shown)

- 2,700 pounds of PVC (Exhibit 3.6)
- 30,400 lbs of sand/gravel (Exhibit 3.6)
- 31,200 lbs of cement for grout (Exhibit 3.6)
- Bentonite negligible relative to other materials
- 2,000 lbs of steel for well covers (estimated)
- 12 tons of concrete for surface finish (estimated)

Based on Exhibit 3.10B, drilling of 4,000 vertical feet might involve 40 days with a 150 HP rig operating a 75% load.

The following are items associated with operation that passed the screening process:

- 500,000 pounds (250 tons) of emulsified vegetable oil injected over three events, shipped from approximately 1,000 miles away, empty return trip not required
- 10,000,000 gallons of water extracted, blended, and reinjected
- Average injection rate (multiple wells simultaneously) is 100 gpm
- Consultants and contractors visit site 200 times over three years

  - Travel in three light-duty trucks
  - Roundtrip daily commute is 40 miles
  - Total is 3 x 40 x 200 = 24,000 miles
- Mixers and pumps powered by on-site electricity for 1,800 hours total
  - Four 0.75 HP extraction pumps
  - Two 0.5 HP mixers
  - Two 1 HP transfer pumps
- Local fuel blend for electricity generation is as follows:
  - 40% natural gas
  - 15 % coal
  - 20% hydro (15% large hydro and 5% small, eligible hydro)
  - 20% nuclear
  - 2% biomass
  - 3% wind

The following are items associated with monitoring that passed the screening process:
- 1,200 samples collected and analyzed for VOCs at $100/sample is $120,000
- Sampling requires a total of 2,500 hours of two 2.5 HP gasoline compressors (12,500 HP-hrs)

Part 2: Energy Inventory

This step converts the above transportation and equipment use into fuel use and converts electrical equipment use into electricity use. For case study expediency, energy inventory for three tasks are combined. A formal analysis might split the inventory into three tasks: construction, O&M, and long-term monitoring.

Fuel Use for Personnel Transportation

Personnel or Equipment	Trips	Roundtrip Distance (miles)	Total Distance (miles)	Vehicle Type	Fuel Efficiency	Fuel Use (gallons)
Gasoline						
Injection contractor #1	200	40	8,000	Truck	17 mpg	470
Injection contractor #2	200	40	8,000	Truck	17 mpg	470
Injection consultant	200	40	8,000	Truck	17 mpg	470
					Total Gasoline	1,410

**Driller and drill rig transport, drilling oversight, and sampling tech transportation to site excluded based on screening.*

Fuel Use for Equipment Use

Equipment Type	HP	Hours	BFSC	PLF	Fuel Use (gallons)
Diesel					
Drill rig	150	320	0.052	0.75	1,900
Gasoline					
Sampling compressors	2 x 2.5	2,500	0.057	0.75	530

Fuel Use for Equipment, Materials, and Waste Transport

Equipment	Tons	Travel Distance (miles)	Vehicle Type	Fuel Efficiency	Fuel Use (gallons)
Diesel (transport)					
Drill rig	Excluded				
Well PVC & Steel					
Sand, cement, concrete					
Sand, cement, concrete					
Vegetable Oil	250	1,000	Truck	0.029 gptm	7,250
				Total	7,250

gptm = gallons per ton-mile

On-Site Electricity Use

Equipment	HP	% Full Load	Motor Efficiency	kW	Hours	kWh
Two 0.5 HP mixers	1	80%	65%	0.92	1,800	1,660
Four 0.75 HP extraction pumps	3	80%	65%	2.75	1,800	4,950
Two 1 HP transfer pumps	2	80%	75%	1.6	1,800	2,880
					Total	**~9,500**

1 HP = 0.746 kW, See Exhibit 3.12 for calculations and assumptions.

Part 3: Convert to Energy & Air Metrics

See accompanying tables

Findings:

The largest contributor to the energy & air metrics is the production of the emulsified vegetable oil, but the following items/activities are also significant contributors that merit focus when attempting to reduce the energy & air metrics:

- Transportation of the emulsified vegetable oil
- Laboratory analysis
- Drill rig operation
- Generators for low-flow sampling

The conversion factor to estimate energy use and emission from laboratory analysis is generic and derived without specific consideration of what occurs within a laboratory. This additional uncertainty in the laboratory footprint should be considered when interpreting the footprint results. The materials for well installation were generally insignificant with respect to the calculated energy & air metrics.

ENERGY & AIR CASE STUDY #1 - DETERMINING FOOTPRINT CONVERSION FACTORS FOR GRID ELECTRICITY BASED ON UTILITY OR LOCATION

Power Content from Electric Service Provider

Energy Source	Percentage of Power Mix Delivered to Customers
Coal	15%
Natural gas	40%
Oil	0%
Nuclear	20%
Large hydroelectric	15%
Eligible hydroelectric*	5%
Biomass	2%
Geothermal	0%
Wind	3%
Solar	<1%

** Meets the definition of "green power" by the EPA Green Power Partnership*

Converting Resource Mix to Footprint Conversion Factors and Portion of Energy Derived from Renewable Resources

Type	% of Total Used	Energy (MMbtu/MWh)		CO_2e (lbs/MWh)		NOx (lbs/MWh)		SOx (lbs/MWh)		PM (lbs/MWh)		HAPs (lbs/MWh)	
		Full Load	Adj. by %	Full Load	Adj. by %	Full Load	Adj. by %	Full Load	Adj. by %	Full Load	Adj. by %	Full Load	Adj. by %
<u>Conventional Energy</u>													
Coal	15%	6.9	1.035	2200	330	6	0.9	15	2.3	0.092	0.014	0.66	0.099
Natural Gas	40%	6.9	2.76	1300	520	1.1	0.44	0.0066	0.0026	0.08	0.032	0.025	0.01
Oil	0%	6.9	0	1800	0	2.2	0	2.8	0	0.13	0	0.066	0
Nuclear	20%	6.9	1.02	0	0	0	0	0	0	0	0	0	0
Subtotal Conventional	**75%**		**5.175**										
<u>Renewable Energy</u>													
Biomass	2%	6.9		0	0	1.4	0.028	0.65	0.013	0.084	0.0017	5.3E-6	1.1E-7
Geothermal	0%	6.9		0	0	0	0	0	0	0	0	0	0
Hydro	20%	6.9		0	0	0	0	0	0	0	0	0	0
Solar	0%	6.9		0	0	0	0	0	0	0	0	0	0
Wind	3%	6.9		0	0	0	0	0	0	0	0	0	0
Subtotal Renewable	**25%**		**1.725**										
Total	**100%**		**6.9**		**850**		**1.4**		**2.4**		**0.048**		**0.1**

Full load emission values for each fuel type obtained from www.nrel.gov/lci.
All values do not include energy and emissions for resource extraction or for transmission losses, which are accounted for in off-site (Scope 3).
Energy conversion factors exclude the energy contained in the MWh of electricity used by the remedy to avoid double counting of on-site energy use.
For simplicity, energy conversion factors are assumed to be 6.9 MMBtu per MWh (equivalent to 33% efficiency) for all energy sources.

ENERGY & AIR CASE STUDY #1 - CALCULATING AND PRESENTING ON-SITE ENERGY & AIR METRICS

Contributors to Footprints	Units	Usage	Energy		Greenhouse Gas		NOx		SOx		PM		HAPs	
			Conv. Factor	**MMBtus**	**Conv. Factor**	**lbs CO_2e**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**
On-Site Renewable Energy														
Elec. generated on-site by renewable resources	MWh	0	3.413	0										
Grid electricity from renewable resources	MWh	2.4	3.413	8.2										
Grid electricity offset by purchased renewable electricity	MWh	0		0		0		0		0		0		0
Landfill gas combusted on-site	ccf CH_4	0		0		0		0		0		0		0
Biodiesel used on-site	Gal	0	0.127	0	22.3	0	0.20	0	0	0	0.00099	0	NP	
Other forms of on-site renewable energy use	TBD	0		0		0		0		0		0		0
On-Site Renewable Energy Subtotals				**8.2**		**0**		**0**		**0**		**0**		**0**
On-Site Conventional Energy														
Grid electricity from conventional resources	MWh	7.1	3.413	24.2										
Grid electricity offset by purchased renewable energy	MWh	0	(3.413)	0										
On-site diesel use	Gal	1,900	0.139	264.1	22.5	42,750	0.17	323	0.0054	10.26	0.0034	6.46	0.0003	0.57
On-site gasoline use	Gal	530	0.124	65.72	19.6	10,388	0.11	58.3	0.0045	2.385	0.00054	0.2862	0.0003	0.159
On-site natural gas use	ccf	0	0.100	0	12.2	0	0.01	0	0.0000063	0	0.00076	0	0.0000084	0
Other forms of on-site conventional energy use	TBD	0		0		0		0		0		0		0
On-Site Conventional Energy Subtotals				**354.02**		**53,138**		**381.3**		**12.645**		**6.7462**		**0.729**
Other On-Site Contributions														
On-site HAP process emissions	Lbs	0												0
On-site GHG emissions	Lbs	0				0								
On-site carbon storage	Lbs	0			(1)	0								
GHG offset by combusting landfill methane	Lbs	0			(20)	0								
Other contributions		0		0		0		0		0		0		0
Other On-Site Subtotals						**0**		**0**		**0**		1		**0**
				1										
On-Site Totals				**362.22**		**53,138**		**381.3**		**12.645**		**6.7462**		**0.729**

TBD = to be determined *Values in parentheses are negative values.* *Energy for electricity is only that energy of that electricity and not the energy required to generate the electricity.*

ccf CH_4 = 100 cubic feet of methane. Obtained by multiplying total volume of landfill gas in 100 ccf by the percentage of the gas that is methane.

If fuel is a blend of conventional fuel and renewable resource fuel, enter the amount of fuel from conventional sources into appropriate conventional fuel categories and enter amount of fuel from renewable resources into appropriate renewable fuel categories (e.g., for 100 gallons of B20 biodiesel blend, 20 gallons would be entered under biodiesel and 80 gallons would be entered under diesel).

1. Enter usages into blue cells in "Usage" column in indicated units.
2. Convert usages into indicated units of each parameter by multiplying usage by the indicated conversion factors. Enter result into blue cells in parameter columns.
3. Sum On-Site Renewable Energy results for each parameter and enter in green "On-Site Renewable Energy Subtotals" cells.
4. Sum On-Site Conventional Energy results for each parameter and enter in green "On-Site Conventional Energy Subtotals" cells. Be sure to subtract the energy from electricity offset by purchased renewable energy (e.g., renewable energy certificates).
5. Sum Other On-Site Contributions results for each parameter and enter in green "Other On-Site Subtotals" cells.
6. Sum green cells for each parameter and enter result in green "On-Site Totals" cells.

ENERGY & AIR CASE STUDY #1 –CALCULATING AND PRESENTING ELECTRICITY GENERATION ENERGY & AIR METRICS

			Energy		Greenhouse Gas		NOx		SOx		PM		HAPs	
Contributors to Footprints	**Units**	**Usage**	**Conv. Factor**	**MMBtus**	**Conv. Factor**	**lbs CO_2e**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**
Grid Electricity from Renewable Resources	MWh	2.4	6.9	16.6										
Grid Electricity from Conventional Resources	MWh	7.1	6.9	49										
Total Grid Electricity	MWh	9.5		65.6	850	8,075	1.4	13.3	2.4	22.8	0.048	0.456	0.1	0.99
Offsets from Purchased Renewable Energy	MWh	0	6.9	0		0		0		0		0		0
Net Energy from Conventional Resources				**49**										
Total Energy from Renewable Resources				**16.6**										
Electricity Generation Net Emissions						**8,075**		**13.3**		**22.8**		**0.456**		**0.99**

Grid electricity from Renewable Resources includes renewable energy purchased from green pricing programs from the electric service provider.

See Exhibit 3.16 for how to determine the percentage of grid electricity that is from renewable resources and then multiply this percentage by the total grid electricity usage to obtain the grid electricity from renewable resources.
See Exhibit 3.16 for how to determine the percentage of grid electricity from conventional resources and then multiply this percentage by the total grid electricity usage to obtain the grid electricity from conventional resources.
Use the information from the "product content label" from the Renewable Energy Certificate vendor to determine the emission conversion factors for greenhouse gas, NOx, SOx, and PM, if available.
If the "product content label" for renewable energy certificates does not provide conversion factors for all parameters use the renewable energy portion of the table in Exhibit 3.16 to determine those conversion factors.

Total Energy from Renewable Resources = Energy Associated with Grid Electricity from Renewable Resources + Energy Associated with Purchased Renewable Energy Certificates

Net Energy from Conventional Resources = Energy Associated with Grid Electricity from Conventional Resources – Energy Associated with Purchased Renewable Energy Certificates

Electricity Generation Net Emissions = Emissions Associated with Total Grid Electricity – Emissions Associated with Purchased Renewable Energy Certificates

ENERGY & AIR CASE STUDY #1 –CALCULATING AND PRESENTING TRANSPORTATION ENERGY & AIR METRICS

			Energy		Greenhouse Gas		NOx		SOx		PM		HAPs	
Category	**Units**	**Usage**	**Conv. Factor**	**MMBtus**	**Conv. Factor**	**lbs CO_2**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**
Conventional Energy														
Diesel use	gal	7,250	0.139	1008	22.5	163125	0.17	1233	0.0054	39	0.0034	25	5E-06	0.038
Gasoline use	gal	1,410	0.124	175	19.6	27636	0.11	155	0.0045	6	0.00054	1	3.9E-05	0.055
Natural gas use	ccf		0.103	0	13.1	0	0.01	0	0.0000063	0	0.00076	0	8.4E-06	0.000
Subtotal				**1,183**		**190,761**		**1,388**		**45**		**25**		**0.093**
Renewable Energy														
Biodiesel use	gal	0	0.127	0	22.3	0	0.20	0	0	0	0.00099	0	NP	
Transportation Totals				**1,183**		**190,761**		**1,388**		**45**		**25**		**0**

3. *Enter usages of each material or service into "Usage" column in indicated units.*
4. *Convert usages into indicated units of each parameter by multiplying usage by the indicated conversion factor. Enter result into blue cells in parameter columns.*

ENERGY & AIR CASE STUDY #1 – CALCULATING AND PRESENTING OFF-SITE ENERGY & AIR METRICS

			Energy		Greenhouse Gas		NOx		SOx		PM		HAPs	
Category	**Units**	**Usage**	**Conv. Factor**	**MMBtus**	**Conv. Factor**	**lbs CO_2**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**
Construction Materials														
Cement	dry-lbs	31,200	0.0021	65.52	0.9	28080	0.0018	56.16	0.00105	32.76	0.0000032	0.09828	2.9E-05	0.9048
Concrete	Lbs	24,000	0.00034	8.16	0.14	3360	0.00029	6.96	0.00017	4.08	0.0000022	0.0528	4.40E-06	0.1056
Gravel/sand/clay	Lbs	30,400	0.000028	0.8512	0.0034	101.84	0.000017	0.5016	0.000015	0.456	0.0000020	0.0608	2.1E-10	6.232E-06
HDPE	Lbs	0	0.031	0	1.9	0	0.0032	0	0.0041	0	0.00064	0	3.4E-06	0
Photovoltaic system (installed)	W	0	0.034	0	4.5	0	0.015	0	0.032	0	0.00063	0	2.9E-06	0
PVC	Lbs	2,700	0.022	59.4	2.6	7020	0.0048	12.96	0.0076	20.52	0.0012	3.24	4.7E-04	1.269
Stainless Steel	Lbs	0	0.012	0	3.4	0	0.0075	0	0.012	0	0.0044	0	1.4E-04	0
Steel	Lbs	2,000	0.0044	8.8	1.1	2200	0.0014	2.8	0.0017	3.4	0.00056	1.12	6.7E-05	0.134
Other refined construction materials	Lbs	0	0.014	0	1.98	0	0.0037	0	0.0053	0	0.0014	0	1.4E-04	0
Other unrefined construction materials	Lbs	0	0.000028	0	0.00335	0	0.000017	0	0.000015	0	0.000002	0	2.1E-10	0
Treatment Materials & Chemicals														
Cheese Whey	Lbs	0	0.0025	0	0.031	0	0.000062	0	0.000033	0	0.000002	0	NP	
Emulsified vegetable oil	Lbs	500,000	0.0077	3850	3.44	1720000	0.0066	3300	0.0019	950	0.000033	16.5	NP	
Molasses	Lbs	0	0.0044	0	0.48	0	0.0011	0	0.00024	0	0.0000041	0	NP	
Treatment materials & chemicals*	Lbs	0	0.015	0	1.7	0	0.003	0	0.0065	0	0.00061	0	1.6E-05	0
Virgin GAC (coal based)	Lbs	0	0.015	0	5.8	0	0.014	0	0.034	0	0.00078	0	1.2E-03	0
Fuel Processing														
Biodiesel Produced	Gal	0	0.029	0	-16.8	0	0.018	0	0.033	0	0.00082	0	NP	
Diesel Produced	Gal	9,150	0.019	169.275	2.7	24705	0.0064	58.56	0.013	118.95	0.00034	3.111	1.2E-04	1.098
Gasoline Produced	Gal	1,940	0.021	40.74	4.4	8536	0.008	15.52	0.019	36.86	0.00052	1.0088	1.6E-04	0.3104
Natural Gas Produced	Ccf	0	0.0052	0	2.2	0	0.0037	0	0.0046	0	0.000072	0	6.1E-06	0
Public water	gal x 1000	10,000	0.0092	92	5	50000	0.0097	97	0.0059	59	0.016	160	1.50E-05	0.15
Off-Site Services														
Off-site waste water treatment	gal x 1000	0	0.015	0	4.4	0	0.016	0	0.015	0	NP		NP	
Off-site Solid Waste Disposal	Ton	0	0.16	0	25	0	0.14	0	0.075	0	0.4	0	1.40E-03	0
Off-site Haz. Waste Disposal	Ton	0	0.176	0	27.5	0	0.154	0	0.0825	0	0.44	0	1.54E-03	0
Off-site Laboratory Analysis	$	120,000	0.0065	780	1	120000	0.0048	576	0.0036	432	0.0004	48	1.30E-04	15.6

ENERGY & AIR CASE STUDY #1 – CALCULATING AND PRESENTING OFF-SITE ENERGY AND AIR METRICS (continued)

			Energy		Greenhouse Gas		NOx		SOx		PM		HAPs	
Category	**Units**	**Usage**	**Conv. Factor**	**MMBtus**	**Conv. Factor**	**lbs CO_2**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**
Resource Extraction for Electricity														
Coal extraction and processing	MWh	1.425	3.1	4.35	180	256.5	0.77	1.09725	0.15	0.21375	0.018	0.02565	NP	
Natural gas extraction and processing	MWh	3.8	1.6	6.20	270	1026	0.18	0.684	13	49.4	0.0071	0.02698	NP	
Nuclear fuel extraction and processing	MWh	1.9	0.16	0.30	25	47.5	0.15	0.285	0.5	0.95	0.0015	0.00285	NP	
Oil extraction and processing	MWh	0	2.3	0	270	0	1.7	0	0.069	0	0.042	0	NP	
Grid renewable energy	MWh	2.375	0	0	0	0	0	0	0	0	0	0	0	0
Offset by purchased renewable energy	MWh	0	0	0	0	0	0	0	0	0	0	0	0	0.00
Net Emissions for Resource Extraction						**0**		**0**		**0**		**0**		**0**
Net Conventional Energy				**10.85**										
Net Renewable Energy				**0**										
Electricity Transmission	MWh													
Conventional energy	MWh	0.71	10.03	7.1464	638	454	1.1	0.75	1.8	1.3	0.036	0.026	0.075	0.053
Renewable energy	MWh	0.24	10.03	2.3821										
Total Off-Site Conventional				**5,093**		**1,965,787**		**4,129**		**1,710**		**233**		**20**
Total Off-Site Renewable				**2.3821**										

5. *Enter usages of each material or service into "Usage" column in indicated units.*
6. *Convert usages into indicated units of each parameter by multiplying usage by the indicated conversion factor. Enter result into blue cells in parameter columns.*
7. *Fuel processing refers to all fuel used, including that for on-site equipment use and transportation.*
8. *Electricity from various resources is obtained from generation mix that is used in Exhibit 3.16 and the resource extraction conversion factors from Exhibit 3.13.*
9. *For electricity transmission, enter 10% of the grid electricity used for calculating energy and emission from electricity generation. The conversion factors are the same as those used for electricity generation. The energy conversion factor also includes the 3.413 MMbtus embodied in the actual electricity that is used.*
10. *Resource extraction conversion factors are calculated using values in Exhibit 3.13 and the specified fuel blend for electricity generation.*
11. *RECs, if purchased, are assumed to 1) offset emissions associated with transmission losses and resource extraction, 2) eliminate the energy associated with resource extraction, and 3) convert the energy associated with transmission losses to renewable energy.*

ENERGY & AIR CASE STUDY #1 – SUMMARY OF METRICS

Category	Energy from Renewable Resources	Energy from Conventional Resources	Total Energy	Greenhouse Gas	NOx	SOx	PM	NOx+SOx+PM	HAPs
	MMbtus	MMbtus	MMbtus	lbs CO_2e	lbs	lbs	lbs	lbs	lbs
On-site (Scope 1)	8.2	354	362	53,138	381	12.7	6.8	400.5	0.73
Electricity Generation (Scope 2)	20	49	69	8,075	13.3	22.8	0.46	36.56	0.99
Transportation (Scope 3)	0	1,183	1,183	190,761	1,388	45	25	1,459	0.093
Other Off-Site (Scope 3)	2.38	5,093	5,095	1,965,787	4,129	1,710	233	6,072	20
Off-site (Scope 2 + Scope 3)	22	6324	6,347	2,217,761	5,911	1,791	266	7,968	21
Remedy Totals	31	6,678	6,709	2,270,899	6,292	1,804	273	8,368	21
% of Total Energy from Renewable Resources	0.46%								

Values in green cells represent the summation of values presented in other cells in this table.
Summary level metrics are provided in outlined cells. All other cells and values are provided for transparency and analysis purposes only.

ENERGY & AIR CASE STUDY #2

Case Study Background:

This case study involves quantifying the energy & air metrics over a 30-year period for an operating P&T system:

- O&M of P&T system that is containing VOC and SVOC plume
- VOC influent is 1,000 µg/L, SVOC influent is 600 µg/L
- Combined extraction rate of 200 gpm from three extraction wells
- 50 feet to water table
- Treatment with air stripping, GAC treatment of air stripper off-gas, and GAC treatment of air stripper effluent
- Treated water is reinjected
- Semi-annual sampling at 50 points for 30 years
- All samples analyzed for VOCs and SVOCs
- Estimated remedy duration of 30 years

Screening:

The step identifies the largest contributors to the energy and on-site air metrics and develops screening limits for use in identifying important potential contributors to the footprint and providing the rationale for excluding minor contributors.

On-Site NOx+SOx+PM Emission Screening

The only source of on-site emissions is expected to be the low-flow sampling equipment.

On-Site HAP Emission Screening

No additional sources beyond those accounted for in the NOx+SOx+PM screening.

Total Energy Screening

The screening limit is based on the higher of a magnitude based limit of 100 screening units or a percentage-based limit equal to 1% of the largest contributor to the total energy footprint. Because no appreciable renewable energy is used, it is assumed that the total energy screening process reasonably screens items/activities for the total air emissions metrics. Based on professional judgment, the largest total energy contributor is the electricity (204,000 kWh per year for 30 years, which translates to 6,120,000 kWh). According to Exhibit 3.2, this translates to 6,120,000 screening units. Therefore, the percentage based screening unit is 61,200 (6,120,000 × 1%). Items or activities associated with the remedy that would equate to less than 61,200 screening units will be omitted.

The following table presents the primary items/activities associated with the remedy and preliminary engineering estimates regarding the quantities of those items/activities. Screening unit conversions from Exhibit 3.2 are applied to calculate the number of screening units, and a decision to include or exclude each item/activity is stated. Items exceeding the screening limit of 61,200 will be quantified more accurately during footprint calculation. Some items that are available from the materials or waste footprint or for the on-site emissions footprint are included even if the values are below the screening limit because the information is already available.

Item	Quantity	Screening Units	Limit = 61,200 Decision
Electricity	6,120,000 kWh	6,120,000	Include
Laboratory analysis (GW monitoring)	>$100,000	>100,000	Include
Laboratory analysis (process)	>$100,000	>100,000	Include
GAC	>100,000 lbs	>100,000	Include
GAC transport	>100,000 ton-miles	>33,000	Include
Operator & sampling tech transport	>100,000 miles	>50,000	Include
Sampling equip.	Used for on-site NOx+SOx+PM footprint		Include
Sampling materials	<1,000 lbs	<1,000	Exclude

The engineering estimates for GAC transport and personnel transport were not sufficiently detailed to confirm they would be below the screening limit. Therefore, they are included in the footprint calculation step, and will be included in the footprint analysis.

Footprint Calculation:

Part 1: Inventory Remedy Travel, Equipment Use, Materials, and Off-site Services

The following are items associated with remedy operation that passed the screening process:

- 7,000 pounds of GAC per year for 30 years (210,000 pounds or 105 tons)
  - 1,000 miles round-trip distance from regeneration facility to local warehouse
  - 100 miles round-trip distance from warehouse to site, two trips per year (60 trips total)

- Estimated 2000 operator/technician/oversight visits over next 30 years
  - Travel in light-duty trucks
  - Roundtrip daily commute is 40 miles

- Pumps and blowers powered by on-site electricity for 250,000 hours over next 30 years
  - Typical electrical bill is 204,000 kWh per year
    - Three 3 HP extraction pumps with VFDs
    - One 3 HP transfer pump with VFD
    - One 3 HP effluent pump with VFD
    - One 10 HP blower with VFD

- Site located in Colorado, generation mix not available from utility, use eGRID Subregion RMPA fuel blend for electricity generation is as follows:
  - 71.7% coal
  - 19.5 % natural gas
  - 7.4% hydro
  - 1.4% wind

- Renewable Energy Certificates each year to offset all electricity usage that is not from renewable resources
  - RECs purchased from wind facility located in RMPA Subregion

- Process sampling, 3 samples for VOCs ($100 /sample) and SVOCs ($200/sample) each month for 30 years

The following are items associated with long-term monitoring that passed the screening process:

- 500 trips to site by sampling team in one light-duty truck (100 miles round trip)
- 3,000 samples collected and analyzed for VOCs at $100 per sample and SVOCs at $200 per sample (includes cost of QA samples)
- Sampling requires a total of 6,000 hours of 2.5 HP gasoline compressors
- Purge water disposed of in treatment plant

Part 2: Energy Inventory

This step converts the above transportation and equipment use into fuel use and converts electrical equipment use into electricity use. For case study expediency, energy inventory for three tasks are combined. A formal analysis might split the inventory into three tasks: construction, O&M, and long-term monitoring.

Fuel Use for Personnel Transportation

Personnel	Trips	Roundtrip Distance (miles)	Total Distance (miles)	Vehicle Type	Fuel Efficiency	Fuel Use
Diesel						
None						
Gasoline						
Operator	2000	40	80,000	Truck	17 mpg	4,706
Sampling techs	500	100	50,000	Truck	17 mpg	2,941
					Total Gasoline	7,647

Fuel Use for Equipment Use

Equipment Type	Hours	Fuel Consumption Rate (gals/hr)	Fuel Use (gals)
Diesel			
None			
Gasoline			
Sampling compressors	6000	0.14	840

Fuel Use for Materials, Equipment, and Waste Transport

Equipment	Tons	Travel Distance (miles)	Vehicle Type	Fuel Efficiency	Fuel Use
Diesel					
GAC facility to warehouse	105	1,000	Truck	0.029 gptm	3,045
GAC warehouse to site	105	60 x 100	Truck	6 mpg	1,000
				Total	4,045

gptm = gallons per ton-mile

On-Site Electricity Use

Equipment	HP	% Full Load	Motor Efficiency	kW	Hours	kWh
Extraction pumps	9	80%	75%	9.6	250,000	2,160
Two process pumps	6	80%	75%	6.4	250,000	5,760
One air stripper blower	10	80%	75%	10.7	250,000	3,780
				Calculated Total		**6,675,000**
			Total from Electric Bills			**6,120,000**

Calculated and actual values are close. Use actual value from electric bills and use calculated values to help understand breakdown of electricity use.

Part 3: Convert to Energy & Air Metrics

See accompanying tables

Findings:

The purchase of RECs substantially affects the metrics for 1) percentage of total energy from renewable energy and 2) various air pollutant emissions. As a result of purchasing the RECs, 90% of the remedy energy is from renewable resources compared to under 9% if RECs had not been purchased. In addition, because of the REC purchase, the laboratory analysis, GAC manufacturing, and various aspects of transportation are the largest contributors to greenhouse gases instead of electricity generation. Additional footprint reduction would likely consider optimization of GAC usage, operator transportation, and GAC transportation.

Power Content from eGRID RPMA Subregion

Energy Source	Percentage of Power Mix Delivered to Customers
Coal	71.7%
Natural gas	19.5%
Oil	0%
Nuclear	0%
Hydro	7.4%
Biomass	0%
Geothermal	0%
Wind	1.4%
Solar	0%

For offsets associated with RECs:

Direct Non-Baseload Emissions from eGRID
CO2 = 2187.41 lbs/MWh
CH4 = 26.69 lbs/GWh
N2O = 33.47 lbs/GWh
NOx = 3.6573 lbs/MWh
SOx = 3.8099 lbs/MWh

$CO_2e = 2187.41+26.69/1000\times21+33.47/1000\times310$

$=2198.35$ *lbs/MWh*

Converting Utility Resource Mix to Footprint Conversion Factors and Portion of Energy Derived from Renewable Resources

Type	% of Total Used	Energy (MMbtu/MWh)		CO_2e (lbs/MWh)		NOx (lbs/MWh)		SOx (lbs/MWh)		PM (lbs/MWh)		HAPs (lbs/MWh)	
		Full Load	**Adj. by %**	**Full Load**	**Adj. by %**	**Full Load**	**Adj. by %**	**Full Load**	**Adj. by %**	**Full Load**	**Adj. by %**	**Full Load**	**Adj. by %**
Conventional Energy													
Coal	71.7%	6.9	4.947	2200	1577	6	4.3	15	10.8	0.092	0.06596	0.66	0.47322
Natural Gas	19.5%	6.9	1.346	1300	254	1.1	0.21	0.0066	0.014	0.08	0.0156	0.025	0.00488
Oil	0%	6.9	0	1800		2.2		2.8		0.13	0	0.066	0
Nuclear	0%	6.9	0	0							0	0	0
Subtotal Conventional	**91.2%**												
Renewable Energy					0		0		0				
Biomass	0%	6.9	0	0	0	1.4	0	0.65	0	0.084	0	5.3E-6	0
Geothermal	0%	6.9	0	0	0	0	0	0	0	0	0	0	0
Hydro	7.4%	6.9	0.511	0	0	0	0	0	0	0	0	0	0
Solar	0%	6.9	0	0	0	0	0	0	0	0	0	0	0
Wind	1.4%	6.9	0.0966	0	0	0	0	0	0	0	0	0	0
Subtotal Renewable	**8.8%**												
Total	**100%**		**6.9**		**1831**		**4.5**		**10.8**		**0.081**		**0.47**

Full load emission values for each fuel type obtained from www.nrel.gov/lci.
All values do not include energy and emissions for resource extraction or for transmission losses, which are accounted for in Scope 3.
Energy conversion factors exclude the energy contained in the MWh of electricity used by the remedy to avoid double counting of Scope 1 energy use.
For simplicity, energy conversion factors are assumed to be 6.9 MMBtu per MWh (equivalent to 33% efficiency) for all energy sources.

ENERGY & AIR CASE STUDY #2 - CALCULATING AND PRESENTING ON-SITE ENERGY & AIR METRICS

			Energy		Greenhouse Gas		NOx		SOx		PM		HAPs	
Contributors to Footprints	**Units**	**Usage**	**Conv. Factor**	**MMBtus**	**Conv. Factor**	**lbs CO_2e**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**
On-Site Renewable Energy														
Elec. generated on-site by renewable resources	MWh	0	3.413	0										
Grid electricity from renewable resources	MWh	539	3.413	1839.607										
Grid electricity offset by purchased renewable electricity	MWh	0		0		0		0		0		0		0
Landfill gas combusted on-site	ccf CH_4	0		0		0		0		0		0		0
Biodiesel used on-site	Gal	0	0.127	0	22.3	0	0.20	0	0	0	0.00099	0	NP	
Other forms of on-site renewable energy use	TBD	0		0		0		0		0		0		0
On-Site Renewable Energy Subtotals				**1,840**		**0**		**0**		**0**		**0**		**0**
On-Site Conventional Energy														
Grid electricity from conventional resources	MWh	5581	3.413	19049										
Grid electricity offset by purchased renewable energy	MWh	5581	-3.413	-19049										
On-site diesel use	Gal	0	0.139	0	22.5	0	0.17	0	0.0054	0	0.0034	0	0.0003	0
On-site gasoline use	Gal	840	0.124	104.16	19.6	16464	0.11	92.4	0.0045	3.78	0.00054	0.4536	0.0003	0.252
On-site natural gas use	ccf	0	0.1	0	12.2	0	0.01	0	0.0000063	0	0.00076	0	0.0000084	0
Other forms of on-site conventional energy use	TBD	0		0		0		0		0		0		0
On-Site Conventional Energy Subtotals				**104.16**		**16464**		**92.4**		**3.78**		**0.4536**		**0.252**
Other On-Site Contributions														
On-site HAP process emissions	Lbs	0											1	0
On-site GHG emissions	Lbs	0			1	0								
On-site carbon storage	Lbs	0			-1	0								
GHG offset by combusting landfill methane	Lbs	0			-20	0								
Other contributions		0		0		0		0		0		0		0
Other On-Site Subtotals				**0**		**0**		**0**		**0**		**0**		**0**
On-Site Totals				**1,944**		**16,464**		**92**		**3.8**		**0.45**		**0.25**

TBD = to be determined   Values in parentheses are negative values.   Energy for electricity is only that energy of that electricity and not the energy required to generate the electricity.

ccf CH_4 = 100 cubic feet of methane. Obtained by multiplying total volume of landfill gas in 100 ccf by the percentage of the gas that is methane.

If fuel is a blend of conventional fuel and renewable resource fuel, enter the amount of fuel from conventional sources into appropriate conventional fuel categories and enter amount of fuel from renewable resources into appropriate renewable fuel categories (e.g., for 100 gallons of B20 biodiesel blend, 20 gallons would be entered under biodiesel and 80 gallons would be entered under diesel).

1. Enter usages into blue cells in "Usage" column in indicated units.
2. Convert usages into indicated units of each parameter by multiplying usage by the indicated conversion factors. Enter result into blue cells in parameter columns.
3. Sum On-Site Renewable Energy results for each parameter and enter in green "On-Site Renewable Energy Subtotals" cells.
4. Sum On-Site Conventional Energy results for each parameter and enter in green "On-Site Conventional Energy Subtotals" cells. Be sure to subtract the energy from electricity offset by purchased renewable energy (e.g., renewable energy certificates).
5. Sum Other On-Site Contributions results for each parameter and enter in green "Other On-Site Subtotals" cells.
6. Sum green cells for each parameter and enter result in green "On-Site Totals" cells.

ENERGY & AIR CASE STUDY #2 – CALCULATING AND PRESENTING ELECTRICITY GENERATION ENERGY & AIR METRICS

Contributors to Footprints	Units	Usage	Energy		Greenhouse Gas		NOx		SOx		PM		HAPs	
			Conv. Factor	**MMBtus**	**Conv. Factor**	**lbs CO_2e**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**
Grid Electricity from Renewable Resources	MWh	539	6.9	3719.1										
Grid Electricity from Conventional Resources	MWh	5581	6.9	38508.9										
Total Grid Electricity	MWh	6120		42228	1831	11,205,720	4.5	27,540	10.8	66,096	0.081	496	0.47	2,876
Offsets from Purchased Renewable Energy Certificates	MWh	5581	6.9	38508.9	2198	12267038	3.66	20426.46	3.8	21207.8	0.081	452.061	0.47	2623.07
Net Energy from Conventional Resources				**3719**										
Total Energy from Renewable Resources				**42228**										
Electricity Generation Net Emissions						**0**		**7,114**		**44,888**		**44**		**253**

Grid electricity from Renewable Resources includes renewable energy purchased from green pricing programs from the electric service provider.

See Exhibit 3.16 for how to determine the percentage of grid electricity that is from renewable resources and then multiply this percentage by the total grid electricity usage to obtain the grid electricity from renewable resources.
See Exhibit 3.16 for how to determine the percentage of grid electricity from conventional resources and then multiply this percentage by the total grid electricity usage to obtain the grid electricity from conventional resources.
Use the information from the "product content label" from the Renewable Energy Certificate vendor to determine the emission conversion factors for greenhouse gas, NOx, SOx, and PM, if available.
If the "product content label" for renewable energy certificates does not provide conversion factors for all parameters use the renewable energy portion of the table in Exhibit 3.16 to determine those conversion factors.

Total Energy from Renewable Resources = Energy Associated with Grid Electricity from Renewable Resources + Energy Associated with Purchased Renewable Energy Certificates

Net Energy from Conventional Resources = Energy Associated with Grid Electricity from Conventional Resources – Energy Associated with Purchased Renewable Energy Certificates

Electricity Generation Net Emissions = Emissions Associated with Total Grid Electricity – Emissions Associated with Purchased Renewable Energy Certificates

ENERGY & AIR CASE STUDY #2 –CALCULATING AND PRESENTING TRANSPORTATION ENERGY & AIR METRICS

Category	Units	Usage	Energy		Greenhouse Gas		NOx		SOx		PM		HAPs	
			Conv. Factor	MMBtus	Conv. Factor	lbs CO_2	Conv. Factor	lbs	Conv. Factor	lbs	Conv. Factor	lbs	Conv. Factor	lbs
Conventional Energy														
Diesel use	gal	4,045	0.139	562	22.5	91013	0.17	688	0.0054	22	0.0034	14	5E-06	0.021
Gasoline use	gal	7,647	0.124	948	19.6	149881	0.11	841	0.0045	34	0.00054	4	3.9E-05	0.298
Natural gas use	ccf		0.103	0	13.1	0	0.01	0	0.0000063	0	0.00076	0	8.4E-06	0.000
Subtotal				**1,510**		**240,894**		**1,529**		**56**		**18**		**0.319**
Renewable Energy														
Biodiesel use	gal	0	0.127	0	22.3	0	0.20	0	0	0	0.00099	0	NP	
Transportation Totals				**1,510**		**240,894**		**1,529**		**56**		**18**		**0.319**

1. *Enter usages of each material or service into "Usage" column in indicated units.*
2. *Convert usages into indicated units of each parameter by multiplying usage by the indicated conversion factor. Enter result into blue cells in parameter columns.*

ENERGY & AIR CASE STUDY #2 –CALCULATING AND PRESENTING OFF-SITE ENERGY & AIR METRICS

Category	Units	Usage	Energy		Greenhouse Gas		NOx		SOx		PM		HAPs	
			Conv. Factor	MMBtus	Conv. Factor	lbs CO_2	Conv. Factor	lbs	Conv. Factor	lbs	Conv. Factor	lbs	Conv. Factor	lbs
Construction Materials														
Cement	dry-lbs	0	0.0021	0	0.9	0	0.0018	0	0.00105	0	0.0000032	0	2.9E-05	0
Concrete	Lbs	0	0.00034	0	0.14	0	0.00029	0	0.00017	0	0.0000022	0	4.40E-06	0
Gravel/sand/clay	Lbs	0	0.000028	0	0.0034	0	0.000017	0	0.000015	0	0.0000020	0	2.1E-10	0
HDPE	Lbs	0	0.031	0	1.9	0	0.0032	0	0.0041	0	0.00064	0	3.4E-06	0
Photovoltaic system (installed)	W	0	0.034	0	4.5	0	0.015	0	0.032	0	0.00063	0	2.9E-06	0
PVC	Lbs	0	0.022	0	2.6	0	0.0048	0	0.0076	0	0.0012	0	4.7E-04	0
Stainless Steel	Lbs	0	0.012	0	3.4	0	0.0075	0	0.012	0	0.0044	0	1.4E-04	0
Steel	Lbs	0	0.0044	0	1.1	0	0.0014	0	0.0017	0	0.00056	0	6.7E-05	0
Other refined construction materials	Lbs	0	0.014	0	1.98	0	0.0037	0	0.0053	0	0.0014	0	1.4E-04	0
Other unrefined construction materials	Lbs	0	0.000028	0	0.00335	0	0.000017	0	0.000015	0	0.000002	0	2.1E-10	0
Treatment Materials & Chemicals														
Cheese Whey	Lbs	0	0.0025	0	0.031	0	0.000062	0	0.000033	0	0.000002	0	NP	
Emulsified vegetable oil	Lbs	0	0.0077	0	3.44	0	0.0066	0	0.0019	0	0.000033	0	NP	
Molasses	Lbs	0	0.0044	0	0.48	0	0.0011	0	0.00024	0	0.0000041	0	NP	
Treatment materials & chemicals*	Lbs	210000	0.015	3150	1.7	350700	0.003	630	0.0065	1365	0.00061	128.1	1.6E-05	3.36
Virgin GAC (coal based)	Lbs	0	0.015	0	5.8	0	0.014	0	0.034	0	0.00078	0	1.2E-03	0
Fuel Processing														
Biodiesel Produced	Gal	0	0.029	0	-16.8	0	0.018	0	0.033	0	0.00082	0	NP	
Diesel Produced	Gal	4,045	0.019	74.8325	2.7	10921.5	0.0064	25.888	0.013	52.585	0.00034	1.3753	1.2E-04	0.4854
Gasoline Produced	Gal	8,487	0.021	178.227	4.4	37342.8	0.008	67.896	0.019	161.253	0.00052	4.41324	1.6E-04	1.35792
Natural Gas Produced	Ccf	0	0.0052	0	2.2	0	0.0037	0	0.0046	0	0.000072	0	6.1E-06	0
Public water	gal x 1000	0	0.0092	0	5	0	0.0097	0	0.0059	0	0.016	0	1.50E-05	0
Off-Site Services														
Off-site waste water treatment	gal x 1000	0	0.015	0	4.4	0	0.016	0	0.015	0	NP		NP	
Off-site Solid Waste Disposal	Ton	0	0.16	0	25	0	0.14	0	0.075	0	0.4	0	1.40E-03	0
Off-site Haz. Waste Disposal	Ton	0	0.176	0	27.5	0	0.154	0	0.0825	0	0.44	0	1.54E-03	0
Off-site Laboratory Analysis	$	1,100,000	0.0065	7150	1	1100000	0.0048	5280	0.0036	3960	0.0004	440	1.30E-04	143

ENERGY & AIR CASE STUDY #2 –CALCULATING AND PRESENTING OFF-SITE ENERGY & AIR METRICS (continued)

			Energy		Greenhouse Gas		NOx		SOx		PM		HAPs	
Category	**Units**	**Usage**	**Conv. Factor**	**MMBtus**	**Conv. Factor**	**lbs CO_2**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**	**Conv. Factor**	**lbs**
Resource Extraction for Electricity														
Coal extraction and processing	MWh	4388	3.1	13400	180	789847	0.77	3378.7908	0.15	658.206	0.018	78.98472	NP	
Natural gas extraction and processing	MWh	1193	1.6	1947	270	322218	0.18	214.812	13	15514.2	0.0071	8.47314	NP	
Nuclear fuel extraction and processing	MWh	0	0.16	0	25	0	0.15	0	0.5	0	0.0015	0	NP	
Oil extraction and processing	MWh	0	2.3	0	270	0	1.7	0	0.069	0	0.042	0	NP	
Grid renewable energy	MWh	539	0	0	0	0	0	0	0	0	0	0	0	0
Offset by purchased renewable energy	MWh	6120	2.51	15348	-181.71	-1112065	-0.59	-3593.6028	-2.64	-16172.406	-0.01	-87.45786		0.00
Net Emissions for Resource Extraction						**0**		**0**		**0**		**0**		**0**
Net Conventional Energy				**0**										
Net Renewable Energy				**15348**										
Electricity Transmission	MWh													
Conventional energy	MWh		10.03	0	638	0	1.1	0.00	1.8	0.0	0.036	0.000	0.075	0.000
Renewable energy	MWh	6120.00	10.03	61384										
Total Off-Site Conventional				**10,553**		**1,498,964**		**6,004**		**5,539**		**574**		**148**
Total Off-Site Renewable				**76,731**										

1. *Enter usages of each material or service into "Usage" column in indicated units.*
2. *Convert usages into indicated units of each parameter by multiplying usage by the indicated conversion factor. Enter result into blue cells in parameter columns.*
3. *Fuel processing refers to all fuel used, including that for on-site equipment use and transportation.*
4. *Electricity from various resources is obtained from generation mix that is used in Exhibit 3.16 and the resource extraction conversion factors from Exhibit 3.13.*
5. *For electricity transmission, enter 10% of the grid electricity used for calculating energy and emissions from electricity generation. The conversion factors are the same as those used for electricity generation. The energy conversion factor also includes the 3.413 MMbtus embodied in the actual electricity that is used.*
6. *Resource extraction conversion factors are calculated using values in Exhibit 3.13 and the specified fuel blend for electricity generation.*
7. *RECs, if purchased, are assumed to 1) offset emissions associated with transmission losses and resource extraction, 2) eliminate the energy associated with resource extraction, and 3) convert the energy associated with transmission losses to renewable energy.*

ENERGY & AIR CASE STUDY #2 – SUMMARY OF METRICS

Category	Energy from Renewable Resources MMbtus	Energy from Conventional Resources MMbtus	Total Energy MMbtus	Greenhouse Gas lbs CO_2e	NOx lbs	SOx lbs	PM lbs	NOx+SOx+PM lbs	HAPs lbs
On-site (Scope 1)	1,840	104	1944	16,464	92	3.78	0.45	97	0.25
Electricity Generation (Scope 2)	42228	49	42277	0	7,114	44,888	44	52045	253
Transportation (Scope 3)	0	1,510	1,510	240,894	1,529	56	18	1,603	0.319
Other Off-Site (Scope 3)	76731	10,553	87,284	1,498,964	6,004	5,539	574	12,117	148
Off-site (Scope 2 + Scope 3)	118,959	12113	131,072	1,756,322	14,739	50,487	636	65,862	402
Remedy Totals	120,799	12,217	133,015	1,772,786	14,831	50,491	636	65,958	402
% of Total Energy from Renewable Resources	90.82%								

Values in green cells represent the summation of values presented in other cells in this table.
Summary level metrics are provided in outlined cells. All other cells and values are provided for transparency and analysis purposes only.