ENVIRONMENTAL FOOTPRINT ANALYSIS OF FOUR POTENTIAL REMEDIES

SITE DP039, TRAVIS AIR FORCE BASE FAIRFIELD, CALIFORNIA

Final Report
August 5, 2011

NOTICE

Work described herein was performed by Tetra Tech GEO (formerly GeoTrans, Inc.) for the U.S. Environmental Protection Agency (U.S. E.P.A). Work conducted by Tetra Tech GEO, including preparation of this report, was performed under Work Assignment #58 of EPA contract EP-W-07-078 with Tetra Tech EM, Inc., Chicago, Illinois. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

EXECUTIVE SUMMARY

This study quantifies the environmental footprints of options for remediating a chlorinated solvent ground source area and plume at Site DP039 at Travis Air Force Base (Travis AFB) in Fairfield, California by estimating for each option the emissions of various environmental parameters, such as greenhouse gases, criteria pollutants, and air toxics, and the resources used, such as energy and water. The study considers contributions to the footprints from multiple components of the remedies, including construction, operations and maintenance, and long-term monitoring. Both on-site and off-site activities associated with each remedy component are included in the study.

This report documents the process used for estimating the footprints, provides the library of resources and reference values used in the study, documents findings specific to the evaluated remedies, and presents both site-specific and more generalized observations and lessons learned from conducting the study. Although the process, information, and lessons learned may apply to environmental footprint analysis efforts at other sites, the contents of this report are not intended as EPA policy statements regarding environmental footprint analyses.

One of the objectives of this analysis is to provide some of the information necessary to determine the level of detail that is merited for environmental footprint analysis of site remediation. It is therefore expected that the level of detail for this footprint analysis surpasses that which is needed to make informed decisions to reduce the environmental footprints of a typical remedy and that future footprint analyses at other sites will involve less detail. Other primary objectives of this study include, but are not limited to, the following:

- Identify or develop "footprint conversion factors" to calculate the footprints from various types of energy, materials, and services used in the remedy

- Estimate the footprints of up to 18 environmental parameters for two source area remedial alternatives and two plume control remedial alternatives

- Estimate the contribution to the various footprints from on-site activities, electricity generation, transportation, and non-transportation off-site activities

- Identify those components of the various remedial alternatives that have a significant effect on the environmental footprint and those components that have a negligible effect on the environmental footprint

- Conduct a sensitivity analysis for variations in the remedy design information, footprint conversion factors, or other input values

This study is not a formal life-cycle assessment following ISO Standards 14040 and 14044, but like a life-cycle assessment attempts to account for the total footprints from all energy, materials, and activities associated with the remedies, from resource extraction through use and "end-of-life" treatment.

This environmental footprint analysis has been conducted independently of Superfund site remedial activities at Site DP039. Travis AFB, its consultants, and EPA Region 9 have provided the footprint analysis study team information so that the study could be performed for illustrative purposes. Travis AFB, its consultants, and EPA Region 9 are acknowledged for this assistance.

Background and Methodology

Footprints from on-site activities and off-site activities are calculated for the following remedy alternatives:

Source Area

- Source area bioreactor consisting of buried mulch, iron, and vegetable oil and operated with a solar-powered pump
- Continued operation of the dual-phase extraction (DPE) system

Plume Migration Control

- Biobarrier implemented using injections of emulsified vegetable oil
- Permeable reactive barrier (PRB) constructed with guar gum and zero valent iron

Each of the above options includes remedy specific performance monitoring. In addition to the above remedial options and their associated performance monitoring programs, the footprint for long-term monitoring associated with Site DP039 was calculated so that the additional footprint associated with site-wide monitoring could be considered alongside these various remedial options.

The study was conducted after the bioreactor and biobarrier alternatives were installed at Site DP039 to demonstrate their effectiveness under site-specific conditions. Therefore, the final results of this study were not considered when optimization measures to improve the performance of interim groundwater remedies at Site DP039 were being developed. Some available information from the bioreactor and biobarrier implementation was used as input for this study. In addition, information was available for the dual-phase extraction system and the pilot study for a permeable reactive barrier.

The results are organized into the following three analyses:

- Primary analysis – results are organized according to on-site activities, electricity generation, transportation, and non-transportation off-site activities.
- Secondary analysis – results are organized according to three main remedy components: remedy construction, operations and maintenance (O&M), and long-term monitoring (LTM).
- Sensitivity analysis – results are obtained for variations in remedy assumptions and other input information.

Many observations are made based on the findings from these analyses. Some of the observations are specific to Site DP039 and others are more general observations that might apply to footprint analyses conducted at other cleanup sites. The following is a limited sample of both types of observations. Many more observations are provided in the Observations section of this report.

Sample of Observations Specific to Site DP039

- The DPE alternative has substantially higher energy and emission footprints relative to the bioreactor alternative. The DPE alternative also has a substantially higher water footprint because the extracted water is treated and discharged to surface water, which changes the nature of that water resource.

- PRB involves substantially more materials than the biobarrier alternative, and as a result, the PRB alternative has substantially higher footprints for most environmental parameters, primarily due to the manufacturing of the materials.

- The DPE alternative has the highest total water footprint due to the change in the water resource caused by discharging extracted groundwater to surface water. The PRB and biobarrier alternatives have the highest potable water footprint because of the potable water used to blend and inject the reagents for in-situ remediation.

- Although emulsified vegetable oil (bioreactor and biobarrier alternatives) and guar gum (PRB alternative) are plant based products, there are substantial footprints associated with producing them. The NOx footprint, in particular, is higher for these plant based products on a pound per pound basis than it is for many other manufactured products, including steel, PVC, and HDPE. This may be due to emissions from nitrogen fertilizers used in growing the crops.

- For the biobarrier alternative, the use of fire hydrants to provide water for blending and injecting reagents presents a tradeoff. Using the fire hydrant involves use of a potable water resource but not additional energy or on-site emissions for extracting groundwater. By contrast, using extracted groundwater for reagent blending and injection might involve on-site emissions if generators are needed to provide power but would not use potable water as a resource.

- The amount of emulsified vegetable oil used for the bioreactor and biobarrier remedies are engineering estimates made during remedy selection, remedy design, remedy construction, and initial remedy operation. Actual values typically are not known until remedy operation is underway and the remedy performance has been evaluated. The effect of doubling the amount of emulsified vegetable oil depends on the remedy alternative and the environmental parameter. The increase in the energy footprint from doubling the amount of emulsified vegetable oil is 11% for the bioreactor alternative and almost 30% for the biobarrier alternative. By contrast, the increase in the SOx footprint is 58% for the bioreactor alternative and almost 90% for the biobarrier alternative.

- Assumptions regarding the fuel mix for grid electricity generation and converting that fuel mix to emissions factors have a strong influence on the emissions-related footprints for remedies with high electricity use. The calculated CO2e footprint for the DPE remedy varied by over 290,000 lbs of CO2e based on various assumptions regarding the fuel mix and the derivation of the emissions factors. This 290,000-lb range results in 159% increase from the low-end of the range (184,000 lbs) or a 61 % decrease from the high end of the range (477,000 lbs). Although effects on the NOx, SOx, PM, and air toxics footprints were not modeled, a similar range of results is expected for these parameters.

- Reasonable generic values were used for approximating materials transportation distances and the mode of transportation. Decreasing the fuel used for transportation by 50% or doubling it resulted in an observable change in the remedy footprints, but not sufficiently significant to greatly alter conclusions drawn from the footprint analysis. This is because the footprint for manufacturing the materials is substantially higher than the footprint for transporting the materials. This observation is relevant to the bioreactor and biobarrier remedies at the DP039 Site but may not apply to other sites or remedy types, particularly excavation and off-site disposal remedies where there is substantial transportation but limited materials use.

Sample of General Observations that May Apply to Other Sites

- **On-site activities, electricity generation, transportation, and off-site activities (e.g., manufacturing) all have the potential to contribute significantly to the footprints of remedies.** For evaluating most remedy technologies at most sites, it appears that environmental footprint analysis should consider all four of these types of activities. However, contributions from these four categories of activities may differ from remedy to remedy. The large or significant contributors to a remedy footprint may not become apparent unless a wide range of contributors are included in the footprint analysis.

- **Footprint analysis results derived during the remedy selection phase can be used to identify those components of a remedy that have the largest influence on environmental footprints, allowing these components to receive extra attention during design and implementation for potential ways of reducing the remedy footprint.** For example, a footprint analysis of a DPE remedy alternative that uses thermal oxidation will indicate a significant footprint contribution from natural gas usage associated with thermal oxidizer operation. The design team can use this information and footprint analyses of competing vapor treatment options to identify an off-gas treatment option that minimizes the footprint while meeting compliance standards.

- **Footprint analysis results may be dominated by one or two contributors. If this is the case, it may be helpful to analyze footprint contributions without these large contributors so that other footprint contributors can be identified and more options for footprint reduction can be considered.** For example, a footprint analysis of a DPE remedy alternative that uses thermal oxidation will indicate a significant footprint contribution from natural gas usage associated with thermal oxidizer operation. The contributions are significantly large from the natural gas usage that relatively high contributions from UV/Oxidation treatment of extracted groundwater (also a component of the DPE remedy) may be missed. Optimization (and green remediation) opportunities exist in alternative technologies for both thermal oxidation for vapor treatment and UV/Oxidation for water treatment.

- **For remedies that involve use of electricity from the power grid, the outcome of an environmental footprint analysis is heavily dependent on the fuel used to generate the electricity.** Common practice is to use readily available regional mixes (e.g., www.epa.gov/egrid), but there are many instances where there is a special power provider or local power provider that uses a substantially different mix of fuel to generate electricity that is used by the remedy. For example, the Western Area Power Administration provides Travis AFB with electricity that is a blend of the California regional mix, Northwest regional mix, and hydroelectric power from Bureau of Reclamation hydroelectric projects. This blended mix is different from the mix found in eGRID. This finding suggests the importance of identifying and contacting the specific electricity provider to determine the fuel blend used to generate electricity. However, care needs to be taken in researching and contacting local electricity providers to ensure that the correct information is obtained.

- The use of renewable energy for a remedy does not reduce the remedy's energy footprint but can substantially reduce the emissions of CO2e, NOx, SOx, and other air pollutants. **Focus on energy efficiency and energy reduction may be a preferred first step for footprint reduction because it reduces both the energy footprint and the emissions footprints. Renewable energy can then be applied more cost-effectively to address the remaining energy needs and to further reduce emissions.**

- On-site renewable energy systems, particularly photovoltaic systems, have a relatively significant footprint associated with the manufacturing of the system components and installation of the system. **In many cases, it can take several years for this upfront footprint associated with manufacturing and installation of the renewable energy system to be offset by the renewable energy generated from the system.** The use of renewable energy systems might not be beneficial to the environmental footprint if the expected duration of the remedy is less than the time required to more than offset the manufacturing and installation footprint of the renewable energy system. However, in cases where grid electricity is not readily available (such as remote sites or sites with sensitive habitat precluding grid infrastructure), on-site renewable energy may be the preferred option.

- **Additionally, due to the footprint of system manufacturing and installation, using on-site photovoltaic (PV) panels to power a remedy may increase the CO2e, NOx, SOx, and PM footprints of the remedy if that remedy already uses electricity from hydroelectric or renewable resources.**

- Given the uncertainties in quantifying environmental footprints (described in the body of the report), **environmental footprint analyses should be applied with caution if used during remedy selection.** The primary factors for remedy selection should be those established by the remedial program, such as protectiveness of human health and the environment. The results of an environmental footprint analysis, however, can help further inform remedy selection as part of the other balancing criteria associated with remedy selection.

- When estimating the magnitudes of footprints of site remedies, it may be unclear what is considered a "large" footprint for a particular parameter and what is considered a "small" footprint for a particular parameter. The footprint for a particular parameter may be a small percentage of the overall remedy at one site, but may be a sufficiently large footprint relative to those from other sites to merit further attention. **In general, for specific parameters it may be valuable from a programmatic perspective to identify what is considered to be a significant footprint, what is considered to be a significant footprint reduction, and what the programmatic objectives are with respect to managing environmental footprints of remedies.**

Conclusion

The DP039 study has provided insight into key contributors to the environmental footprints associated with site remediation. It has also provided a preliminary framework for conducting an environmental footprint analysis. EPA has already completed a detailed footprint analysis at two remediation sites prior to this analysis for Site DP039. It is expected that this work will enhance the understanding of the environmental footprint process for site remediation.

PREFACE

This report was prepared as a collaborative pilot effort between U.S. EPA Region 9, the U.S. EPA Office of Superfund Remediation and Technology Innovation (OSRTI), and the U.S. EPA Office of Resource Conservation and Recovery (ORCR), in support of furthering the understanding of the process of estimating environmental footprints of various environmental remedies. This report is available for download from www.cluin.org/greenremediation.

Two additional pilot studies of similar scope have been completed at two additional cleanup sites and are also available at www.cluin.org/greenremediation. The authors of this report recognize that green remediation and the footprint analysis component of green remediation are developing practices, and comments and feedback are welcome on this report. Comments and feedback should be directed to Carlos Pachon and Karen Scheuermann (contact information below).

Organization	Key Contact	Contact Information
U.S. EPA Office of Superfund Remediation and Technology Innovation (OSRTI)	Kathy Yager	USEPA Region 1 - New England Regional Laboratory 11 Technology Drive Mail Code: ECA North Chelmsford, MA 01863-2431 phone: 617-918-8362 yager.kathleen@epa.gov
U.S. EPA Office of Superfund Remediation and Technology Innovation (OSRTI)	Carlos Pachon	USEPA Headquarters – Potomac Yard 2777 Crystal Drive Arlington, VA 22202 phone: 703-603-9904 pachon.carlos@epa.gov
U.S. EPA Region 9	Karen Scheuermann	US EPA Region 9 75 Hawthorne Street San Francisco, CA 94105 phone: (415) 972-3356 scheuermann.karen@epa.gov
Tetra Tech EM, Inc. (Contractor to EPA)	Jody Edwards	Tetra Tech EM Inc. 1881 Campus Commons Drive, Suite 200 Reston, VA 20191 phone: 802-288-9485 Jody.Edwards@tetratech.com
Tetra Tech GEO (Contractor to Tetra Tech EM, Inc.)	Doug Sutton	Tetra Tech GEO 2 Paragon Way Freehold, NJ 07728 phone: 732-409-0344 doug.sutton@tetratech.com

ACKNOWLEDGMENTS

This study was performed independently of the Superfund remedial efforts conducted at Site DP039 at Travis AFB but was supported by the programmatic and technical staff at EPA Region 9 overseeing the site cleanup, including James Chang and Nadia Hollan Burke. Steve Armann, manager of the Corrective Action Office in EPA Region 9, also provided valuable recommendations regarding the Pilot Study. Finally, we also appreciate the information provided by Glenn Anderson and Lonnie Duke of Travis AFB.

TABLE OF CONTENTS

<u>TABLES</u>

<u>SUPPLEMENTAL CHARTS</u>

APPENDICES

LIST OF ACRONYMS

CO_2e – Carbon dioxide equivalents of global warming potential

DPE – Dual phase extraction

EPA – U.S. Environmental Protection Agency

GHGs – Greenhouse gases

HAP – Hazardous air pollutant as defined by the Clean Air Act

HDPE – High density polyethylene

ISO – International Standards Organization

Lbs – pounds

LTM – Long-term monitoring

MNA – Monitored natural attenuation

MBtus – thousands of British Thermal Units

NOx – Nitrogen oxides (e.g., nitrogen dioxide)

O&M – Operations and maintenance

PM – Particulate matter (particles 10 microns or less in diameter)

POTW – Publicly owned treatment works

PRB – Permeable reactive barrier

PV - Photovoltaic

PVC – Polyvinyl chloride

SOx – Sulfur oxides (e.g., sulfur dioxide)

SVE – Soil vapor extraction

VOCs – Volatile organic compounds

1.0 INTRODUCTION

1.1 ENVIRONMENTAL FOOTPRINT ANALYSIS

U.S. EPA defines green remediation as the practice of considering all environmental effects of remedy implementation and incorporating options to minimize the environmental footprints of a cleanup. To this end, green remediation involves quantifying the environmental effects of a remedy and then taking steps to reduce negative environmental effects and enhance positive environmental effects, while meeting the regulatory requirements governing the remedy.

Two concepts are central to quantifying the environmental effects of a remedy. The first is to establish those parameters that are to be quantified, and the second is to establish a straightforward methodology for quantifying those parameters. 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 parameter that has been assigned some meaning. For example, the carbon footprint is the quantification or measure of carbon dioxide (and other greenhouse gases) emitted by a particular activity, facility, individual, or remedy. The carbon footprint is of interest because emissions of carbon dioxide (and other green house gases) have been linked to environmental effects such global warming and related climate change. The term “footprint” can be expanded to other environmental parameters such as energy use, water use, land use, and air pollutant emissions. In addition, an environmental footprint can be local, regional, or global. For example, the combustion of diesel fuel at a site will result in nitrogen oxide emissions (among other compounds) in the immediate vicinity of the site. The most significant environmental effects from this nitrogen oxide may be greatest near the site where it is most concentrated (i.e., a local effect). Contrastingly, diesel combustion at a site and diesel production at a refinery located far from the site will both emit carbon dioxide into the atmosphere. The environmental effects of carbon dioxide are of global not local concern, and a pound of carbon dioxide emitted at the site or far from the site will have equal environmental effect (i.e., a global effect).

Estimating the environmental footprint of remediation projects is becoming increasingly commonplace as are the development of tools to assist with the effort. However, as yet there is no standardized process, set of parameters, or accepted tool. Some projects focus on the carbon footprint and omit other parameters. Some projects limit the scope of the footprint analysis to fuel consumption and electricity use and omit contributions from manufacture of materials or off-site services that are required for a remedy. In general, however, the objective of the footprint analysis is to identify the most significant contributors to a remedy’s footprint so that efforts to reduce a remedy’s footprint can be targeted appropriately.

1.2 STUDY OBJECTIVES

This study involves the detailed environmental footprint analysis of options for remediating a chlorinated solvent source area and plume at Site DP039 at Travis Air Force Base (Travis AFB) in Fairfield, California. For each of the potential remedial options, the study estimates the footprint for a variety of parameters and attempts to consider all practical contributions to each footprint. This study is not a formal life-cycle assessment following ISO Standards 14040 and 14044. Rather, it is a footprint analysis that borrows from life-cycle assessment principles. Like a life-cycle assessment, this study uses data from life-cycle inventory databases to convert energy usage, materials usage, and various services associated with a particular activity (e.g., site remediation) into the environmental footprints of that activity. Like life-cycle assessment, the environmental footprints from resource extraction through use and "end-of-life" treatment are considered. Unlike a formal life-cycle assessment, this study estimates environmental footprints but does not convert them into actual human or ecological impacts or effects through a formal impact assessment.

One of the objectives of this detailed analysis is to provide some of the information necessary to determine the level of detail that is merited for environmental footprint analysis of site remediation. It is therefore expected that the level of detail for this footprint analysis surpasses that which is needed to make informed decisions regarding the remedy footprint and that future footprint analyses at other sites will involve less detail. The other primary objectives of this study are as follows:

- Identify or develop "footprint conversion factors" to calculate the footprints of each environmental parameter given a known usage of a specific type of energy, material, or service. Identify gaps in available information that, if filled, would improve the quantification of environmental footprints.

- Estimate the footprints of 18 environmental parameters for two source area remedial alternatives and two plume control remedial alternatives and determine the remedial alternatives for each part of the site that have the smallest estimated footprint for each parameter.

- For each environmental parameter, estimate the contribution to the footprint from on-site activities (e.g., on-site fuel combustion), electricity generation, transportation (e.g., personnel transportation, freight), and off-site activities (e.g., waste disposal, material manufacturing).

- Based on the estimated on-site and off-site footprints for the various parameters, consider which remedy a hypothetical group of site stakeholders might see as having the more favorable environmental footprint.

- Identify components of the various remedial alternatives that have a significant effect on the environmental footprint and those components that have a negligible effect on the environmental footprint.

- Conduct a sensitivity analysis for key components of remedies or key footprint conversion factors.

- Identify how the outcome of a footprint analysis conducted during the remedy selection phase might assist with optimizing the remedy during the remedy design and implementation phases.

Travis AFB, its consultants, and EPA Region 9 have provided site-specific information from Site DP039 so a footprint analysis study could be performed by U.S. EPA for illustrative purposes. However, this footprint analysis was conducted independently of Superfund site remedial activities and decision-making at Site DP039. That is, Site DP039 served as a test case of for the development of the methodology of the footprint analysis, and the conclusions and lessons discussed in this report pertain to the methodology for conducting such an analysis, rather than the application of the specific results to the Site DP039 remedy. Any decisions on how or whether the results of this study may be used by EPA Region 9 or Travis AFB will be made independently.

The findings from this analysis are specific to Site DP039 and to the remedies evaluated. The Observations section of this document provides, where applicable, general conclusions and lessons learned that may apply to other sites.

1.3 Brief Site Background

The remediation at Site DP039 addresses soil and groundwater contamination near Building 755 (the Battery and Electric Shop) at Travis AFB. Prior to 1978, battery acid solutions and solvents were discharged from Building 755 into a sump. These historical practices resulted in contamination of the groundwater with chlorinated VOCs, primarily TCE. According to the September 2008 Five-Year Review, the sump was removed in 1993, and left undisturbed, lead in the surface soil around the edges of the former sump area would not present an unacceptable risk to local workers or the environment. An interim remedy for groundwater included source control with a dual-phase extraction system. The interim remedy also called for an evaluation of monitored natural attenuation (MNA) as a potential remedy component. The primary objectives of the remedy are to remediate the contaminant source area and control migration of the existing plume that has already migrated from the source area. Evaluation of the implemented interim remedies found that additional measures were needed to meet objectives and that MNA would not be implemented. The dual-phase extraction system was expanded and additional alternatives were considered, including the following:

Source Area

- Source area bioreactor consisting of buried mulch, iron, and vegetable oil and operated with a solar-powered pump
- Continued operation of the dual-phase extraction system

Plume Migration Control

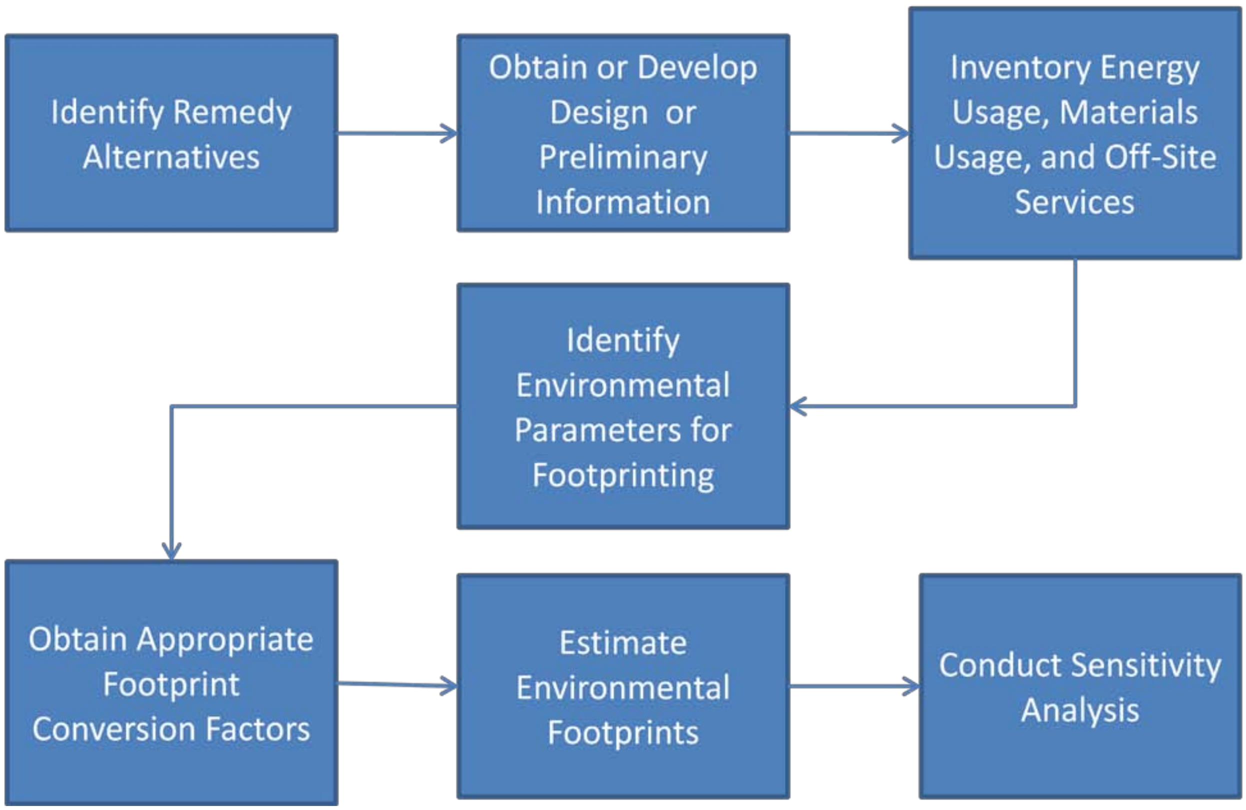
- Biobarrier implemented using injections of emulsified vegetable oil
- Permeable reactive barrier constructed with guar gum and zero valent iron

In addition, a phytoremediation area downgradient from DP039 has been in place for about 10 years, and the feasibility of applying it to the cleanup of DP039 is currently under evaluation.

1.4 Scope and Methodology

For this study, footprints from on-site activities and off-site activities for the remedy alternatives are organized into two main analyses. The first or primary analysis organizes the footprint analysis results according to on-site activities, electricity generation, transportation, and non-transportation off-site activities. The second or secondary analysis organizes the footprint analysis results according to three major remedial components. For each analysis and for each analyzed remedy alternative, preliminary design information is developed from which an expected inventory of energy usage, materials usage, and off-site services can be quantified. Based on the items in the inventory, appropriate footprint conversion factors are obtained or developed that can be used to convert the items in the inventory into the environmental footprints. The footprints for the various environmental parameters are then estimated by applying the conversion factors to the items in the inventory. Once the process is conducted for one remedy alternative or sets of remedy alternatives, various components of the remedy designs are modified to conduct a sensitivity analysis. Figure 1 illustrates this process, and each step is described in more detail in the following sections.

Figure 1. Schematic of Footprinting Analysis Process



1.5 Remedy Alternatives to be Analyzed

This study evaluates the following remedial alternatives:

Source Area

- Alternative A1 (Bioreactor) – Source area bioreactor consisting of buried mulch, iron, and vegetable oil and operated with a solar-powered pump that extracts water from the aquifer and reinjects it through the bioreactor

- Alternative A2 (Dual-Phase Extraction or DPE) – Continued operation of the existing dual-phase extraction system, which involves soil vapor and water extraction plus treatment in a centralized treatment system (all construction is assumed to have already been completed for this alternative)

Plume Migration Control

- Alternative B1 (Biobarrier) – Installation of a biobarrier along the width of the downgradient plume by injection of emulsified vegetable oil through permanent injection wells

- Alternative B2 (Permeable Reactive Barrier or PRB) **-** Permeable reactive barrier along the width of the downgradient plume constructed using jet grouting of zero valent iron suspended in guar gum.

Each of the above options includes alternative-specific performance monitoring. In addition to the above remedial options and their associated performance monitoring programs, the footprint for long-term monitoring associated with Site DP039 was calculated so that the additional footprint associated with site-wide monitoring could be considered alongside these various remedial options.

The two source area alternatives are assumed to provide appropriate and equivalent protection of human health and the environment. Similarly, the two plume migration alternatives are assumed to provide appropriate and equivalent protection of human health and the environment. The long-term monitoring, depicted alongside the other alternatives for comparison purposes only, is not considered a protective remedy alternative alone.

1.6 Remedy Design Information

Sufficient information for each remedial alternative is necessary to quantify or inventory the use of energy, materials, and off-site services for implementing the alternative. This information includes but is not limited to the number and depths of wells, reagents or materials used, and soil or materials to be moved. The level of detail of this information and the assumptions made have a direct effect on the calculated footprints. For this study, all aspects of the remedial design for the bioreactor and biobarrier alternatives and most aspects of the other two alternatives have been provided by the site owner. For the DPE alternative, operations and maintenance information was used. For the PRB alternative, construction information from the treatability study were extrapolated for a full size application.

Appendix A provides for each remedial option a printout of a set of spreadsheet modules that is used to document the remedy information and inventory the level of effort, fuel, electricity, water, and materials usage. The printouts include a more detailed description of the remedies. The inventory files provided in Appendix A include the assumptions and information used to convert remedy activities (well installation or chemical applications) into services, materials, or energy use (such as quantity of laboratory analysis, amount of PVC used for well casing, or diesel fuel used for equipment).

1.7 Remedy Inventory

Footprint analysis for environmental remedies is relatively new, so footprint conversion factors are not readily available for common activities involved in site remediation. For example, a conversion factor to estimate the carbon footprint for extraction well installation is not readily available. Rather, information from life-cycle databases for common, fundamental energy types, materials, and services are available. As a result, the remedy design information is reduced to these fundamental components. An inventory is developed for electricity, diesel, gasoline, GAC, PVC, steel, concrete, waste disposal, and other energy, materials, or services directly involved in remedy implementation. For this study, the materials used on-site are included in the inventory, but materials used to manufacture equipment or materials not dedicated to the site are not included. For example, the energy used to transport a drill rig to the site and to operate the drill rig on-site is included, but the energy, materials, and services used to manufacture the drill rig are not included.

For each remedial alternative, Appendix A includes the remedy design information plus the inventory for the following:

Five types of energy

• gasoline[1]	• natural gas[3]
• diesel[1]	• solar energy converted to electricity by a photovoltaic system
• grid electricity[2]	

16 common materials[4]

• Acetic acid	• Hydrogen peroxide
• Bentonite	• Materials for a small photovoltaic system
• Cement grout	• Molasses (surrogate for high fructose corn syrup)
• Concrete	• Mulch
• Emulsified vegetable oil	• PVC
• Granular activated carbon	• Sand/gravel/clay
• Guar gum	• Stainless steel
• HDPE	• Steel

Two types of water[5]

• Potable water	• Extracted groundwater

Four types of off-site services

• Solid waste disposal[6]	• Hazardous waste disposal[6]
• Laboratory analysis	• Off-site water treatment at a POTW

Notes

[1] *The inventory includes the use of these energy forms in on-site activities and for transportation of personnel and materials to and from the site.*

[2] *The inventory includes electricity used on-site, electricity lost due to transmission and distribution over the grid, and losses during the production of electricity by power plants (including an estimate of sacrificial loads by the power plants). Off-site electricity usage from materials manufacturing and other off-site activities is also estimated and included in the electricity footprint (see next section).*

[3] *The inventory includes combustion of natural gas on-site plus extraction and production of the natural gas.*

[4] *The inventory includes materials used on-site*

[5] *The inventory includes potable water used on-site and groundwater extracted on-site. Other types of water (e.g., reclaimed water) were not considered for this project. Off-site water usage from materials manufacturing and other off-site activities is estimated as a footprint parameter (see next section).*

[6] *The inventory accounts for solid and hazardous waste that is generated on-site and requires off-site disposal.*

Each of the above items is expected to contribute to the footprint of one or more environmental parameters selected for use in the study. For example, the manufacturing of PVC for on-site use is expected to contribute to the footprints for carbon dioxide emissions, water use, waste generation, and many other environmental parameters. As another example, combustion of diesel fuel on-site and in transportation is expected to contribute to the footprints of carbon dioxide, NOx, SOx, and PM emissions.

1.8 ENVIRONMENTAL PARAMETERS

For this study, 18 environmental parameters that represent a cross-section of environmental effects were chosen for the footprint analysis. Footprints are estimated for the following environmental parameters, which are briefly described in Table 1. Other studies might choose a refined or expanded list of environmental parameters depending on the scope and objectives of the study.

Parameters for On-Site Activities	**Parameters for Electricity Generation, Transportation and Off-Site Activities**
Energy	Energy
Electricity	Electricity
All water	All water
Potable water	
Local groundwater extracted	
Carbon dioxide equivalents (CO2e) for greenhouse gas potential	Carbon dioxide equivalents (CO2e) for greenhouse gas potential
Nitrogen oxide (NOx) emissions	Nitrogen oxide (NOx) emissions
Sulfur oxide (SOx) emissions	Sulfur oxide (SOx) emissions
Particulate matter (PM) emissions	Particulate matter (PM) emissions
Solid (non-hazardous) waste generated	Solid (non-hazardous) waste generated
Hazardous waste generated	Hazardous waste generated
Air toxics (hazardous air pollutants emitted)	Air toxics (hazardous air pollutants emitted)
Mercury released to the environment	Mercury released to the environment
Lead released to the environment	Lead released to the environment
Dioxins released to the environment	Dioxins released to the environment
Refined (manufactured) materials used	
Unrefined (not manufactured) materials used	
Ecosystem services affected	

On-site parameters refer to parameters generated, emitted, or otherwise used on-site. The parameters in the right-hand column refer to parameters generated, emitted, or otherwise used from electricity generation, transportation, and other off-site activities (e.g., materials manufacturing and laboratory analysis). Potable water and groundwater, refined and unrefined materials, and ecosystems services are parameters for which the on-site footprint is estimated but the off-site footprint is not estimated.

The remedy footprints for NOx, SOx, PM, air toxics, mercury, lead, and dioxins estimated in this study result from various contributing sources of these pollutants. These sources were included in the footprint estimate regardless of whether or not they are regulated or governed by a permit. The footprints of these parameters are quantified for the purpose of estimating the environmental footprints of the two source area remedial alternatives and the two plume control remedial alternatives being evaluated, not for the purpose evaluating the compliance of off-site sources of these parameters or the regulations or permits governing them.

Each of the items in the remedy inventory (see Section 1.7) is expected to contribute to the footprints of one or more of these environmental parameters. The on-site, off-site, and total on-site/off-site footprints of these parameters are determined. The on-site footprint refers to the use, generation, or emission of a parameter within the boundaries of the site (e.g., the NOx emitted from combusting diesel on-site). Off-site would apply to the use, generation, or emission of a parameter during transportation, materials manufacturing, or some other off-site activity (e.g., the NOx emitted off-site during the production of diesel at the refinery or during combustion of diesel for off-site transportation). The reason for distinguishing between on-site and off-site is to quantify the portion of the footprint that may be of importance to the local community (such as PM emissions or local groundwater extraction) and at the same time quantify aspects of the footprint that have global effects (such as greenhouse gas emissions) or regional effects (e.g., ozone, aerosol, or acid rain formation).

For this study, on-site "all water" use refers to on-site potable water use plus on-site groundwater extraction if the water resource is not returned to its original location (e.g. the same aquifer) and to its original water quality. On-site "all water" use could also include on-site use of reclaimed water, storm water, or any other on-site use of a fresh water resource, but these other water resources are not used in the evaluated remedies at Site DP039. On-site potable water use and on-site groundwater extracted are tracked separately from "all water" because they are of potential interest to the local community and because accurate information is available about on-site use of these water resources. On-site potable water use, in particular, is use of a refined resource that may be relatively scarce and of particular value to some local communities, especially in Northern California. The study team did not attempt to track potable water and groundwater sources used in association with off-site activities such as waste disposal and sand and gravel production. This is because it is not possible for the study team to determine, based on generalized available information, the quality of the groundwater used in off-site activities, or the source of the potable water used in these activities. Furthermore, the fate of the water after use in off-site processes is unclear. It may be returned to the same off-site aquifer, evaporated, or discharged to local fresh surface water.

Off-site "all-water" use refers to all fresh water resources that are used as part of the off-site activities associated with the remedy, such as the production of materials. In obtaining or developing conversion factors for off-site "all water", the study team attempted to quantify water "consumed" by a process, rather than water "withdrawn". However, the LCI data bases available to the study team did not always account for water in a consistent manner. In addition, for conversion factors developed by the study team, it was not always possible to make the distinction between water consumed and water withdrawn. In spite of these difficulties, the off-site "all water" footprints in this study should be seen as approximations for "all water" consumed. Total "all water" refers to the on-site "all water" (as defined above) plus off-site "all water".

Additional comments are relevant to water used for hydroelectric power production (one of the power sources for electricity used at Travis AFB). The water use associated with hydroelectric plants is primarily due to evaporation from reservoirs used for the hydroelectric power. Based on the data sources used to develop the water footprint conversion factors for electricity production (see Appendix B), loss of water from hydroelectric reservoirs is apparently orders of magnitude higher than water use associated with fossil-fuel or nuclear power plants. Assuming that the reservoirs serve other purposes (such as flood control, urban and agricultural water supply, and recreation), it is recognized that water loss from the hydroelectric reservoirs would occur regardless of whether or not electricity for site remediation is drawn from hydroelectric sources. In fact, electricity usage from a hydroelectric plant actually reduces the residence time of water in the reservoir and therefore would decrease the amount of evaporation, although this reduction may be negligible for the amount of electricity required by site remediation of the scale at DP039. As a result, the factor used to convert grid electricity to "all water" use does not include the evaporative loss of water from hydroelectric facilities.

Refined materials use and unrefined materials use are included to provide a metric for material use consistent with the EPA core elements of green remediation. Refined materials refer to materials that are manufactured, such as steel, plastics (e.g., PVC, HDPE), treatment chemicals, fertilizers, and other materials that undergo a substantial refining process. Unrefined materials refer to materials that do not require a substantial refining process (e.g., sand, gravel, clay, and borrow/fill). For both categories, the amount of materials from recycled or reused materials can be stated.

Identifying temporary or permanent effects to ecosystem services (e.g., agriculture, carbon storage, nutrient uptake, soil erosion control) is a means of tracking the effects of the remedy on the local land and ecosystems.

The environmental parameters described in Table 1, along with the process of documenting the materials usage that contribute to the footprints of these parameters, address four of the core elements of green remediation (energy, air, water, and materials) outlined in *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites* (April 2008, EPA 542-R-08-002). The fifth core element (ecosystem) is considered qualitatively in this report.

The following additional parameters relevant to transportation and labor are tracked for each alternative:

- miles traveled, by vehicle type
- trips to the site, by vehicle type
- man-days worked on site

1.9 FOOTPRINT CONVERSION FACTORS

A footprint conversion factor provides a means of converting the quantity of each energy type, material, or off-site service used in the remedy into the footprints of the environmental parameters (i.e., the emission, use, or generation of a particular environmental parameter). A footprint conversion factor for a particular environmental parameter, when multiplied by a quantity of energy, material, or service used, provides the footprint for the use of that quantity. For example, a carbon footprint conversion factor for PVC can be multiplied by the mass of PVC used in a well casing to estimate the carbon footprint associated with the production of that PVC pipe as follows:

Quantity of one item in inventory	×	*Footprint conversion factor for converting that item to footprint of one environmental parameter*	=	*Footprint for that environmental parameter from that inventory item*
Total PVC used on-site (in pounds)	×	*Footprint conversion factor for converting pounds of PVC to CO2e emitted for producing one pound of PVC*	=	*CO2e footprint from producing total amount of PVC used*

Similarly, the amount of nitrogen oxides emitted (or NOx footprint) for producing 100 gallons of diesel can be obtained by multiplying 100 gallons of diesel by a NOx footprint conversion factor for the production of diesel. This NOx conversion factor for producing diesel is different from the NOx conversion factor for using or combusting a gallon of diesel. In this study, where possible, a conversion factor is used for both the production and the use of items like diesel.

For this study, most conversion factors are obtained from life-cycle inventory databases. The study team expects that these are reasonable conversion factor values that would apply to most remedial sites because the conversion factors were developed from nationwide or industry-wide information rather than information from a specific manufacturer. This study refers to these generalized conversion factors as "default" conversion factors. In some cases, conversion factors are based on site-specific or local information. This study refers to these site-specific conversion factors as "actual" conversion factors. Examples of actual conversion factors used in this study are the conversion factors applied to electricity production because they are developed based on the documented local fuel blend rather than the average fuel blend used for electricity production in the United States. Other footprint analysis projects may choose to use the conversion factors developed as part of this study, but may identify more specific conversion factors for some of the more predominant materials used in the evaluated remedy. For example, a site team that uses a vendor that provides "carbon neutral" solid waste disposal (if properly documented and verified) would appropriately choose an "actual" carbon footprint conversion factor of zero for solid waste disposal, rather than the "default" generalized conversion factor used in this study.

Where possible, publicly-available databases are used to obtain the footprint conversion factors used in this study so that the information is readily available for confirmation and use by others. The following publicly-available databases are the primary sources of information for this study:

- The U.S. Dept. of Energy, National Renewable Energy Laboratory (NREL), Life-Cycle Inventory Database (NREL LCI) available at www.nrel.gov/lci and maintained by the Alliance for Sustainable Energy

- European Reference Life Cycle Database (EUROPA ECLD), 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 available at http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm

- LCA Food Database (Nielsen PH, Nielsen AM, Weidema, BP, Dalgaard R and Halberg N, 2003), based on activities in Denmark and available at www.lcafood.dk (used primarily for food-based products, such as molasses, cheese whey, and vegetable oil in bioremediation remedies)

It is recognized that the life-cycle data developed for Europe may not translate directly to materials manufactured in the United States, but it is assumed that the manufacturing and food processing practices are similar and that the life-cycle inventory values reasonably represent those associated with activities in the United States, especially given that the life-cycle databases are based on average values from multiple manufacturing facilities. The information from these databases typically includes environmental footprints from resource extraction through the production of material. The information, however, is not specific to the form of the material. For example, the databases include the footprints for manufacturing of steel and PVC resin beginning at resource extraction, but do not include the specific footprints for manufacturing steel fencing, steel pipe, PVC pipe, or PVC liner.

Conversion factors for some items and services were not available from the life-cycle data resources used, such as those associated with regenerating granular activated carbon, producing guar gum, and performing laboratory analyses. The study team used a combination of professional judgment and data from individual facilities to estimate these conversion factors.

For example, the conversion factors for laboratory analysis are based on assumptions made by the study team. The study team assumed that laboratory activity is comparable to the general activity of the United States economy such that the CO2e emissions associated with each dollar of laboratory revenue is comparable to each dollar of United States gross domestic product (GDP). It is further assumed that the CO2e emissions for the laboratory analysis can be equally distributed between electricity use and diesel combustion. This electricity use and diesel combustion can then be used to generate conversion factors for other parameters related to laboratory analysis. Refer to Appendix B for additional information.

The reference file that contains the footprint conversion factors that are used in this study is included in Appendix B, along with the reference information used to develop the conversion factors.

1.10 CALCULATION OF ENVIRONMENTAL FOOTPRINTS

The calculation of the environmental footprints is relatively straightforward once the remedy inventory is established, the environmental parameters for footprint analysis have been selected, and appropriate footprint conversion factors are identified. As stated in Section 1.9, the footprint for a specific environmental parameter from a particular item (e.g., energy type, material, or off-site service) is obtained by multiplying the quantity of the item by the footprint conversion factor for that item and the specific environmental parameter. The footprints derived for a particular environmental parameter from all items in the remedy inventory are summed to obtain the total footprint for that environmental parameter. For example, the on-site and off-site CO2e footprints for a remedy alternative are calculated as follows:

On-Site Remedy CO2e footprint	=	*CO2e footprint for on-site diesel combustion* + *CO2e footprint for on-site gasoline combustion* + *CO2e footprint from on-site process GHG emissions*

Off-Site Remedy CO2e footprint	=	*CO2e footprint for off-site diesel combustion* + *CO2e footprint for off-site gasoline combustion* + *CO2e footprint for electricity production* + *CO2e footprint for manufacturing of various products (e.g., PVC, HDPE, potable water, diesel, gasoline, etc.)* + *CO2e footprint for off-site wastewater treatment* + *CO2e footprint for solid waste disposal* + *CO2e footprint for hazardous waste disposal* + *CO2e footprint for laboratory analysis*

Note that the above example for the off-site footprint includes the footprint associated with producing the gasoline or diesel that is combusted.

1.11 Analyses

There are three sets of footprint analyses conducted for this study, each of which is described below.

1.11.1 Primary Analysis

In the primary analysis, the four alternatives and the long-term monitoring are analyzed to evaluate how on-site activities, transport to and from the site, and off-site activities (e.g., manufacturing) contribute to the on-site and total footprints for the remedies. The contribution to the footprint from generation of electricity used on-site is also accounted for separately. The footprint spreadsheet output files for this analysis are presented in Appendix C.

1.11.2 Secondary Analysis

In the secondary analysis, each of the four alternatives and the long-term monitoring is divided into three components to determine which remedy components are negligible and which remedy components contribute significantly to the various footprints:

- Construction
- Operations and maintenance (O&M)
- Performance monitoring

The footprint spreadsheet output files for this analysis are presented in Appendix C.

1.11.3 Sensitivity Analysis

The estimated footprints are anticipated to be more sensitive to some input information than other input information. The output (estimated footprint) is considered sensitive to a parameter when a reasonable variation in input value results in a significant variation in the output. The output is not sensitive when large variations in input values do not substantially change the output. The sensitivity of the output to various input information can be determined by conducting sensitivity analyses, which involves varying the input and tracking the magnitude of the output. In general, footprint analysis output is sensitive to the input values associated with the largest contributors to the footprints. For example, electricity is a large component of the DPE alternative. As a result, variations in electricity usage, or variations in the conversion factors used to convert electricity usage into footprints, would be expected to result in significant changes in the footprint estimate.

Determining the sensitivity of various parameters has the following two important functions for footprint analyses conducted during the remedy selection, design, or implementation phases.

- First, if the footprint is sensitive to a particular input parameter, then it suggests that modifications during design and implementation could help significantly reduce the footprint.

For example, if the bioreactor alternative is highly sensitive to the amount of vegetable oil that needs to be added each year, then consideration can be given to limiting the amount of this material used while maintaining remedy effectiveness, identifying local sources of this material, or finding an alternative material that has lower footprint.

- Second, if the footprint is sensitive to a particular input parameter and the value of that input parameter is uncertain, then the quality and accuracy of the analysis is called into question because the value of the estimated footprint is similarly uncertain. For example, if the duration of the DPE alternative is uncertain between 10 and 30 years, then the calculated footprints are also similarly uncertain, making it difficult to compare the footprint of this remedial option to another remedial option.

The following items are evaluated as part of the sensitivity analysis.

- Double the amount of vegetable oil injected each year for the bioreactor.

- Change the treatment technologies for the DPE alternative from UV/oxidation to granular activated carbon for water treatment and thermal oxidation to granular activated carbon for soil vapor treatment.

- For the DPE alternative, utilize various electricity generation mixes for calculating the footprint associated with electricity generation.

- Power the DPE alternative with a photovoltaic system instead of using grid electricity.

- Double the number of injection events for the biobarrier, and, separately, leave the number of injection events unchanged but double the amount of vegetable oil injected for the biobarrier.

- Cut transportation distances of materials for all alternatives by 50%.

2.0 RESULTS

Some findings are presented below for each of the above-mentioned analyses as a sample of the types of findings that are available from a detailed footprint analysis. The Supplemental Charts section of this report provides a graphical representation for other footprints calculated but not discussed in the text. Appendices A through C provide detailed information regarding each of the remedies, the remedial parameters, and the environmental footprints. This supplemental information could be used to develop many other relevant findings.

2.1 PRIMARY ANALYSIS

2.1.1 TOTAL FOOTPRINTS FOR SELECTED GLOBAL/REGIONAL ENVIRONMENTAL PARAMETERS, BY REMEDY

Charts 1 through 4 present the total (i.e., the on-site plus off-site) footprints for energy, CO2e, SOx, and mercury for each remedy alternative and for long-term monitoring. These environmental parameters are presented because they are representative of the global or regional environmental effects resulting from the remedies. Energy is a resource that is used locally but can derive from global resources (e.g., oil for fuel) or regional resources (e.g., regional hydroelectric power). CO2e is a measure of greenhouse gas potential, which can contribute to global climate change; SOx can lead to the formation of aerosols and acid rain, which are regional effects; and mercury is persistent in the environment and bioaccumulates.

The results for the plume control alternatives show that the DPE alternative has large footprints for energy, CO2e, SOx, and mercury relative to the bioreactor. This is due to the natural gas used for operation of a thermal oxidizer and electricity use for operating equipment associated with the DPE system.

The results for the plume control alternatives are similarly high for the PRB relative to the biobarrier. For all four parameters, the PRB has a significantly higher footprint than the biobarrier, primarily resulting from the production of materials used in the PRB construction. Note that the PRB alternative has a significantly higher mercury footprint than the other alternatives. Although the footprint is relatively small, it is orders of magnitude higher than the mercury footprint of the other alternatives. More than 90% of this footprint is associated with the production of steel, which is used as a surrogate parameter for the zero valent iron used in the construction of the PRB.

For more information on how the total footprints for the other parameters compare among the remedy alternatives and long-term monitoring, refer to the charts labeled “Primary Analysis – Output by Parameter” in the Supplemental Charts section of this report and to the tables in Appendix C.

Chart 1

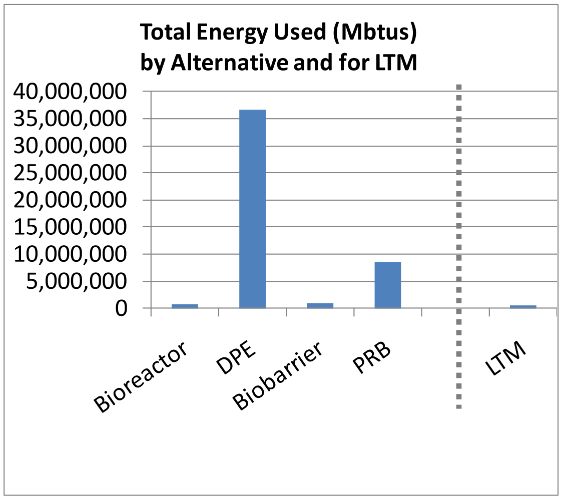


Chart 2

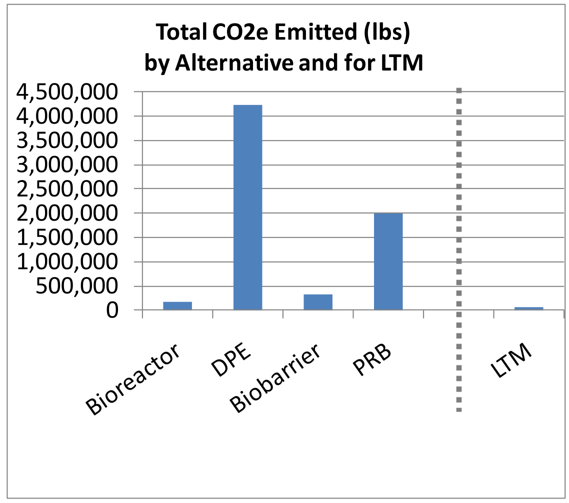


Chart 3

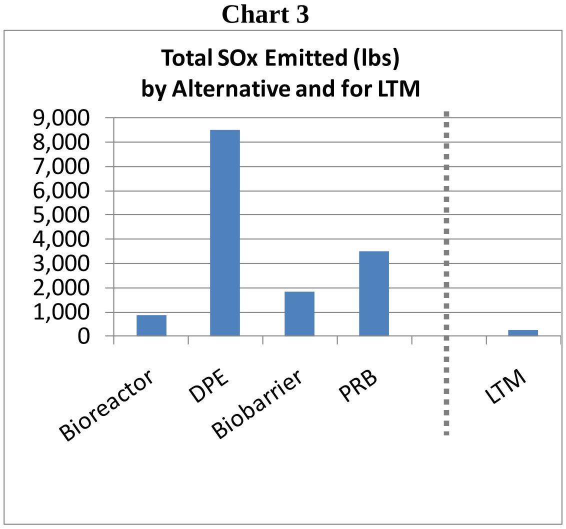
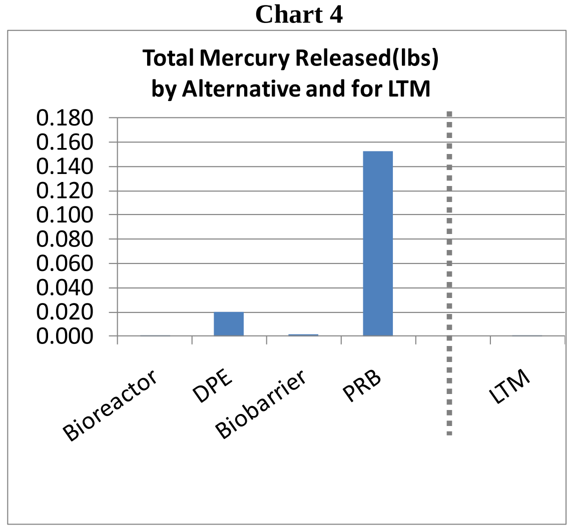


Chart 4



"Total" refers to on-site plus off-site footprint for the life-time of the remedies. The site-wide long-term monitoring (LTM) is depicted alongside the alternatives for comparison purposes and is not a protective remedy alone.

2.1.2 On-Site Footprints for Selected Local Environmental Parameters, by Remedy

Charts 5 through 7 present the on-site footprints for NOx, PM, and air toxics (i.e., the amount of NOx, PM, and air toxics emitted on-site) for each of the alternatives and long-term monitoring. These three environmental parameters are presented because they are representative of the local or regional environmental effects resulting from the remedies. NOx contributes to local or regional ground-level ozone formation, and PM and air toxics can lead to health problems when inhaled. For all three parameters, on-site emissions for the DPE alternative are significantly higher than the other alternatives due to the on-site use of natural gas for the thermal oxidizer. For more information on how the on-site footprints for the other parameters compare among the alternative remedies and long-term monitoring, refer to the "Primary Analysis Charts – Output by Parameter" in the Supplemental Charts section of this report and to the tables in Appendix C.

Chart 5

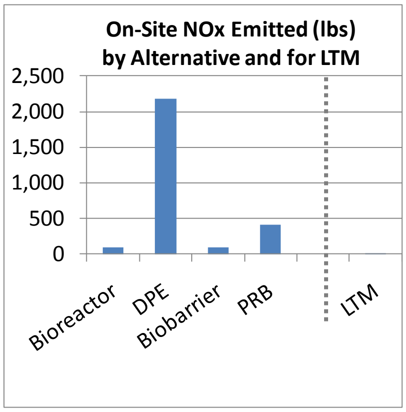


Chart 6

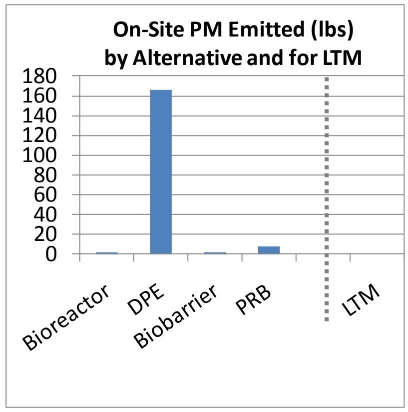
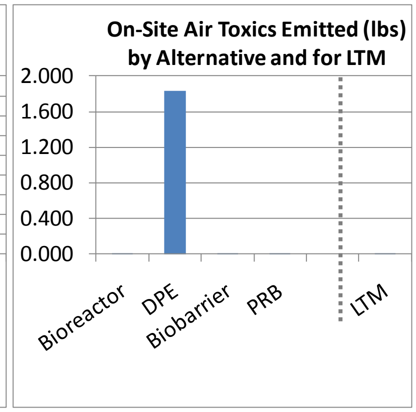


Chart 7



These charts show the on-site footprints over the life-time of the remedies. The site-wide long-term monitoring (LTM) is depicted alongside the other alternatives for comparison purposes and is not a protective remedy alone.

2.1.3 On-Site, Electricity, Transportation, and Other Off-Site Distribution of Footprints

Charts 8 through 10 present, for each of the remedies, the distribution of CO2e, NOx, and air toxics emissions from on-site, transportation, and non-transportation off-site activities, as well as generation of electricity used on-site.

Chart 8

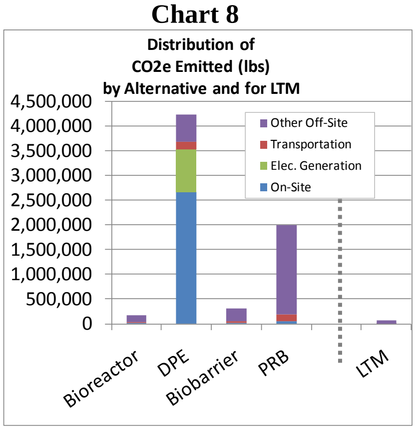


Chart 9

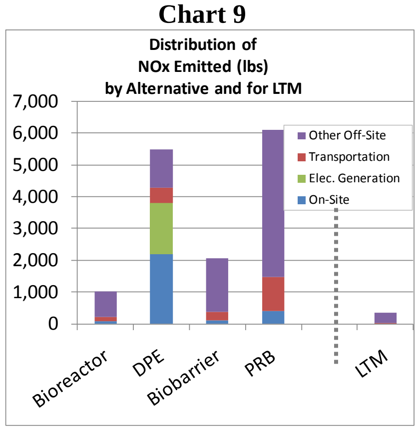
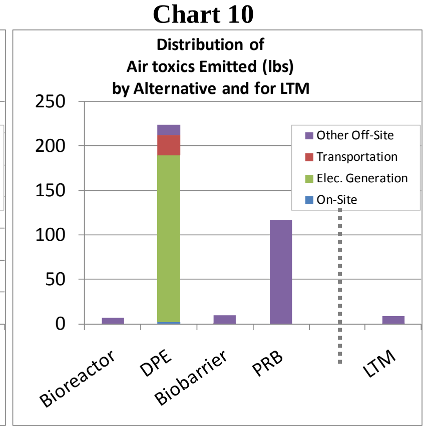


Chart 10



"Off-site" refers to non-transportation off-site sources (e.g., manufacturing) over the life-time of the remedies. The site-wide long-term monitoring (LTM) is depicted alongside the other alternatives for comparison purposes and is not a protective remedy alternative alone.

The following findings are noteworthy:

- The patterns of total emissions for all three parameters are similar. For each parameter, the magnitudes of the footprints for the bioreactor and biobarrier alternatives are relatively similar and the footprints for the DPE and PRB alternatives are substantially higher.

- The "other off-site" activities appear to be the largest contributors to the total footprints of these parameters for all alternatives except for the DPE alternative. Transportation is the next largest contributor to the CO2e and NOx footprints, but is a substantially smaller contributor than other off-site activities. For the DPE alternative, the on-site (from natural gas) and the electricity sources are the largest contributors.

- The DPE is the only alternative for which electricity generation contributes substantially to the total footprint. This is because the DPE is the only alternative in which grid electricity is used on-site in large quantities.

2.1.4 Findings Related to Various Other Environmental Parameters

A review of the spreadsheet output in Appendix C indicates the following additional findings related to solid waste generation, water use, materials use, and effects to land and ecosystems.

- The PRB alternative has the largest footprint for solid waste generation, and most of this footprint is due to off-site activities. The PRB alternative involves substantial use of manufactured materials, and the manufacturing processes involve generation of waste.

- With the exception of 7 tons of hazardous waste in the bioreactor alternative for removing contaminated soil, the hazardous waste generated by all alternatives and long-term monitoring is less than 0.04 tons (or 80 pounds). The DPE alternative, which uses hydrogen peroxide as a reagent in the treatment process, has the second highest hazardous waste footprint (0.029 tons), which is less than 1% than the above-mentioned 7 tons.

- The DPE alternative has the highest overall water use because groundwater is extracted, treated, and then discharged to surface water. Because it is not applied to beneficial purposes or reinjected into the aquifer, the extracted groundwater is no longer an available aquifer resource, and therefore is considered to be “used”.

- With respect to potable water use, the biobarrier and PRB alternatives have the highest usage because potable water is used to blend reagents prior to subsurface injection.

- None of the remedy alternatives would appear to have a significant land/ecosystem footprint. Continued operation of the DPE alternative does not involve any disturbance to the land surface. The bioreactor, biobarrier, and PRB involve use of heavy equipment to excavate soils, drill new wells, or inject remediation materials.   However, the land areas involved are relatively small, and there do not appear to be any sensitive ecosystems or extensive “ecosystem services” (e.g., agriculture, soil erosion control, nutrient uptake, carbon storage, etc.) provided by this space that would be affected for any significant amount of time by the activities.

- All of the remedy alternatives involve the use of materials. The two source area remedy alternatives each use approximately 25,000 lbs of refined materials. However, the amount of materials used by the two plume migration remedy alternatives differs substantially. The biobarrier uses approximately 50,000 lbs of refined materials (mostly emulsified vegetable oil), and the PRB uses approximately 1.56 million lbs of refined materials (mostly steel, which is used as a surrogate for zero valent iron).

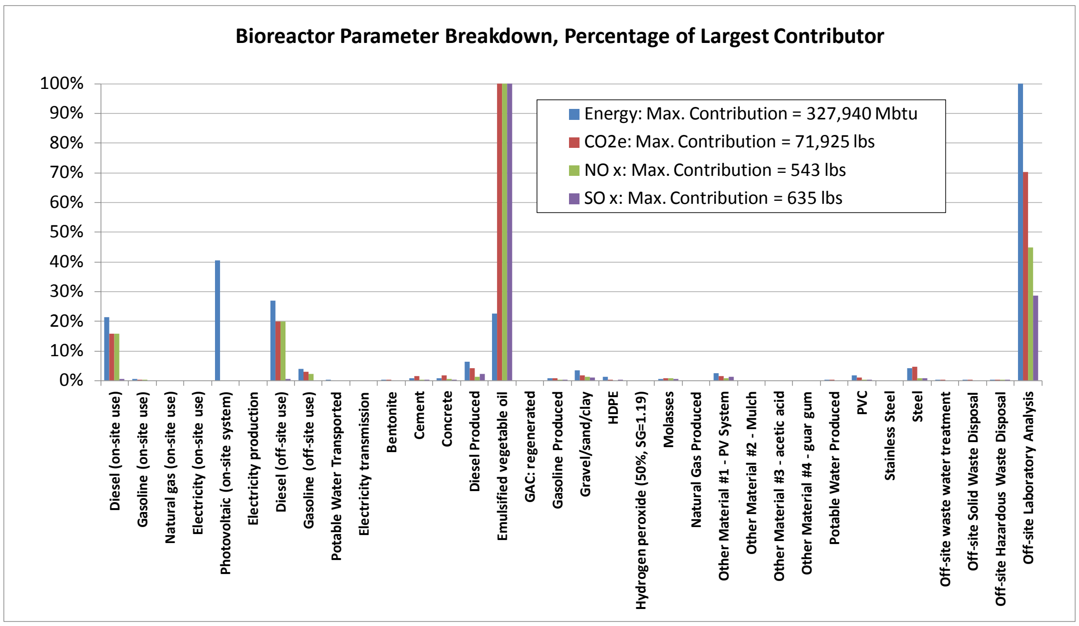
2.1.5 Individual Contributors to Footprints of Selected Parameters

Charts 11, 12, 13, and 14 show the relative contributions of the full array of remedial activities (on-site and off-site) to the footprints of selected environmental parameters. These charts are designed to focus attention on the highest contributors to the environmental footprints. Note that the highest contributors differ substantially among the four charts. For example, the highest contributor to energy for the DPE system (Chart 12) is almost two orders of magnitude greater than the highest contributor for the bioreactor (Chart 11).

Chart 11 presents the footprints for energy, CO2e, NOx, and SOx for the bioreactor alternative. The footprints for other parameters may be distributed differently. The chart is designed to indicate the contribution in terms of percentage of the maximum contributor, such that the largest contributor for each parameter is depicted as 100%. The chart indicates that, for CO2e, NOx, and SOx emissions, the key contributors are emulsified vegetable oil production and laboratory analysis. Other lower, but significant contributors are on-site diesel use (for heavy equipment operation) and off-site diesel use (for transportation of materials). For energy, the highest contributors also include laboratory analysis and electricity produced by the on-site PV system.

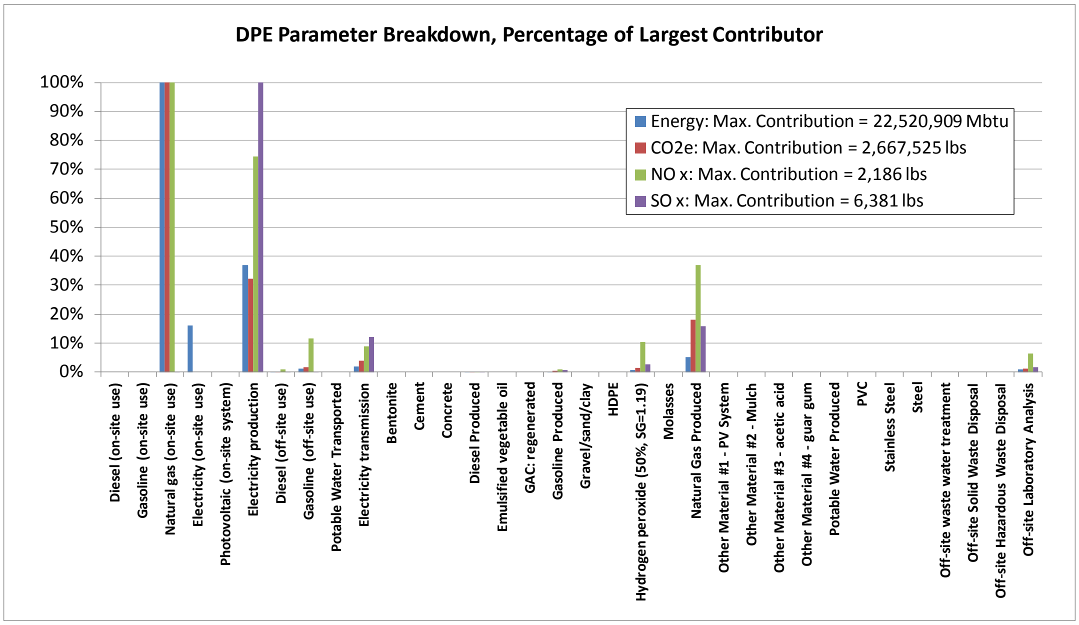
Chart 12 presents the same information for the DPE alternative. The key contributors to the footprints for all four parameters are on-site natural gas usage, grid electricity production, grid electricity transmission, and natural gas production. Laboratory analysis appears as a relatively small contributor to the various footprints because the footprints associated with natural gas usage and electricity production are so high.

Chart 11



Notes: Electricity transmission refers to electricity lost due to transmission. Electricity production refers to the process of producing the electricity at an off-site power plant, including an estimate of sacrificial loads by the power plant. Electricity transmission and production are based on the amount of electricity used on-site. "Photovoltaic (On-Site System)" refers to the solar energy required by an on-site PV system to produce a specified amount of electricity. "Other Material #1 – PV System" refers to the manufacturing and installation of the PV system.

Chart 12



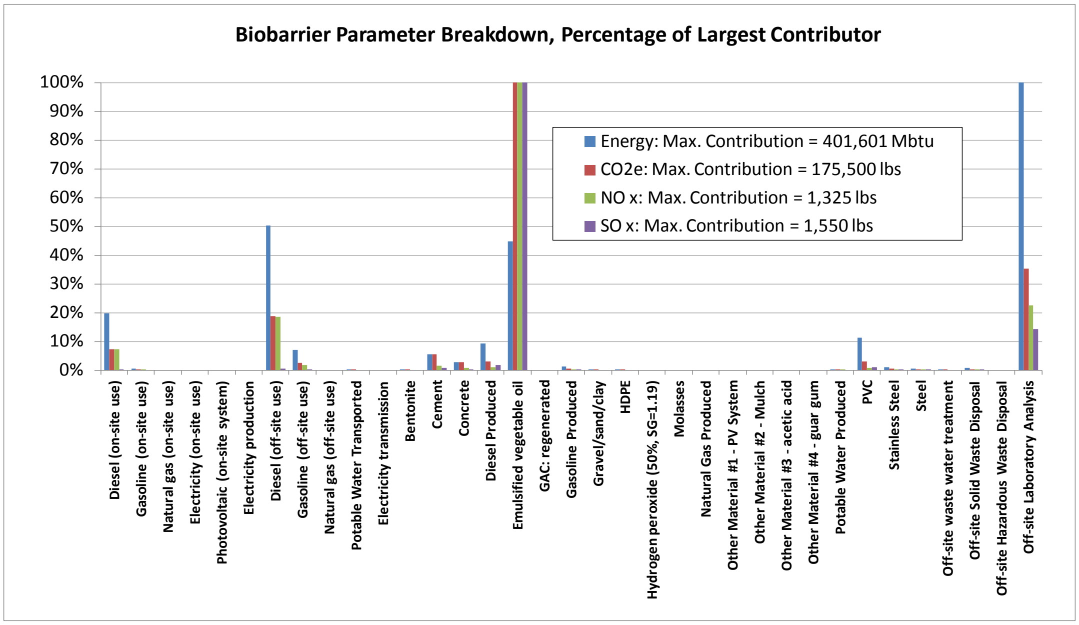
Notes: Electricity transmission refers to electricity lost due to transmission. Electricity production refers to the process of producing the electricity at an off-site power plant, including an estimate of sacrificial loads by the power plant. Electricity transmission and production are based on the amount of electricity used on-site. "Photovoltaic (On-Site System)" refers to the solar energy required by an on-site PV system to produce a specified amount of electricity. "Other Material #1 – PV System" refers to the manufacturing and installation of the PV system.

Chart 13 presents the same information for the biobarrier alternative. The primary contributor to CO2e, NOx, and SOx emissions is the production of emulsified vegetable oil. Laboratory analysis is another large contributor to these air pollutant footprints. The primary energy contributors are laboratory analysis, the production of emulsified vegetable oil, on-site diesel use (e.g., drill rig operation), and off-site diesel use (e.g., materials transportation).

Chart 14 presents the same information for the PRB alternative. The primary contributor to the footprints for all four parameters is the production of steel, which is used as a surrogate material for zero valent iron. The production of guar gum has a NOx footprint that is nearly equal to the NOx footprint associated with the steel production. On and off-site diesel use are also significant contributors to the NOx footprints, but not as significant as the contributions from steel and guar gum production. Similar to the DPE alternative, laboratory analysis associated with the PRB alternative is a relatively small contributor to the various footprints. This is because the footprints associated with zero valent iron production are so high.

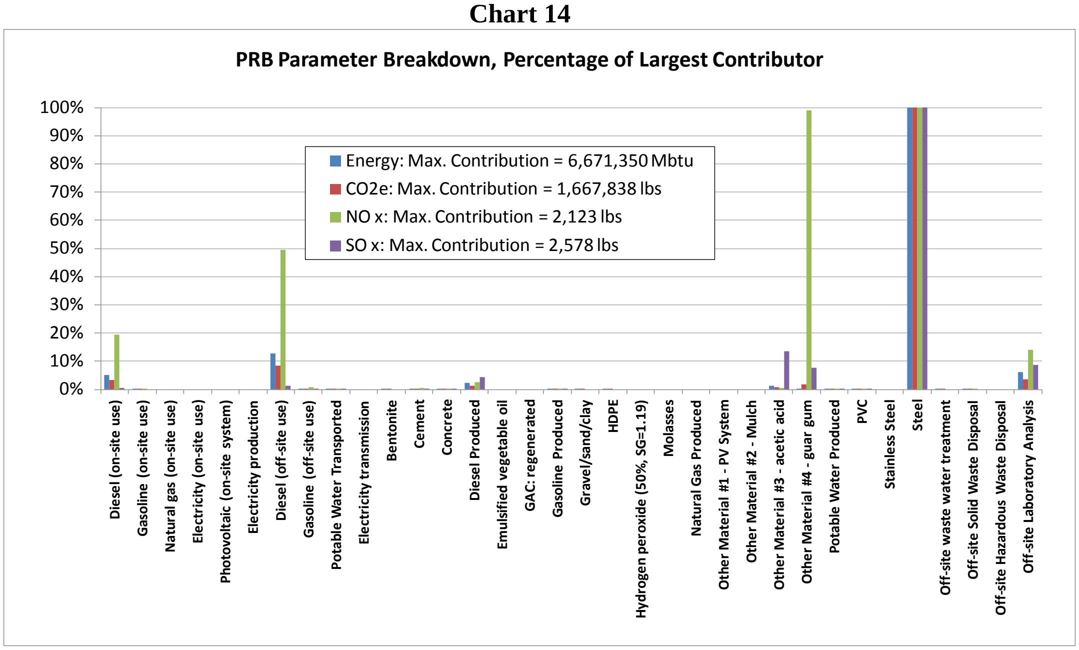
As noted in Section 1.9, the environmental conversion factors for laboratory analysis are based on assumptions made by the study team. The accuracy and appropriateness of these laboratory analysis conversion factors has a significant influence on the footprints for two of the four remedy alternatives, and the actual laboratory analysis footprints may be substantially higher or lower than presented in Charts 11,12, 13, and 14.

Chart 13



Notes: Electricity transmission refers to electricity lost due to transmission. Electricity production refers to the process of producing the electricity at an off-site power plant, including an estimate of sacrificial loads by the power plant. Electricity transmission and production are based on the amount of electricity used on-site. "Photovoltaic (On-Site System)" refers to the solar energy required by an on-site PV system to produce a specified amount of electricity. "Other Material #1 – PV System" refers to the manufacturing and installation of the PV system.

Chart 14



Notes: Electricity transmission refers to electricity lost due to transmission. Electricity production refers to the process of producing the electricity at an off-site power plant, including an estimate of sacrificial loads by the power plant. Electricity transmission and production are based on the amount of electricity used on-site. "Photovoltaic (On-Site System)" refers to the solar energy required by an on-site PV system to produce a specified amount of electricity. "Other Material #1 – PV System" refers to the manufacturing and installation of the PV system.

The tables from which Charts 11, 12, 13, and 14 were developed are provided in Appendix C and include the same information for other 11 environmental parameters for each remedy alternative. Similar charts that display the breakdown for other environmental footprints are provided in the Supplemental Charts section of this report.

2.1.6 Findings Related to Remedy Duration, Labor, and Travel

The following table presents results for remedy duration, travel, and labor. The table is color-coded to indicate the lowest (green), middle (yellow), and highest (orange) values in each category. The results are generally mixed, with no one source area remedy alternative or no one migration control remedy alternative having a significantly higher or lower footprint than the competing alternative. Relative to the DPE alternative, the bioreactor alternative has a higher number of truck trips, truck miles, and heavy equipment operation. However, the bioreactor alternative has a lower number of passenger vehicle trips and miles and a shorter remedy duration. For the migration control remedy alternatives, the biobarrier has a higher number passenger vehicle trips and miles but a lower number of heavy truck trips and miles than the PRB alternative.

		Trips to Site		Miles Driven		Man-Hours Worked On-Site	On-Site Heavy Equipment Operation
	Remedy Duration	**Passenger Vehicle**	**Heavy-Duty Truck***	**Passenger Vehicle**	**Heavy-Duty Truck***		
	Years	**Trips**	**Trips**	**Miles**	**Miles**	**Man-hrs**	**Equip.-hrs**
Source Area							
Bioreactor	10	575	85	1,603	23,000	706	303
DPE	20	1040	2	34,320	1,000	4,160	0
Migration Control							
Biobarrier	10	131	26	3,446	8,652	2,408	466
PRB	10	87	101	1,780	46,884	1,536	637

**Materials, waste, or heavy equipment transportation*

2.1.7 Interpreting the Results

The footprints that are calculated as part of this study can be grouped into the following general categories that are consistent with the EPA core elements of green remediation:

- Energy usage and air quality
  - Energy usage
  - Air pollutant emissions associated with energy usage (e.g., CO_2e, NOx, SOx, and PM)
  - Hazardous air pollutant and toxic pollutant emissions (air toxics)
- Water usage
  - All water usage
  - Potable water usage

- Materials and waste
    - Refined materials usage - total pounds of all manufactured materials such as steel, concrete, and chemicals (no overlap between unrefined and manufactured materials)
    - Unrefined materials usage - total tons of unrefined materials such as gravel/sand/clay borrow that are used directly in the remedy
    - Waste generated, including both hazardous and non-hazardous wastes
- Land and ecosystems
    - Effects on local ecosystem services

This grouping eliminates some of the redundancy in parameters that typically track together. For example, with few exceptions, energy, CO2e, NOx, SOx, and PM track together such that an alternative that has a high footprint for one would likely have a high footprint for the others. If these parameters are not grouped together, interpretation of the footprint analysis results may place more focus on energy use and related emissions than on the other core elements. The footprints associated with the above groupings for each remedy alternative are summarized in the following table and discussed below. The table ranks the footprints for each parameter grouping as low, neutral, or high relative to the other alternatives. These designations consider the magnitude of a parameter footprint for an alternative relative to the magnitude of the same parameter footprint for the competing alternative. "High" or "low" are typically reserved for situations where the parameter footprints for two competing alternatives are considered to be significantly different by the study team (e.g., greater than 30%). For cases where the parameter footprints are not significantly different a "neutral" designation is given.

	Source Area			**Migration Control**	
	Bioreactor	**DPE**		**Biobarrier**	**PRB**
Energy usage	Low	High		Low	High
CO2e, NOx, SOx & PM emissions	Low	High		Low	High
Air toxics	Low	High		Low	High
All water usage	Low	High		Low	High
Potable water usage	Neutral	Neutral		Low	High
Refined materials usage	Neutral	Neutral		Low	High
Unrefined materials usage	High	Low		Neutral	Neutral
Waste generated	Neutral*	Neutral*		Low	High
Ecosystem services affected	Neutral	Neutral		Neutral	Neutral

**Although the bioreactor alternative has more waste generated than the DPE alternative (3.8 tons vs. 1.4 tons), the study team considered both quantities relatively low and therefore the difference between the two insignificant.*

The above table illustrates that for the source area remedies, the DPE alternative has more "high" footprints than the bioreactor alternative. The table does not, however, illustrate the substantial difference in the magnitudes of the energy and air emission footprints for these competing alternatives. For the plume migration control remedies, the PRB has "high" footprints for 7 of the 9 categories. The two remaining categories are given a "neutral" designation.

In some cases, a remedy alternative with the most parameter footprints characterized as "low" may not necessarily be the most favorable alternative from an environmental footprint perspective. This will depend of the relative importance that stakeholders give to the various groupings. However, for the scenarios presented here, one remedy for the source area (the bioreactor) and one remedy for plume migration control (the biobarrier) clearly have more favorable environmental footprints than their respective competing remedies.

2.2 SECONDARY ANALYSIS

2.2.1 BIOREACTOR

Charts 15 through 17 present the total footprints for the bioreactor alternative for the same three global or regional environmental parameters (CO2e, SOx, and mercury) depicted in Charts 2 through 4, but organize the information according to remedy component. Chart 15 indicates that remedy construction, O&M, and performance monitoring have very similar CO2e footprints for this alternative. The SOx footprints for the three remedy components are within an order of magnitude of each other, but the O&M component is significantly larger than construction and performance monitoring. With respect to mercury released, the construction and monitoring components have similar footprints, and the footprint from O&M is negligible.

Chart 15

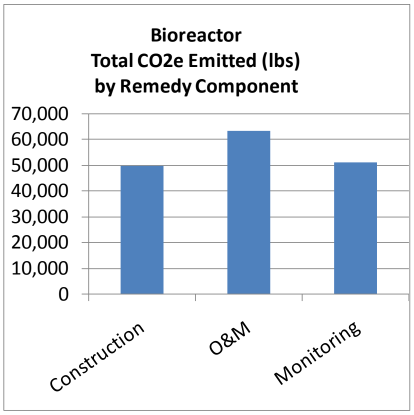


Chart 16

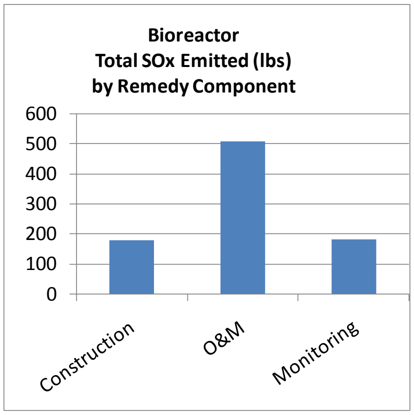
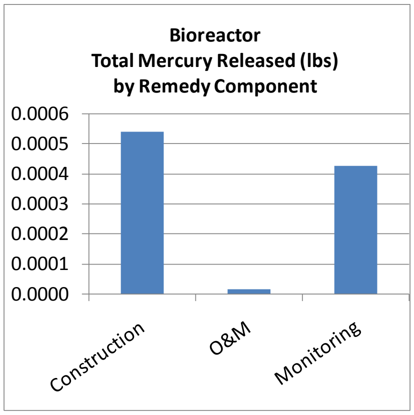


Chart 17



"Total" refers to on-site plus off-site footprint for the life-time of the remedy.
"Monitoring" refers to Bioreactor-specific performance monitoring, not site-wide long-term monitoring (LTM).

Charts 18 through 20 present the on-site footprints for the bioreactor alternative for the same three local or regional environmental parameters (NOx, PM, and air toxics) depicted in Charts 5 through 7, but organize the information according to remedy component. The charts indicate that for this alternative, the construction component is the only significant on-site contributor to these parameters. There are NOx and PM emissions associated with limited use of gasoline-powered generators during groundwater monitoring, but the emissions are too low to be observable on these charts.

Chart 18

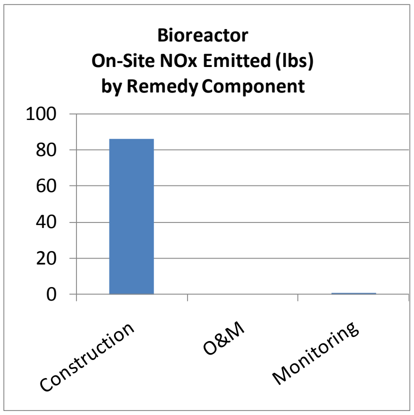


Chart 19

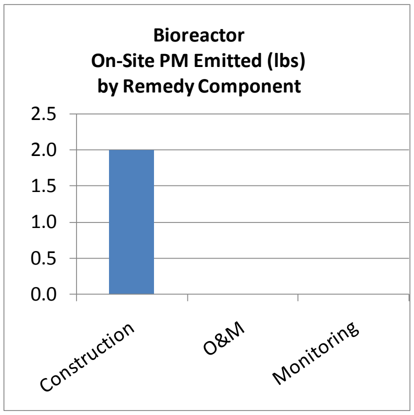
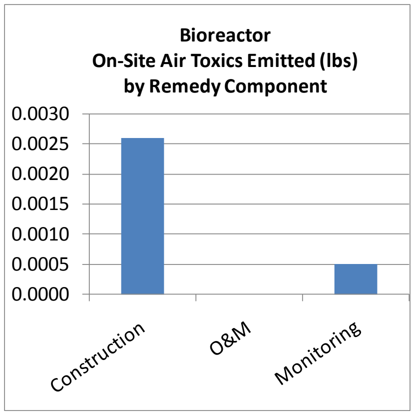


Chart 20



These charts show the on-site footprints over the life-time of the remedy.
"Monitoring" refers to Bioreactor-specific performance monitoring, not site-wide long-term monitoring (LTM).

More information regarding the distribution of total and on-site footprints for various parameters is included in the Supplemental Charts and in Appendix C.

2.2.2 DPE

The DPE alternative involves no additional construction because the remedy is already constructed, and no additional monitoring beyond the site-wide monitoring is required; therefore, O&M is the only remedy component that contributes to the footprints. As indicated in Chart 12, the majority of the energy footprint results from electricity usage and the majority of the remaining footprints from chemical usage, transportation, and laboratory analysis for treatment system sampling. More information regarding the distribution of total and on-site footprints for various parameters is included in the Supplemental Charts and in Appendix C.

2.2.3 BIOBARRIER

Charts 21 through 23 present the total footprints for the biobarrier alternative for the same three global or regional environmental parameters (CO2e, SOx, and mercury) depicted in Charts 2 through 4, but organize the information according to remedy component. O&M is the largest contributor to the CO2e and SOx footprints, primarily because of the production of emulsified vegetable oil that is used during O&M. (Note that construction of the biobarrier alternative includes the installation of the injection wells and O&M includes both the initial injection of emulsified vegetable oil and the maintenance injection 5 years later.) Whereas construction and monitoring are significant contributors to the CO2e footprint, construction is not a significant contributor to the SOx footprint and monitoring is only a marginally significant contributor to the SOx footprint. By contrast, construction is the largest contributor to the mercury footprint because of the mercury that is released in association with the production of injection well materials such as PVC pipe and cement grout. Footprint contributions from monitoring are primarily associated with the laboratory analysis and not the actual collection of samples at the wells.

Chart 21

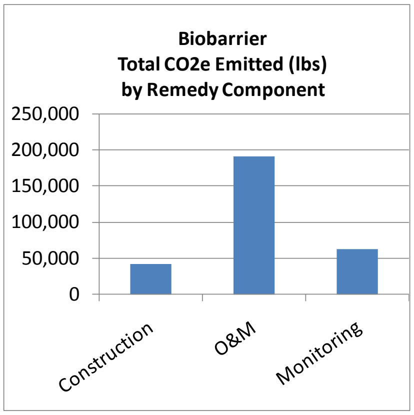


Chart 22

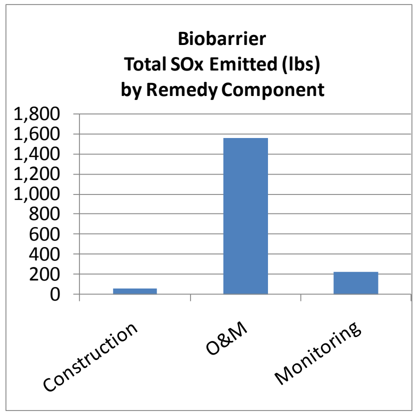
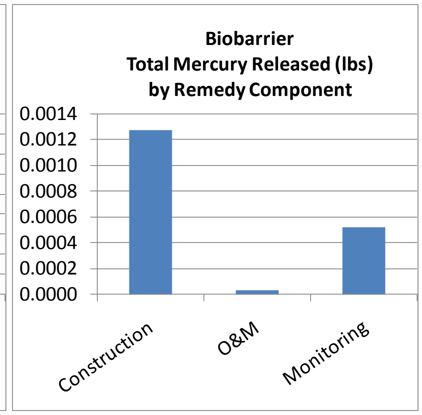


Chart 23



These charts show the on-site footprints over the life-time of the remedy.
"Monitoring" refers to Biobarrier-specific performance monitoring, not site-wide long-term monitoring (LTM).

Charts 24 through 26 present the on-site footprints for the biobarrier alternative for the same three local or regional environmental parameters (NOx, PM, and air toxics) depicted in Charts 5 through 7, but organize the information according to remedy component. The construction phase is the largest contributor, primarily due to the use of drill rigs to install the injection wells. The O&M phase contributes little to the on-site footprint because fire hydrants are used to provide the water and pressure for injecting the emulsified vegetable oil. This represents a tradeoff for on-site or local footprints. The use of fire hydrants lowers on-site air emissions but requires the use of potable water for the injections, which would be reflected in a higher potable water footprint. By contrast, extracting and using groundwater for blending and injecting the emulsified vegetable oil might use an on-site generator to power the extraction pumps (if local electricity is not available) but does not involve the use of potable water. The on-site air toxics emissions are limited in quantity and are the result of the gasoline generators for operating the sampling pumps.

Chart 24

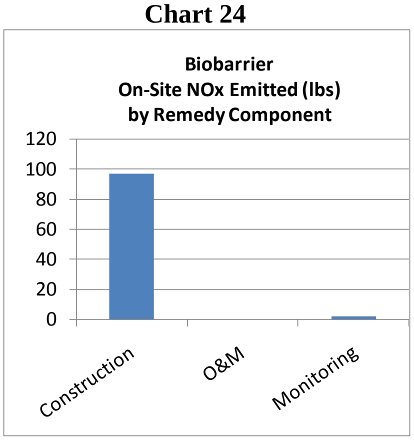


Chart 25

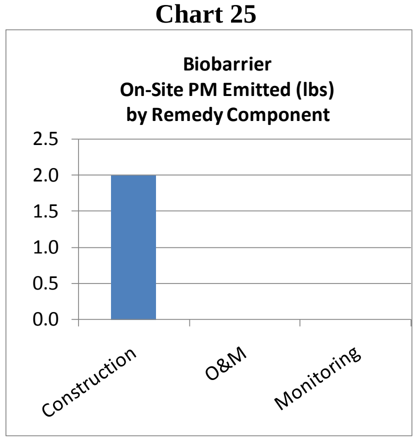
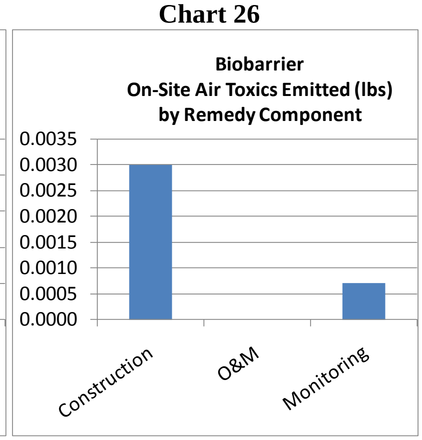


Chart 26



These charts show the on-site footprints over the life-time of the remedy.
"Monitoring" refers to Biobarrier-specific performance monitoring, not site-wide long-term monitoring (LTM).

More information regarding the distribution of total and on-site footprints for various parameters is included in the Supplemental Charts and in Appendix C.

2.2.4 PRB

The PRB alternative includes only construction and monitoring. There is no O&M component. As is evident in Chart 14, the large majority of the footprints for energy and air pollution result from construction-related items, including steel and guar gum production and diesel usage for material transportation and heavy equipment operation. The monitoring component represents less than 10% of these footprints.

The distribution of the on-site footprints for NOx, PM, and air toxics among the various remedy phases is similar to that for the biobarrier alternative (Charts 24 through 26) but with higher values. The heavy equipment used to install the PRB is the primary contributor during the construction phase, and the gasoline-powered generators for monitoring are the primary contributors for the performance monitoring.

More information regarding the distribution of total and on-site footprints for various parameters is included in the Supplemental Charts and in Appendix C.

2.3 SENSITIVITY ANALYSIS

The scope of the sensitivity analysis is described in Section 1.11.3. The findings are summarized below.

2.3.1 DOUBLE THE AMOUNT OF VEGETABLE OIL ADDED EACH YEAR

The secondary analysis for the bioreactor indicated that O&M is a significant contributor to the CO2e and SOx footprints. Review of the supplementary charts indicates that O&M is also a significant contributor to the energy, NOx, and PM footprints. O&M involves weekly checks and vegetable oil addition. The amount of vegetable oil that is assumed to be added annually to maintain remedy effectiveness (200 lbs) is an engineering estimate, and actual conditions may suggest the need for greater amounts of vegetable oil. The following table presents the increases in the total remedy footprints for CO2e, NOx, and SOx that would result from doubling the amount of vegetable oil added to the bioreactor each year from 200 gallons to 400 gallons.

Scenario	Energy (Mbtus)	CO2e (lbs)	NOx (lbs)	SOx (lbs)	PM (lbs)
Original scenario (200lbs/yr total)	783,730	164,084	1,026	869	66
Additional oil (400 lbs/yr total)	872,547	225,766	1,489	1,373	93
% Increase	**11%**	**38%**	**45%**	**58%**	**41%**

Doubling the amount of oil added each year for maintenance injections results in a relatively small (but significant) increase in the total energy use but causes a more than 50% increase in the SOx footprint. This finding indicates that the amount of oil added for maintenance injections is an important parameter in evaluating the environmental footprint of this remedy and that all environmental parameters do not increase or decrease evenly with changes in remedy assumptions. Approximately 66% of the energy increase results from the production of the emulsified vegetable oil, and the remaining increase is associated with diesel fuel use for transportation and production of that diesel. By contrast, over 90% of the increase in NOx emissions results from the production of emulsified vegetable oil and less than 10% results from increased diesel fuel use for transportation.

This sensitivity analysis highlights one of the challenges of conducting footprint analyses at early stages of the remedial process (such as during remedy selection or preliminary remedy design) and the difficulty in using the results in remedy decision-making. Consideration of this high degree of variation in the footprint that may result from typical uncertainties such as amount of bionutrients required is merited when interpreting and applying the results of the footprint analysis.

2.3.2 Optimizing the Treatment Components of the DPE System

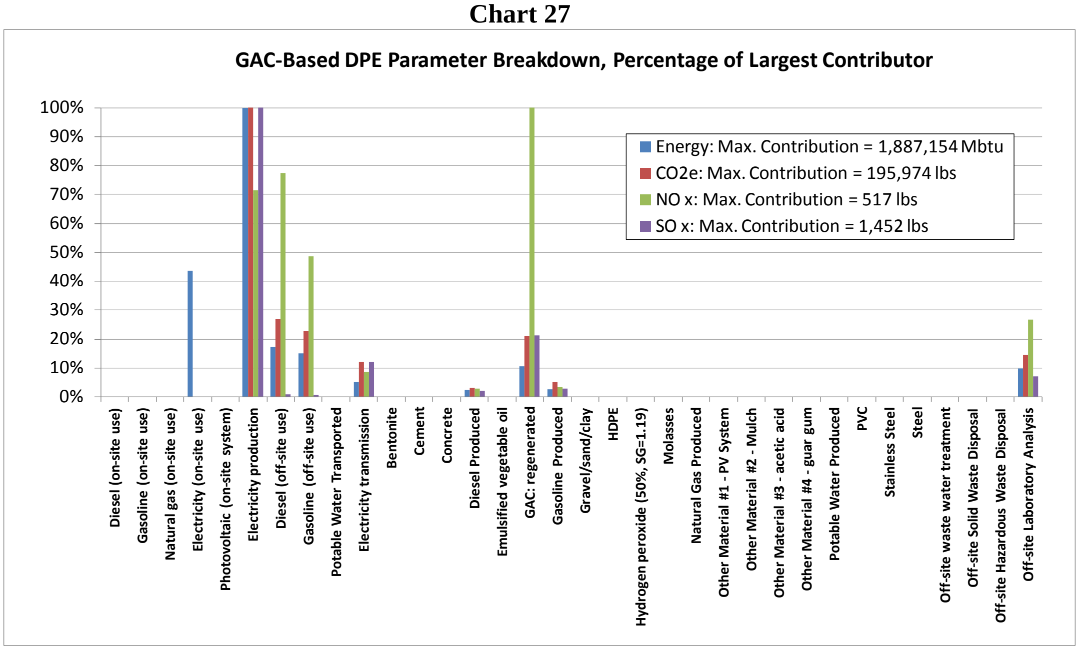
The DPE system footprinted in Sections 2.1 and 2.2 includes energy intensive treatment processes such as UV/oxidation for water treatment and thermal oxidation for soil vapor treatment. Granular activated carbon (GAC) is a common treatment technology that is also appropriate for treating the water and soil vapors. The following table summarizes how changing from the existing treatment components to GAC changes the footprint for the DPE alternative.

Scenario	Energy (Mbtus)	CO2e (lbs	NOx (lbs)	SOx (lbs)	PM (lbs)
DPE with UV/oxidation & thermal oxidation	36,668,706	4,235,826	5,476	8,487	645
DPE with GAC for water & vapor	3,899,924	184,373	1,340	511	23
% change	(89%)	(96%)	(76%)	(94%)	(96%)

** reductions indicated in parentheses*

The change in technology reduces all five of these parameters by 76% to 96%, depending on the parameter. The energy footprint reduction is primarily the results of eliminating the extensive on-site natural gas use and reducing electricity usage. Some of this energy reduction is offset by the energy requirements associated with the production, regeneration, and transportation of the GAC. Chart 27 presents the various contributors to energy and air emission footprints for the GAC-based DPE system.

Chart 27



Notes: Electricity transmission refers to electricity lost due to transmission and distribution. Electricity production refers to the process of producing the electricity at an off-site power plant and includes an estimate of sacrificial loads by the power plant. Electricity transmission and production are based on the amount of electricity used on-site. "Photovoltaic (On-Site System)" refers to the solar energy required by an on-site photovoltaic system to produce the generated amount of electricity. "Other Material #1 – PV System" refers to the manufacturing and installation of the PV system.

As is evident from the differences between Chart 12 and Chart 27, eliminating the natural gas usage allows more attention to be placed on other contributors. It is apparent that the footprint contributions are more balanced between electricity generation, diesel use, gasoline use, GAC regeneration, and laboratory analysis, as compared with the results for the DPE system (with UV/Ox and thermal oxidation) shown in Chart 12.

Prior to this study, the site team modified the system from UV/Ox and thermal oxidation to GAC, representing a good example of reducing the footprint of a treatment system while maintaining performance and compliance with ROD requirements.

2.3.3 Modifying the Assumed Generation Mix for the DPE Alternative

The study team encountered a number of options for characterizing the power mix for grid electricity used by Travis AFB. These options depend on the degree of research conducted and on the set of assumptions made about footprint conversion factors. Since the study team expects that footprint analyses at other sites may encounter a similar array of options regarding the power mix, this sensitivity analysis explores the options encountered for Travis AFB, and estimates the total CO2e footprint for the various options. This sensitivity analysis is applied to the GAC-based DPE alternative.

The electricity for Travis AFB is provided by the Western Area Power Administration (WAPA), which is a power supplier operated by the U.S Department of Energy, and provides electricity to entities such as municipalities, public utility districts, military installations, and educational institutions. The website for WAPA describes WAPA as providing primarily hydroelectric power from Bureau of Reclamation hydroelectric projects to these entities. Initial contact by the study team with a representative of WAPA confirmed this was likely the case for Travis AFB. However, for some entities a blend of power is provided, and additional contact with WAPA revealed that this was the case for Travis AFB. WAPA described the mix provided to Travis AFB as 22% hydroelectric power from the Bureau of Reclamation hydroelectric projects. WAPA further stated that 70% of the non-hydroelectric power comes from the general California power mix, and 30% of the non-hydroelectric power comes from the Northwest Power Pool.

The experience of the study team in researching the power mix shows that varying degrees of research would have led to differing assumptions regarding the power mix for electricity generation. Little or no research would have resulted in choosing the California mix from eGRID (www.epa.gov/egrid) or from the California Energy Commission (CEC). Initial research into the local provider (WAPA) could likely have resulted in the assumption that all electricity is provided by hydroelectric power. Thorough research into WAPA revealed yet a different power mix.

This sensitivity analysis tests the effect of the electricity generation fuel mix on the footprint results by using the following generation mixes:

- eGRID CAMX Subregion mix
- California 2008 Total System Power mix from the California Energy Commission
- the WAPA power mix for Travis AFB
- a hypothetical 100% hydroelectric power mix
- all electricity provided by an on-site photovoltaic system.

The California 2008 Total System Power mix and eGRID CAMX mix may be appropriate for much of California, but are different from the actual fuel mix supplied by WAPA to Travis AFB (see table below). The following table presents the three generation mixes.

Fuel Type	eGRID CAMX 2007 Mix	% of California Total System Power for 2008	WAPA Power Mix for Travis AFB for 2010
Biomass & waste	2.4%	2.1%	1.4%
Geothermal	4.4%	4.5%	2.6%
Hydroelectric	12.1%	12.4%	40%
Solar	0.3%	0.2%	0%
Wind	2.5%	2.4%	1.8%
Coal	7.6%	18.2%	17.4%
Natural gas	52.5%	45.7%	28.1%
Nuclear	16.3%	14.5%	8.7%
Other	0.9%	0%	0%
Total	**100%**	**100%**	**100%**

In addition to the generation mixes, there are different assumptions or sources of information that can be used to convert the generation mix into emission footprints. The following table presents the CO2e emission factor (footprint per kWh) for five different assumptions. Two of the assumptions use emission factor information from the NREL life-cycle inventory database, one of which accounts for extraction of fuels used in electricity generation. Two of the assumptions use the emission factors from the CFR 98.3 Subpart C. One uses a generic 33% thermal efficiency for natural gas power plants, and the other uses an increased efficiency of 42% for a natural gas power plant. The fifth assumption is the actual base-load emission factor developed by eGRID.

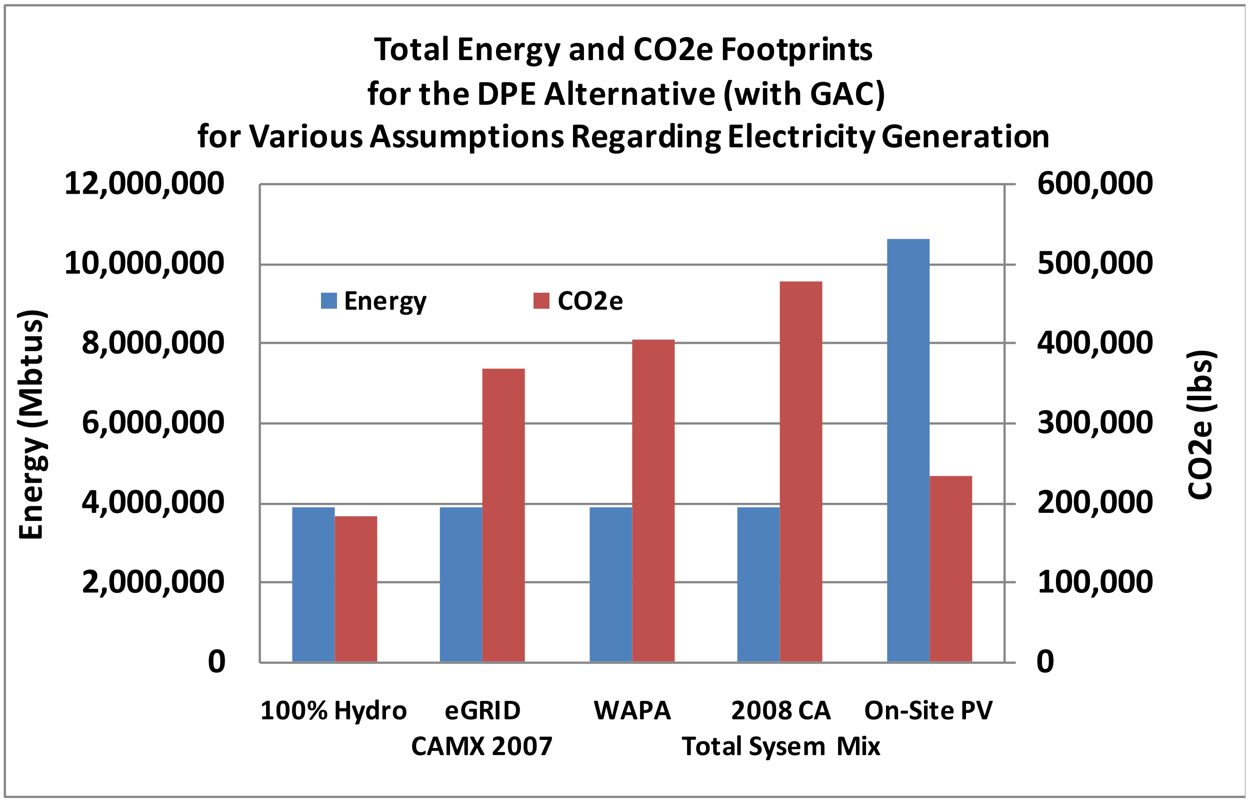
	CO2e Footprint (lbs per kWh)		
Generation Mix	**California 2008 Mix from CEC**	**eGRID 2007 CAMX**	**WAPA Mix**
NREL, with extraction	1.05	0.91	0.79
NREL, no extraction	0.99	0.86	0.74
CFR 98.3, no extraction	0.94	0.81	0.71
CFR 98.3, no extraction and increased efficiency	0.82	0.68	0.64
Actual eGRID CAMX		0.68	

It is apparent that resource extraction increases the footprint per kWh by approximately 6%. In addition, it appears that the NREL information increases the footprint per kWh by approximately 5% relative to the CFR 98.3 Subpart C information. Finally, it is apparent that a higher efficiency for natural gas power plants (or some other modification) is needed to align calculated footprints using the eGRID generation mix with the actual eGRID emission factors. All of these assumptions for emissions factors would have been appropriate to apply to Travis AFB for a footprint analysis, but it is apparent that there is a 39% to 64% difference between the highest and lowest values, so either an intentional or default choice of one set of assumptions over another could lead to a significant variation in the results of the footprint analysis.

The hydroelectric and photovoltaic options are clearly different than these more conventional power mixes, in that the hydro power source is assumed to have a CO2e footprint of zero, and the CO2e footprint of photovoltaic cells is based on manufacturing and installation of the cells.

The study team estimates that a 10kW photovoltaic system would be sufficient to offset the electricity demand from the DPE remedy that uses GAC for water and vapor treatment. Chart 28 presents the energy usage and CO_2e emissions for four different power mix assumptions.

Chart 28



Notes:

- *100% Hydro – scenario uses electricity that is generated by 100% hydroelectric power*
- *eGRID CAMX 2007 - scenario uses base-load emission factor provided in eGRID for the CAMX subregion in 2007. This emission factor does not include emissions associated with extraction of fuel used for electricity generation*
- *WAPA – scenario uses generation mix provided by WAPA and converted to a CO2e emission factor using emission factors from NREL life-cycle inventory database for each generation source. This emission factor includes emissions associated with extraction of the fuel used for electricity generation.*
- *2008 CA Total System Mix – scenario uses generation mix provided by the California Energy Commission for 2008 and converted to a CO2e emission factor using emission factors from NREL life-cycle inventory database for each generation source. This emission factor includes emissions associated with extraction of the fuel used for electricity generation.*
- *On-site PV – scenario assumes all electricity is provided by an on-site PV system. The emissions associated with PV system manufacturing and installation are included.*

Chart 28 indicates that the energy usage for the hydroelectric, eGRID, WAPA, and CA Total System scenarios are the same. This is because this study assumes an approximate generic efficiency of 33% for all sources of electricity generation. That is, the efficiency of all hydroelectric, coal, natural gas, nuclear, etc. are assumed to be the same. (This is not likely the case. That is, efficiencies can vary substantially from facility to facility, but more detail on power plant efficiency is not readily available for this study or green remediation evaluations in general, and the additional detail may not substantially change the footprint results or interpretation.) Chart 28 also indicates that the energy usage for on-site PV generation is substantially higher than the other two sources of electricity. This is because this analysis uses the incident solar energy on the PV modules based on an efficiency of 9% for generating electricity from solar energy. This efficiency of PV modules is based on the PVWATTs system developed by the National Renewable Energy Laboratory and a nominal electricity output of approximately 12 watts per square foot based on typical values for commercially available multi-crystalline photovoltaic modules. An efficiency of 9% is substantially lower than the 33% efficiency assumed for other electricity generation methods.

Chart 28 indicates that the CO2e footprint for the eGRID, WAPA, and CA Total System mixes range from approximately 370,000 lbs to 480,000 lbs. Because of the increased percentage of hydroelectric power in the WAPA mix, the CO2e footprint associated with the WAPA mix is approximately 15% to 20% lower than that of the CA Total System mix, but because of slight differences in the generation mix and differences in the various assumptions for calculating the CO2e emission factors (see above table), the CO2e footprint for the eGRID scenario is approximately 23% lower than the CA Total System mix. These differences are differences in the CO2e footprint for the remedy as a whole, and not just the footprint associated with electricity generation. It is apparent from the CO2e footprint for the hydroelectric scenario (which involves no CO2e footprint for electricity generation) that approximately 200,000 lbs of CO2e result from remedy components other than electricity generation. The difference in the CO2e footprint between the eGRID mix and the Total CA System mix that is associated only with electricity generation is more substantial (almost 40%).

Chart 28 also indicates that the CO2e footprint for the scenario with an on-site photovoltaic system is somewhat higher than that of the hydroelectric system. This is because there is a CO2e footprint associated with manufacturing and installing the photovoltaic system on site. No emissions-related footprints were assumed for the construction of hydroelectric power plants for two primary reasons. First, the hydroelectric facilities would likely have been created before the remedy was conceived; therefore, the footprint for construction is not an “additional” footprint due to remedy operation. Second, although the footprint for construction of each power plant is large, the distribution of that footprint over all of the electricity generated by the plant over many years would result in a negligible footprint per unit of electricity used by the DPE system. For this study and other footprint quantifications studies conducted by EPA, these two reasons are also applied to other types of power plants, fuel refineries, and manufacturing plants. No footprint was assumed for the operation of the hydroelectric plant as well because the footprint associated with the operation is assumed to be negligible given the relatively small amount of emissions that would be generated from maintenance activities and the large amount of electricity generated. The scenario with the CA Total System Mix is substantially higher than either of the other two scenarios because the CA Total System Mix includes the use of fossil fuels such as coal and natural gas.

Chart 28 highlights the importance of knowing and selecting the appropriate fuel blend that is used to generate the electricity used at the site. It also conveys that there is a measureable footprint for manufacturing and installing a photovoltaic system at a site (approximately 4.5 lbs of CO2e per installed Watt or 45,000 lbs of CO2e for the assumed 10 kW system at Travis). Given that photovoltaic systems have a measureable and reasonably high footprint for manufacturing and installation, it is important that the photovoltaic system generate electricity over a long period of time so that the renewable energy that is generated can more than offset the footprint for manufacturing and installation. The vapor extraction portion of the DPE system is anticipated to operate for 10 years, and the groundwater extraction portion of the DPE system is anticipated to operate for 20 years. For comparison, PV modules typically have a warrantee for 20 years or longer.

2.3.4 MODIFY NUMBER OF BIOBARRIER INJECTION EVENTS AND AMOUNT OF INJECTED OIL

The frequency of injection events and the amount of vegetable oil that needs to be added per event to maintain biobarrier effectiveness is an engineering estimate, and actual conditions may suggest the need for more frequent injections or more injected oil per event. Chart 29 presents the increases for total energy, CO2e, NOx, and SOx footprints that would result from doubling the frequency of events using the same amount of oil per event. This is essentially the same level of effort and resources required for keeping the number of events the same but doubling the amount of oil per event because doubling the amount of oil injected per event would require longer events.

Chart 29

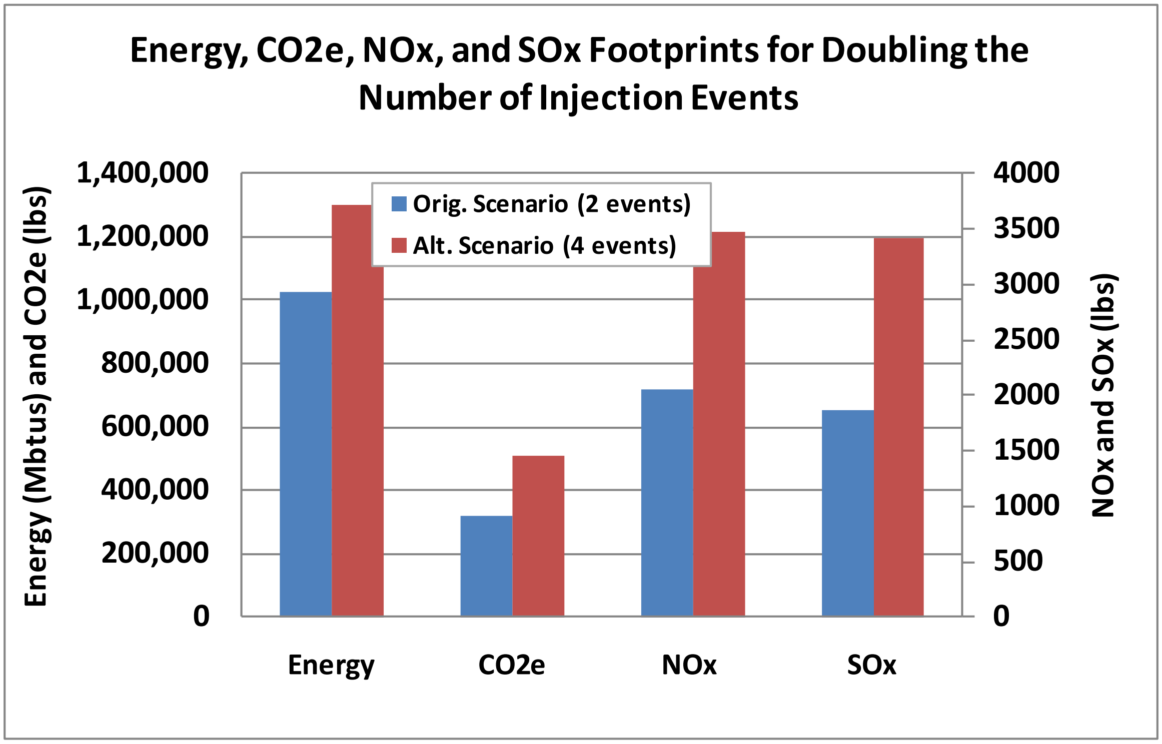


Chart 29 illustrates that doubling the number of injection events nearly doubles the NOx and SOx footprints but does not quite double the energy and CO2e footprints. More than 90% of the increases in CO2e, NOx, and SOx emissions result from the production of emulsified vegetable oil. By contrast, approximately 66% of the increase in energy footprint results from the production of emulsified vegetable oil.

2.3.5 MODIFYING AMOUNT OF FUEL USED FOR TRANSPORTATION

Transportation distances and the mode of transportation are additional uncertainties in quantifying environmental footprints, especially at the remedy selection or remedy design state when material vendors and service providers have not been specifically identified. Reducing the distances between vendors and service providers would reduce fuel use and therefore the energy and emissions associated with fuel use. The mode of transportation can also affect the fuel use. This sensitivity analysis only considers truck transportation to avoid additional complexity from considering other transportation types and also because there is substantial variation in how trucks may be used to transport freight. Material transportation can also occur by train, air, or cargo ship.

Truck transportation by specialty freight involves carrying only a specific order for a single customer on a vehicle whereas common freight would involve carrying several different orders for various customers on a truck so that the truck can travel at near capacity. Calculating fuel usage for specialty freight would involve multiplying the distance traveled by the fuel economy of the truck, which is typically around 7 miles per gallon but varies to some degree due to driving conditions, vehicle make/model, vehicle maintenance, and cargo weight. The empty return trip for the vehicle also typically needs to be considered. Calculating fuel usage for common freight is typically based on the ton-mile (e.g., the weight of the cargo multiplied by the distance traveled) and an average fuel economy per ton-mile. This study considers two average fuel economies for common freight. The "light load" assumes that the cargo carried by the truck is not particularly dense (e.g., PVC pipe), such that the volume of the cargo is the limiting constraint rather than the weight. The "heavy load" considers that the cargo is dense (e.g., sand or gravel), such that the weight is the limiting constraint. On a per ton basis, the "light load" uses more fuel per ton of cargo because the truck itself comprises a larger percentage of the total weight that is moved. 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 the inventory sheets provided in Appendix A.

Specialty freight (includes empty return trip)

Delivery trip:	*500 miles*	÷	*7.2 miles per gallon*	=	*69.4 gallons*
Empty return trip:	*500 miles*	÷	*8.5 miles per gallon*	=	*58.8 gallons*
			Total:		*128 gallons*

Specialty freight (excludes empty return trip)

500 miles ÷ 7.2 miles per gallon = 69.4 gallons

Common freight "light load" (i.e., truck is partially loaded, including freight not related to the site.)*

1.5 tons × 500 miles × 0.024 gallons per ton-mile = 18 gallons

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

1.5 tons × 500 miles × 0.011 gallons per ton-mile = 8.25 gallons

** a set weight of cargo (e.g., 1.5 tons) comprises a larger percentage of the overall cargo weight for a "light load" than a "heavy load" resulting in a higher fuel usage per ton of transport for "light loads"*

The fuel use differs substantially (ranging from 8 to 128 gallons) depending on the mode of truck transportation assumed. In reality, transportation required for a remedy alternative may consist of a combination of modes. For example, the vegetable oil may be carried via heavy load common freight for 450 miles to a local distribution center and then transported another 50 miles via specialty freight with an empty return trip. Using the same types of calculations and fuel economies above, this would translate to a fuel usage of approximately 20 gallons.

Identifying specific modes of transportation and distances is expected to be beyond the scope of most footprint quantification studies, including this one. Instead, this sensitivity analysis evaluates different modes of transportation and distances by proxy. That is, it varies the diesel usage for transportation related to materials and off-site services for the bioreactor and biobarrier alternatives, and presents the changes in the total energy, CO2e, and NOx footprints for each remedy alternative. The baseline fuel use, half of the baseline fuel use, and double the baseline fuel use are considered. Charts 30 through 32 illustrate the results for the bioreactor, and Charts 33 through 35 illustrate the results for the biobarrier.

Bioreactor Charts

Chart 30

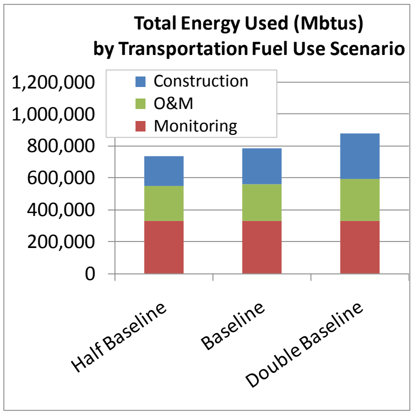


Chart 31

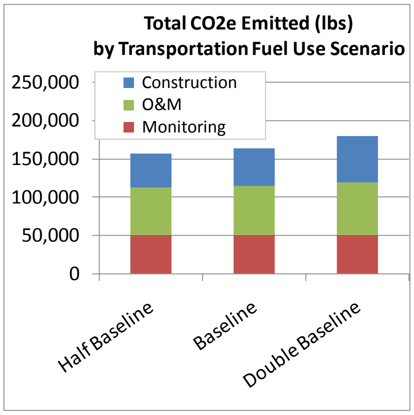
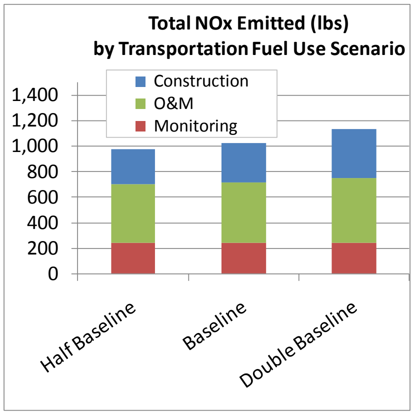


Chart 32



"Total" refers to on-site plus off-site footprint for the life-time of the remedy.

Biobarrier Charts

Chart 33

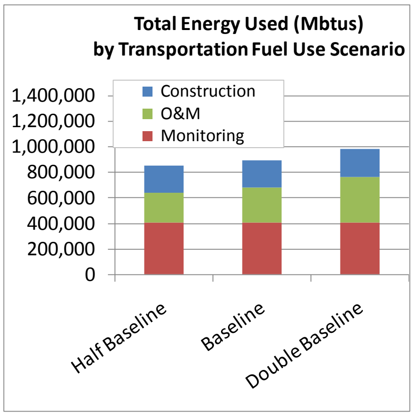


Chart 34

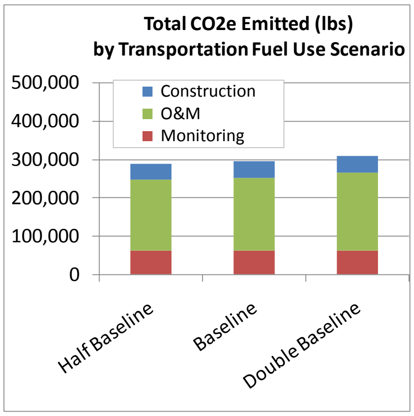
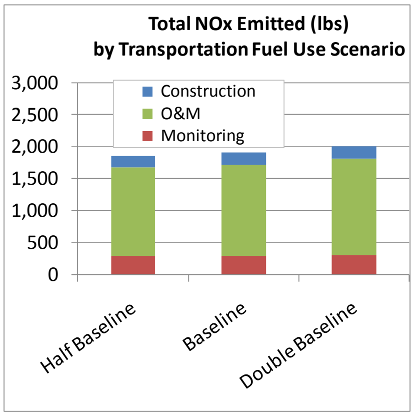


Chart 35



"Total" refers to on-site plus off-site footprint for the life-time of the remedy.

As is evident from Charts 30 through 35, there is an observable change in the energy, CO2e, and NOx footprints as a function of the amount of fuel used for transportation. The change is on the order of a 7%

to 15% increase between the “half baseline” and “double baseline” scenarios. That is, there is a 7% to 15% change in the various footprints for a factor of 4 change in the fuel used for transportation. This suggests that although reasonable approximations should be made for quantifying fuel use, the substantial effort required to identify modes of transportation and specific transportation distances would not be merited in many cases. This conclusion applies to the bioreactor and biobarrier remedies, which are both remedies that are heavily dependent on materials use. The footprint from materials manufacturing and other aspects of the remedy overshadow the footprint associated with transporting those materials. The conclusion regarding the relatively minor impact of transportation assumptions may not be valid for an excavation and off-site disposal remedy where material use is limited, but transportation requirements are high. In those cases, the distance to the specific disposal facility and the likely mode of transportation should be identified as accurately as possible.

3.0 OBSERVATIONS

The observations discussed here are divided into two categories: those specifically relevant to the conditions and assumptions at the DP039 Site and lessons learned that might apply to footprint analysis of remediation in general.

3.1 Observations Relevant to Remediation at DP039 Site

The following observations are based on the results for the remedy alternatives considered for the DP039 Site. The footprint analysis results are highly dependent on the site-specific assumptions, and these observations do not necessarily apply to environmental footprints in general or other sites, even if the remedial technologies are the same as those considered here.

3.1.1 A Comparison of Footprints for Different Remedies

- The DPE alternative has substantially higher energy and emission footprints relative to the bioreactor alternative. The DPE alternative also has a substantially higher water footprint because the extracted water is treated and discharged to surface water, which changes the nature of that water resource.

- PRB involves substantially more materials than the biobarrier alternative, and as a result, the PRB alternative has substantially higher footprints for most environmental parameters, primarily due to the manufacturing of the materials.

- The environmental footprints for the biobarrier alternative (i.e., the migration control remedy) are generally larger than the footprints for the bioreactor alternative (i.e., the source area remedy). This is primarily because the biobarrier alternative requires more refined materials (e.g., emulsified vegetable oil) than the bioreactor alternative. The use of refined materials directly affects the refined materials footprint and the manufacturing of the refined materials contributes significantly to the energy and emissions footprints. Additionally, for the biobarrier, potable water is used to blend and inject the emulsified vegetable oil. The biobarrier alternative involves more materials use compared to the bioreactor alternative primarily due to the larger area of application.

- The on-site footprints for the bioreactor, DPE, and biobarrier are primarily due to on-site diesel used to power drill rigs or other heavy equipment, but the on-site footprints for the DPE alternative are primarily due to the extensive on-site use of natural gas.

- With the exception of 7 tons of hazardous waste generated from soil excavation associated with the bioreactor alternative, the remedy alternatives considered at the DP039 Site generally do not involve substantial hazardous waste generation. The minimal hazardous waste generated from these other alternatives are associated with materials production and total less than 1% of the above-mentioned 7 tons generated from the bioreactor alternative.

- The DPE alternative has the highest total water footprint due to the change in the water resource caused by discharging extracted groundwater to surface water. The PRB and biobarrier alternatives have the highest potable water footprint because of the potable water used to blend and inject the reagents for in-situ remediation.

3.1.2 Contributing Factors to Footprints of the Four Alternatives

- The natural gas used for the DPE alternative is the single largest contributor to the footprints of several parameters, making it difficult to pay attention to other potential contributors. Optimization of the remedy can result in reducing or eliminating use of natural gas, allowing more attention to be placed on other contributors.

- Although emulsified vegetable oil (bioreactor and biobarrier alternatives) and guar gum (PRB alternative) are plant based products, there are substantial footprints associated with producing them. The NOx footprint, in particular, is higher for these plant based products on a pound per pound basis than it is for many other manufactured products, including steel, PVC, and HDPE. This may be due to emissions from nitrogen fertilizers used in growing the crops.

- With the exception of on-site natural gas use and electricity use for the DPE alternative, the CO2e, NOx, SOx, and PM footprints are dominated by off-site activities such as materials production and laboratory analysis. Transportation is the next largest contributor for the GAC-based DPE alternative and the three other alternatives.

- For the biobarrier alternative, the use of fire hydrants to provide water for blending and injecting reagents presents a tradeoff. Using the fire hydrant involves use of a potable water resource but not additional energy or on-site emissions for extracting groundwater. By contrast, using extracted groundwater for reagent blending and injection might involve on-site emissions if generators are needed to provide power but would not use potable water as a resource.

3.1.3 Relative Contributions from Each Remedy Component

- The construction phase is generally the largest contributor to the on-site footprints for the alternatives evaluated. O&M is the largest contributor to the total (on-site plus off-site) footprints for the bioreactor, DPE, and biobarrier alternatives. Construction is the largest contributor to the total footprint for the PRB because in the PRB alternative there is no O&M and performance monitoring is not an extensive activity for the PRB alternative.

3.1.4 Sensitivity to Input

- The amount of emulsified vegetable oil used for the bioreactor and biobarrier remedies are engineering estimates made during remedy selection, remedy design, remedy construction, and initial remedy operation. Actual values typically are not known until remedy operation is underway and the remedy performance has been evaluated. The effect of doubling the amount of emulsified vegetable oil depends on the remedy alternative and the environmental parameter. The increase in the energy footprint from doubling the amount of emulsified vegetable oil is 11% for the bioreactor alternative and almost 30% for the biobarrier alternative. By contrast, the increase in the SOx footprint is 58% for the bioreactor alternative and almost 90% for the biobarrier alternative.

- Assumptions regarding the fuel mix for grid electricity generation and converting that fuel mix to emissions factors have a strong influence on the emissions-related footprints for remedies with high electricity use. The calculated CO2e footprint for the DPE remedy varied by over 290,000 lbs of CO2e based on various assumptions regarding the fuel mix and the derivation of the emissions factors. This 290,000-lb range results in 159% increase from the low-end of the range (184,000 lbs) or a 61 % decrease from the high end of the range (477,000 lbs). Although effects on the NOx, SOx, PM, and air toxics footprints were not modeled, a similar range of results is expected for these parameters.

- Reasonable generic values were used for approximating materials transportation distances and the mode of transportation. Decreasing the fuel used for transportation by 50% or doubling it resulted in an observable change in the remedy footprints, but not sufficiently significant to greatly alter conclusions drawn from the footprint analysis. This is because the footprint for manufacturing the materials is substantially higher than the footprint for transporting the materials. This observation is relevant to the bioreactor and biobarrier remedies at the DP039 Site but may not apply to other sites or remedy types, particularly excavation and off-site disposal remedies where there is substantial transportation but limited materials use.

3.2 Observations Relevant to Environmental Footprint Analysis of Remedies in General

The following observations are based on generalizations that may apply to environmental footprint analysis in general. Although these observations are made on the basis of the analysis for the DP039 site, some general principles from that analysis may extend to environmental footprint analysis at other sites. However, specific observations from the DP039 analysis should not be applied to another site, without first taking into account the unique aspects of the new site, and the specific design of the remedial technology used. In addition, the general observations resulting from this study may change or be refined as more experience is gained by conducting similar analyses at other sites and for different remedial technologies.

- **It can be difficult to interpret the significance of environmental footprints and to determine which remedial alternative has the preferable footprint, without clear programmatic and site-specific green remediation objectives.** For this study, the determination of the remedial alternative with the preferable environmental footprint is relatively straightforward because the bioreactor alternative for the source area and the biobarrier alternative for plume migration control have substantially lower footprints for most of the environmental parameters compared to the other alternatives. At another site, the differences between remedy alternatives may be less dramatic. For example, the footprints for the environmental parameters with greatest stakeholder interest may be similar among remedy alternatives, resulting in no clear preference. Or, there may be large differences, but the differences may strongly favor one remedy alternative for some of the parameters (e.g., water use, CO2e, and PM), and strongly favor another remedy alternative for other parameters (e.g., air toxics and waste generated).

- **On-site activities, electricity generation, transportation, and off-site activities (e.g., manufacturing) all have the potential to contribute significantly to the footprints of remedies.** For evaluating most remedy technologies at most sites, it appears that environmental footprint analysis should consider all four of these types of activities. However, contributions from these four categories of activities may differ from remedy to remedy. The large or significant contributors to a remedy footprint may not become apparent unless a wide range of contributors are included in the footprint analysis.

- **The energy and air emission footprints associated with materials production may significantly exceed the footprint for transportation of that material or use of that material on site.** For example, the energy and CO2e footprints for transportation of the steel (iron) for the PRB alternative are approximately 10% of the footprints associated with producing the material. Similarly, for the bioreactor and biobarrier alternatives, the CO2e footprint for transportation of emulsified vegetable oil is approximately 10% of the footprint associated with producing the material. By contrast, however, for the bioreactor and biobarrier alternatives, the energy footprint for transportation of emulsified vegetable oil is approximately 50% of the energy footprint for producing the material. These findings suggest that footprint reduction might first focus on optimizing materials use and then, as a second priority, focus on the transportation of those materials.

- **Footprint analysis results derived during the remedy selection phase can be used to identify those components of a remedy that have the largest influence on environmental footprints, allowing these components to receive extra attention during design and implementation for potential ways of reducing the remedy footprint.** For example, a footprint analysis of a DPE remedy alternative that uses thermal oxidation will indicate a significant footprint contribution from natural gas usage associated with thermal oxidizer operation. The design team can use this information and footprint analyses of competing vapor treatment options to identify treatment options for air stripper and SVE off-gas that minimize the footprint while meeting compliance standards.

- **Footprint analysis results may be dominated by one or two contributors. If this is the case, it may be helpful to analyze footprint contributions without these large contributors so that other footprint contributors can be identified and more options for footprint reduction can be considered.** For example, a footprint analysis of a DPE remedy alternative that uses thermal oxidation will indicate a significant footprint contribution from natural gas usage associated with thermal oxidizer operation. The contributions are significantly large from the natural gas usage that relatively high contributions from UV/Oxidation treatment of extracted groundwater (also a component of the DPE remedy) may be missed. Optimization (and green remediation) opportunities exist in alternative technologies for both thermal oxidation for vapor treatment and UV/Oxidation for water treatment.

- **Environmental footprint analysis and the use of best management practices are complimentary tools in applying green remediation and reducing the environmental footprint of a remedy.** Due to the quantitative nature of environmental footprint analysis, the results of environmental footprint analysis will generally draw the user's attention to the aspects of a remedy with the higher percent contributions to the environmental footprints. As a result, an activity that contributes a small percentage to the total footprint may not receive attention, although it may still be large in magnitude and may offer opportunities for significant reductions.

Appropriate best management practices, when applied, can reduce the environmental footprints of both big and small contributors to the environmental footprints.

- **The outcome of an environmental footprint analysis may be dependent on the quality of remedy design information input into the analysis.** While some remedy design information may be straightforward to determine and predict during the remedy selection phase, other information can be difficult to estimate or predict. For example, the footprints for bioreactor and biobarrier remedies may be highly sensitive to the amount of emulsified vegetable oil injected, and these quantities are engineering estimates made during design stages that will likely require adjustment over the life of the remedy.

- **For remedies that involve use of electricity from the power grid, the outcome of an environmental footprint analysis is heavily dependent on the fuel used to generate the electricity.** Common practice is to use readily available regional mixes (e.g., www.epa.gov/egrid), but there are many instances where there is a special power provider or local power provider that uses a substantially different mix of fuel to generate electricity that is used by the remedy. For example, the Western Area Power Administration provides Travis AFB with electricity that is a blend of the California regional mix, Northwest regional mix, and hydroelectric power from Bureau of Reclamation hydroelectric projects. This blended mix is different from the mix found in eGRID. This finding suggests the importance identifying and contacting the specific electricity provider to determine the fuel blend used to generate electricity. However, care needs to be taken in researching and contacting local electricity providers to ensure that the correct information is obtained.

- The use of renewable energy for a remedy does not reduce the remedy's energy footprint but can substantially reduce the emissions of CO2e, NOx, SOx, and other air pollutants. **Focus on energy efficiency and energy reduction may be a preferred first step for footprint reduction because it reduces both the energy footprint and the emissions footprints. Renewable energy can then be applied more cost-effectively to address the remaining energy needs and to further reduce emissions.**

- On-site renewable energy systems, particularly photovoltaic systems, have a relatively significant footprint associated with the manufacturing of the system components and installation of the system. **It can take several years for this upfront footprint associated with manufacturing and installation of the renewable energy system to be offset by the renewable energy generated from the system.** The use of renewable energy systems might not be beneficial to the environmental footprint if the expected duration of the remedy is less than the time required to more than offset the manufacturing and installation footprint of the renewable energy system.

- **Additionally, due to the footprint of system manufacturing and installation, using on-site photovoltaic (PV) panels to power a remedy may increase the CO2e, NOx, SOx, and PM footprints of the remedy if that remedy already uses electricity from hydroelectric or renewable resources.**

- **Transportation fuel use contributes to energy and air emission footprints and the amount of fuel used is highly dependent on the assumptions made in how materials are transported to the site.** Materials can be transported to a site in bulk, via specialty freight, via common freight, or via a combination of these transportation methods. The calculated fuel used for specialty freight, especially if an empty return trip is included, is significantly higher than the calculated fuel use for bulk or common freight. The mode of transport depends on the type of material, the vendor, and the distance to the site and may not be obvious to the study team that is attempting to quantify the environmental footprint. Depending on the type of remedy and types of materials used, this variation in fuel use estimates could significantly affect the footprint results.

- Given the above-mentioned uncertainties, **environmental footprint analyses should be applied with caution if used during remedy selection.** The primary factors for remedy selection should be those established by the remedial program, such as protectiveness of human health and the environment. The results of an environmental footprint analysis, however, can help further inform remedy selection as part of the other balancing criteria associated with remedy selection.

- **Laboratory analysis can contribute significantly to a remedy's environmental footprint.** The study team estimated the conversion factors for laboratory analyses using best engineering judgment. Additional research on footprint conversion factors associated with laboratory analysis is merited to improve the accuracy of footprint analyses in the future.

- **Use of renewable energy by outside providers (e.g., laboratories and off-site waste water treatment plants) can substantially reduce a remedy footprint.** For example, at the DP039 Site, if half of the footprint from laboratory analysis is due to the electricity use (rather than production of materials and supplies) and this electricity were renewable electricity, the CO2e footprints for the bioreactor and biobarrier remedy alternatives discussed in this study would be reduced from 10% to 15%. Reducing contributions to the remedy footprint from laboratories and other off-site service providers would make contributions from other sources more apparent.

- **The amount of solid waste, hazardous waste, air toxics, mercury, lead, and dioxin generated in association with off-site materials manufacturing may be very small and may seem insignificant when compared with on-site parameters of a remedy that will potentially affect the local community.** Given all of the other information that is considered by site stakeholders over the course of a remedy, tracking parameters associated with manufacturing processes far from the site may not be merited in environmental footprint studies, especially considering the potential variation in footprint conversion factors depending on the manufacturing source. It may be more appropriate to recognize that, with respect to off-site footprints for these parameters, the release or generation of certain parameters is regulated under various environmental programs, and may best be addressed in the remedial process by best management practices of minimizing materials use, maximizing reuse/recycling, and identifying manufacturers/suppliers that have strong, positive environmental records. This approach does not necessarily apply to on-site generation of hazardous waste or on-site emissions of air toxics, lead, mercury, dioxins, and other pollutants. The approach also does not apply to off-site footprints of certain other parameters, such as greenhouse gases, water, and energy, which may be large in comparison with on-site footprints.

- NOx, SOx, and PM all have adverse effects on human health and the environment, and are regulated under the same federal regulations as "criteria pollutants". In addition, fossil fuel combustion is a major source of these pollutants. Considering energy, CO2e, NOx, SOx, and PM separately leads to five categories that are all closely linked to the combustion of fossil fuels. This large number of closely-related categories may result in biased focus on fossil fuel use rather than other important environmental parameters related to remedies, such as toxic pollutants emitted, materials used and waste generated, and water used. **In order to more clearly interpret**

the information obtained from a footprint analysis, it may be appropriate to combine these "criteria pollutants" and CO2e into one category.

- When estimating the magnitudes of footprints of site remedies, it may be unclear what is considered a "large" footprint for a particular parameter and what is considered a "small" footprint for a particular parameter. The footprint for a particular parameter may be a small percentage of the overall remedy at one site, but may be a sufficiently large footprint relative to those from other sites to merit further attention. **In general, for specific parameters it may be valuable from a programmatic perspective to identify what is considered to be a significant footprint, what is considered to be a significant footprint reduction, and what the programmatic objectives are with respect to managing environmental footprints of remedies.**

- **Conducting a detailed footprint analysis for an environmental cleanup can require a substantial level of effort. The process can be significantly streamlined** by using an existing framework that organizes the information and provides the necessary footprint conversion factors. The process can be further streamlined if the footprint analysis is done in conjunction with other site activities that provide relevant remedy information, such as the feasibility studies, remedial designs, and remedy optimization evaluations.

4.0 SUMMARY

This study quantifies the environmental footprints of two source area remedial options and two plume control remedial options at the DP039 Site at Travis Air Force Base in Fairfield, California by estimating for each option the emissions of various environmental parameters, such as greenhouse gases, criteria pollutants, and air toxics, and the resources used, such as energy and water. A total of 18 environmental parameters plus four other parameters related to remedy duration, labor, and traffic are considered. The study accounts for footprints from production and use of four forms of energy, production of over 10 materials, and use of four off-site services. The following three analyses are conducted.

- Primary analysis - For each parameter, footprints from on-site activities, electricity generation, transportation, and off-site activities are estimated separately and then summed together to estimate the total remedy footprint for each parameter.

- Secondary analysis - Footprints are estimated for three main remedy components: construction, operations and maintenance, and long-term monitoring.

- Sensitivity analysis – Footprints are estimated for different configurations of the remedies to assess the sensitivity of the outcome to variations in design, various remedial parameters, and the footprint conversion factors.

This report documents the process used for estimating the footprints, provides the library of resources and reference values used in the study, documents findings specific to the evaluated remedies, and presents both site-specific and more generalized observations and lessons learned from conducting the study. Although the selected parameters, process, reference information, and lessons learned may apply to environmental footprint analysis efforts at other sites, the contents of this report are not to be seen as EPA policy statements regarding environmental footprint analyses.

It is expected that the level of detail for this footprint analysis surpasses that which is needed to make informed decisions to reduce the environmental footprints of a typical remedy and that future footprint analyses at other sites will involve less detail. Other footprint analysis efforts at other sites might also consider additional, fewer, or different environmental parameters than those considered for this study. EPA has already completed a detailed footprint analysis at two remediation sites prior to this analysis for the DP039 Site. EPA expects that these footprint analyses will enhance the understanding of the environmental footprint analysis process for cleanup activities and expand the inventory of information needed for conducting footprint analyses.

This environmental footprint analysis has been conducted independently of Superfund site remedial activities at Site DP039. Travis Air Force Base and EPA Region 9 have provided the study team information so a footprint study could be performed for illustrative purposes. Travis Air Force Base owners and the EPA Region 9 site team are acknowledged for this assistance.

TABLES

Table 1. Summary of Environmental Parameters for which Footprints are Estimated

Parameter	Unit of Measure	Brief Description	Reason for Inclusion in the Study
Energy	Mbtu	Total energy used, including coal, natural gas, oil, hydroelectric, and renewable energy	• Fossil fuel-based energy (e.g., coal, oil, natural gas, etc.) is generally considered to be a limited resource • Energy use has a large environmental footprint and energy may be an appropriate proxy for other environmental parameters
Grid Electricity	MWh	Amount of grid electricity used on-site and in off-site manufacturing and services	• Grid Electricity and the means to provide it is generally considered to be a limited resource • Grid Electricity usage puts strain on existing infrastructure
All Water	gal x 1000	Total amount of water used, including potable water (see below), extracted water (see below), reclaimed water, and water from various other fresh water resources.	Water in some locations is a limited resource.
Potable Water (on-site)	gal x 1000	Amount of potable water (or drinking water quality groundwater) used on-site.	• Potable water in some locations is a limited resource. • Furnishing potable water requires energy for production and transmission • Potable water use can be reduced by (among other methods) using alternative water resources.
Ground Water (on-site)	gal x 1000	Total amount of groundwater extracted on-site that is not returned to the same aquifer as part of the remedy.	• Groundwater in some locations is a limited resource. • Groundwater extraction can have a detrimental effect on yield of nearby wells • Groundwater extraction rates are closely linked to energy and materials usage of a pump and treat remedy
CO2e	Lbs	Global warming potential measured in carbon dioxide equivalents considering carbon dioxide, methane, nitrous oxide, and CFCs (where significant quantities of CFCs are emitted)	• Global warming can have global detrimental effects on the climate and can lead to an increase in sea levels. • Carbon footprints are commonly determined for other aspects of the economy and the means/information for determining carbon footprints is rapidly growing, facilitating the footprint analysis of this parameter relative to some other parameters.
NO x	Lbs	Total amount of nitrogen oxides emitted.	Nitrogen oxides lead to the formation of ground-level ozone, particulate matter, and acid rain and can cause respiratory irritation and illness.
SO x	Lbs	Total amount of sulfur dioxide emitted.	Like nitrogen oxides, sulfur dioxide leads to the formation of particulate matter and acid rain and can cause respiratory irritation and illness.

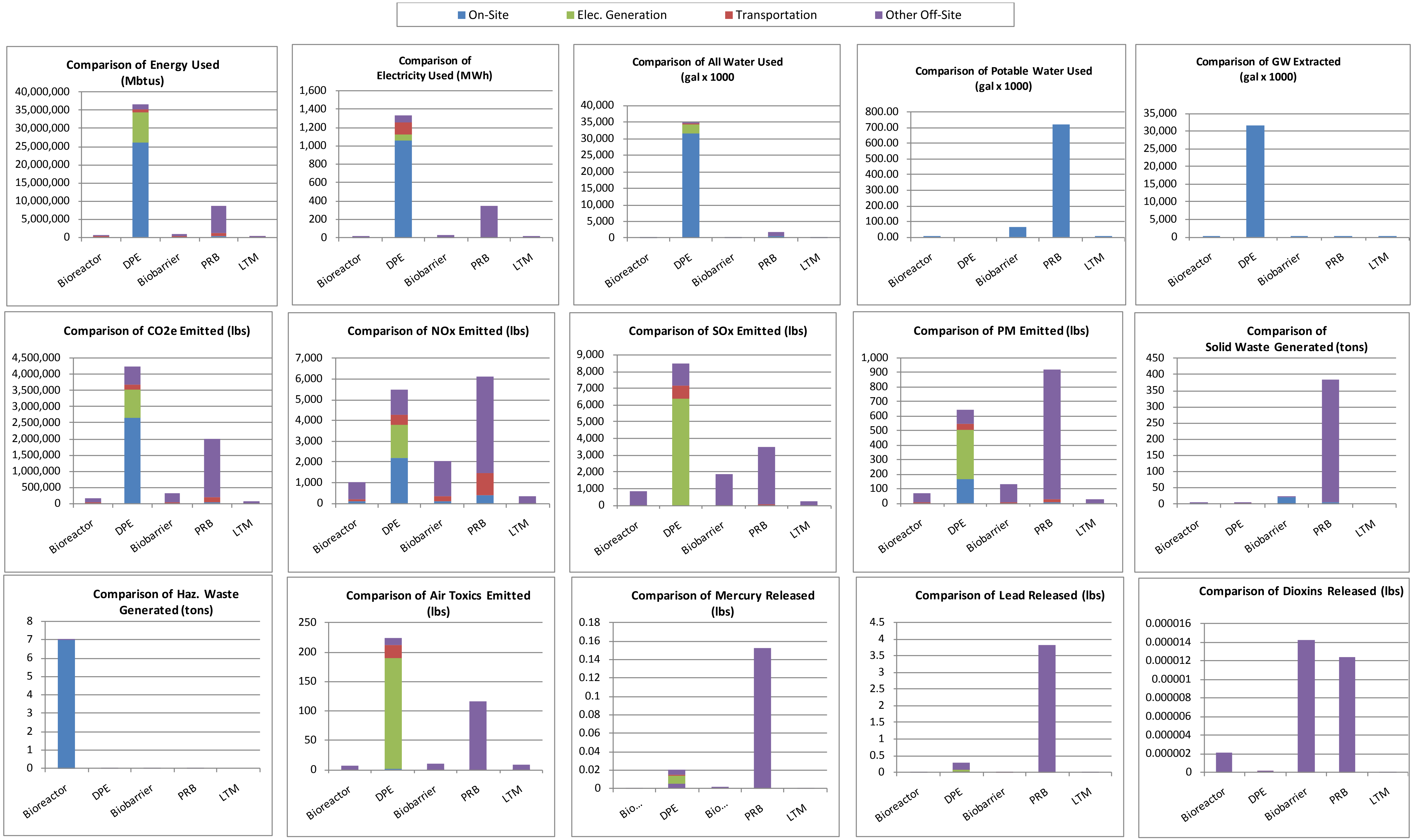
Table 1. Summary of Environmental Parameters for which Footprints are Estimated (continued)

Parameter	Unit of Measure	Brief Description	Reason for Inclusion in the Study
PM	Lbs	Total particulate matter 10 microns or less in diameter that is emitted.	Particulate matter has been linked to a number of health problems including respiratory illness and heart attacks. Particulate matter also contributes to haze, visibility reduction, and acid rain.
Solid Waste	Tons	Solid waste generated and disposed of at a permitted RCRA Subtitle D facility.	Solid waste transportation increases heavy truck traffic, landfilling solid waste requires space that is relatively close to communities, involves activities with a substantial environmental footprint, and residents are often averse to the development of additional landfills in their local community.
Haz. Waste	Tons	Hazardous waste generated and disposed of at a permitted RCRA Subtitle C facility.	Hazardous waste transportation increases heavy truck traffic, landfilling hazardous waste requires space, and handling of hazardous waste involves activities with a substantial environmental footprint, and residents are often averse to the development of additional landfills in their local community.
Air Toxics	Lbs	Total hazardous air pollutants (HAPs), as defined by EPA, that are emitted to the atmosphere.	Each HAP or degradation byproduct in the atmosphere has a toxic effect.
Lead	Lbs	Total amount of lead released to air, water, or soil.	Lead has a particularly toxic effect and the ability to persist in the environment.
Mercury	Lbs	Total amount of mercury released to air, water, or soil.	Mercury has a toxic effect and the ability to persist in the environment.
Dioxins	Lbs	Total amount of dioxins released to air, water, or soil.	Dioxins have a toxic effect and the ability to persist in the environment.
Refined materials	Lbs	Manufactured materials (e.g., steel, PVC, treatment chemicals, cement, fertilizer)	The refined materials category is a proxy for demand for specific natural resources and an intensive processing component. Reducing refined materials use through reuse or recycling can reduce this demand for natural resources and the energy and resources required to extract and process those resources.
Unrefined materials	Tons	Non-manufactured materials (e.g., sand, gravel, clay, borrow)	The unrefined materials category is a proxy for demand for natural resources. Reducing unrefined materials use through reuse or recycling can reduce this demand for natural resources and the energy and resources required to extract and process those resources. Note that although concrete and asphalt contain both refined and unrefined materials, both are reported as unrefined materials because the majority of these items consist of aggregate, which is consistent with the definition of an unrefined material.
Ecosystem services	Qualitative	Services provided by the local ecosystem (e.g., agriculture, carbon storage, nutrient uptake, etc.)	Ecosystems provide a valuable resource to human society and the environment.

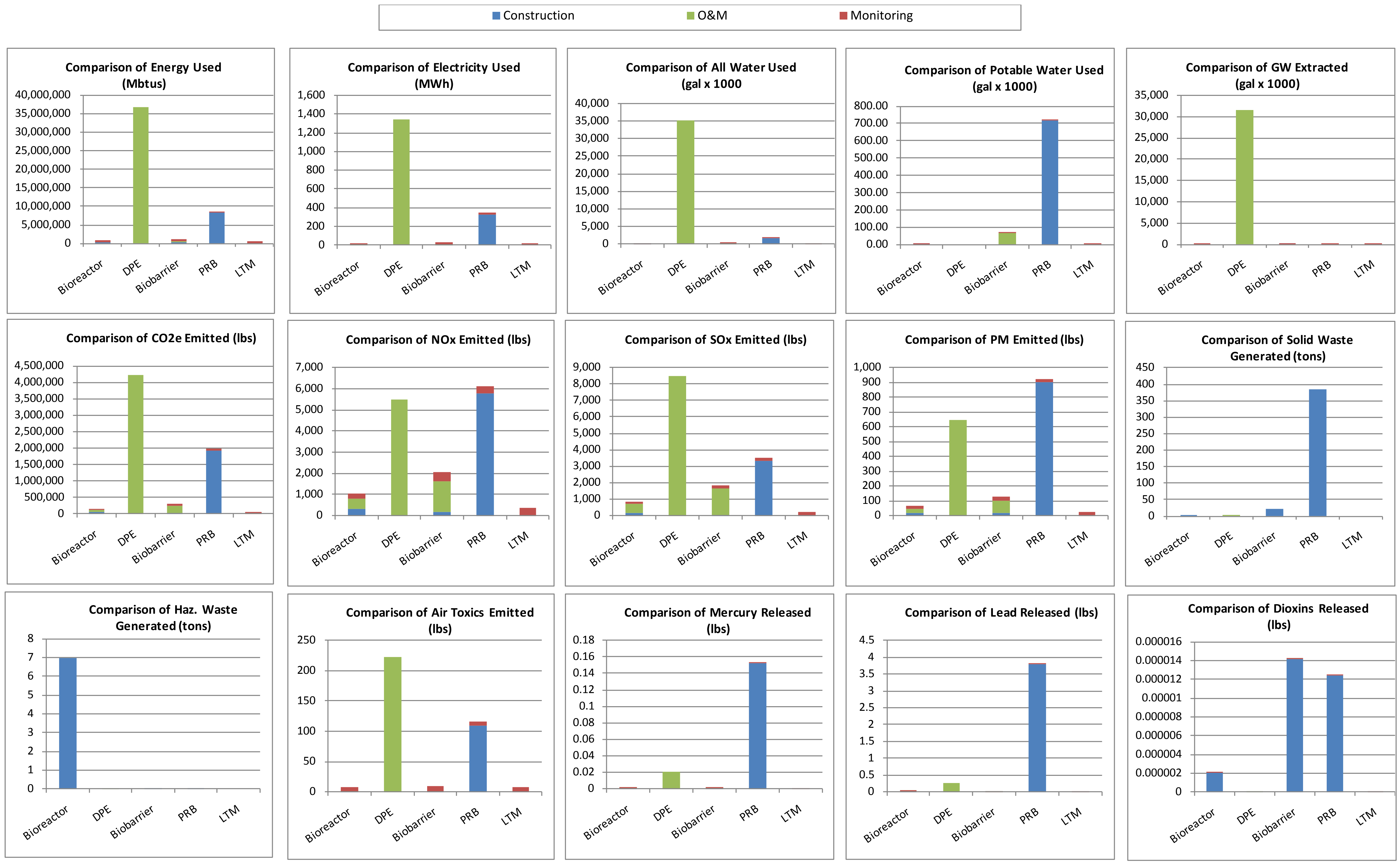
Groundwater extraction, potable water use, refined materials use, unrefined materials use, and ecosystem services are only estimated as on-site parameters. All other parameters are estimated as both on-site and off-site parameters

SUPPLEMENTAL CHARTS

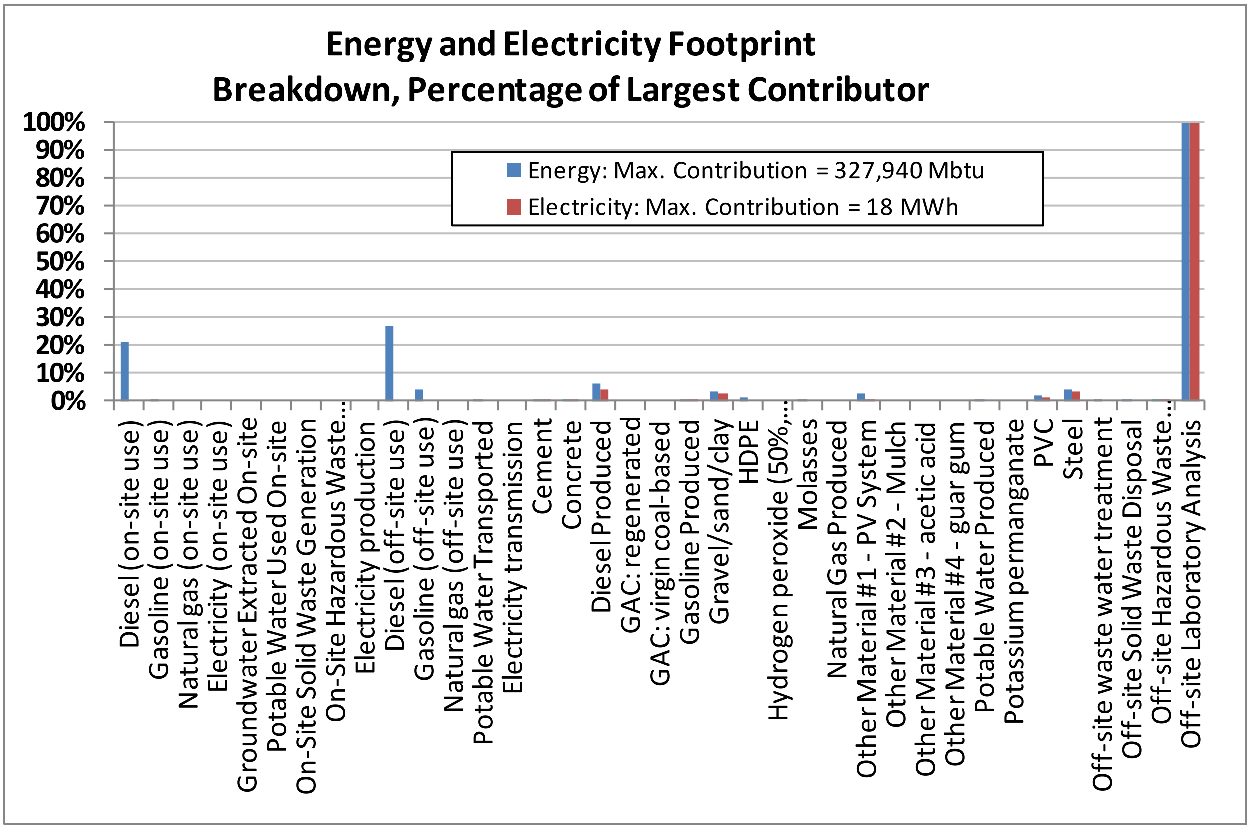
Site DP039, Travis Air Force Base - Primary Analysis - Output by Parameter

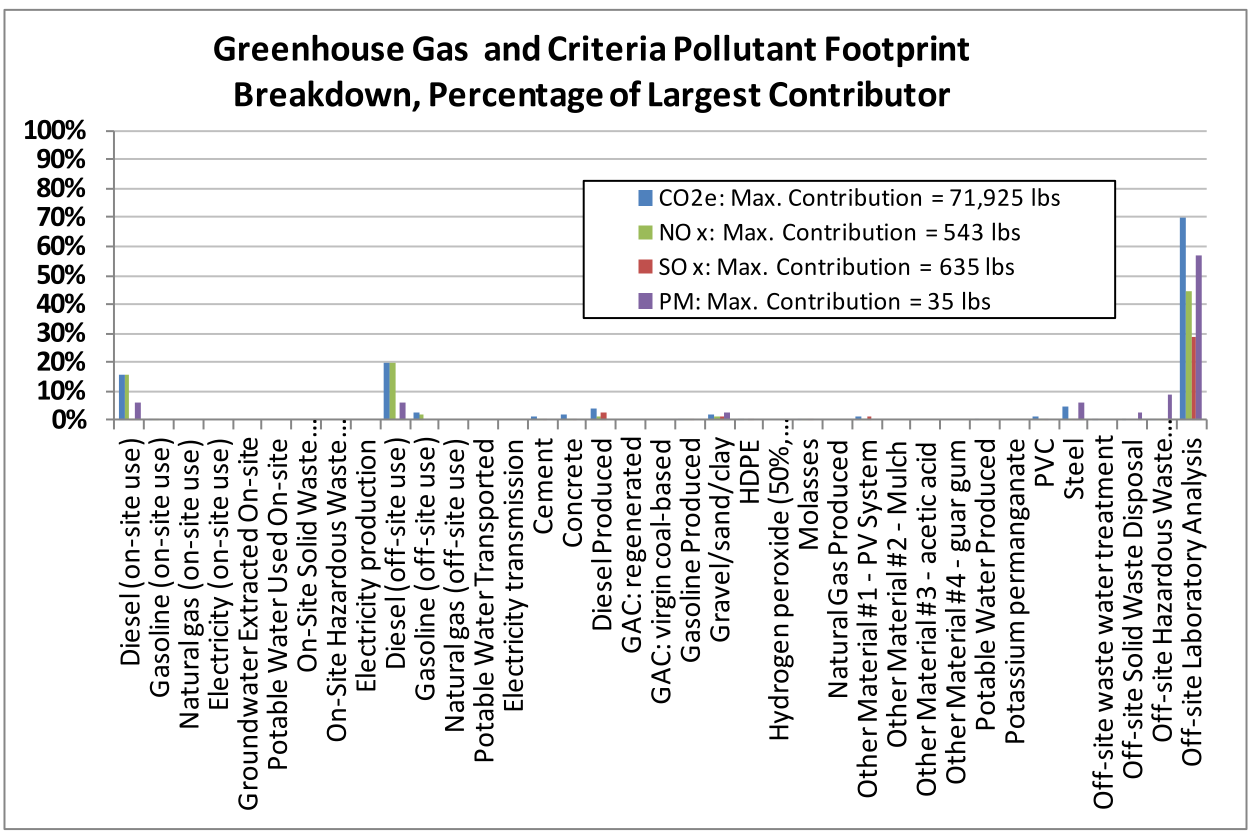


Site DP039, Travis Air Force Base - Secondary Analysis - Output by Parameter

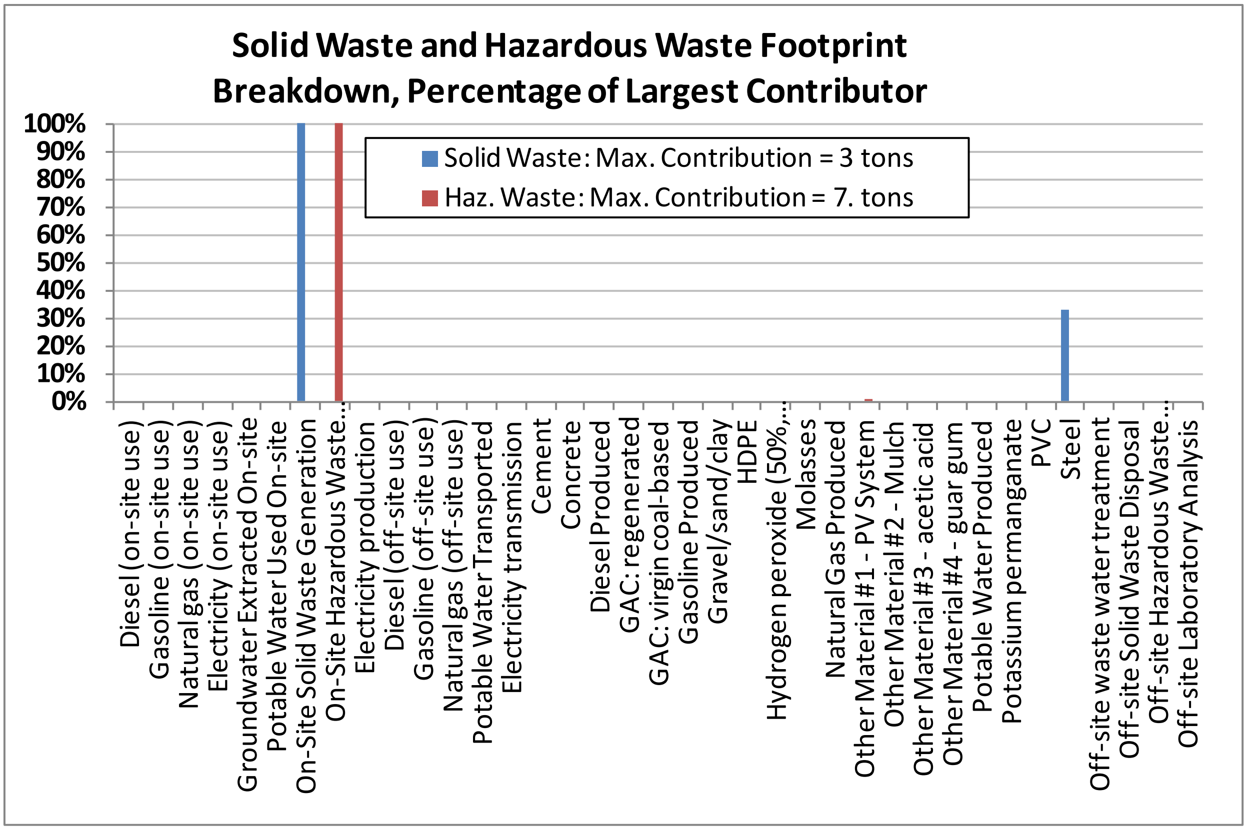


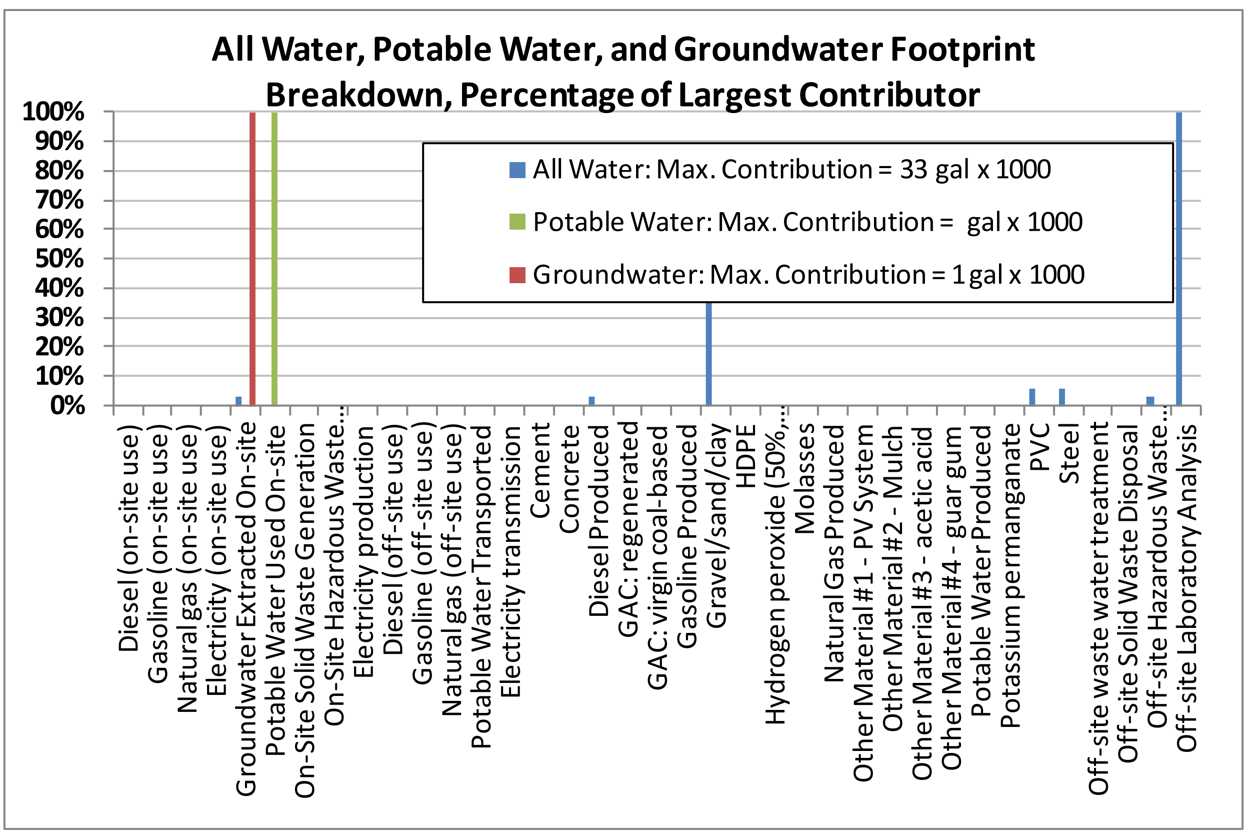
Bioreactor Breakdown of Energy/Air, Water, Waste, and Toxic Pollutant Footprints



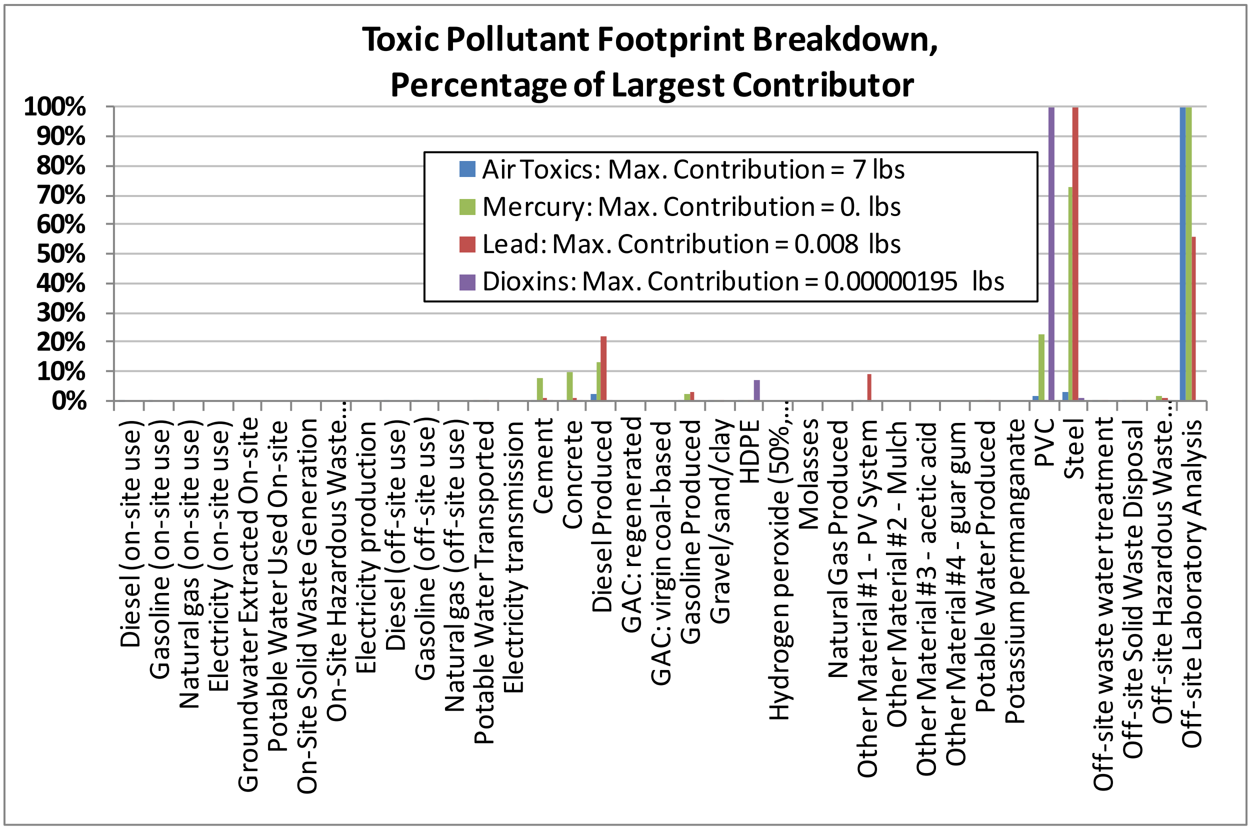


Bioreactor Breakdown of Energy/Air, Water, Waste, and Toxic Pollutant Footprints

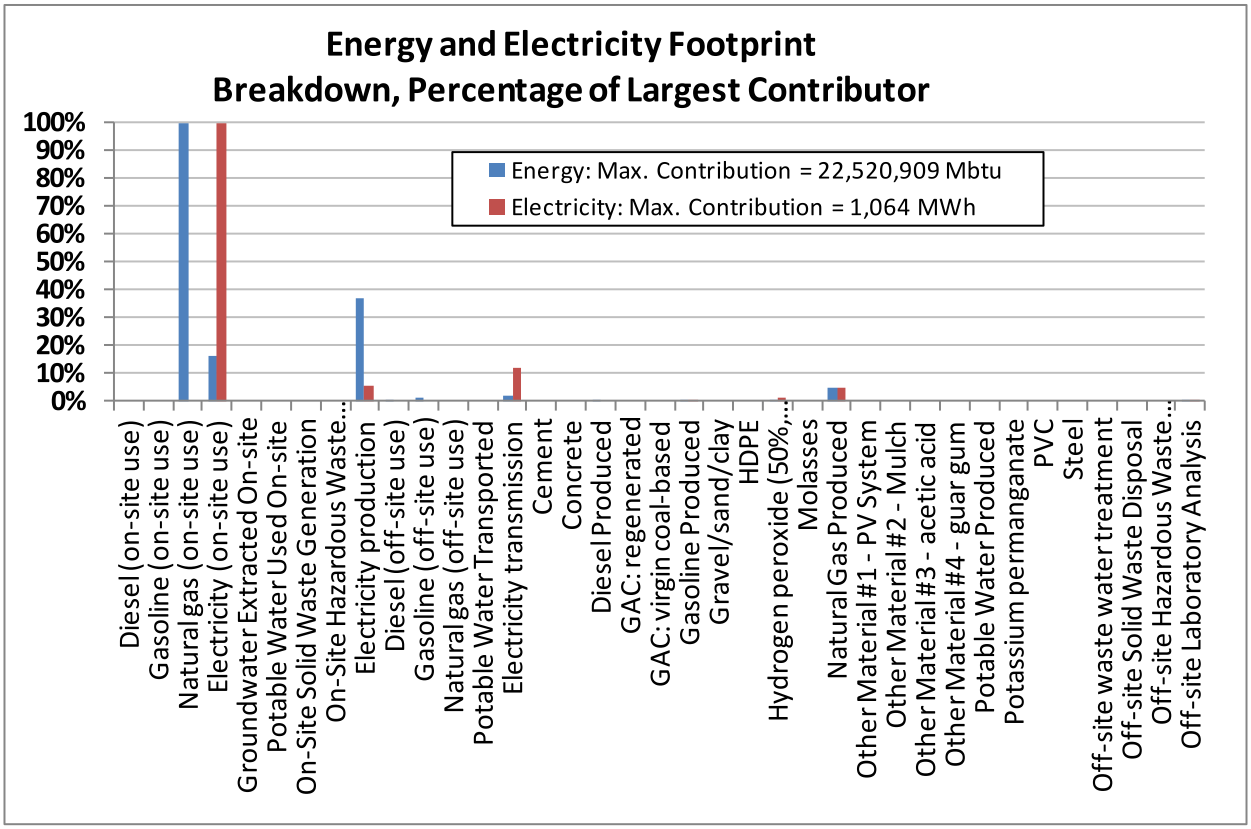


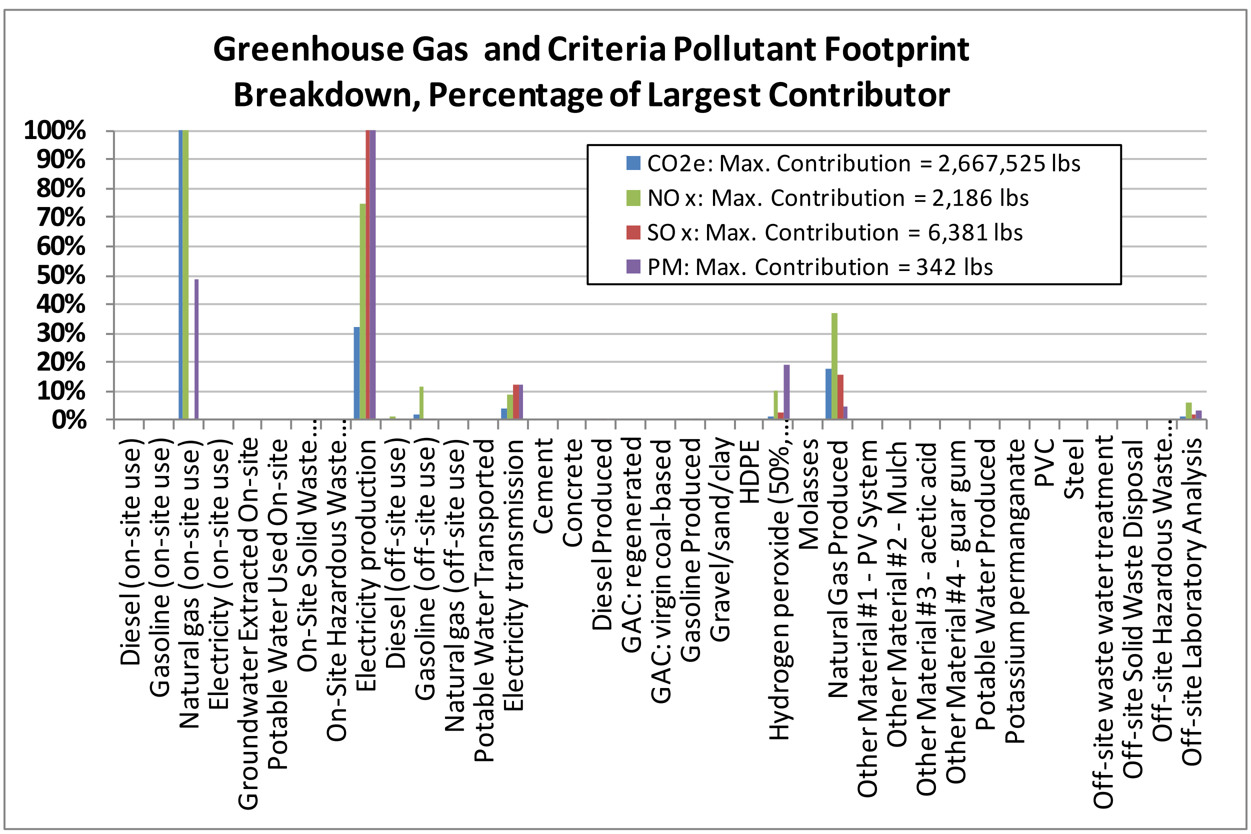


Bioreactor Breakdown of Energy/Air, Water, Waste, and Toxic Pollutant Footprints

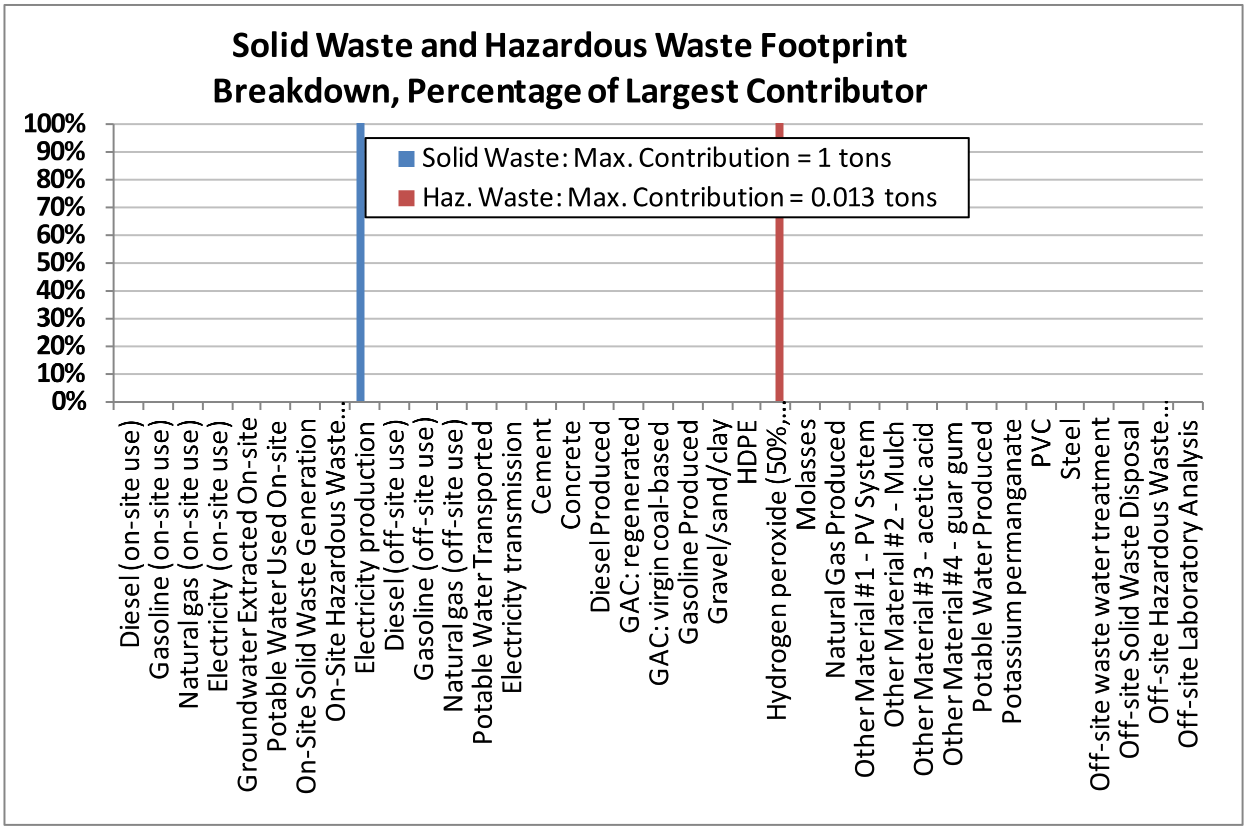


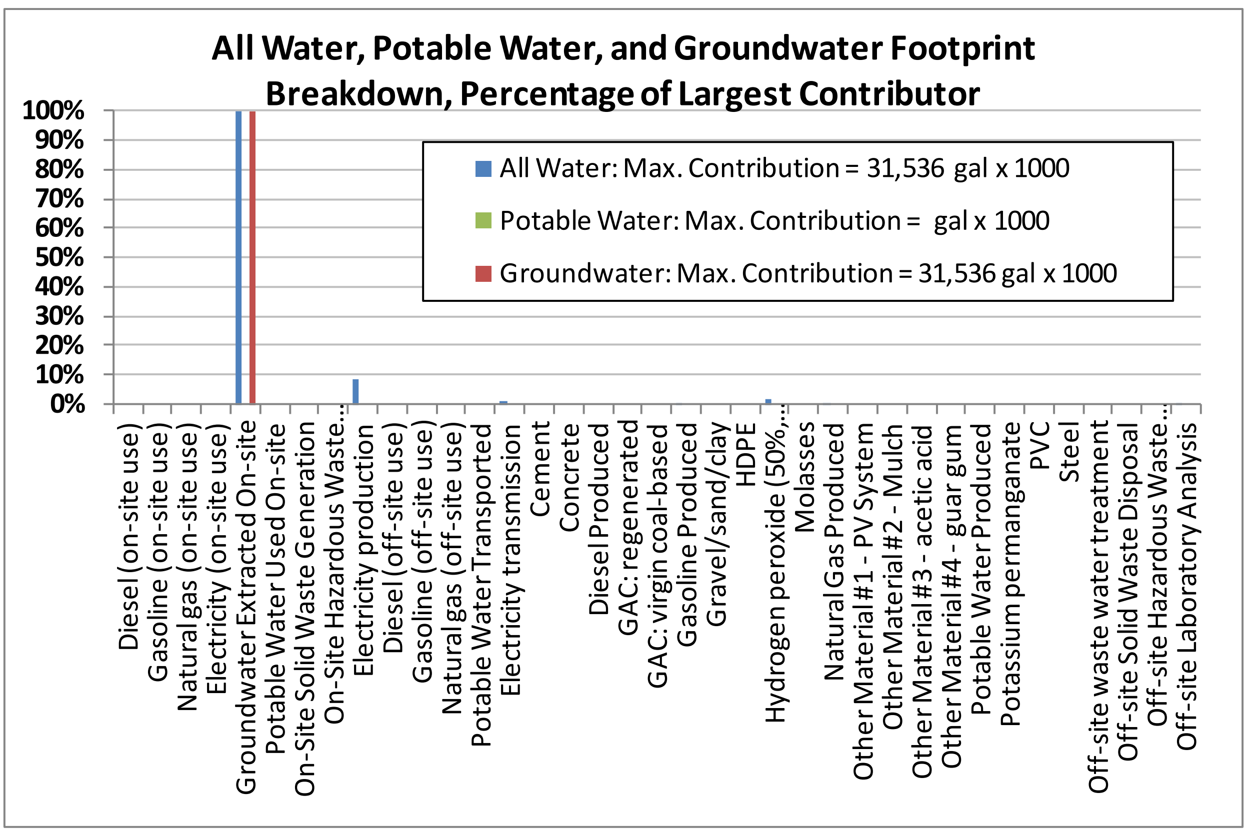
DPE Breakdown of Energy/Air, Water, Waste, and Toxic Pollutant Footprints

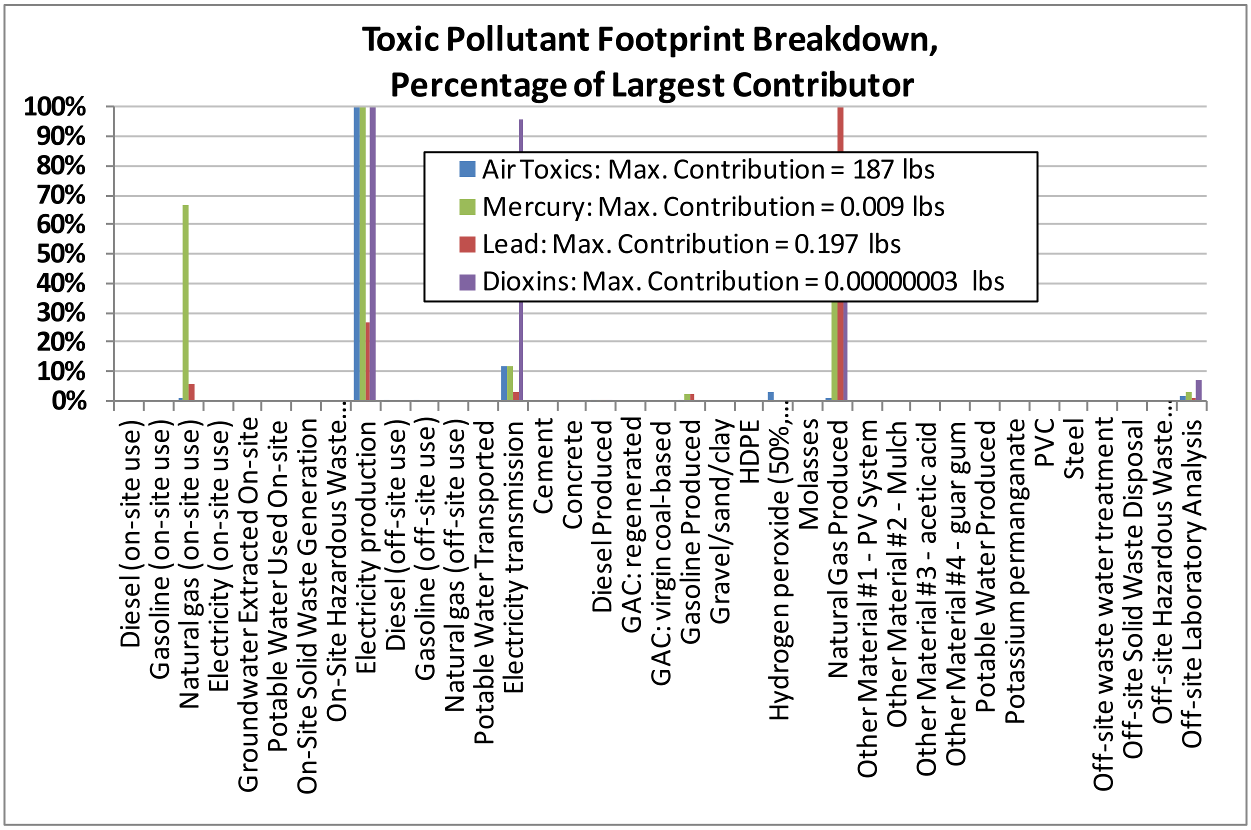




DPE Breakdown of Energy/Air, Water, Waste, and Toxic Pollutant Footprints

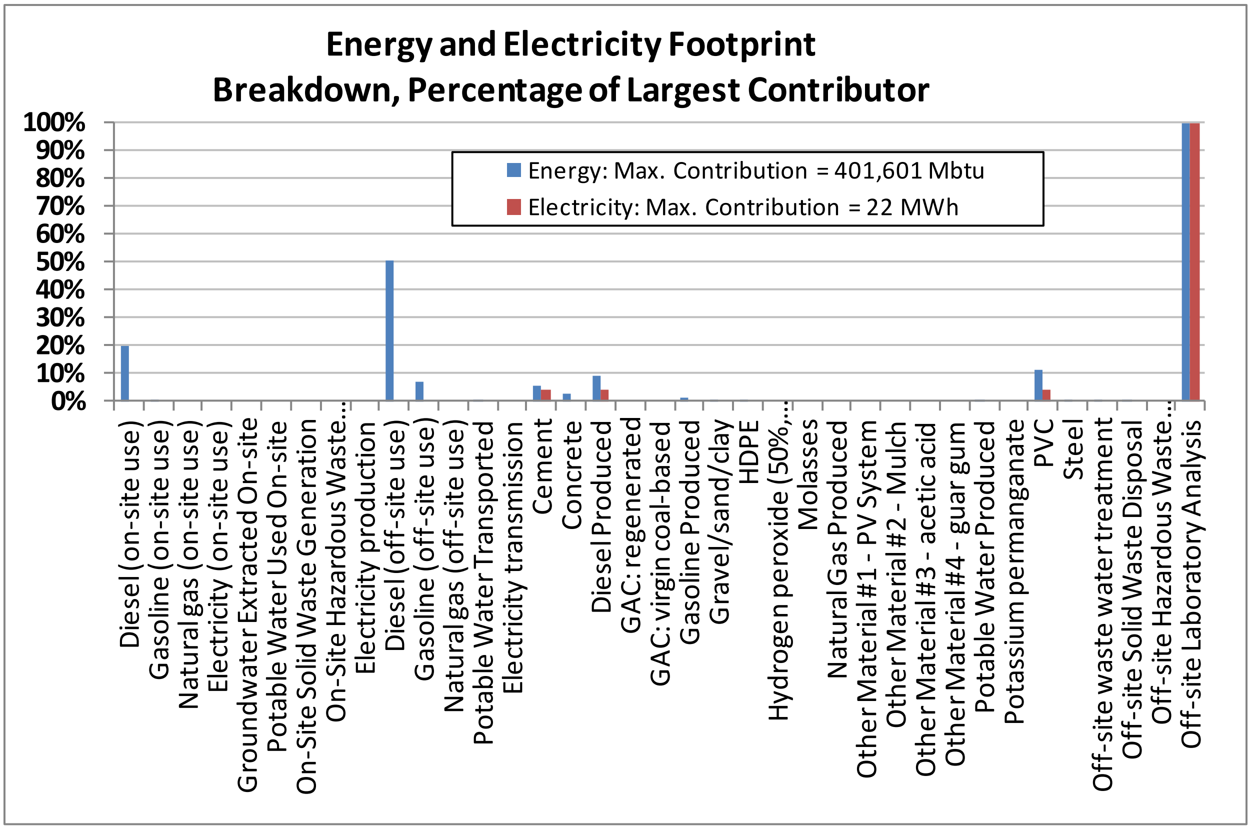


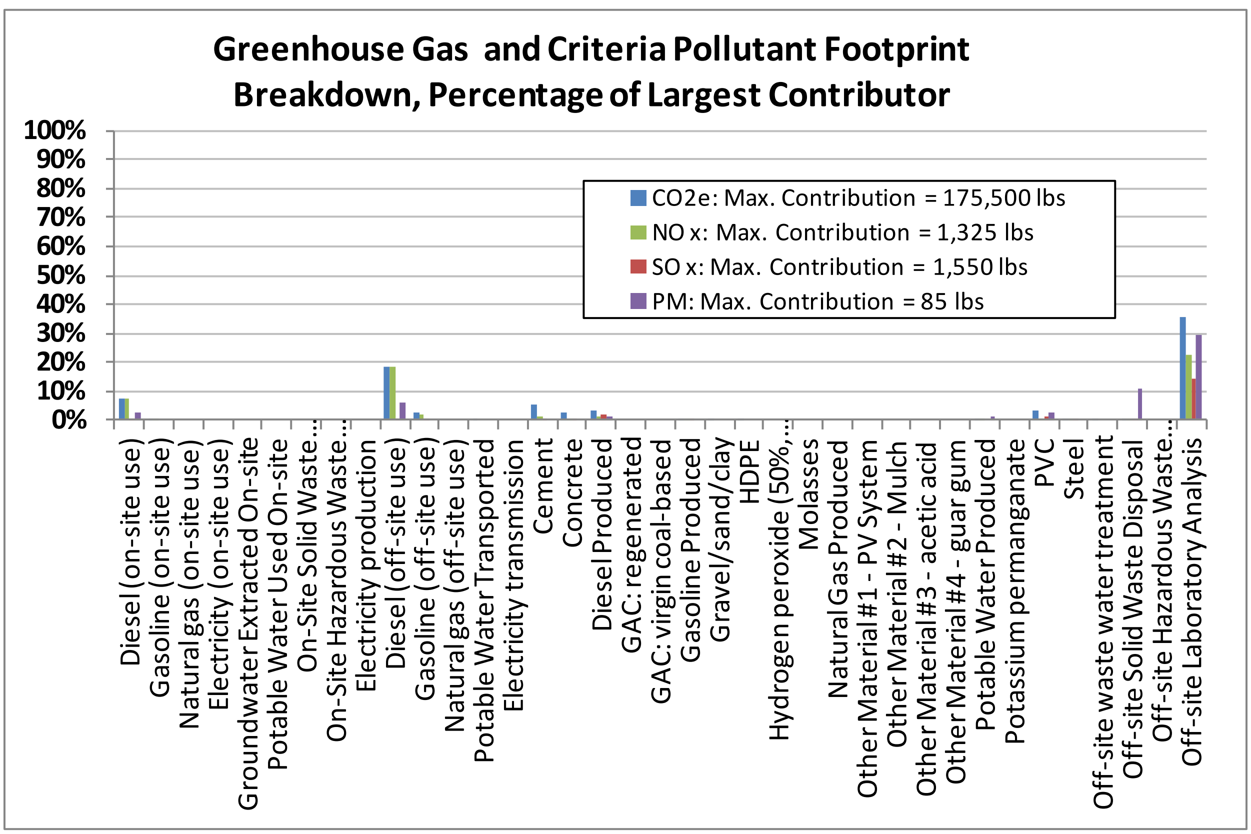




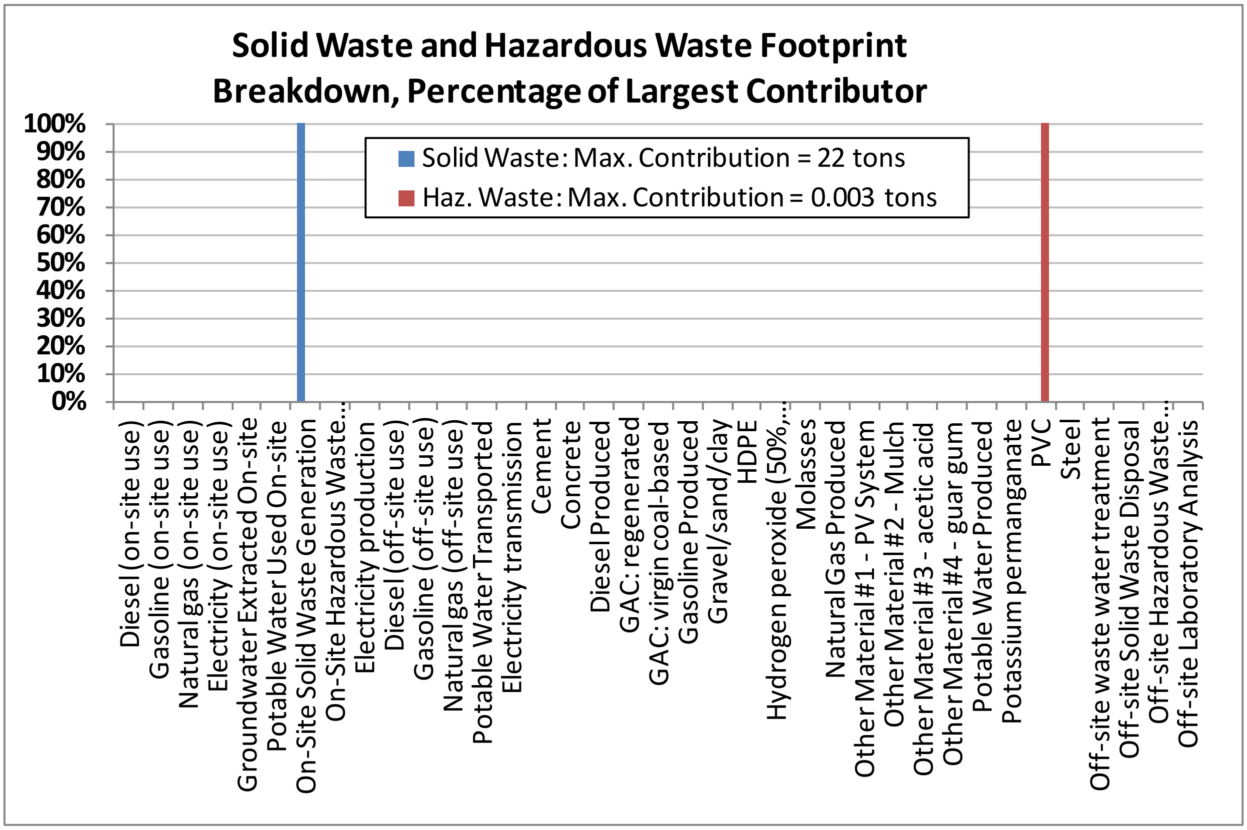
Toxic Pollutant Footprint Breakdown, Percentage of Largest Contributor
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Air Toxics: Max. Contribution = 187 lbs
Mercury: Max. Contribution = 0.009 lbs
Lead: Max. Contribution = 0.197 lbs
Dioxins: Max. Contribution = 0.00000003 lbs
Diesel (on-site use)
Gasoline (on-site use)
Natural gas (on-site use)
Electricity (on-site use)
Groundwater Extracted On-site
Potable Water Used On-site
On-Site Solid Waste Generation
On-Site Hazardous Waste...
Electricity production
Diesel (off-site use)
Gasoline (off-site use)
Natural gas (off-site use)
Potable Water Transported
Electricity transmission
Cement
Concrete
Diesel Produced
GAC: regenerated
GAC: virgin coal-based
Gasoline Produced
Gravel/sand/clay
HDPE
Hydrogen peroxide (50%,...
Molasses
Natural Gas Produced
Other Material #1 - PV System
Other Material #2 - Mulch
Other Material #3 - acetic acid
Other Material #4 - guar gum
Potable Water Produced
Potassium permanganate
PVC
Steel
Off-site waste water treatment
Off-site Solid Waste Disposal
Off-site Hazardous Waste...
Off-site Laboratory Analysis

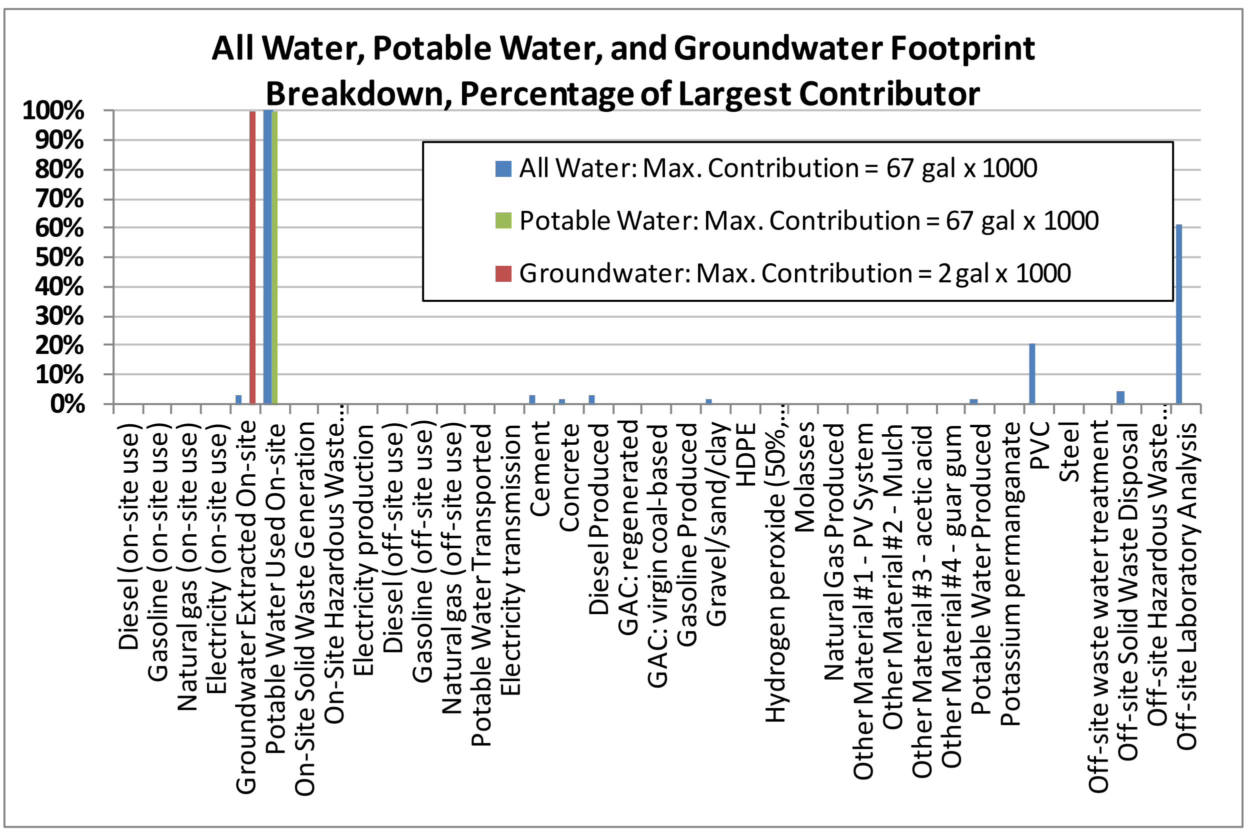
Biobarrier Breakdown of Energy/Air, Water, Waste, and Toxic Pollutant Footprints



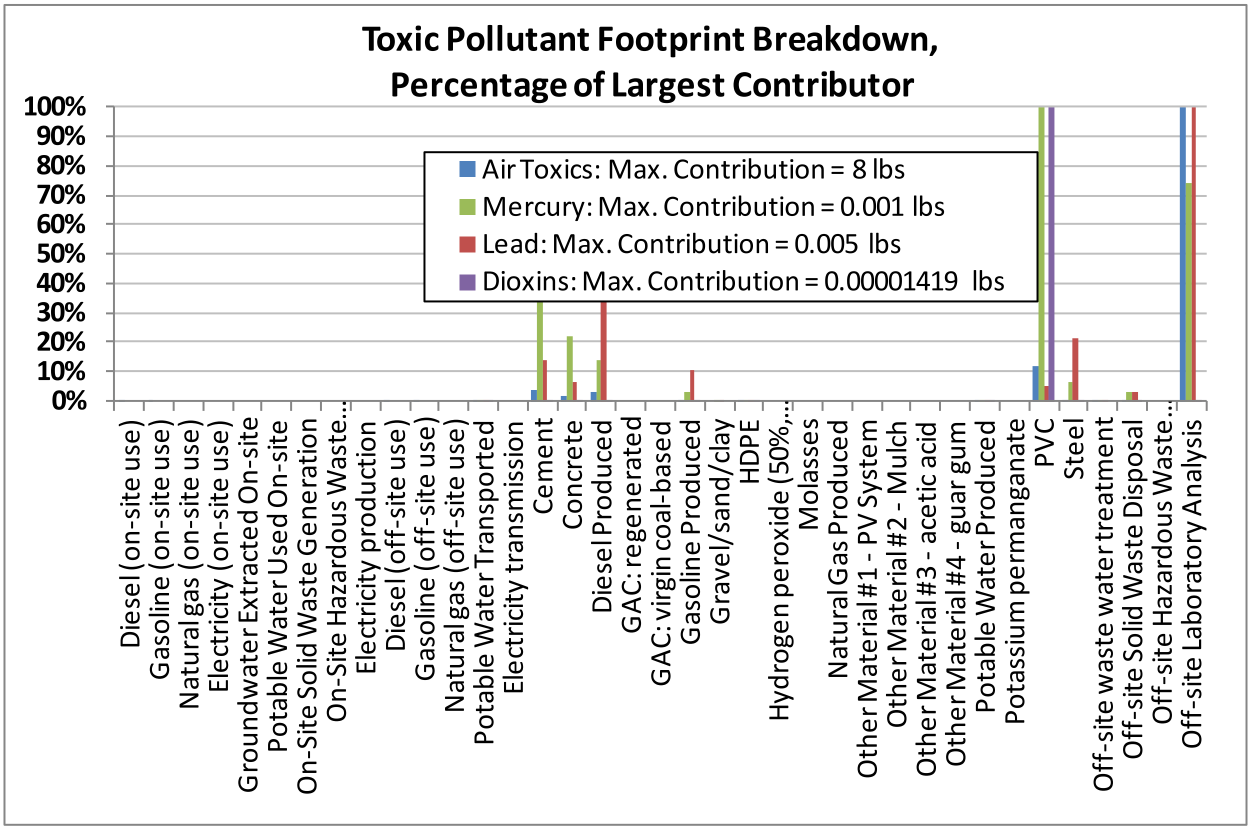


Biobarrier Breakdown of Energy/Air, Water, Waste, and Toxic Pollutant Footprints

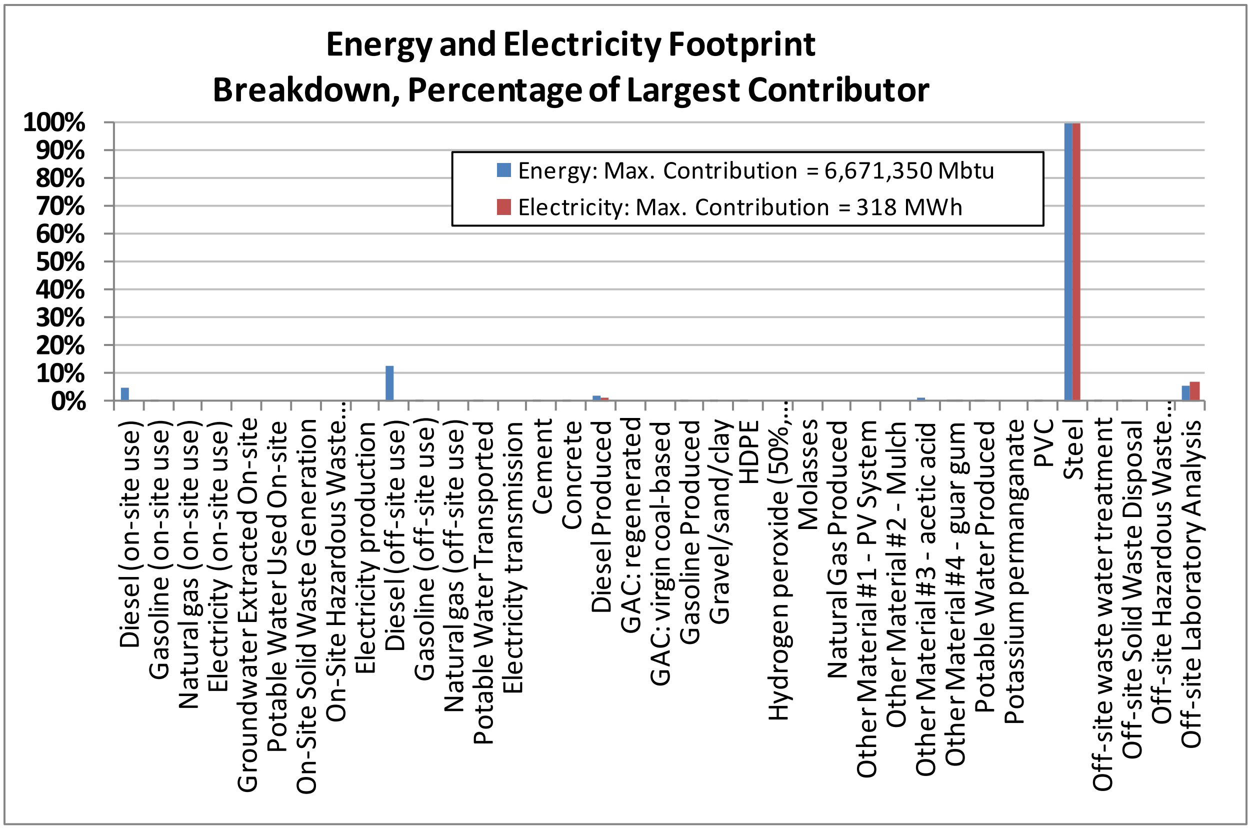


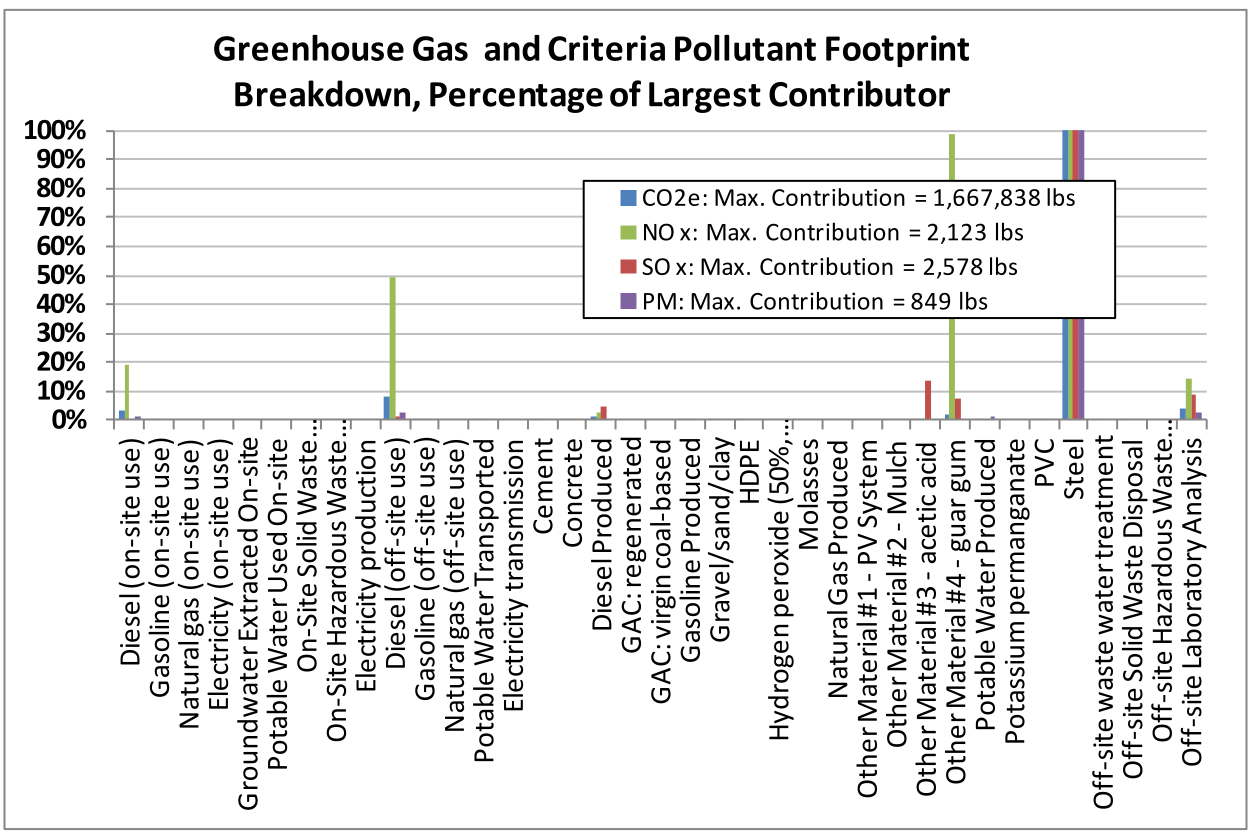


Biobarrier Breakdown of Energy/Air, Water, Waste, and Toxic Pollutant Footprints

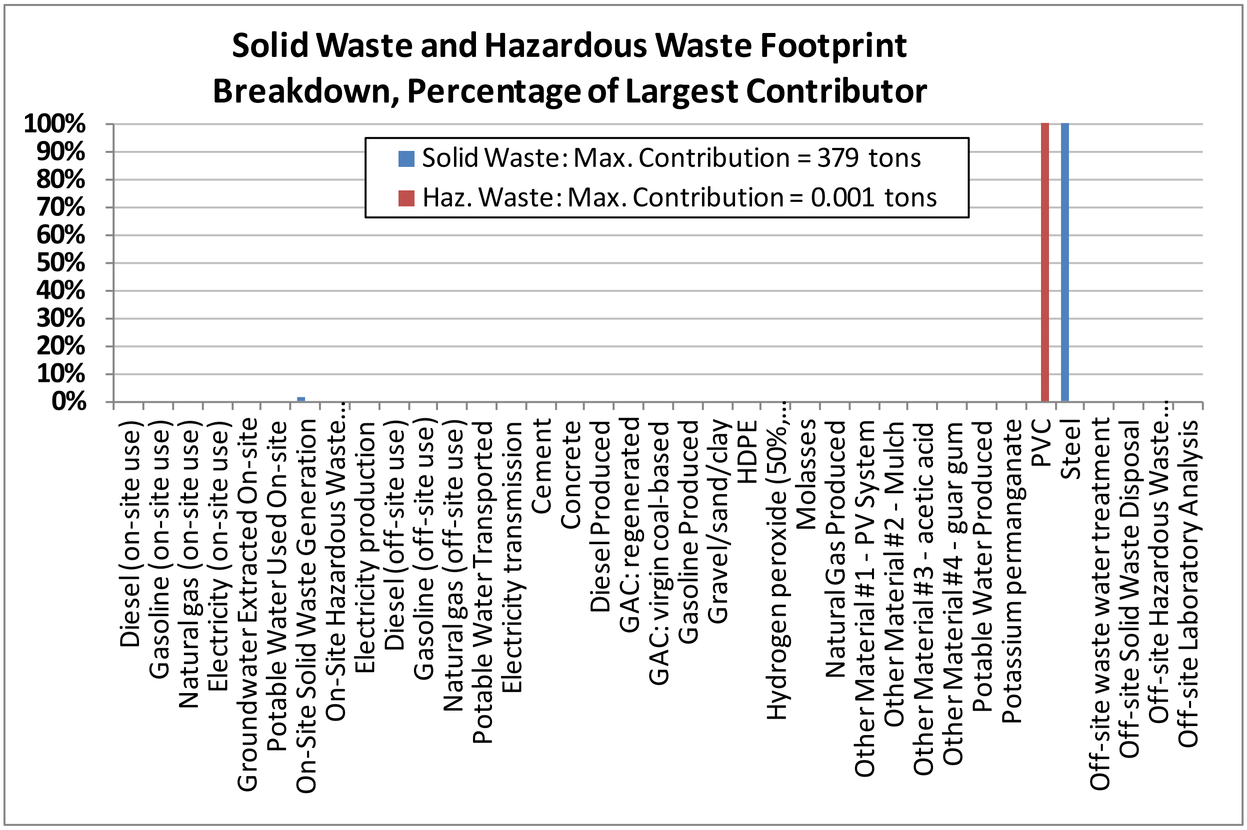


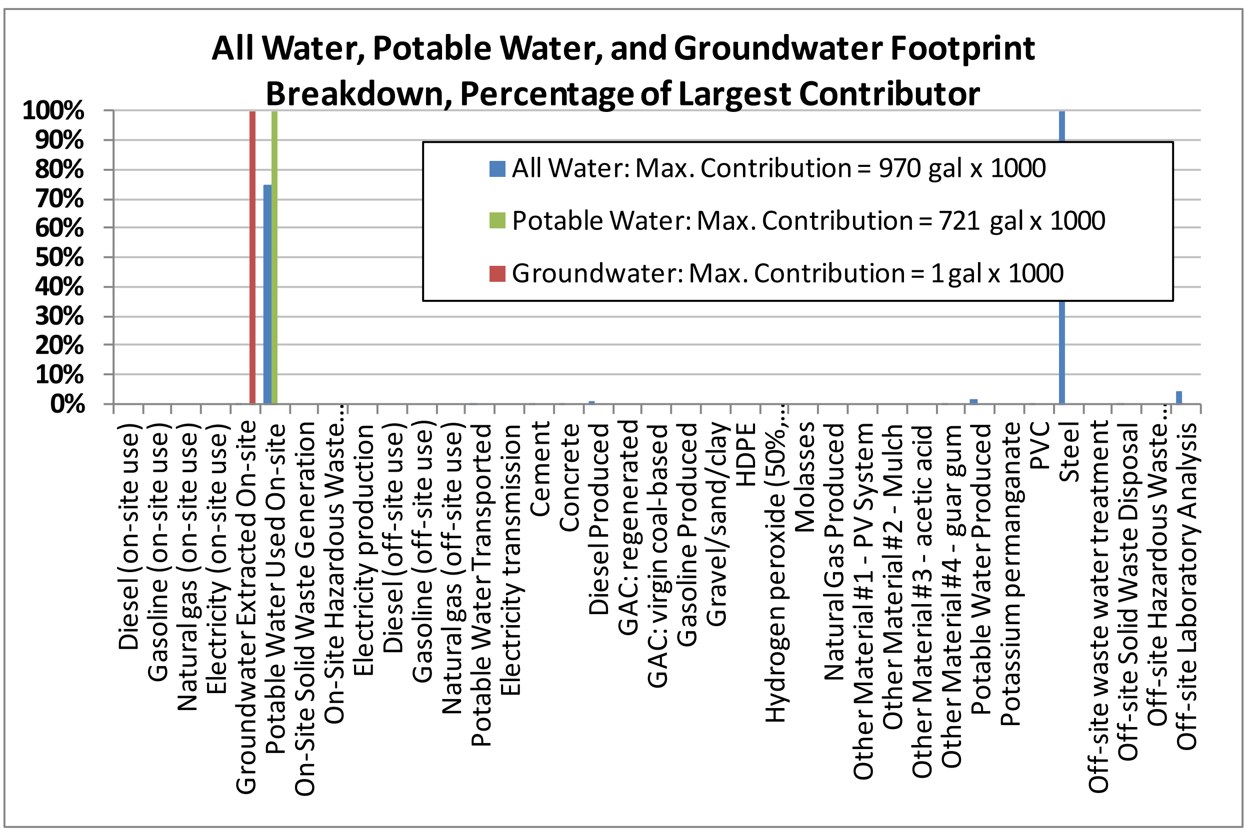
PRB Breakdown of Energy/Air, Water, Waste, and Toxic Pollutant Footprints



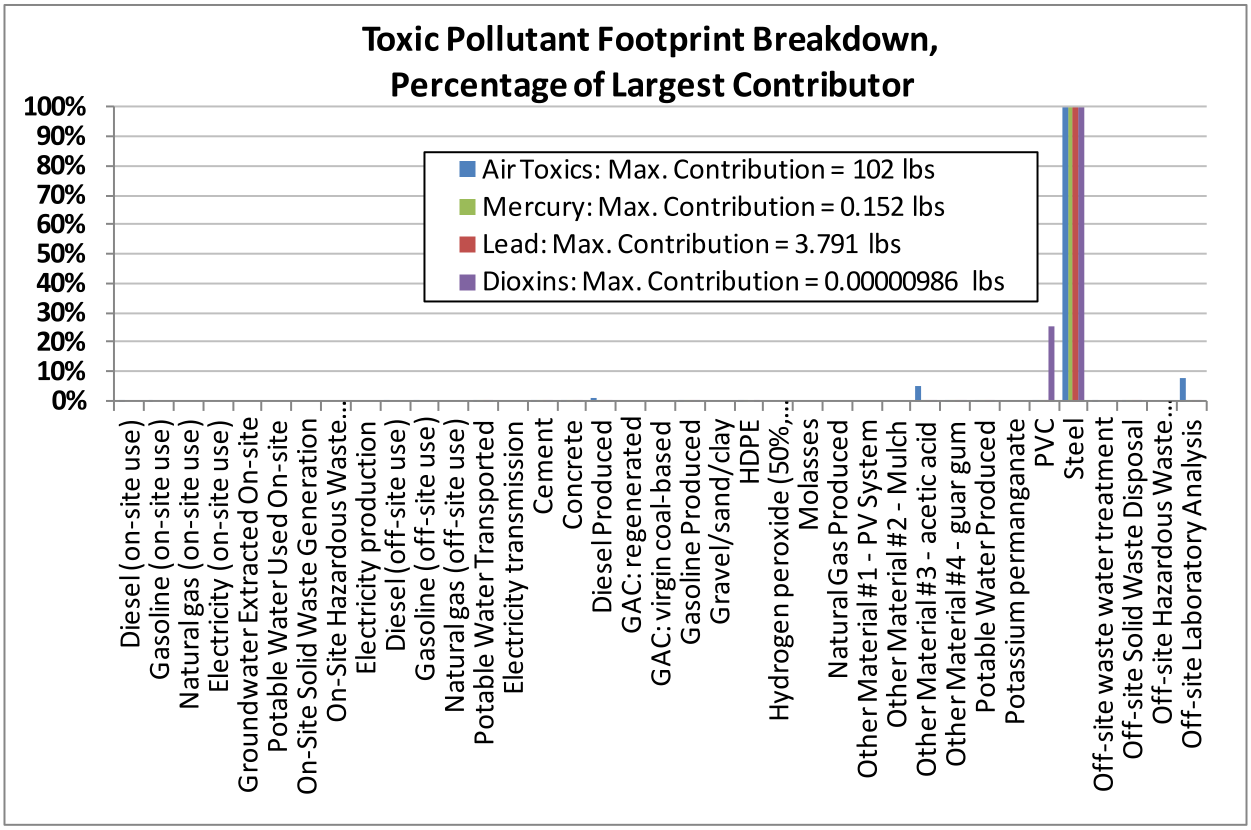


PRB Breakdown of Energy/Air, Water, Waste, and Toxic Pollutant Footprints

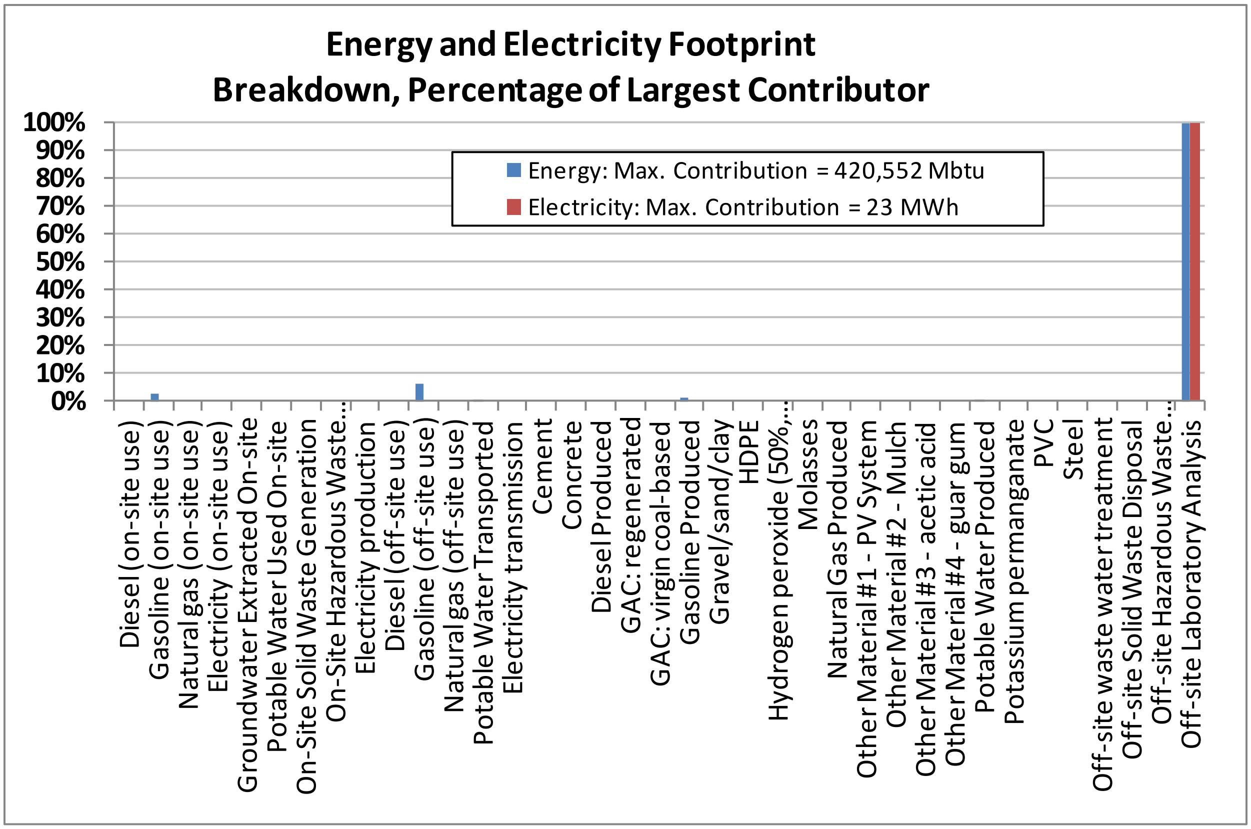


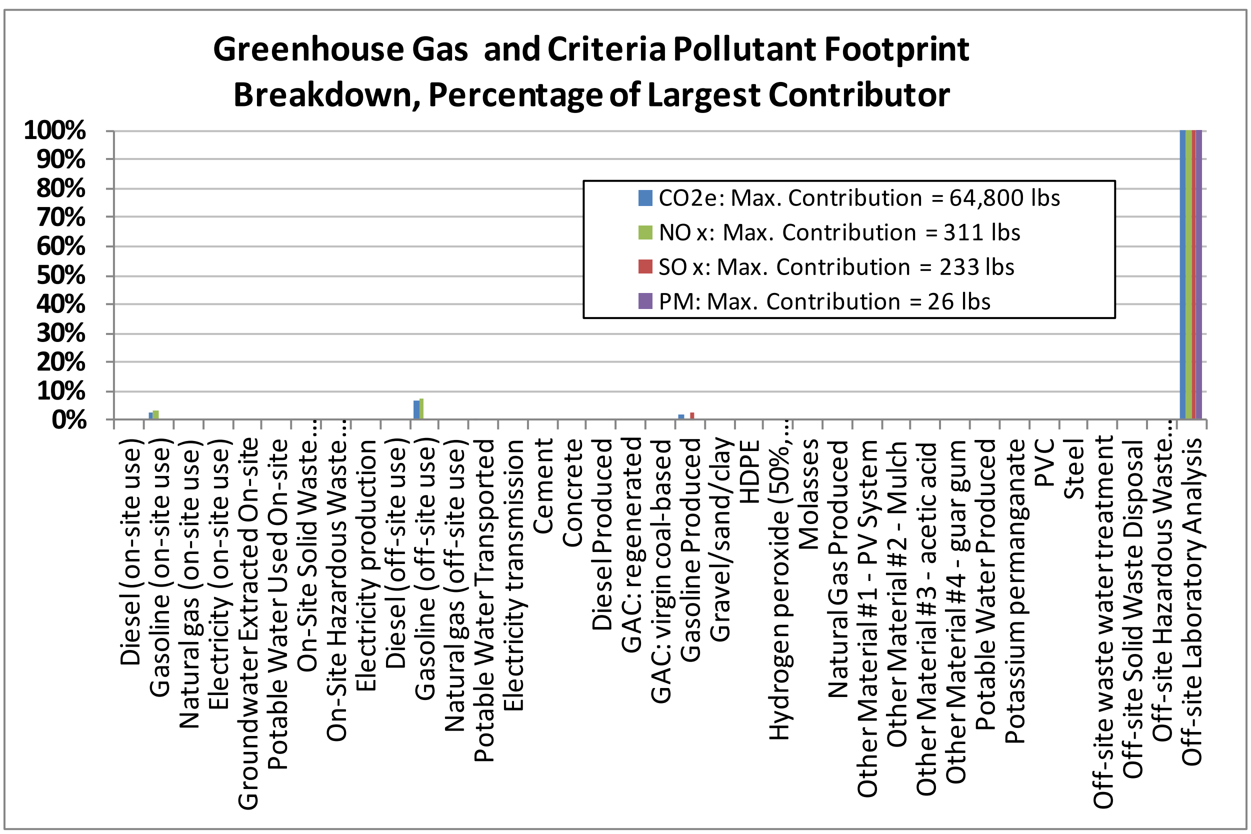


PRB Breakdown of Energy/Air, Water, Waste, and Toxic Pollutant Footprints

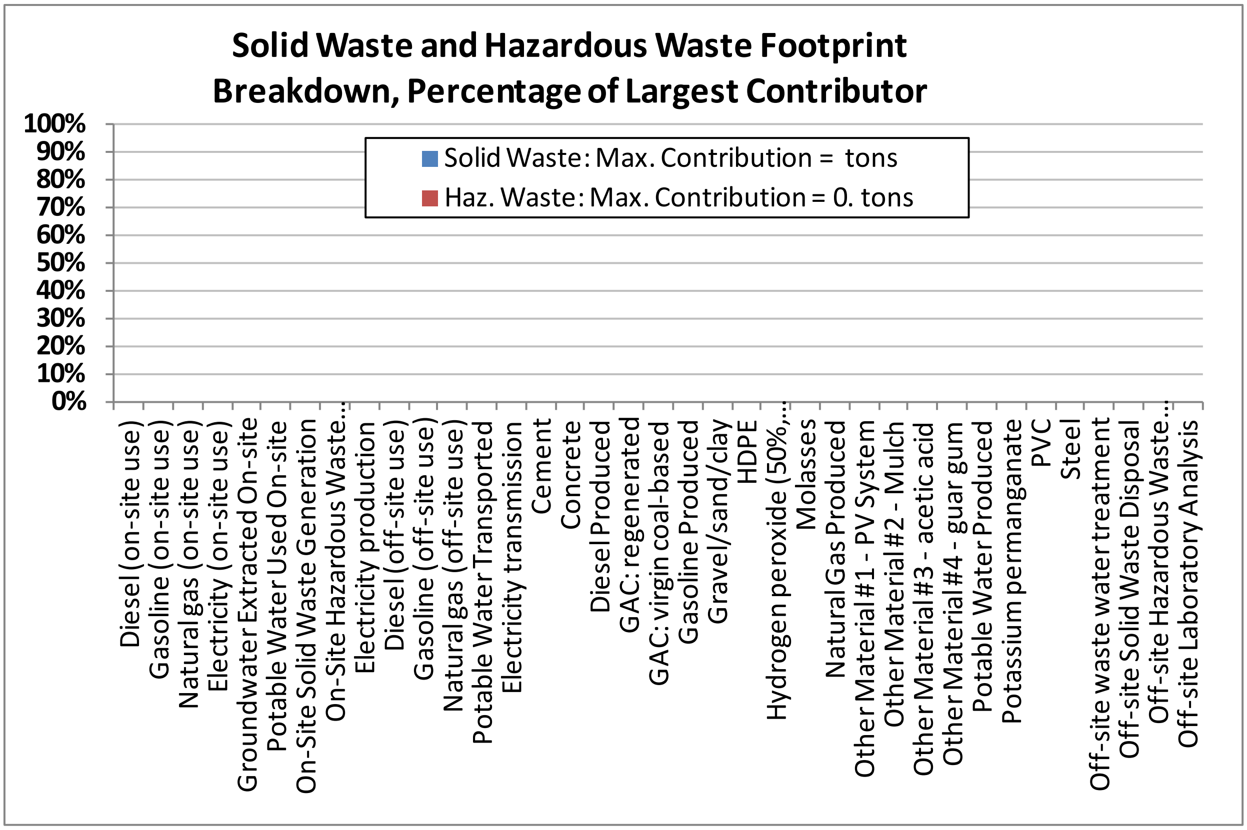


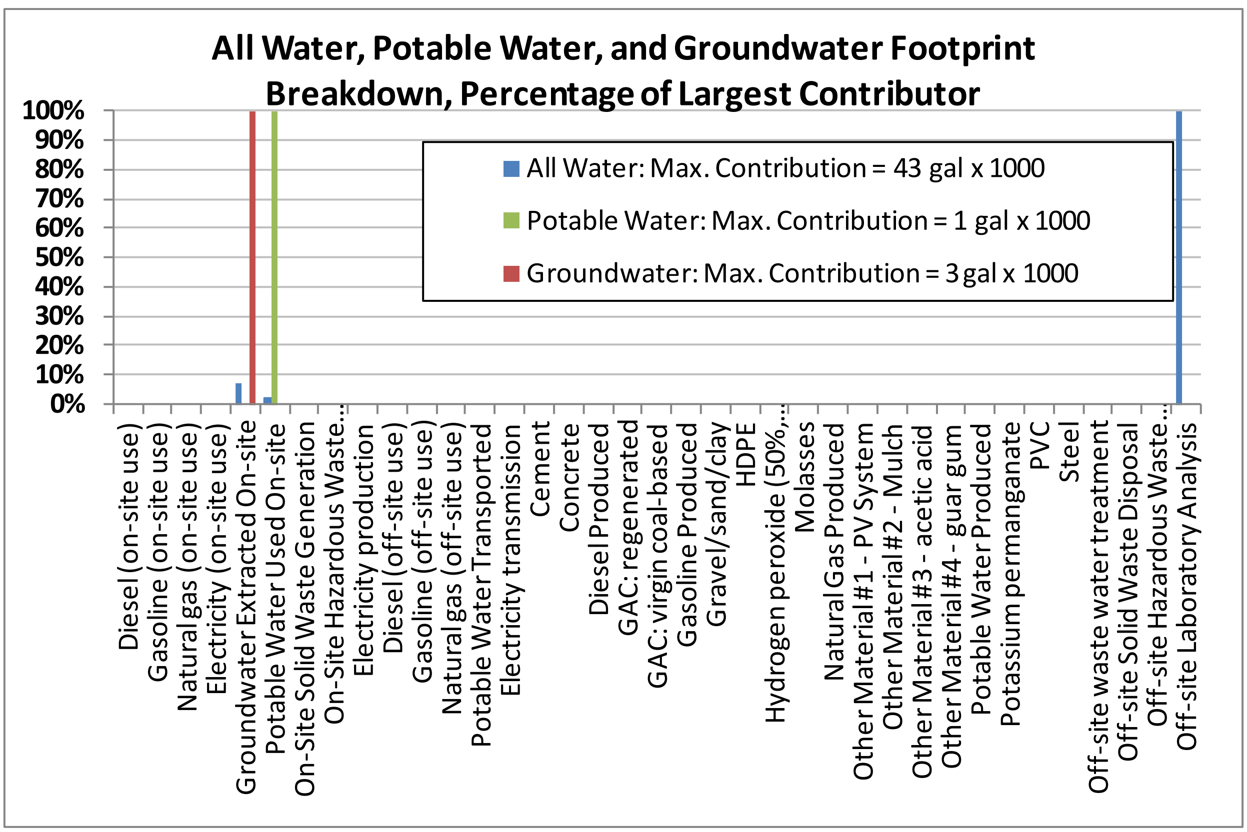
LTM Breakdown of Energy/Air, Water, Waste, and Toxic Pollutant Footprints





LTM Breakdown of Energy/Air, Water, Waste, and Toxic Pollutant Footprints





LTM Breakdown of Energy/Air, Water, Waste, and Toxic Pollutant Footprints