ENVIRONMENTAL FOOTPRINT ANALYSIS OF THREE POTENTIAL REMEDIES

FORMER ROMIC ENVIRONMENTAL TECHNOLOGIES CORPORATION FACILITY EAST PALO ALTO, CALIFORNIA

Final Report
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NOTICE

Work described herein was performed by GeoTrans, Inc. (GeoTrans) for the U.S. Environmental Protection Agency (U.S. E.P.A). Work conducted by GeoTrans, 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 three remedial options for corrective action at the Romic Environmental Technologies Corporation (Romic) facility in East Palo Alto, 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 site investigation, 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 footprinting 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 footprinting 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 appropriate and applicable "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 15 environmental parameters for three remedial alternatives
- Estimate the contribution to the various footprints from on-site activities, 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 that follows 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.

Background and Methodology

Romic is a 12.6-acre former hazardous waste management facility located in East Palo Alto, California. Due to historical waste management practices dating back to the mid 1950's, soil and groundwater at the facility are contaminated with hazardous constituents, primarily volatile organic compounds (VOCs). Interim groundwater remediation has occurred at the site in the form of pump and treat (P&T), and pilot tests for in-situ bioremediation have been conducted. Based on this experience, EPA has selected a remedy that uses in-situ bioremediation and monitored natural attenuation for groundwater contamination, excavation and off-site disposal for soil contamination, and maintenance of the existing site cover. This environmental footprint analysis has been conducted independently of site activities at Romic. The Romic site owners and EPA site team have provided the footprint analysis study team information so that the study could be performed for illustrative purposes. The Romic site owners and EPA site team are acknowledged for this assistance.

This footprinting study was conducted after remedy selection. Therefore, the final results of this study were not considered during the actual remedy selection process. Since the remedy is in the design phase and has not been implemented as of the preparation of this report, actual remedial design information and footprints are not available for this study. Instead, this study uses conceptualized preliminary design information, partially provided by the site team and partially developed by the study team, to estimate the energy and materials required to implement the alternative remedies. The observations in this study that are based on site-specific findings may not be readily applicable to designing and implementing the actual Romic remedy because the design and implementation of the remedy are occurring independently from this study.

For this study, footprints from on-site activities and off-site activities are calculated for the following three remedy alternatives:

- In-situ bioremediation
- Pump and treat (P&T)
- Hybrid in-situ bioremediation and P&T remedy

The results are organized into the following three analyses:

- Primary analysis – results are organized according to on-site activities, transportation, and non-transportation off-site activities.

- Secondary analysis – results are organized according to six main remedy components: site investigation, excavation, construction, operations and maintenance (O&M), long-term monitoring (LTM), and decommissioning.

- Sensitivity analysis – results are obtained for variations in remedy designs and other input information.

Many observations are made based on the findings from these analyses. Some of the observations are specific to the Romic site and others are more general observations that might apply to footprint analyses conducted at other clean-up 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 the Romic Site

- When considering the total footprints (i.e., on-site plus off-site footprints), the Bioremediation alternative has smallest environmental footprint for most of the 15 environmental parameters by a relatively wide margin. The only two parameters where the Bioremediation alternative has the highest total footprints are local potable water use (for blending and injecting bioremediation nutrients on site) and dioxins released to the environment (during the off-site manufacturing of PVC for injection well casings).

- The above findings for total footprints are sensitive to remedy design assumptions. Potential modifications to the assumed P&T design may result in environmental footprints that are closer in magnitude to those of the original Bioremediation alternative, and potential modifications to the original Bioremediation design may eliminate the potable water use for blending and injecting bioremediation nutrients.

- When considering on-site footprints only, the Bioremediation alternative has the highest footprints for on-site potable water usage and for on-site NOx, SOx, and PM emissions. The P&T and Hybrid alternatives, however, have substantial and significant on-site air toxics footprints from the air stripper off-gas.

- The O&M component is the largest contributor for the total energy, water, CO2e, NOx, and SOx footprints for all three remedy alternatives. For the Bioremediation alternative, the excavation, LTM, and construction components also contribute significantly to the footprints for these parameters. For the original design configuration for the P&T alternative, all the remedy components other than O&M are insignificant contributors to these parameter footprints.

- For all three remedy alternatives, the construction component contributes most significantly to off-site releases of mercury, lead, and dioxins. These releases are associated with materials manufactured off-site. Although the proportion contributed by the construction component to the total footprints of these parameters is large, the magnitudes of the releases are relatively small.

Sample of General Observations that May Apply to Other Sites

- On-site activities, transportation, and off-site activities (e.g., manufacturing) all have the potential to contribute significantly to the footprints of clean-up remedies. For evaluating most remedy technologies at most sites, it appears that environmental footprint analysis should consider all three of these types of activities.

- Remedial design may have a substantial influence on the environmental footprint. For example, modifications to the design of a P&T remedy (e.g., selecting different treatment equipment) may have a similar or perhaps a greater influence on the environmental footprint than the choice between implementing a P&T remedy or bioremediation remedy.

- The outcome of an environmental footprint analysis may be dependent on the quality of remedy design information input into the analysis. For example, in many cases it is difficult to determine the duration of a P&T remedy, the changes in influent concentrations over time, and when potential for downsizing remedy components will be possible. The environmental footprint of the remedy may be heavily dependent on these assumptions.

- The outcome of an environmental footprint analysis may be dependent on the quality, accuracy, and appropriateness of the footprint conversion factors. A variation by a factor of 2 for an important conversion factor could dramatically change the outcome of the results of the footprint analysis. In some analyses, the "error bars" for the footprints of various remedial alternatives may overlap, complicating the determination of which remedy alternative has the preferable environmental footprint.

- 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 footprinting is done in conjunction with other site activities that involve identifying relevant remedy information, such as the feasibility studies, remedial designs, and remedy optimization evaluations.

Conclusion

The Romic 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 is conducting similar studies at additional sites in order to explore other remediation technologies, increase the inventory of information needed for conducting footprint analyses, and further develop the framework for conducting footprint analyses. It is expected that this work will enhance the understanding of the environmental footprinting 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 are underway at two additional cleanup sites and will also be made available at www.cluin.org/greenremediation when completed. The authors of this report recognize that green remediation and the footprinting 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).

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LIST OF ACRONYMS

CFCs – Chlorofluorocarbons

CO2e – Carbon dioxide equivalents of global warming potential

EPA – U.S. Environmental Protection Agency

GAC – Granular activated carbon

GHGs – Greenhouse gases

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

HDPE – High density polyethylene

ISO – International Standards Organization

LTM – Long-term monitoring

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

O&M – Operations and maintenance

P&T – Pump and treat

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

POTW – Publicly owned treatment works

PVC – Polyvinyl chloride

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

VOCs – Volatile organic compounds

1.0 INTRODUCTION

1.1 ENVIRONMENTAL FOOTPRINTING

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 footprinting exercise 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 footprinting efforts 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 footprinting of three remedial options at the Romic Environmental Technologies Corporation (Romic) facility in East Palo Alto, California. For each of the three 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 that follows ISO Standards 14040 and 14044. Rather, it is a footprinting 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 remedy sustainability and that future footprinting analyses at other sites will involve less detail. The other primary objectives of this study are as follows:

- Identify or develop appropriate and applicable "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 15 environmental parameters for three remedial options and determine the remedial option that has 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), 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.

- Estimate the environmental footprint for alternative engineering designs for a given remedial alternative and compare the footprints to determine if the design alternatives have a significant effect on the environmental footprint.

- 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.

The Romic site owners and EPA site team have provided site-specific information from Romic so a footprinting study could be performed by EPA for illustrative purposes. However, this footprinting analysis was conducted independent of site activities and decision-making at Romic. That is, Romic 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 Romic site. Any decisions on how or whether the results of this study may be used by EPA or the site owner at Romic will be an independent process within the site remediation program at EPA.

The findings from this analysis are specific to the Romic facility 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

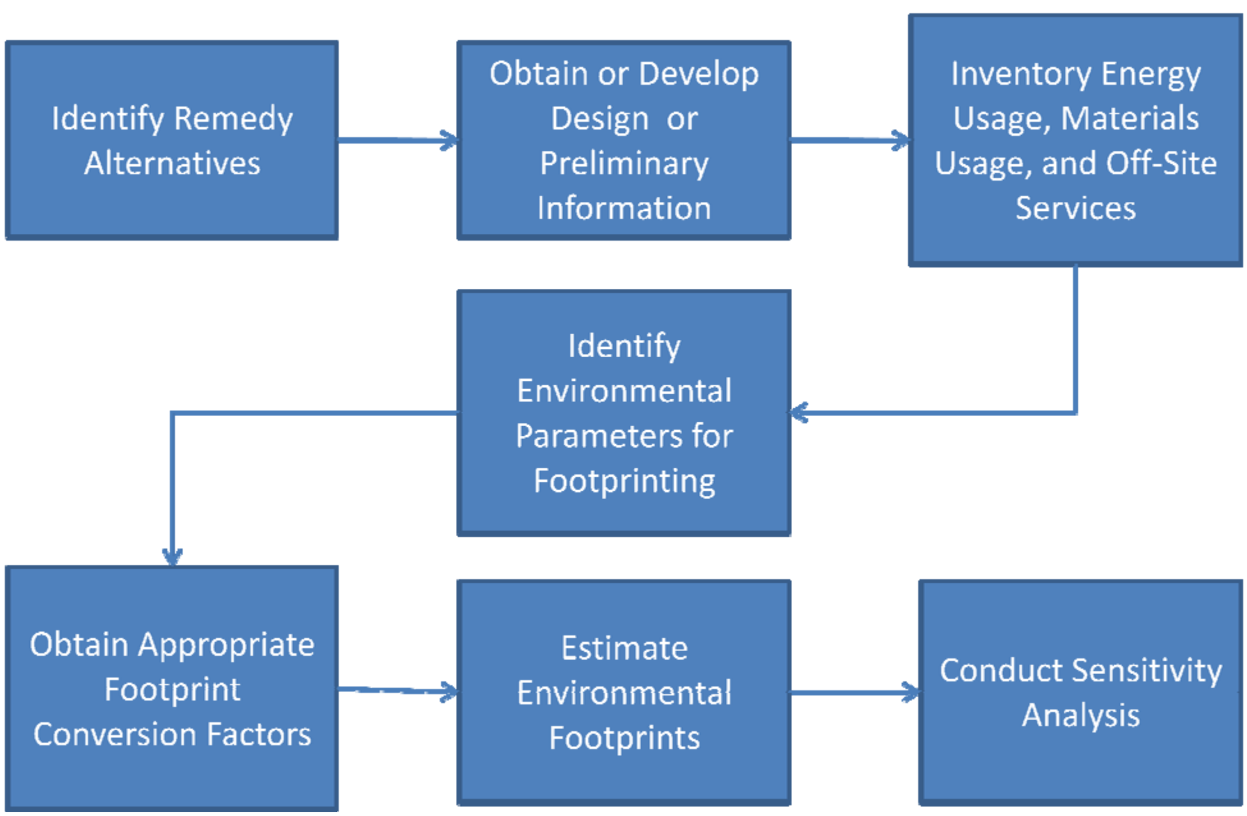
Romic is a 12.6-acre former hazardous waste management facility located in East Palo Alto, California. Facility operations have included solvent recycling, fuel blending, wastewater treatment, and hazardous waste storage and treatment. Due to historical waste management practices dating back to the mid 1950's, soil and groundwater at the facility are contaminated with hazardous constituents. The primary contaminants in the soil and groundwater are volatile organic compounds (VOCs). Typical VOCs include dry cleaning chemicals, carburetor cleaning liquids, paint thinners, and chemicals used to manufacture computers. Groundwater contamination extends across most of the facility to a depth of at least 80 feet below ground surface. Groundwater at the site flows east toward San Francisco Bay. Groundwater at the Romic facility is not a drinking water source. The property is located in an industrial setting along San Francisco Bay with good access to area infrastructure, making it a suitable for redevelopment.

Interim groundwater remediation has occurred at the site in the form of pump and treat (P&T), and pilot tests for in-situ bioremediation have been conducted. Based on this experience, EPA has selected a remedy that uses in-situ bioremediation and monitored natural attenuation for groundwater contamination, excavation and off-site disposal for soil contamination, and maintenance of the existing site cover. Other remedial options considered by EPA were a hybrid remedy, which included both bioremediation and P&T, and a no-action alternative. This study was conducted after the remedy had been selected. Therefore, the final results of this study were not considered during the remedy selection process. Since the remedy is in the design phase and has not been implemented as of the preparation of this report, actual remedial design information and footprints are not available for this study. Instead, this study uses conceptualized preliminary design information, partially provided by the site team and partially made by footprint analysis study team, to estimate the energy and materials required to implement the alternative remedies. The conceptualized preliminary designs for the three remedies are not necessarily those that would be implemented at the site because the actual remedial design is ongoing independent of this study. Similarly, the observations that are based on site-specific findings may not be readily applicable to designing and implementing the actual Romic remedies because the actual design and implementation are occurring independently from this study.

2.0 SCOPE AND METHODOLOGY

For this study, footprints from on-site activities and off-site activities for three remedy alternatives are organized into two main analyses. The first or primary analysis organizes the footprinting results according to on-site activities, transportation, and non-transportation off-site activities. The second or secondary analysis organizes the footprinting results according to six major remedial components from site investigation through decommissioning. 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



2.1 Remedy Alternatives to be Analyzed

This study evaluates the following three remedial alternatives:

- Alternative 2 (Hybrid) – This alternative involves a combination of in-situ bioremediation and P&T for the groundwater remedy. In-situ bioremediation addresses one part of the plume and P&T addresses the other.

- Alternative 3 (Bioremediation) – This alternative involves in-situ bioremediation for the groundwater remedy. The bioremediation component is larger in scope than that of Alternative 2 because there is no P&T component.

- Alternative 4 (P&T) – This alternative involves P&T for the groundwater remedy. The P&T component is larger in scope than that of Alternative 2 because there is no in-situ bioremediation component.

In addition, all three of the remedial alternatives include site investigation, soil excavation with off-site disposal (including concrete removal prior to excavation and resurfacing with concrete after excavation), long-term monitoring, and remedy decommissioning.

All of the remedy alternatives evaluated are assumed to provide appropriate protection of human health and the environment. That is, each remedy alternative is assumed to provide equivalent control of plume migration, restore the aquifer and soil to beneficial use as defined by applicable standards, and prevent direct exposure to potential receptors. As a result, the no-action alternative originally considered by the site team during actual remedy selection was not evaluated in this study. To provide an additional remedial alternative, for illustrative purposes only, Alternative 4 is included in this study even though it was not considered by EPA during the later stages of remedy selection.

2.2 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 of extraction wells, the number of injection wells, estimated volume of soil to be excavated, type and mass of nutrients to be injected, volume of groundwater to be extracted, method for treating extracted water, and design parameters for the treatment methods. The level of detail of this information and the assumptions made has a direct effect on the calculated footprints. For this study, many aspects of the remedial design have been provided by the site owner, such as the number of wells for the P&T alternative, the treatment processes used in the P&T alternative, the type and amount of nutrient for bioremediation, and the number of operator trips. Some design information, particularly for the P&T alternative, was developed as part of this study, including the type of extraction pump, the air to water ratio for the air stripper, and the granular activated carbon (GAC) usage.

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 (such as excavation, well installation, or freight transport) into services, materials, or energy use (such as quantity of waste disposed, amount of PVC used for well casing, or diesel fuel used for freight).

2.3 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 or water treatment with an air stripper 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 refined to these fundamental components. An inventory is developed for the usage of 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:

Three types of energy

- gasoline[1]
- diesel[1]
- grid electricity[2]

12 common materials[3]

- PVC
- HDPE
- Steel
- Stainless steel
- Sand and gravel
- Cement grout
- Concrete
- Bentonite
- Regenerated GAC
- Molasses (for in-situ bioremediation)
- Cheese whey (for in-situ bioremediation)
- Vegetable oil (for in-situ bioremediation)

Two types of water[4]

- Potable water
- Extracted groundwater

Four types of off-site services

- Solid waste disposal[5]
- Laboratory analysis
- Hazardous waste disposal[5]
- 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).*

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

[4] *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).*

[5] *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.

2.4 ENVIRONMENTAL PARAMETERS

For this study, 15 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.

On-Site Parameters	Off-Site Parameters
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

On-site parameters refer to parameters generated, emitted, or otherwise used on-site whereas off-site parameters refer to parameters generated, emitted, or otherwise used off-site. Potable water and groundwater are two 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 three 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 2.3) 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).

The environmental parameters related to water merit additional discussion, because of the unique considerations involved. 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 water quality. For example, potable water that is injected on-site into a brackish aquifer or groundwater that is extracted on-site and discharged to San Francisco Bay no longer have their original water quality and therefore both contribute to on-site "all water" use. 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 Romic. 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. 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 required for production of hydroelectricity, which is part of the off-site "all water" parameter. 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 a 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 a site remediation of the scale at Romic. Despite the above considerations, the factor used to convert grid electricity to water use includes the evaporative loss of water from hydroelectric facilities in order to be consistent with the literature cited.

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). With respect to the fifth core element (ecosystem), the remedies considered for this study are assumed to be equally protective of local human health and the environment, including the ecosystem of nearby San Francisco Bay. Further evaluation of local ecosystem impacts is not conducted given this equivalent level of protectiveness from the remedy alternatives and the industrial setting of the site.

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

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

2.5 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 project 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.

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

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.

2.6 CALCULATION OF ENVIRONMENTAL FOOTPRINTS

The calculation of the environmental footprints is relatively straightforward once the remedy inventory is established, the environmental parameters for footprinting have been selected, and appropriate footprint conversion factors are identified. As stated in Section 2.5, the footprint for a specific environmental parameter from a particular energy type, material, or off-site service is obtained by multiplying the quantity of the relevant item by the footprint conversion factor for 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 remedy footprint for a specific environmental parameter. For example, the on-site and off-site CO_2e footprints for a remedial 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 includes the footprint associated with producing the gasoline or diesel that is combusted.

2.7 ANALYSES

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

2.7.1 PRIMARY ANALYSIS

In the primary analysis, the three remedy alternatives 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 footprinting spreadsheet output files for this analysis are presented in Appendix C.

2.7.2 SECONDARY ANALYSIS

In the secondary analysis, only the Bioremediation and P&T alternatives are studied with the intent of analyzing which components of the remedies contribute most to the overall remedy footprints. Each of the two alternatives is divided into six components to determine which remedy components are negligible and which remedy components contribute significantly to the various footprints:

- Site investigation
- Excavation (including concrete demolition and resurfacing)
- Construction (e.g., well installation, piping installation, and treatment plant construction)
- Operations and maintenance (O&M) for the treatment plant and/or bioremediation injections
- Long-term monitoring (LTM)
- Decommissioning

The footprinting spreadsheet output files for this analysis are presented in Appendix D.

2.7.3 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 and GAC usage are large components of the P&T remedy. As a result, variations in the usages or the conversion factors used to convert these usages 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 or remedy design 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 site team identifies that a bioremediation remedy is highly sensitive to the distance nutrients are transported to the site, then the site team may focus on identifying local sources of bioremediation nutrients or energy efficient means of transporting them.

- 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 a P&T remedy is uncertain between 40 and 100 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, which primarily focuses on variations that would be considered during remedial design or implementation, and that would likely contribute a large amount to the environmental footprints. These variations were chosen for illustrative purposes in this study and do not necessarily reflect potential variations considered by the Romic site team for actual site remediation.

- Evaluation of alternative bioremediation nutrients other than molasses and cheese whey
- Evaluation of variations in the frequency of bioremediation injections and the total mass of nutrients injected
- Use of extracted groundwater, in place of potable water, for the bioremediation injections, since this approach is common in bioremediation remedies for assistance in dispersing the nutrients
- Evaluation of alternative treatment strategies for the P&T option
- Use of on-site renewable energy in powering the remedies
- Use of a different blend of fuels for grid electricity generation (e.g., the average blend for the U.S. rather than the local blend)

The footprinting spreadsheet output files for the variations in the bioremediation design are included in Appendix E, and the footprinting spreadsheet output files for the variations in the P&T design are included in Appendix F.

Comments regarding sensitivity analysis are also provided related to the following:

- Variations in key footprint conversion factors
- Variations in the distances traveled for personnel transport and materials delivery
- Variations in the amount of soil excavated
- The results of reusing concrete on site rather than disposing of it off-site
- Extending the remedy life-time for P&T from 40 to 100 years and altering assumptions regarding remedy performance
- Reducing the long-term monitoring frequency from quarterly to semi-annual

For the comments on the above six topics, the discussion is generally limited to the CO2e footprint as an indicator or example parameter. Additional information pertaining to the other parameters can be extracted from Appendices E and F.

3.0 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 footprinting 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 F 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.

3.1 PRIMARY ANALYSIS

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

Charts 1 through 3 present the total (i.e., the on-site plus off-site) footprints for CO2e, SOx, and mercury for each of the three remedy alternatives. These three environmental parameters are presented because they are representative of the global or regional environmental effects resulting from the remedies. CO2e is a measure of greenhouse gas potential, which can affect 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. For all three parameters, the P&T alternative has a substantially larger footprint than either of the two other alternatives, and the bioremediation alternative has the smallest footprint. For more information on how the total footprints for the other parameters evaluated compare among the three alternative remedies, 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

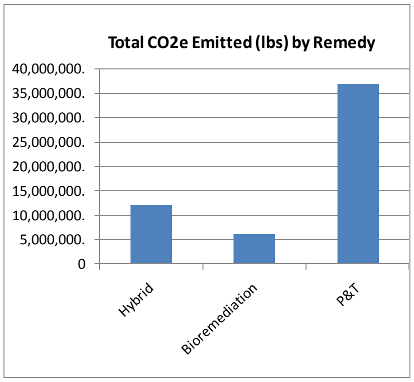


Chart 2

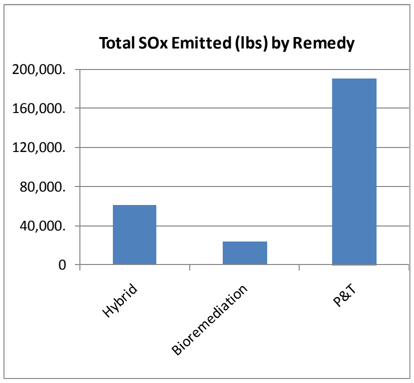
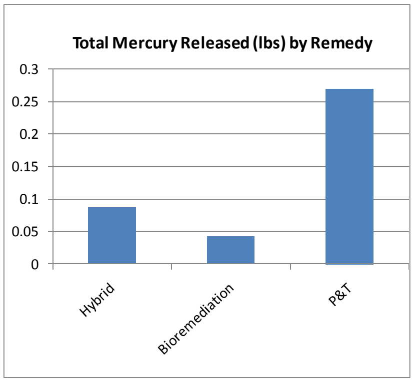


Chart 3



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

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

Charts 4 through 6 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 three remedy alternatives. 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 NOx and PM emissions, the Bioremediation and Hybrid alternatives have the higher on-site emissions, whereas P&T has the highest on-site air toxics emissions. For more information on how the on-site footprints for the other parameters evaluated compare among the three alternative remedies, 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 4

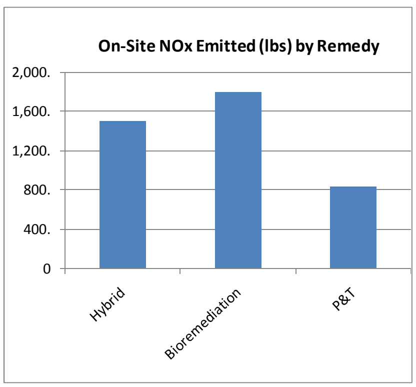


Chart 5

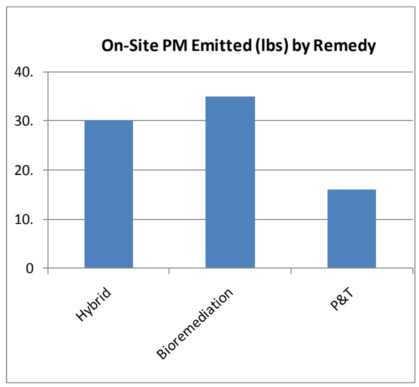
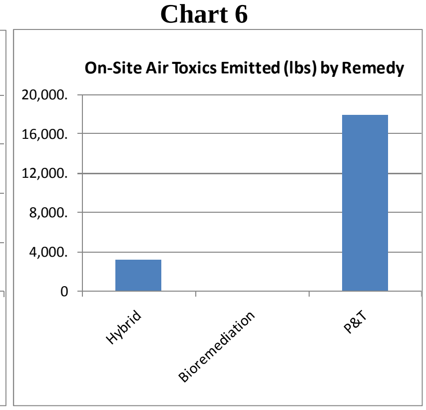


Chart 6



These charts show the on-site footprints over the life-time of the remedies.

3.1.3 On-Site, Transportation, and Non-Transportation Off-Site Distribution of Footprints

Charts 7 through 9 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. The following findings are noteworthy:

- The majority of the CO2e emissions for each of the remedy alternatives are from non-transportation off-site sources.

- The CO2e emissions from transportation sources are of the same order of magnitude for each of the remedy alternatives. However, the importance of the transportation source relative to the non-transportation off-site source differs between among the alternatives. The CO2e emissions from transportation are significant for the Hybrid and Bioremediation alternatives (approximately 16% and 26% of the total CO2e footprints, respectively), but are much less significant for the P&T alternative (approximately 5% of the total CO2e footprint).

- The CO2e emissions from on-site sources are too small relative to those from the off-site sources to see on Chart 7 and are therefore negligible for a parameter such as CO2e that does not have a local environmental effect.

- The distribution of NOx emissions is similar to that of the CO2e emissions.

- The air toxic emissions for the Bioremediation alternative are present but very small, and result from non-transportation off-site sources.

- The air toxic emissions for the P&T alternative are high and predominantly result from on-site activities.

Chart 7

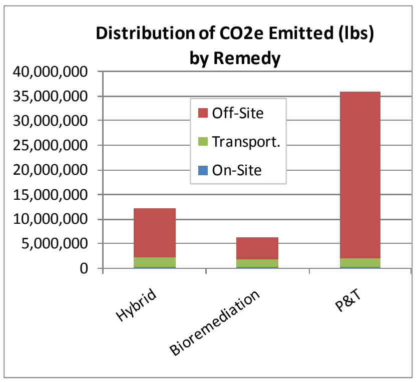


Chart 8

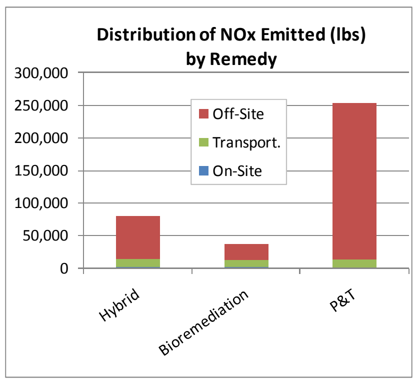
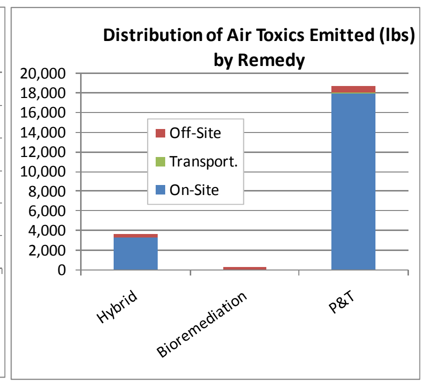


Chart 9



"Off-site" refers to non-transportation off-site sources (e.g., manufacturing) over the life-time of the remedies.

3.1.4 Findings Related to Various Other Environmental Parameters

A review of the spreadsheet output in Appendix C indicates the following additional findings related to hazardous waste generation, potable water use, groundwater extraction, and general water use.

- The hazardous waste generation footprints are relatively equal for all three alternatives because this footprint is dominated by the hazardous waste generated during excavation, which is the same in scope and design for all three alternatives.

- The on-site potable water use is higher for the Bioremediation and Hybrid alternatives than for the P&T alternative because potable water is used for blending and injecting the bioremediation nutrients. Potable water is not used on-site for the P&T alternative.

- The on-site groundwater extraction is highest for the P&T alternative, followed by the Hybrid alternative, because groundwater is extracted, treated, and not returned to the subsurface. No groundwater extraction occurs during Bioremediation alternative or the bioremediation component of the Hybrid alternative.

- For the Bioremediation alternative, the on-site potable water use contributes approximately 70% to the total (on-site plus off-site) "all water" footprint that is defined in Section 2.4 of this report. The majority of the remaining contribution to the total "all water" footprint is associated with waste disposal and the production of sand and gravel to be used as select back fill to meet potential specific backfill requirements.

- For the P&T alternative, on-site groundwater extraction contributes over 90% to the “all water” footprint. Other contributions to “all water” include water used in materials production (approximately 3%) and water used in electricity production (approximately 2%). The extracted groundwater, after treatment and discharge to the POTW, is discharged to San Francisco Bay and is therefore no longer available as a freshwater resource. However, at Romic the extracted groundwater is brackish and would not have been useable for other purposes. In addition, given the relatively low productivity and brackishness of the aquifer, nearby groundwater use is not expected and concerns about lowering the water table and dewatering nearby production wells are not as great as they might be at other sites.

3.1.5 Individual Contributors to Footprints of Selected Parameters

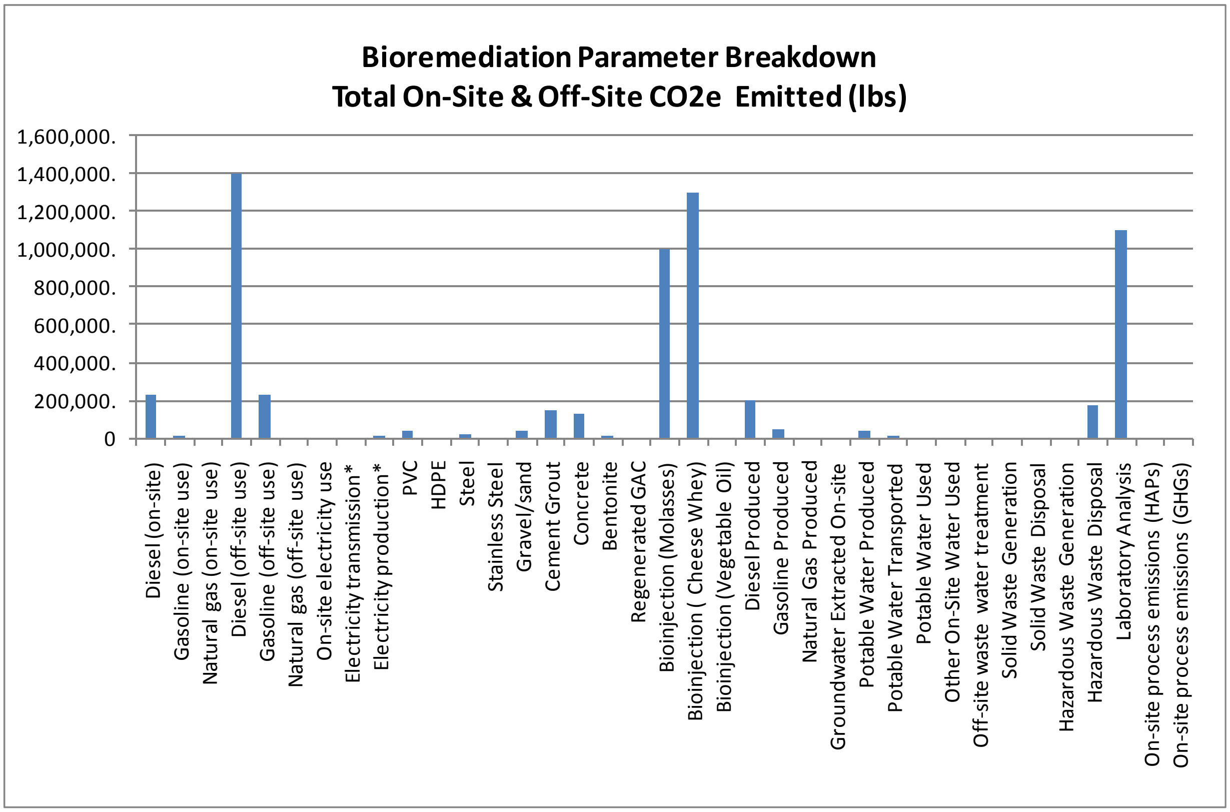
Charts 10, 11, and 12 show the contributions of the full array of remedial activities (on-site and off-site) to the footprints of selected environmental parameters. These charts are designed to focus attention on the highest contributors to the environmental footprints.

Chart 10 presents the output from the Bioremediation alternative for CO2e. For simplicity, CO2e is being used as an indicator parameter. The footprints for other parameters may be distributed differently. The chart indicates that off-site diesel use (for transportation), molasses production, cheese whey production, and laboratory analysis are the primary contributors to total CO2e emissions. These are all items that contribute to the off-site footprints. On-site diesel use (for drill rigs and heavy equipment) is also a significant contributor to CO2e emissions, but is noticeably smaller than the other contributors. However, on-site diesel usage contributes to the on-site footprint (e.g., NOx and PM emissions), which may be more relevant to the local community than the global parameter CO2e. A review of the information in Appendix C indicates that approximately 40% of the off-site diesel usage shown in Chart 10 is from hauling hazardous waste (excavated soils) in the excavation component of the remedy.

Whereas many of the environmental conversion factors used in this study are determined from life-cycle inventory databases or other references, the environmental conversion factors for laboratory analysis are based on assumptions made by the study team. We assumed that approximately 10% of the total cost of laboratory analysis (throughout the laboratory analysis supply chain) is due to electricity and diesel usage, and estimated the amount of electricity and diesel usage that the 10% cost would imply. We then calculated the footprints of the environmental parameters based on the production and usage of this amount of electricity and diesel. The accuracy and appropriateness of these laboratory analysis conversion factors has a significant influence on the footprints, and the actual laboratory analysis footprint may be substantially higher or lower than presented.

The table from which Chart 10 was developed is provided in Appendix C and includes the same information for other 14 environmental parameters. The analogous tables for the other two remedial alternatives are also provided in Appendix C.

Chart 10



Notes:
Electricity transmission refers to electricity lost due to transmission and distribution. Electricity production refers to the process of producing the electricity at the power plant and includes an estimate of sacrificial loads by the power plant. "Electricity transmission" and "electricity production" are based directly on the amount of electricity used on-site.

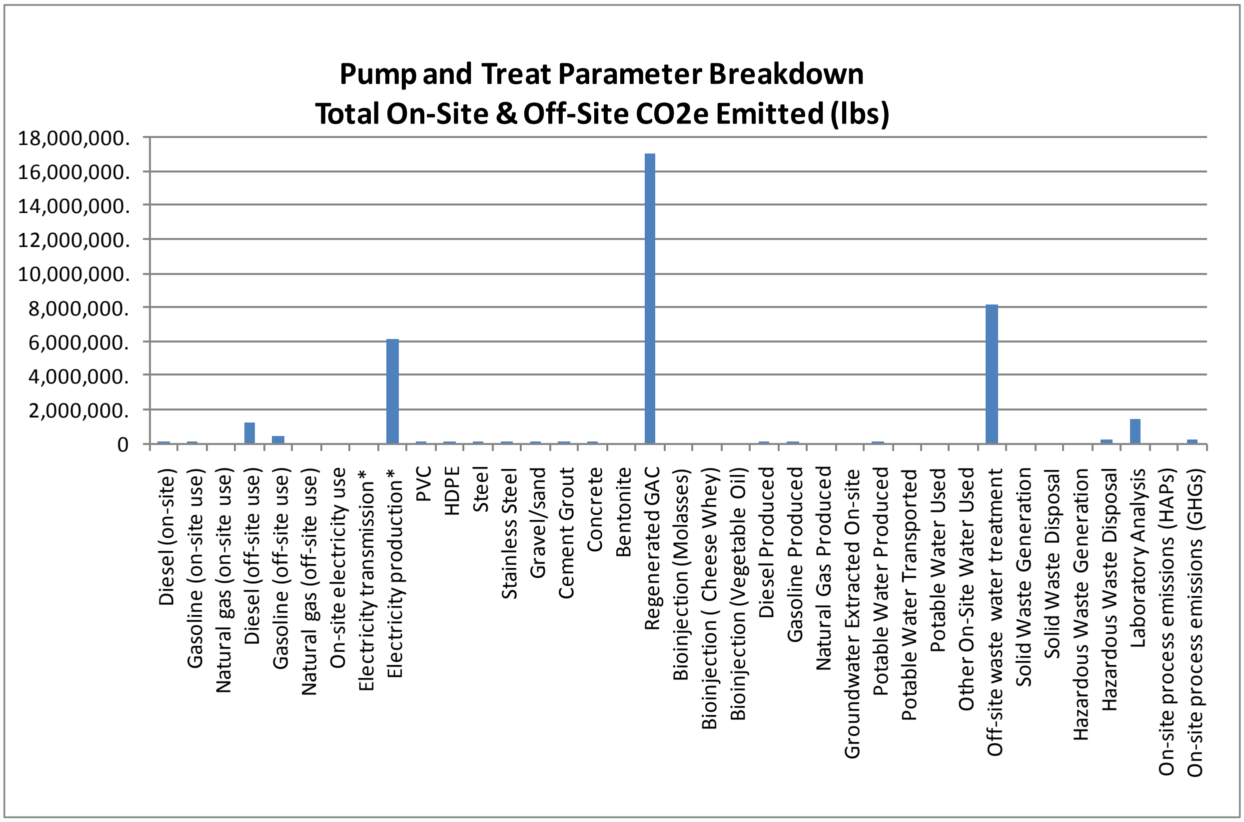
"Molasses", "cheese whey", and "vegetable oil" refer to the process of producing these bioremediation nutrients, not injecting them.

Chart 11 presents the same information for the P&T alternative. The scale of the vertical axis for the P&T alternative is approximately 15 times that of the vertical axis for the Bioremediation alternative, and the magnitude of the CO2e footprint from the P&T alternative is substantially higher than that of the Bioremediation alternative. It is apparent that GAC is the largest contributor, followed by treatment of wastewater at a POTW, and then by the electricity production. All other activities appear to be negligible contributors to the CO2e footprint. However, note that some of the contributors that appear to be negligible for the P&T alternative, such as laboratory analysis and off-site diesel usage, are at the same order of magnitude as they are for the Bioremediation alternative, where they were considered primary contributors.

The environmental conversion factors for the POTW and GAC are based on assumptions made by the study team. The conversion factors for treatment at the POTW were obtained by dividing by 100 the conversion factors from the EUROPA Life-Cycle Inventory database for treating industrial wastewater with low organic loading. The scale factor of 100 was arbitrarily chosen by the study team to represent the discharge of treated groundwater instead of industrial waste water to the POTW. The GAC footprint conversion factors used in this study were developed by the site team for this project based on a literature description of the GAC regeneration process. The method and calculations for a developing these conversion factors is included at the back of Appendix B. These GAC conversion factors were developed with less rigor than those obtained from life-cycle inventory databases. The accuracy and appropriateness of the POTW and GAC conversion factors has a significant influence on the footprints, and the actual POTW and GAC footprints may be substantially higher or lower than presented.

One would expect the footprints for the Hybrid option to be a blend of the P&T and bioremediation footprints, so it is not discussed in further detail.

Chart 11



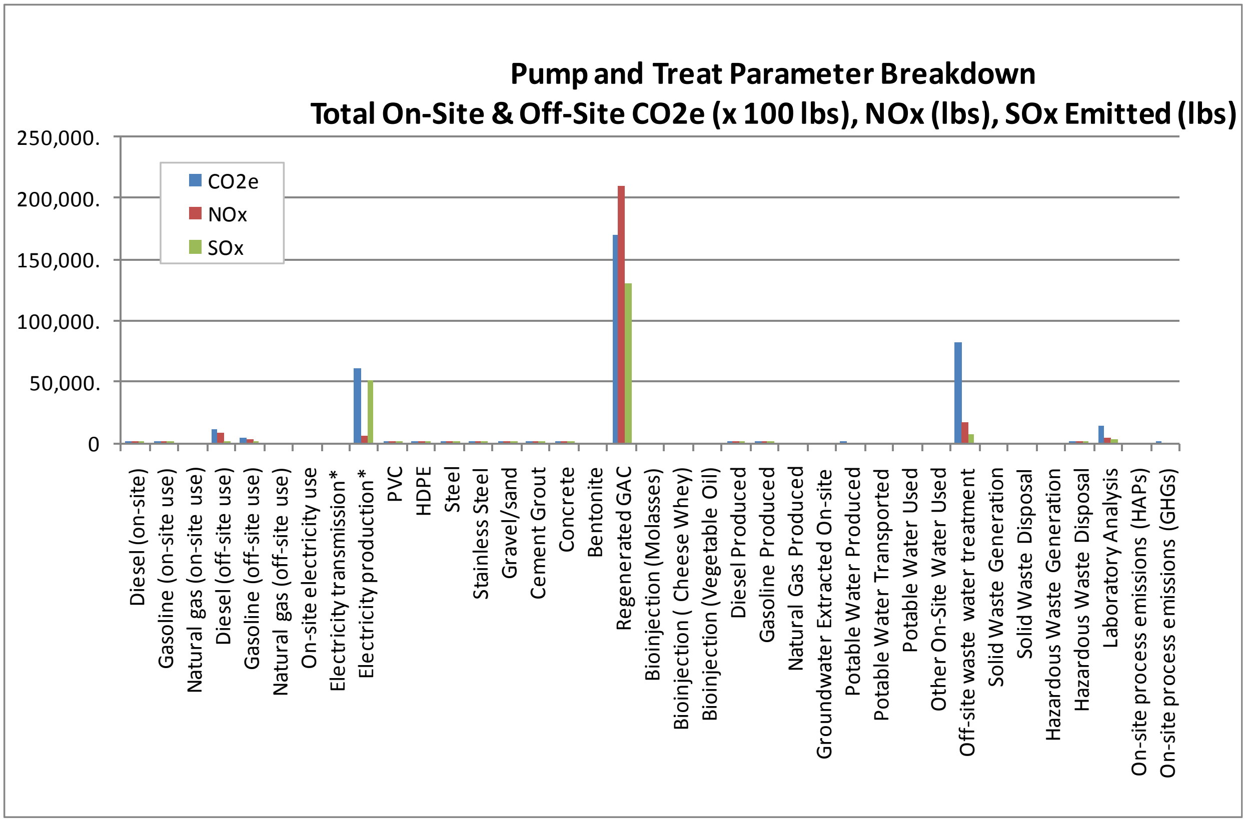
Notes:

Electricity transmission refers to electricity lost due to transmission and distribution. Electricity production refers to the process of producing the electricity at the power plant and includes an estimate of sacrificial loads by the power plant. "Electricity transmission" and "electricity production" are based directly on the amount of electricity used on-site.

"Molasses", "cheese whey", and "vegetable oil" refer to the process of producing these bioremediation nutrients, not injecting them.

Chart 12 presents the same information as Chart 11 but scales the CO2e values by 100 and includes the emissions for NOx and SOx. Chart 12 indicates that the primary contributors of NOx and SOx are similar to those of CO2e, suggesting that in a less detailed analysis it may be appropriate to track relative sources of NOx and SOx by tracking CO2e. NOx and SOx emissions appear to be of similar magnitude for GAC regeneration and waste water treatment, but for electricity production, SOx emissions appear to be significantly higher than NOx emissions. This is likely the result of the choice of conversion factors used for NOx and SOx. For the development of GAC regeneration conversion factors values obtained from the EUROPA database were used, but for electricity production, conversion factors from NREL were used. For electricity production, the NREL emission factor for SOx is approximately an order of magnitude higher than the EUROPA emission factor for SOx for similar fuel blends. The source of this discrepancy is not known but appears to result from the amount of SOx released during desulphurization of the natural gas before distribution to natural gas customers. Both databases assume the natural gas is desulphurized, but the resulting SOx values are different. This underscores some of the uncertainty and variability in published emission factors.

Chart 12



Notes:
Electricity transmission refers to electricity lost due to transmission and distribution. Electricity production refers to the process of producing the electricity at the power plant and includes an estimate of sacrificial loads by the power plant. "Electricity transmission" and "electricity production" are based directly on the amount of electricity used on-site.

"Molasses", "cheese whey", and "vegetable oil" refer to the process of producing these bioremediation nutrients, not injecting them.

3.1.6 FINDINGS RELATED TO REMEDY DURATION, LABOR, AND TRAVEL

The following table presents results for remedy duration, time to redevelopment, travel, and labor.

Remedy Duration, Travel, and Labor

	Remedy Duration	Time to Redevel.	Trips to Site by Vehicle: Car	Trips to Site by Vehicle: Light-Duty Truck	Trips to Site by Vehicle: Heavy-Duty Truck	Miles Driven by Vehicle: Car	Miles Driven by Vehicle: Light-Duty Truck	Miles Driven by Vehicle: Heavy-Duty Truck	Man-Days Worked On-Site
	years	Years	Trips	Trips	Trips	miles	miles	Miles	Man-Days
Hybrid	30.	10.	0	2,916.	1,462.	0	163,170	699,650	5,522.
Bio.	10.	10.	0	1,312.	922.	0	114,828	387,530	4,036.
P&T	40.	3.	0	2,841.	1,680.	0	240,812	691,250	5,191.

The light-duty trucks, which are used by construction crews, oversight consultants, sampling technicians, and treatment plant operators, are higher for the Hybrid and P&T alternatives because of the weekly treatment plant system checks associated with these two alternatives. The heavy-duty truck trips and miles are comparable for the Hybrid and P&T alternatives and are significantly higher than for the Bioremediation alternative. The man-days worked are relatively similar for the three options but highest for the Hybrid alternative, which involves both bioremediation injections and P&T system maintenance, and lowest for the Bioremediation alternative.

3.2 Secondary Analysis

3.2.1 Bioremediation

Charts 13 through 15 present the total footprints for the Bioremediation alternative for the same three global or regional environmental parameters (CO2e, SOx, and mercury) depicted in Charts 1 through 3, but organize the information according to remedy component. The charts indicate that O&M is the largest contributor to the footprints of these three parameters. Excavation, construction, and the long-term monitoring (LTM) components also contribute significantly to the CO2e footprint. The excavation and construction (but not the LTM) components contribute significantly to the mercury footprint. For the SOx footprint, the O&M contribution appears to be the only significant one. For SOx, the LTM component contributes approximately 10% of the amount contributed by O&M.

Chart 13

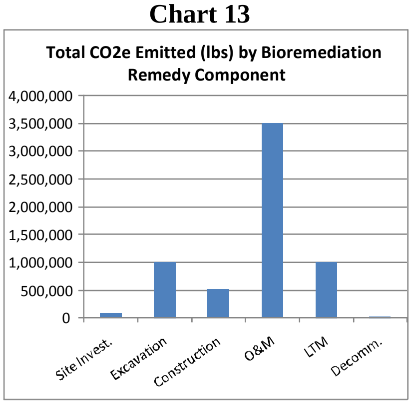


Chart 14

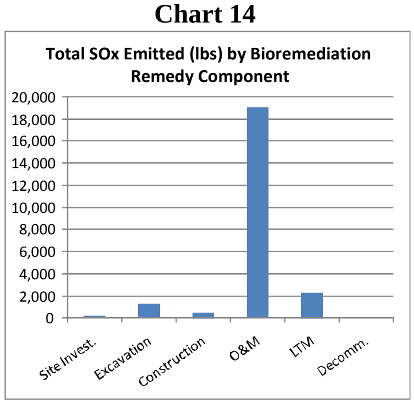
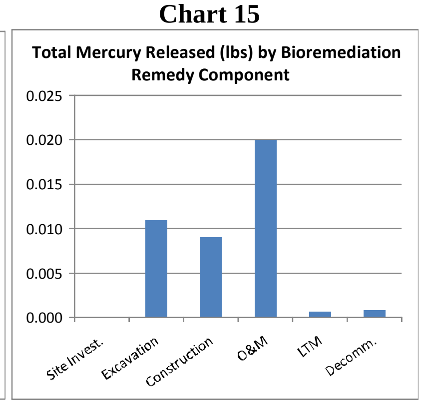


Chart 15



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

Charts 16 through 18 present the on-site footprints for the Bioremediation alternative for the same three local or regional environmental parameters (NOx, PM, and air toxics) depicted in Charts 4 through 6, but organize the information according to remedy component. The charts indicate that the construction component of the remedy dominates the footprints for these three parameters. Further review of the spreadsheet output in Appendix D indicates that all of these contributions come from on-site diesel usage, which is highest for the construction component due to the installation of a large number of wells. Review of the remedy inventory sheets in Appendix A indicates that the on-site diesel usage for the well installation is more than an order of magnitude higher than the on-site diesel usage for the excavation component (which also includes the concrete demolition and resurfacing with concrete).

For both the total and on-site footprints, the site investigation and decommissioning components contribute negligibly for all parameters.

Chart 16

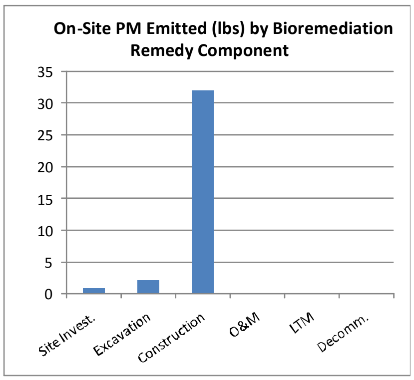


Chart 17

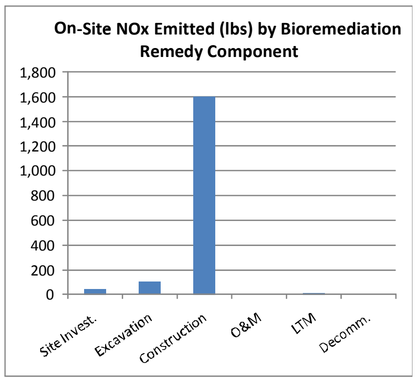
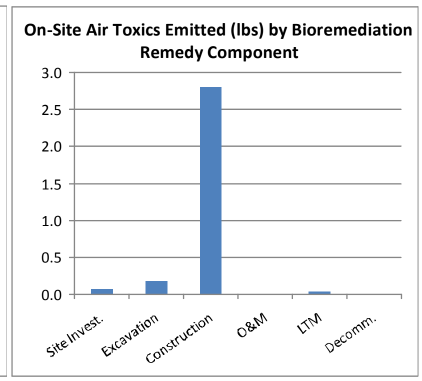


Chart 18



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

The following are some additional findings from the secondary analysis on the Bioremediation alternative, supported by information provided in the Supplemental Charts and in Appendix D:

- The excavation component dominates the hazardous waste generation footprint.

- The excavation component dominates the total PM footprint due to the PM emitted during hazardous waste disposal (i.e., managing waste at the landfill, not transportation of waste to the landfill). PM released from soil during on-site earthmoving is not calculated. It is assumed that this would be controlled to the degree possible with best management practices.

- The O&M component dominates the potable water and "all water" footprints due to the use of potable water for blending and injecting the bioremediation nutrients.

- The air toxics footprint (up to 160 pounds emitted over the life-time of the remedy) is dominated by the LTM component because of the air toxics associated with the laboratory analysis. It is noted that as a result of the conversion factors used, the air toxics associated with the laboratory analysis are those that result from energy usage and not those that are emitted from sample preparation, sample disposal, or chemical usage.

More information regarding the distribution of total and on-site footprints for various parameters is included in the tables and charts of Appendix D.

3.2.2 P&T

As illustrated in Chart 12, the CO2e, NOx, and SOx footprints for the P&T alternative are dominated by GAC usage, electricity production, and wastewater treatment at the POTW. All three of these items are part of the O&M component of the remedy; therefore, the O&M component of the remedy dominates the footprints for these parameters. As shown in the Supplemental Charts, the footprints of all other environmental parameters are also dominated by the O&M component of the remedy with the notable exceptions of hazardous waste generation, PM, and dioxins. Closer analysis of the spreadsheet output in Appendix D indicates that the majority of the hazardous waste generation is from the excavation component of the remedy. The majority of PM generated is from hazardous waste disposal, and the majority of the hazardous waste disposal is associated with the excavation component.

3.3 SENSITIVITY ANALYSIS

The scope of the sensitivity analysis is described in Section 2.7.3, and the findings are summarized below.

3.3.1 FINDINGS FROM EVALUATING MODIFICATIONS TO THE BIOREMEDIATION NUTRIENT TYPE, INJECTION FREQUENCY, AND INJECTION MASS

Charts 19 through 21 illustrate the total CO2e, SOx, and potable water footprints for three different variations of the Bioremediation alternative: 1) the original configuration, 2) using extracted water instead of potable water, and 3) using emulsified vegetable oil with potable water instead of molasses and cheese whey. It is reiterated here that these modifications were chosen for illustrative purposes for this study and do not necessarily reflect potential modifications considered by the site team. The details of these alternative designs are included in Appendix E.

Chart 19

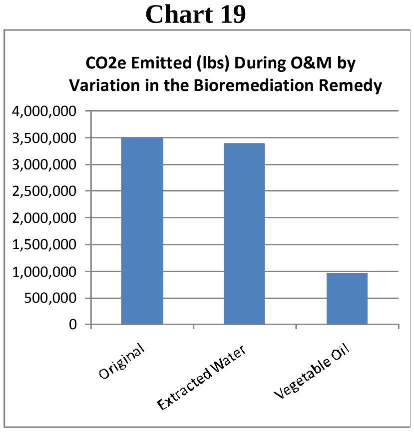


Chart 20

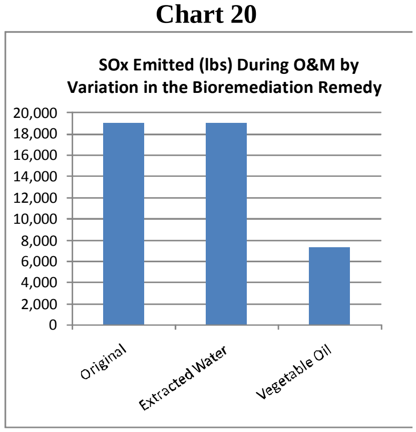
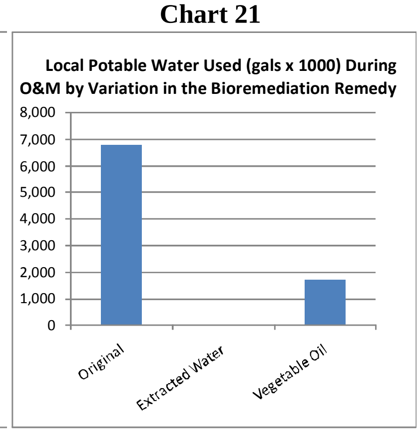


Chart 21



"Original" refers to the original bioremediation configuration.

The use of extracted groundwater instead of potable water has a negligible effect on the CO2e, SOx, and potable water footprints presented above and on other footprints as well, with the exception of potable water used and mercury released. (See the Supplemental Charts for the results for the other parameters.) The reason for this is that the potable water contributes negligibly to the footprints of most parameters relative other contributors such as the production and transport of the nutrients.

The use of emulsified vegetable oil, if it were applicable at Romic, would substantially reduce the footprints for CO2e and SOx. Although the footprints for production of vegetable oil are generally higher than those for production of molasses on a per weight basis, reference to nutritional labels indicate that one gram of vegetable oil has three times the calories of one gram molasses. This increased nutrient density could allow for injecting less vegetable oil than molasses, and so, combined with other remedy performance factors, would result in a reduction of the total footprint. Close examination of the contributors to the footprints (see Appendix E) in the original bioremediation scenario indicates that over 90% of the total CO2e footprint for the O&M component (approximately 50% of the total CO2e footprint for all six remedy components combined) is caused by the production of the nutrients (molasses and cheese whey) and the production and combustion of diesel to transport the nutrients. It therefore follows that the large majority of the observed decrease in the footprints results from the injection of less mass and the reduced mass of nutrients to be transported to the site.

Because of the reduced number of injections with emulsified vegetable oil, the use of emulsified vegetable oil also substantially reduces the potable water requirements, assuming only one injection is needed per year rather than four.

Less vegetable oil also translates to less mass for transport. However, for this study, the emulsified vegetable oil is assumed to come from a producer and vendor in North Carolina, so the transport distances to California are greater than those of cheese whey (which is provided from southern California) and molasses (which is provided from Ohio).

The findings associated with modifying the nutrient selection from molasses and cheese whey to emulsified vegetable oil are also informative with respect to modifications in the injection frequency and mass of nutrients injected. The injection frequency has an apparently small effect on the total footprint as long as the total mass of injected nutrients remains the same. That is, the output is relatively insensitive to the frequency of injections. The injected mass of nutrients and the distance the nutrients need to be transported have a substantial effect on the total footprint, indicating that the output is highly sensitive to these parameters. The output is also sensitive to the CO2e conversion factor. The following table presents the results of 1) reducing the CO2e footprint conversion factors for molasses and cheese whey by a factor of two and 2) leaving the footprint conversion value unchanged but cutting the mass of both nutrients by a factor of two.

Change	Nutrient Production & Transport CO2e Footprint (lbs)	% Decrease in O&M CO2e Footprint	% Decrease in Remedy CO2e Footprint	% of Indicated CO2e Footprint from Nutrient Production &Transport	
				O&M Footprint	Remedy Footprint
Original conversion factors and injection mass	3,207,000			92%	52%
Reduce nutrient CO2e conversion factors by 50%	2,057,000	33%	19%	88%	41%
Reduce injected mass of nutrients by 50%*	1,603,500	46%	26%	85%	35%

** leave the CO2e conversion factor unchanged from original value*

3.3.2 FINDINGS FROM EVALUATING ALTERNATIVE P&T DESIGNS

Charts 22 through 24 depict the total CO2e, NOx, and air toxics footprints for five P&T designs:

- Original design – treatment with an air stripper, polishing of air stripper effluent with liquid phase GAC, discharge of treated water to the POTW, and off-gas treatment with vapor phase GAC
- No liquid phase GAC – treatment with higher capacity air stripper (increased air to water ratio), discharge of treated water to the POTW, and off-gas treatment with vapor phase GAC
- No liquid phase GAC + No POTW – treatment with the same higher capacity air stripper, discharge of treated water to surface water, and off-gas treatment with vapor phase GAC
- No liquid phase GAC + No POTW + Ren. Energy – treatment with the same higher capacity air stripper, discharge of treated water to surface water, off-gas treatment with vapor phase GAC, and system electricity provided by renewable energy from either on-site generation or the purchase of renewable energy credits (both assumed to have no footprint or transmission losses to serve as an idealized case of removing the footprint associated with electricity usage)
- No liquid phase GAC + No POTW + US grid – treatment with the same high capacity air stripper, discharge of treated water to surface water, off-gas treatment with vapor phase GAC, and system electricity provided by electricity that is generated by average U.S. grid blend of fuels (higher footprint than the local electricity generation)

Chart 22 indicates that increasing the size and air to water ratio of the air stripper and eliminating the liquid phase GAC reduces the CO2e footprint substantially. Eliminating the discharge to the POTW further reduces the CO2e footprint, and powering the remedy with CO2e-neutral renewable energy also reduces the CO2e footprint. The magnitude of the reduction is similar for each successive modification.

Also apparent in Chart 22 is that the energy source for grid electricity generation has a considerable effect on the CO2e footprint and NOx footprints, although the significance of electricity generation in the NOx footprint is muted by the substantial reductions from eliminating the GAC. Comparing the CO2e footprints for the "No liquid GAC + No POTW" option to the "No liquid GAC + No POTW + US" option suggests that changing the assumption for the fuel blend can nearly double the footprint because the footprint for electricity production in Northern California is relatively small compared to the footprint for electricity generated with the average United States fuel blend. If the footprint for electricity from the local fuel blend was higher than the footprint for electricity from the U.S. average fuel blend, then using the U.S. average fuel blend as an assumption in footprinting (instead of a local fuel blend) would have resulted in underestimating the footprint.

Chart 23 also indicates improvements in the NOx footprint with each successive modification; however, the first modification (increasing the air stripper air to water ratio and eliminating the liquid phase GAC) provides a substantially greater reduction than the other modifications. The differences between the CO2e footprints and NOx footprints for the various modifications indicate a difference in the NOx to CO2e ratios for electricity generation, GAC usage, and wastewater treatment. Closer examination of the conversion factors in Appendix B shows that the CO2e to NOx ratio is approximately 1000 to 1 for electricity generation, approximately 100 to 1 for GAC regeneration, and approximately 500 to 1 for wastewater treatment. This is an example of where efforts to reduce CO2e emissions may not necessarily result in a similar percentage change in NOx emission reduction. For example, one may invest in avoiding the POTW discharge to reduce CO2e emissions instead of modifying the treatment system to avoid liquid phase GAC usage. Although the CO2e emission reductions may be similar for these two changes, the NOx emission reductions would be substantially greater (based on the assumptions made in developing these conversion factors) by eliminating the liquid phase GAC usage.

Chart 24 indicates that there is a relatively minimal effect in air toxic emissions among the five options if the same fuel blend for grid electricity generation (or use of renewable energy) is assumed. Changing the fuel blend to one that includes more coal (such as the average U.S. fuel blend), however, can result in an approximate 20% increase in air toxics emitted. This increase in air toxics emitted, however, would be off-site and would not necessarily carry the same weight when making local decisions. The relatively uniform emission of air toxics across the various options is due to the large majority of air toxics emissions resulting from the air stripper off-gas (which varies little from option to option) and these emissions overshadowing the contributions of air toxics from other sources (e.g., electricity generation).

Chart 22

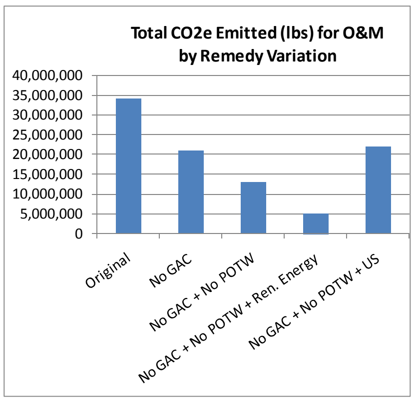


Chart 23

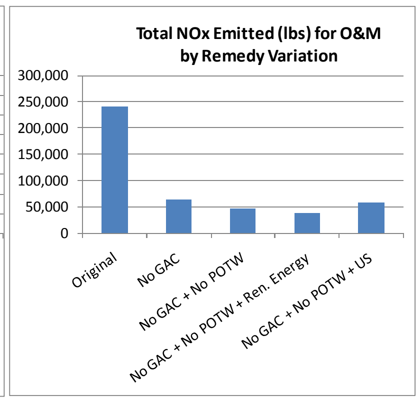
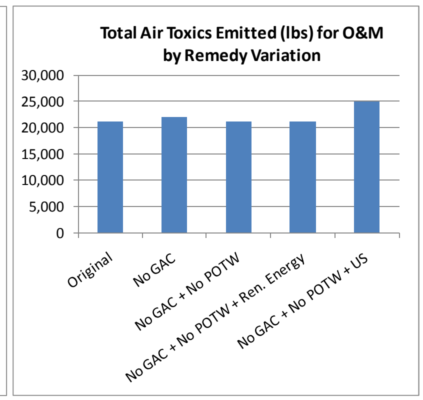


Chart 24



"Original" refers to the original P&T configuration.

Charts 25 through 27 compare the total CO2e, NOx, and SOx footprints of the original P&T system with an optimized P&T system and the original configuration of the Bioremediation alternative. Although the Bioremediation alternative still has a lower footprint for each of these parameters, the footprints for the Bioremediation alternative and optimized P&T option are very close, especially given the inherent uncertainty and variation in some of the remedial parameters and footprint conversion factors.

Chart 25

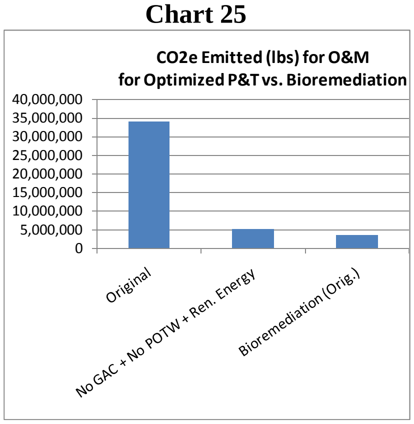


Chart 26

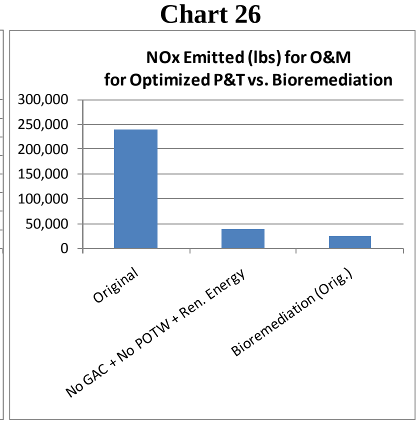
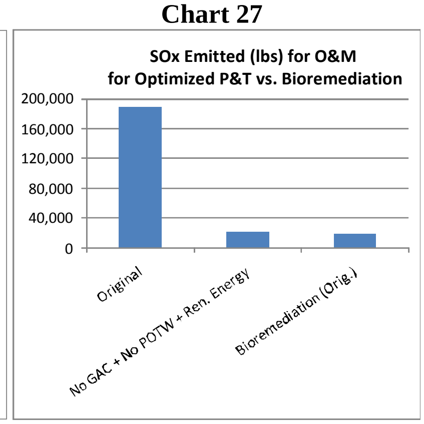


Chart 27



"Original" refers to the original P&T configuration

3.3.3 VARIATIONS IN KEY FOOTPRINT CONVERSION FACTORS

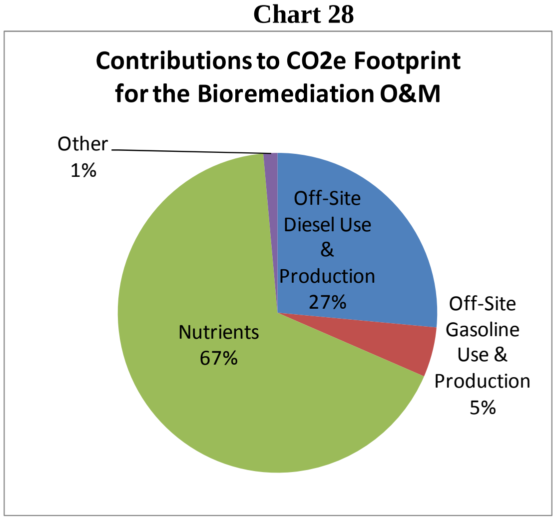
It is apparent from the above analyses that some remedial aspects can dominate the footprints of the remedy. For example, in the Bioremediation alternative, a significant contributor to the footprints of many of the environmental parameters is the production of the bioremediation nutrients. If there is a wide range of possible values for the footprint conversion factors for the bioremediation nutrients, the choice of conversion factor could significantly affect the outcome of the study. For example, as presented above, a 50% reduction in the CO2e conversion factors for molasses and cheese whey would reduce the CO2e footprint for the bioremediation O&M component by 33 % and would reduce the CO2e footprint for the complete Bioremediation alternative by 19%. The footprint conversion factors for GAC regeneration and laboratory analysis were developed by the project team, and the footprint conversion factors for waste water treatment by the POTW were modified by the project team to account for the discharge of treated groundwater rather than industrial process water. The actual footprint conversion factors for these items may be significantly different than those used here, and because of the large influence of these items on the calculated footprints, changes in their conversion factors would significantly affect the outcome of the study, especially as it relates to comparing remedial alternatives.

Because the output from a footprint analysis might be used during design and implementation to reduce the environmental footprint of a remedy, inaccurate footprint conversion factors could result in misdirecting design efforts. Consider the design of the P&T system. If the actual conversion factors for treatment of extracted groundwater by a POTW are substantially lower than those used in this study, then a design team may find that discharge to the POTW with relatively minor pre-treatment may provide a viable, protective, and low-footprint remedy option. However, if higher conversion factors for POTW discharge are used (as they were in this study), then this potential opportunity might be overlooked.

3.3.4 VARIATIONS IN DISTANCES TRAVELED AND TRANSPORTATION FUEL EFFICIENCY

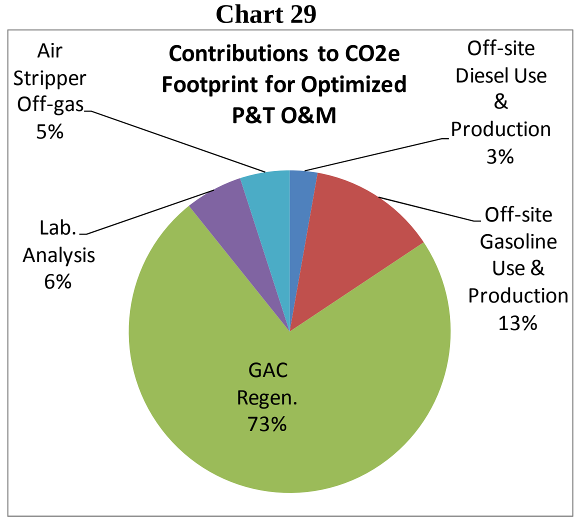
Charts 7 and 8 indicate that transportation plays a minor role in the CO2e and NOx footprints for the original P&T alternative but a significant role in the Bioremediation alternative. In addition, the findings illustrated in Charts 25 through 27 suggest that transportation could play a significant role in the footprint of an optimized P&T option. Charts 28 and 29 illustrate the contributions to the O&M CO2e footprints from transportation for both the Bioremediation alternative and the optimized P&T configuration.

Chart 28



Total Bioremediation O&M
CO2e Footprint - 3,500,000 lbs

Chart 29



Total Optimized P&T O&M
CO2e Footprint - 3,800,000 lbs

Chart 28 indicates that approximately 27% of the CO2e footprint for O&M results from the production and use of diesel required for transportation of materials, specifically, the bioremediation nutrients. Because of contributions to the CO2e footprint from other remedy components (such as construction and long-term monitoring), the diesel usage for transport of bioremediation nutrients results in approximately 15% of the CO2e footprint for the entire remedy. Therefore, the diesel usage for nutrient transport is significant not only for the O&M component but also for the overall remedy. Consequently, locating a regional or local vendor, or using a more fuel efficient mode of transportation, could result in a significant reduction in the CO2e footprint (and likely in the footprints of other parameters). Although not used as part of this study, the NREL life-cycle database indicates that transport by train is approximately 4 times more fuel efficient than by truck (i.e., 0.0025 gallons per ton-mile of freight for a train compared with 0.01 gallons per ton-mile of freight by truck). Transport by train (or transport by truck over a distance that is only 25% of the original distance between the vendor and the site) would reduce the diesel usage associated with bioremediation nutrient transport. The following table summarizes the change in the CO2e footprint as a result of this change.

Change	Nutrient Transportation CO2e Footprint (lbs)	% Decrease in O&M CO2e Footprint	% Decrease in Remedy CO2e Footprint	% of Indicated CO2e Footprint from Nutrient Transportation	
				O&M Footprint	Remedy Footprint
Original distance and mode of transportation	907,000			26%	15%
25% of original distance or equivalent increase in fuel economy	227,000	19%	11%	8%	4%

Nutrient transportation includes production and combustion of diesel used for transport of bioremediation nutrients

Referring to Chart 29, the diesel used to transport GAC for regeneration contributes only 3% of the CO2e footprint for the O&M component of the optimized P&T system (No liquid phase GAC + No POTW + Ren. Energy). This may be sufficiently small that it might be overshadowed by other contributors. The gasoline used for weekly operator transportation and other personnel transport accounts for approximately 13% of the O&M CO2e footprint and less than 8% of the total remedy CO2e footprint. Using a relatively fuel efficient passenger car for the operator commute instead of a light duty truck might result in a reduction of 245,000 pounds of CO2e over the life-cycle of the remedy. This finding, however, may have been overshadowed if the original P&T system was considered instead. For the original P&T system, although the gasoline contribution to the CO2e footprint has the same magnitude (approximately 490,000 pounds of CO2e using a light duty truck or 245,000 pounds of CO2e using a passenger car), the gasoline production and use for the operator commute contributes to only 1.5% of the O&M CO2e footprint for the original P&T configuration. For this P&T configuration, the footprint analysis would have directed site team attention to GAC usage, the POTW discharge, and electricity usage. In fact, for the original P&T configuration, the diesel production and usage for GAC transport is a larger contribution to the O&M CO2e footprint (approximately 2%) than the gasoline contribution. The following table summarizes the contributions of gasoline transportation for the original and optimized P&T remedies considering the difference between using a light-duty truck or passenger car.

Change	Light-Duty Truck CO2e Footprint (lbs)	% of Indicated CO2e Footprint from Light-Duty Truck		Passenger Car CO2e Footprint (lbs) O&M	% of Indicated CO2e Footprint from Light-Duty Truck	
		O&M Footprint	Remedy Footprint		O&M Footprint	Remedy Footprint
Original P&T remedy	490,000	1.5%	1.4%	245,000	<1%	<1%
Optimized P&T remedy (no liquid GAC + no POTW + Ren. Energy.	490,000	13%	8%	245,000	7%	4%

Transportation includes both production and use of gasoline.

It is apparent from these two charts that the footprint calculations for CO2e (and likely other parameters) may or may not be sensitive to fuel use for transportation depending on the remedial technology and the remedial design. Regardless of whether or not the footprint calculation is sensitive to this parameter, the footprint contribution from transportation has the potential to be large. It may simply be overshadowed by even larger contributions. During design and implementation, it may be appropriate to focus attention on large footprint contributors rather than (or in addition to) large percentage contributions.

3.3.5 Variations in Excavation Amounts and the Use of Concrete as Backfill

The excavation component dominates the footprint for hazardous waste generation for all three remedy alternatives because the excavated soil is assumed to be a hazardous waste. In addition, hazardous waste transportation involves a large amount of diesel usage, primarily as the result of the relatively long distance between the closest hazardous waste disposal facility and the site. As illustrated in Chart 30, the CO2e footprint from the transport is more than 60 times the footprint for the actual excavation and is more than 4 times the footprint associated with the disposal activities at the hazardous waste landfill. Therefore, the CO2e footprint from the excavation component is very sensitive to the amount of excavated material transported, the distance to the hazardous waste facility, and the mode of transportation. The actual excavation of the material (soil and concrete), the confirmation sampling, and the back fill represent comparatively small contributions. The calculation of the CO2e footprint for an entire remedial alternative (e.g., Bioremediation alternative or P&T alternative) is also sensitive to the amount of soil excavated. The following tables summarize the effects on the CO2e footprint of increasing the excavated soil volume from 3,000 cubic yards to 10,000 cubic yards.

<table>
<tr><th>Change</th><th>CO2e Footprint for Excavating 3,000 cy (lbs)</th><th>% of Remedy CO2e Footprint from Excavating 3,000 cy</th><th>CO2e Footprint for Excavating 10,000 cy (lbs)</th><th>% of Remedy CO2e Footprint from Excavating 10,000 cy</th><th>% Increase in Remedy CO2e Footprint</th></tr>
<tr><td>Original Bioremediation Alternative</td><td rowspan="3">1,000,000</td><td>16%</td><td rowspan="3">3,300,000

330% increase</td><td>39%</td><td>36%</td></tr>
<tr><td>Original P&T configuration</td><td>3%</td><td>9%</td><td>6%</td></tr>
<tr><td>Optimized P&T configuration (No liquid GAC + No POTW + Ren. Energy)</td><td>16%</td><td>38%</td><td>36%</td></tr>
</table>

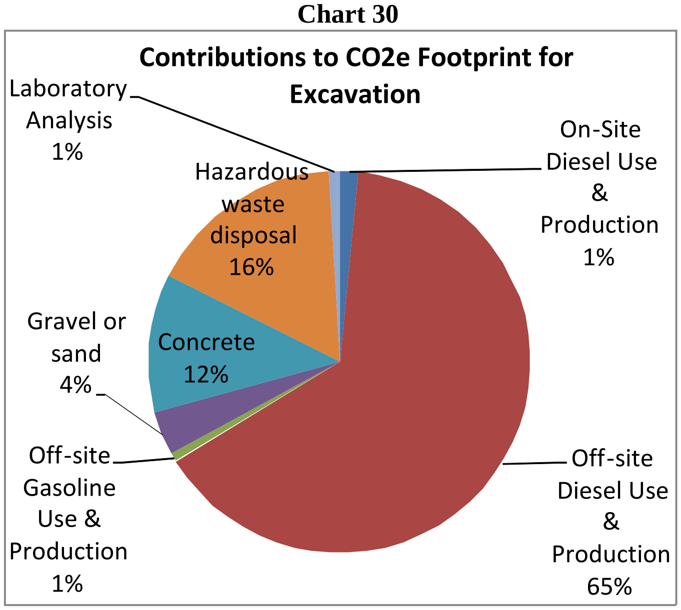
The amount of concrete that is removed in order to access the contamination is small compared to the amount of soil excavated and represents approximately 9% of the mass that is disposed of as hazardous waste. If the concrete could be reused at the site or at a nearby site, then an approximate 7% to 8% decrease in the total CO2e footprint would be expected based on the avoided transportation, hazardous waste disposal, and sand and gravel needed for backfill. In addition, reusing the concrete on-site would avoid the use of hazardous waste landfill space associated with disposing of the concrete. Crushing the approximately 520 tons of concrete removed during site investigation and excavation might require 700 hp-hr of diesel equipment use based on typical vendor concrete crusher specifications. Based on the assumptions used in this study (see fuel usage sheets in Appendix A), this translates to approximately 40 gallons of diesel for concrete crushing, which is very small relative to the estimated 24,000 gallons of diesel required to transport the concrete and excavated soil to the hazardous waste facility. Therefore, if the concrete were reused, the increased diesel required for concrete crushing would not add significantly to the footprint.

3.3.6 Extending the Life of the P&T Remedy

O&M is the primary contributor to the P&T remedy, and the environmental footprints would directly scale with the duration of the remedy. Therefore, extending the remedy duration from 40 years to 100 years would multiply O&M footprints of certain parameters (e.g., CO2e, NOx, SOx, etc.) by a factor of approximately 2.5. This extension of remedy duration would also increase the total remedy footprint for the original P&T configuration of those parameters by a factor of approximately 2.5 because the O&M component of that remedy configuration dominates the remedy footprint. For the optimized P&T remedy (No liquid phase GAC + No POTW + Ren. Energy), an increase in the in remedy duration by a factor of 2.5 would increase the total remedy footprints by a factor of approximately 1.8 because other components of the remedy also contribute significantly to the remedy footprint.

Other assumptions regarding remedy performance can also significantly affect the estimated footprints. During P&T operation influent concentrations to the treatment system may be higher or lower than expected, and more or less groundwater extraction may be necessary to meet remedy objectives. Both of these could affect electricity usage for extraction pumps and the air stripper and GAC usage for air stripper off-gas or liquid phase treatment, with a resulting decrease or increase (respectively) of the footprints of parameters such as CO2e, NOx, and SOx).

Chart 30



"Gravel and sand" refers to gravel and sand production from a quarry. "Concrete" refers to the production of concrete. "Hazardous waste disposal" refers to management of waste at a hazardous waste facility and does not include transportation. "Laboratory analysis" is limited to confirmation sampling and does not include site investigation or long-term monitoring.

3.3.7 Reducing the LTM Frequency from Quarterly to Semi-Annual

For all three remedy alternatives, the primary contributor to the LTM footprints is the laboratory analysis, which contributes approximately 30 times more to the total CO2e footprint of the LTM component than the gasoline used for transportation and sampling equipment combined. Reducing the frequency of monitoring from quarterly to semi-annual would reduce the footprint of the LTM component by approximately 50% since approximately half as many samples would be collected and analyzed. For the Bioremediation alternative, this 50% decrease in the LTM component would result in an approximate 8% decrease in the total remedy CO2e footprint. For the original P&T alternative, a 50% decrease in the LTM component CO2e footprint would result in an approximate 1.5% decrease in the total CO2e footprint for the P&T alternative. Note that these results are based on conversion factors for laboratory analysis developed by the study team. As discussed earlier, modification to these conversion factors based on different assumptions would give different results.

3.3.8 Potential Process Oriented On-Site Sources of CO2e Emissions

Another factor regarding the CO2e footprint at this site is the significant contribution from the air stripper off-gas. Freon-13, a strong greenhouse gas with a global warming potential that is approximately 4,800 times greater than that of carbon dioxide, is a volatile organic compound in the extracted groundwater that would be present in the air stripper off-gas. The isotherms for adsorption to GAC have not been obtained for use in this study, but it is assumed to be reasonably treated by the vapor phase GAC (i.e., in a comparable manner to the treatment of other non-vinyl chloride VOCs in this study as assumed in Appendix A). If GAC is not effective at treating Freon-13, then the magnitude of the CO2e footprint due to the air stripper off-gas would be approximately 100 times higher than estimated in this study. This level of uncertainty and the potential substantial change in outcome could have a large effect on the CO2e footprint for the optimized P&T system. Given the current assumption of reasonable GAC effectiveness for this compound, the percentage contribution of the air stripper off-gas to the CO2e footprint for the optimized P&T O&M component is approximately 5%. If the GAC is not effective at removing Freon-13 (i.e., a comparable effectiveness to the GAC treatment of vinyl chloride), then the percentage contribution of the air stripper off-gas to the CO2e footprint for the optimized P&T O&M component would be approximately 76%. The CO2e footprint for the air stripper off-gas would increase from approximately 190,000 pounds of CO2e to approximately 19,000,000 pounds of CO2e. For comparison, the regeneration of the vapor phase GAC for the optimized P&T system, which is the largest CO2e contributor for that configuration, contributes approximately 2,800,000 pounds of CO2e.

Freon-13 is not expected to degrade over time and the mass of Freon-13 in the subsurface is fixed, so the contributions of this compound to the total CO2e footprint for the P&T remedy is not expected to change based on anticipated remedy duration or influent concentration. It is unclear if this compound will degrade through in-situ bioremediation, but the Bioremediation alternative allows this strong greenhouse gas to continue being sequestered in the subsurface whereas the P&T remedy transfers it directly to the atmosphere.

4.0 OBSERVATIONS

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

4.1 OBSERVATIONS RELEVANT TO REMEDIATION AT ROMIC

The following observations are based on the results for the remedy alternatives considered for the Romic site. The footprint analysis results are highly dependent on the site-specific assumptions, and these observations do not necessarily apply to environmental footprint in general or other sites, even if the remedial technologies are the same as considered here. Unless otherwise noted, these observations pertain to the primary and secondary analyses, and not to the permutations explored in the sensitivity analyses.

4.1.1 A COMPARISON OF FOOTPRINTS FOR DIFFERENT REMEDIES

- When considering the total footprints (i.e., on-site plus off-site), the Bioremediation alternative has smallest environmental footprint for most of the 15 environmental parameters by a relatively wide margin. The only two parameters where the Bioremediation alternative has the highest total footprints are local potable water use and dioxins released to the environment. The local potable water use is for blending and injecting the nutrients for bioremediation. The release of dioxins to the environment is dominated by PVC manufacturing. Due to the large number of injection wells, the use of PVC is highest for the Bioremediation alternative, compared with the other two alternative remedies.

- When considering on-site footprints, the three remedy alternatives have relatively similar footprints. Some exceptions are that the Bioremediation alternative has the highest footprints for on-site potable water usage and for on-site NOx, SOx, and PM emissions. The latter three parameters are associated with the additional on-site diesel usage, and are a factor of two higher than the on-site NOx, SOx, and PM emissions for the P&T alternative. However, when considering overall air quality, the local community stakeholders may favor the Bioremediation alternative to the P&T and Hybrid options because the on-site air toxics from the P&T remedy are higher than those of the Bioremediation remedy. This is because the HAPs in the air stripper off-gas that are not removed by the vapor GAC in the P&T alternative are locally released to the atmosphere. A study of the relative human health effects from NOx, SOx, PM, and HAPs is not conducted here, but the mass of on-site HAPs released over the life-time of the P&T remedy exceed the combined mass of on-site NOx, SOx, and PM from the Bioremediation alternative by an order of magnitude. By comparison, the on-site NOx, SOx, and PM emissions from the Bioremediation alternative are only a factor of two higher than the on-site NOx, SOx, and PM emissions for the P&T alternative.

4.1.2 Contributing Factors to Footprints of the Bioremediation and P&T Alternatives

- Using CO2e as an indicator or example parameter, the largest contributors to the Bioremediation footprint are off-site diesel usage for transportation, production of bioremediation nutrients, and laboratory analysis. Using vendors/suppliers closer to the site, using different types of bioremediation nutrient, and reducing the amount of performance sampling would provide for potential reductions in the remedy footprint.

- Using CO2e as an indicator or example parameter, the largest contributors to the P&T and Hybrid footprint are electricity production, GAC regeneration, and wastewater treatment at the POTW. Modifying the treatment processes (resulting in reducing the amount of electricity and GAC used), and identifying alternative discharge options for treated water, would provide for potential reductions in the remedy footprint.

4.1.3 Contributing Factors to Footprint of the Excavation

- Using CO2e as an indicator or example parameter, the excavation component of all three remedies is dominated by diesel use for transport of the excavated soil to the hazardous waste facility, the footprint of managing the hazardous waste at the disposal facility, and the production of the concrete for restoring the surface at Romic. The on-site diesel usage for excavating equipment contributes minimally to the footprint of the excavation component. On-site treatment of excavated soil and reusing the soil to backfill the excavation and/or segregating non-hazardous soil from hazardous soil would provide for potential reductions in the remedy footprint.

4.1.4 The Role of Transportation in the Overall Remedy Footprint

- For the Bioremediation alternative, the footprint associated with personnel, equipment, and materials transport is an important contributor to the overall remedy footprint. Applying best management practices to reduce the transportation footprint, for example by consolidating work into fewer (but longer) days, carpooling, and using fuel efficient vehicles, would provide for potential reductions in the remedy footprint. These best management practices also apply to the P&T remedy and would result in a footprint reduction of similar magnitude (e.g., pounds of CO2e, NOx, or SOx), but the percentage reduction in remedy footprint would be smaller because of the other, larger contributors to the P&T footprint.

- The footprint from diesel usage for transporting nutrients (molasses and cheese whey) is similar in magnitude to the footprint for producing the nutrients. Therefore, finding local sources of molasses and cheese whey would provide for potential reductions in the remedy footprint, due to reduction in transportation distances.

4.1.5 Footprints from Bioremediation Nutrients

- Although a much smaller mass of cheese whey was injected relative to molasses, the CO2e footprint (and other parameter footprints) for producing the cheese whey are higher than those for producing molasses. This reflects the more energy intensive process of obtaining cheese whey (which involves raising dairy cattle) relative to growing and directly processing crops for sugar production. By contrast, the source of cheese whey is closer to the site than the source of molasses, such that the majority of diesel for transporting nutrients is due to the molasses. Therefore, for the Bioremediation remedy at Romic, there is a tradeoff between the footprint from transporting the nutrient sources and the footprint of producing the nutrients.

4.1.6 Relative Contributions from Each Remedy Component

- The O&M component is the largest contributor for the total energy, water, CO2e, NOx, and SOx footprints for all three remedy alternatives. For the Bioremediation alternative, the excavation, LTM, and construction components also contribute significantly to the footprints for these parameters. For the P&T alternative, all the remedy components other than O&M are insignificant contributors to these parameter footprints.

- For all three remedy alternatives, the excavation component is the largest contributor for the total PM and hazardous waste footprints, but the O&M components also contribute significantly to the total PM footprint.

- For all three remedy alternatives, the site investigation and site decommissioning components generally have small footprints compared to the footprints for other components.

- For all three remedy alternatives, the construction component contributes a large percentage to the on-site footprints for energy usage, NOx, SOx, PM, and CO2e. However, the construction component contributes a much smaller percentage to off-site and total footprints for these parameters.

- For all three remedy alternatives, the construction component contributes most significantly to off-site releases of mercury, lead, and dioxins. These releases are associated with materials manufacturing. Although the proportion contributed is large, the magnitudes of the releases are relatively small. For example, for the Bioremediation alternative, the off-site release of lead to the environment is approximately 0.055 pounds (predominantly from steel and diesel production), and the off-site release of mercury to the environment is approximately 0.0089 pounds (predominantly from PVC and cement production). The releases from the P&T alternative are of a similar order of magnitude.

- For the P&T alternative, the total air toxics footprint is dominated by the O&M component due to the air stripper off-gas. For the Bioremediation alternative, the total air toxics footprint is driven by the laboratory analysis associated with the LTM component. It is noted that potential air toxics emissions from the soil during excavation are not included in the analysis.

- For all three remedy alternatives, the on-site water footprints are dominated by the O&M components. For the P&T alternative, the P&T system involves the extraction (without reinjection) of groundwater. For the Bioremediation alternative, on-site water usage involves the use of potable water from the municipal water supply for blending and injecting nutrients.

4.1.7 VARIATIONS IN REMEDY DESIGN

- Based on the assumptions made in this study, there would be a significant reduction in the overall footprint in the Bioremediation remedy if emulsified vegetable oil were used as a bioremediation nutrient in place of molasses and cheese whey. The selection of emulsified vegetable oil for consideration in the sensitivity analysis was for general illustrative purposes only, as this nutrient has not been pilot tested at the Romic site. The sensitivity analysis highlights the point that using different bioremediation nutrients may result in significantly different environmental footprints due both to the footprint for producing the nutrients and the footprint for transporting the nutrients.

- There appears to be potential for significant improvement to the P&T design. The original, non-optimized design resulted in a large difference in environmental footprint between the P&T alternative and the Bioremediation alternative for most parameters. However, an alternate, optimized P&T design resulted in a smaller difference between the P&T remedy and the Bioremediation remedy. For the groundwater contaminants at this site, improving the original design to increase the air stripper capacity and air to water ratio, eliminate the liquid phase GAC treatment step, and discharge treated water to the surface water rather than the POTW, resulted in smaller footprints for many parameters. Therefore, the design of the P&T remedy influenced the remedy footprint as much as the choice of implementing a P&T remedy or a bioremediation remedy.

- The use of renewable energy would further reduce the environmental footprint of the P&T alternative, to the point where the footprints for many parameters are close to those of the Bioremediation alternative. A P&T option and a bioremediation option at the Romic site could have relatively similar footprints when renewable energy is used, and this outcome would not have become apparent had variations on the P&T design not been considered.

4.1.8 CONCLUSIONS REGARDING WATER

- Interpretation of the water footprints of the remedy alternatives at Romic is complex due to water quality associated with various water resources, how the water is used, the fate of the water after use, the potential for the water to be reused, and the location (local or non-local) of the water resources. The relative importance associated with the different water uses should be determined by the site stakeholders. Given the location of the Romic site, hypothetical site stakeholders may value potable more than other water resources because potable water is a relatively scarce resource in Northern California.

4.1.9 CONCLUSIONS REGARDING TRAVEL AND LABOR

- The Hybrid alternative includes more trips to the site and more man days worked. Therefore, with respect to travel and labor, combining the Bioremediation and P&T technologies does not reduce level of effort but actually increases it.

4.2 OBSERVATIONS RELEVANT TO ENVIRONMENTAL FOOTPRINTING OF REMEDIES IN GENERAL

The following observations are based on generalizations that may apply to environmental footprinting in general. Although these observations are made on the basis of the Romic analysis, some general principles from that analysis may extend to environmental footprinting at other sites. Specific observations from the Romic 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 Romic study, the determination of the remedial alternative with the preferable environmental footprint is relatively straightforward because the original P&T alternative has substantially higher footprints for most of the environmental parameters compared to the Bioremediation alternative. 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 between remedy alternatives. Or, there may be great 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 the other remedy alternatives for other parameters (e.g., air toxics and waste generated).

- **On-site activities, transportation, and off-site activities (e.g., manufacturing) all have the potential to contribute significantly to the footprints of clean-up remedies.** For evaluating most remedy technologies at most sites, it appears that environmental footprint analysis should consider all three of these types of activities. However, there may be some important exceptions. For example, the off-site manufacturing associated with a dig-and-haul remedy may contribute a very small amount to the total footprint for most parameters, while transportation and disposal of the waste would contribute a very large amount. As another example, transportation may contribute a very small amount to the footprint for most parameters for a remedy in which on-site staff or local resources perform all the construction and O&M and all materials are obtained locally.

- **Remedial design may have a substantial influence, and perhaps as substantial an influence as remedial technology, on the environmental footprint.** For example, the design of a P&T remedy (e.g., pump type, extraction rate, treatment process, etc.) or bioremediation remedy (e.g., nutrient choice) may have a greater influence on the environmental footprint than the choice between implementing a P&T remedy or bioremediation remedy. The optimal design of a remedy depends heavily on site-specific conditions, and application of generic rules of thumb that do not consider site-specific conditions may be misleading. When conducting footprint analyses, it is important to consider optimal designs for the various technologies, so that informed decisions can be made between remedies. In the absence of developing an optimal design, which might be difficult at the remedy selection phase, potential variations to remedy design could be considered for the footprint analysis in order to provide an estimated range of the footprints, rather than analyzing only one configuration for the footprint analysis.

- The environmental footprinting process and the results are useful for the remedy selection phase, remedy design, and remedy implementation phases. **During remedy selection, the footprinting**

process and the interpretation of results can help involve local stakeholders in the remedy selection process and help the site team better understand the effects of the remedy on the local community. Input from local community stakeholders may be needed to help interpret the results of a footprinting study and identify the environmental parameters and footprints that are of greatest interest or concern to the community. For example, some communities may be most concerned with water use, others may be concerned with waste generation and associated landfill space, and others may be concerned about traffic and air emissions from fuel combustion.

- **Footprinting 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, it may be valuable to document the footprints associated with producing and transporting various reagents for in-situ remedies so that the final selection of reagents during design and implementation can fully account for balancing the production footprints with the transportation footprints. Similarly, it may be beneficial to know that for a particular site, using extracted groundwater for reagent injection greatly reduces the potable water footprint but does not significantly affect most other footprints.

- **During remedy design and remedy optimization, the footprinting process involves analyzing the remedy from a different perspective, potentially helping the design team or optimization team to identify potential remedy features or modifications that could lead to a more effective and/or efficient remedy**. The process may help with selecting or refining selection of water treatment processes (e.g., GAC vs. air stripping), options for discharging treated water, transportation options, and many other remedial design and implementation parameters.

- **Environmental footprinting 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 footprinting, the results of environmental footprinting 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. For example, in the Romic study, the environmental footprints associated with transportation in the P&T and Bioremediation alternatives are of similar magnitude. However, for the P&T alternative, transportation appears to be negligible next to the large footprints from GAC, wastewater treatment, and electricity production. As a result, one may overlook opportunities to reduce the transportation footprint while focusing on the larger contributors in the P&T alternative. In contrast, the environmental footprints associated with transportation for the Bioremediation alternative appear to be significant next to the smaller footprints from the other components of the alternative. Since transportation appears to have a significant effect on the Bioremediation alternative, transportation activities would likely receive attention when focusing on ways to reduce the remedy's overall footprint. Applying best management practices generally to transportation, regardless of the relative footprint of transportation within each alternative remedy, would likely have a similar effect on the magnitude of footprint reduction for both remedial alternatives (albeit a much smaller percentage reduction for the P&T alternative). By contrast, relying on the results of environmental footprinting and targeting what seem to be "key" aspects of the remedy for footprint reduction may lead to missing potential opportunities for footprint reduction for the P&T alternative.

- **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, it may be straightforward to estimate the initial influent concentrations to a P&T system and the number of wells in the system, but in many cases it will be difficult to determine the duration of a P&T remedy, the changes in influent concentrations over time, and when potential for downsizing remedy components will be possible. The environmental footprint of the remedy may be heavily dependent on these assumptions. Similarly, it may be straightforward to determine the quantity of bioremediation nutrients to be injected per event, but it may be more difficult to estimate the frequency of injection events and the total duration of the remedy. For this reason, environmental footprint analyses should include sensitivity analyses to explore likely variations in the important remedial design information. The sensitivity analysis can help establish "error bars" on the results. In some analyses, the "error bars" for various remedial alternatives may overlap, complicating the determination of which remedy alternative has the preferable environmental footprint.

- **The outcome of an environmental footprint analysis may be dependent on the quality, accuracy, and appropriateness of the footprint conversion factors.** It is quite possible for a particular footprint conversion factor to have values that range by a factor of 2 or more depending on the source of information or a particular circumstance. A factor of 2 for an important conversion factor could dramatically change the outcome of the results of the footprint analysis. For this reason, it is reasonable for environmental footprint analyses to include sensitivity analyses on important footprint conversion factors to help establish "error bars" on the results. In some analyses, the "error bars" for various remedial alternatives may overlap, complicating the determination of which remedy alternative has the preferable environmental footprint.

- 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.

- **The use of food processing byproducts or other manufacturing byproducts in remedies (e.g., using bioremediation nutrients such as molasses, which is a by-product of sugar processing, or cheese whey, which is a by-product of cheese processing) raises interesting questions regarding the appropriate footprints for these byproducts.** Some may argue that the entire footprint of producing the primary product (e.g., sugar or cheese) should be assigned to the primary product and not to the byproducts. Others may argue that some percentage of the footprint be assigned to the byproducts, perhaps based on value (e.g., cost) because many byproducts (e.g., molasses or whey) have alternate uses and are not waste. Yet another approach for establishing the footprint for these byproducts may be based on the footprint of materials or resources that they displace when being used for other purposes (e.g., as animal feed). To better understand and document the footprint conversion factors for these byproducts for specific remedies, it may be helpful to obtain from the vendor/provider specific information pertaining to the fate of that byproduct.

- The sources of various environmental footprints are not limited to energy usage and materials usage. Other sources, such as **emissions from treatment process off-gas or from off-site**

services such as laboratory analysis, off-site water treatment, and waste disposal can contribute significantly influence to a remedy's environmental footprint. Due to variations in remedial approaches at different sites and various site-specific factors, a site may have unique footprint sources. For example, because chlorofluorocarbons (CFCs) are potent greenhouse gases, the presence of these compounds at a site could result in an additional contribution to the CO2e footprint.

- **Laboratory analysis and long-term monitoring can contribute significantly to a remedy's environmental footprint.** Additional research on footprint conversion factors associated with laboratory analysis is merited.

- **Site investigation and decommissioning may contribute significantly less to a remedy's environmental footprint than remedy construction, O&M, or long-term monitoring.** It may be appropriate to invest resources in thorough site investigation (using best management practices to help reduce the site investigation footprint) to provide all the information required to appropriately design and target remedial efforts for minimization of the footprint associated with remedy implementation.

- **The relative contribution of the construction component of a remedy to the total footprint is highly dependent on the magnitude of the footprint for the O&M component.** The following illustration is conducted using CO2e as an indicator or example parameter. The CO2e footprints for the construction components for the original and optimized P&T remedies in this study range from 250,000 pounds of CO2e to 270,000 pounds of CO2e, which are similar in magnitude. By contrast, the CO2e footprints for the O&M components of the same two systems range from approximately 3,800,000 pounds of CO2e to 33,000,000 pounds of CO2e. For both the original nutrient and alternative nutrient bioremediation designs, the CO2e footprint for the construction component is approximately 510,000, and the CO2e footprint for the O&M components range from approximately 960,000 pounds of CO2e to 3,500,000 pounds of CO2e. In both P&T cases and both bioremediation cases, the construction footprints are very similar but the O&M components vary considerably. This suggests that for remedies with a long-term operation component (such as bioremediation and P&T), the percent contribution of the construction component highly depends on the magnitude of the O&M component. In addition, this suggests that during remedy design, it may be important to focus efforts on reducing the contribution of the O&M component to the overall footprint, even if this results in small increases in the construction component.

- **When conducting environmental footprint analyses for a site remedy that consists of multiple remedial phases or components, it may be beneficial to analyze them separately.** When analyzed together, the footprint from one remedial approach may overshadow the footprint of another remedial approach, making it difficult to find opportunities for footprint reductions in the remedial approach that is overshadowed. For example, in the Romic study, soil excavation was evaluated as a component of each of the three alternative remedies. In all three cases, the hazardous waste generation footprint was dominated by the excavation component (due to the off-site disposal of the excavated soil as hazardous waste), making it difficult to determine which of the three alternative remedies had the lowest hazardous waste footprint due to activities other than excavation.

- Given the complexity and difficulty of conducting detailed environmental footprint analyses, **it would be valuable to use the information from detailed studies such as this one to derive**

generic footprint conversion factors for broader activities. For example, in this Romic study, remedy construction for the Bioremediation alternative involved the installation of 272 2-inch, PVC injection wells in unconsolidated material with a total depth of 13,720 feet. The CO2e footprint for the well installation is approximately 510,000 pounds of CO2e, suggesting that approximately 37 pounds of CO2e are emitted per foot of installed 2-inch, PVC well. This value may vary depending on the relative length of the screened interval given that grout along the non-screened casing has a significantly higher footprint than sand and gravel along the screened interval. Increasing the total length of screened interval by a factor of 4 results in an approximate CO2e footprint of 30 pounds of CO2e per foot of installed 2-inch, PVC well. Some additional variation may result from different drilling methods as well. Similar generic factors could be developed for 4-inch wells, 6-inch wells, steel-cased wells, and bedrock wells and for other common remediation activities, such as soil excavation and long-term monitoring.

- **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 emissions 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 these pollutants released by manufacturing processes far from the site may not be merited during environmental footprinting studies, especially considering the potential variation in these footprints 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 these parameters are regulated under different 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.

- **With a few exceptions, NOx and SOx emissions generally track with CO2e emissions, suggesting that it may be appropriate in some instances to use the CO2e footprint as an indicator parameter** for these other parameters during footprinting analyses. Best management practices could then be applied to further reduce NOx and SOx emissions.

- **Interpretation of a water footprint analysis may be heavily site and stakeholder specific.** In addition, the water footprint of a remedy may be complex due to water quality associated with various water sources, how the water is used, fate of the water after use, the potential for the water to be reused, and the location (local or non-local) of the water.

- Given that some materials may be used extensively in a remedy (e.g., GAC for a P&T remedy or bioremediation nutrients for an in-situ bioremediation remedy), **it may beneficial to encourage materials vendors to provide "environmentally friendly" versions of their product** as long as this "environmentally friendly" version can be well documented and verified. An example might be a GAC vendor that purchases carbon offsets or renewable energy credits to off-set the energy usage in producing or regenerating the GAC (e.g., "carbon neutral GAC").

- **Choice of environmental parameters for a footprinting study can influence the apparent outcome.** For example, this Romic study considered 15 environmental parameters and considered both on-site and off-site footprints. If on-site air toxics had not been considered, and the study focused only on on-site parameters such as NOx, SOx, and potable water, it would have appeared that the Bioremediation alternative had the largest footprint for many on-site parameters, and this may have implied to the casual observer that the Bioremediation alternative would not be preferable to the local community. However, inclusion of on-site air toxics and off-site parameters in general, for which the P&T alternative had a significantly higher footprints than the Bioremediation alternative, introduced a balancing effect, in which it was clear that there were trade-offs to be aware of among the various parameters. Therefore, care should be taken in drawing conclusions regarding the relative "greenness" of a remedy, given the limitations on the number and variety of environmental parameters that may be analyzed.

- 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 remedy parameter may be a small percentage of the overall remedy 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 footprinting is done in conjunction with other site activities that involve identifying relevant remedy information, such as the feasibility studies, remedial designs, and remedy optimization evaluations.

5.0 SUMMARY

This study quantifies the environmental footprints of three remedial options for corrective action at the Romic Environmental Technologies Corporation (Romic) facility in East Palo Alto, 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 15 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 three forms of energy, production of 12 materials, and use of four off-site services. The following three analyses are conducted.

- Primary analysis - For each parameter, footprints from on-site activities, 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 individual phases of the remedies, including site investigation, excavation, construction, operations and maintenance, long-term monitoring, and decommissioning.

- 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 footprinting 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 footprinting 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 plans to conduct detailed analyses at two additional remediation sites in order to enhance the understanding of the environmental footprinting process for cleanup activities and expand the inventory of information needed for conducting footprint analyses.

This environmental footprint analysis has been conducted independently of site activities at Romic. The Romic site owners and EPA site team have provided the study team information so a footprinting study could be performed for illustrative purposes. The Romic site owners and EPA 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
Electricity	MWh	Amount of grid electricity used	• 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 footprinting 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.

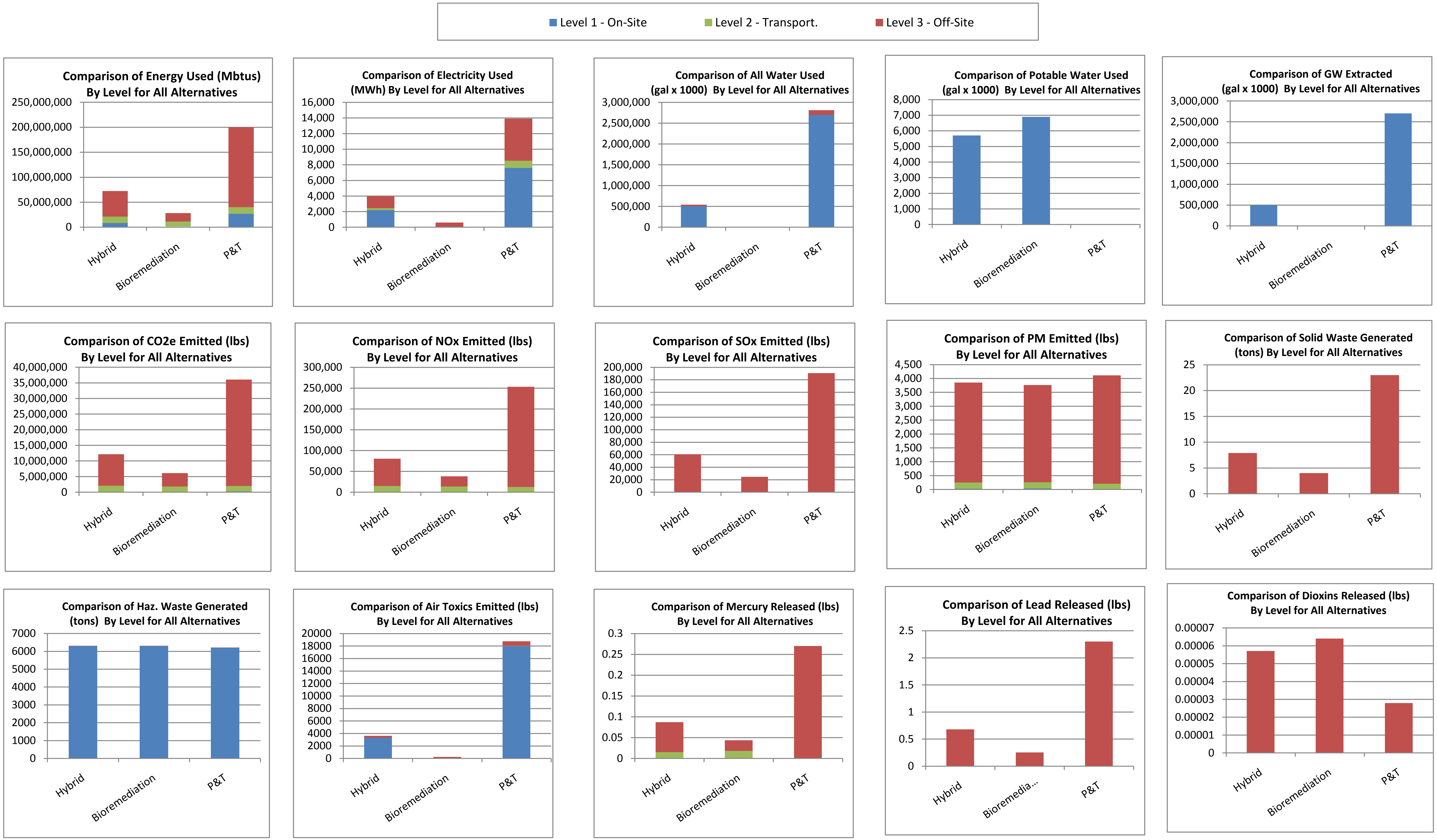
Table 1. Summary of Environmental Parameters for which Footprints are Estimated (continued)

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.
Hazardous 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.	Particularly toxic effect of lead and its ability to persist in the environment.
Mercury	Lbs	Total amount of mercury released to air, water, or soil.	Particularly toxic effect of mercury and its ability to persist in the environment.
Dioxins	Lbs	Total amount of dioxins released to air, water, or soil.	Particularly toxic effect of dioxins and their ability to persist in the environment.

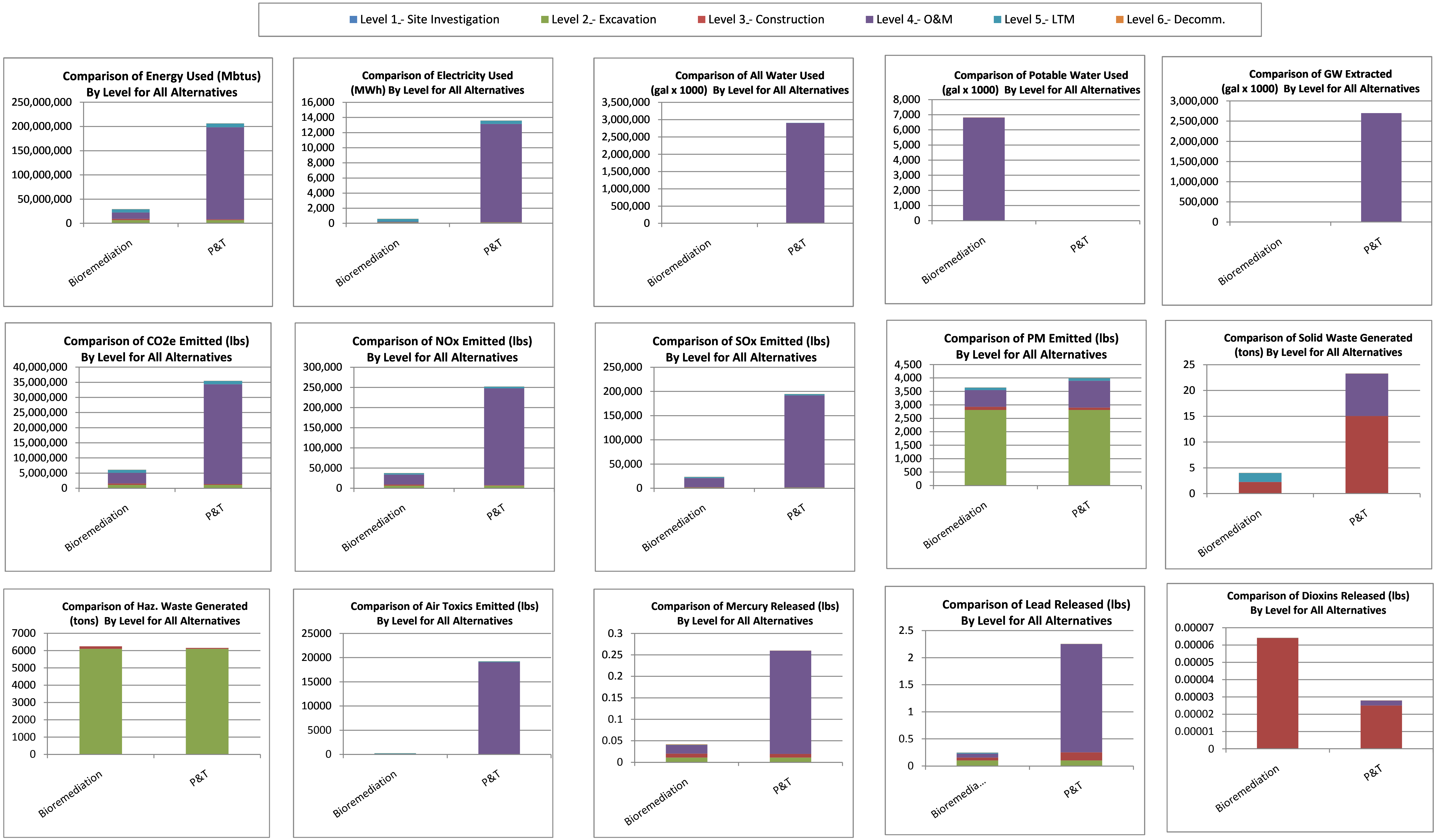
Groundwater extraction and potable water use are only estimated as on-site parameters. All other parameters are estimated as both on-site and off-site parameters

SUPPLEMENTAL CHARTS

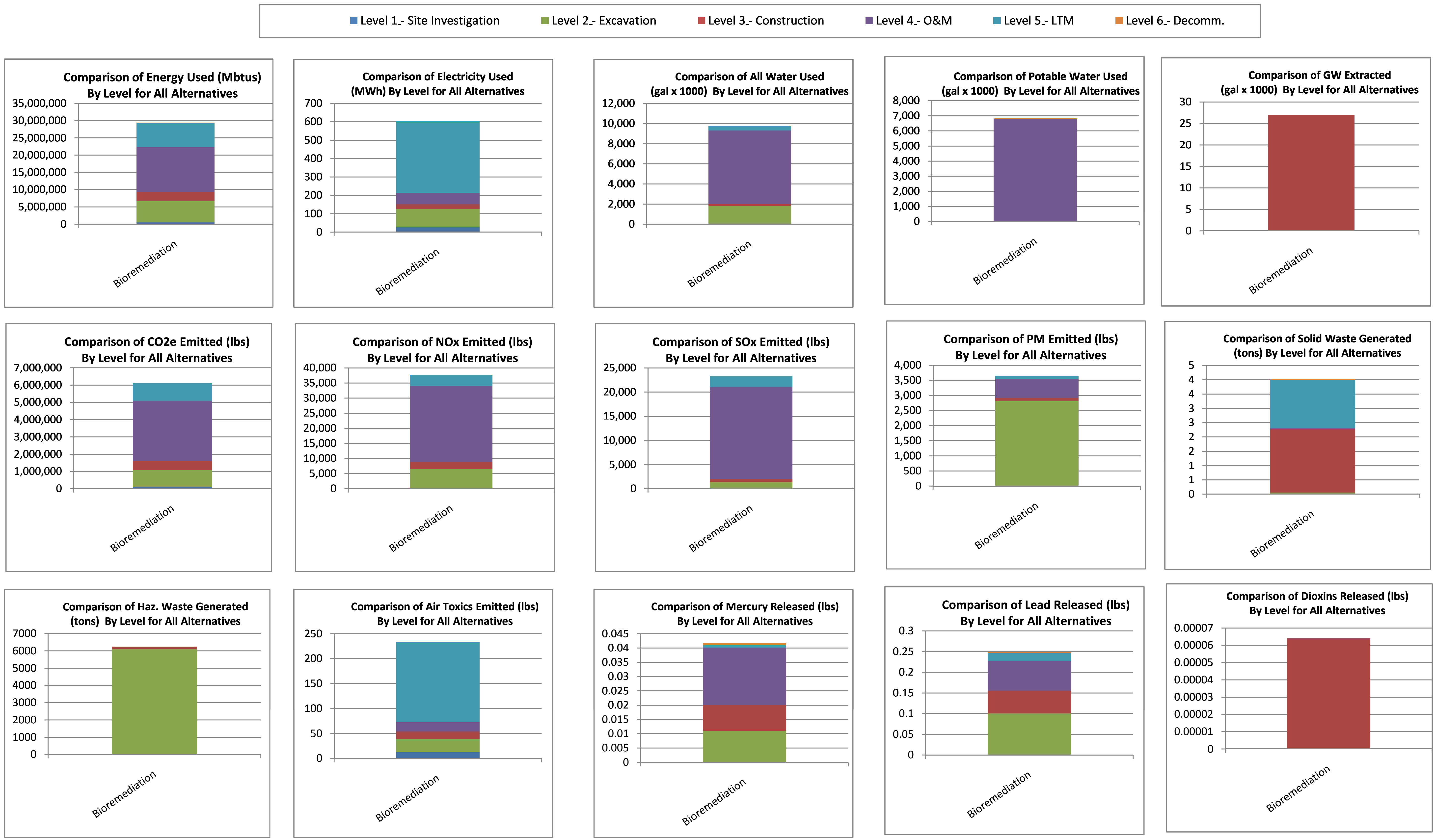
Romic, East Palo Alto, CA - Primary Analysis - Output by Parameter



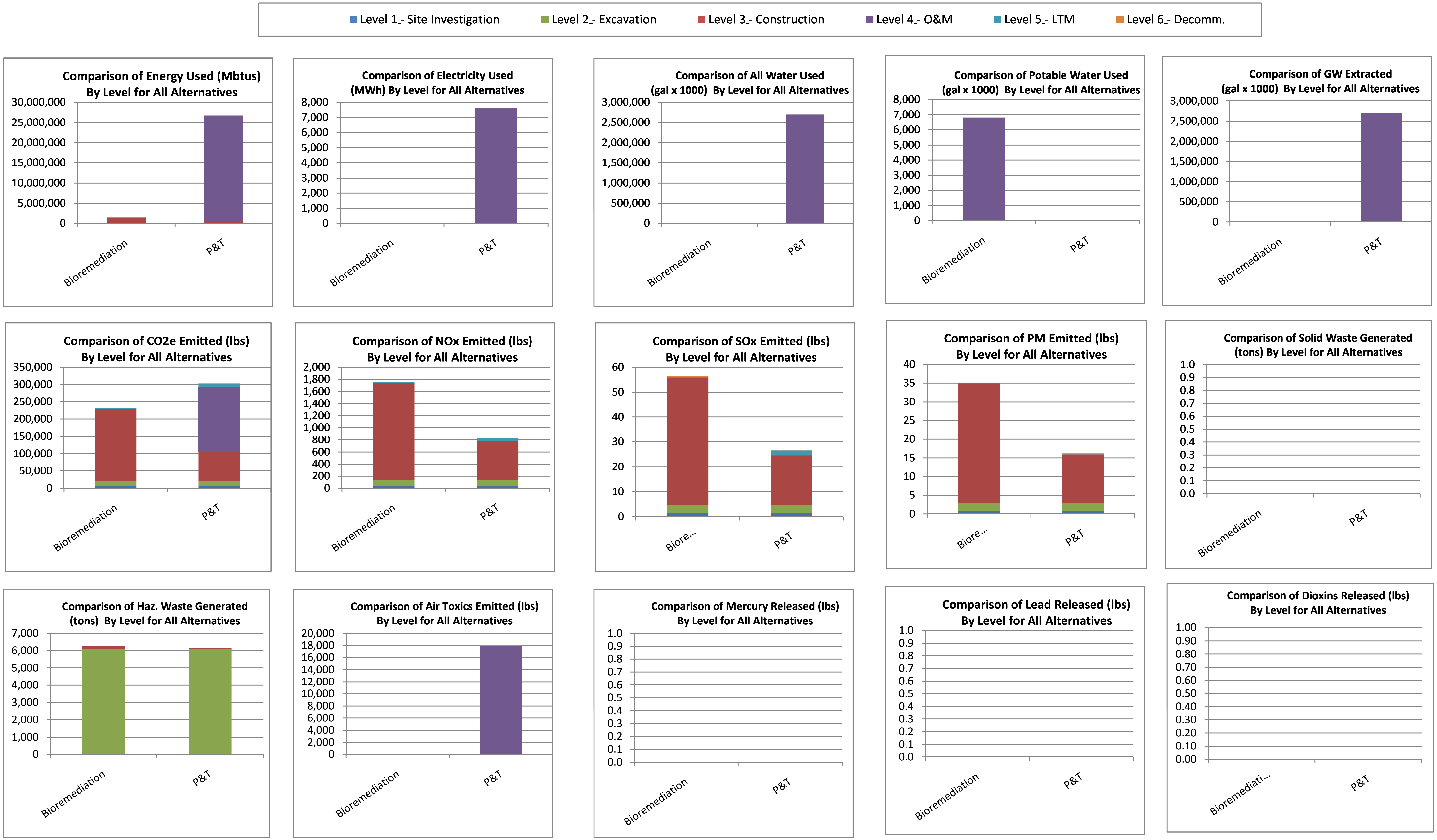
Romic, East Palo Alto, CA - Secondary Analysis - Output by Parameter for Both Remedies - Total (On-Site + Off-Site) Footprint



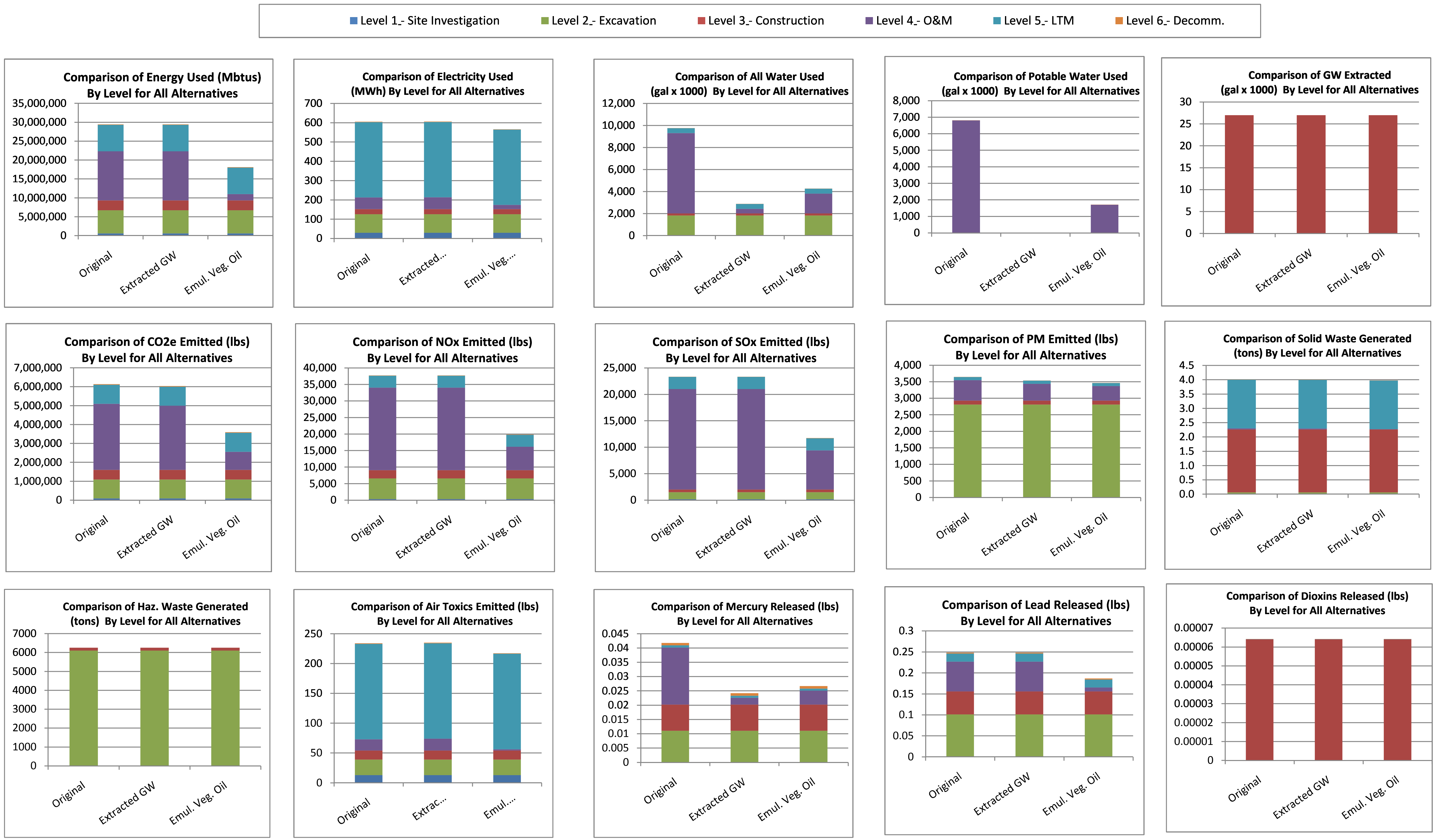
Romic, East Palo Alto, CA - Secondary Analysis - Output by Parameter for Bioremediation - Total (On-Site + Off-Site) Footprint



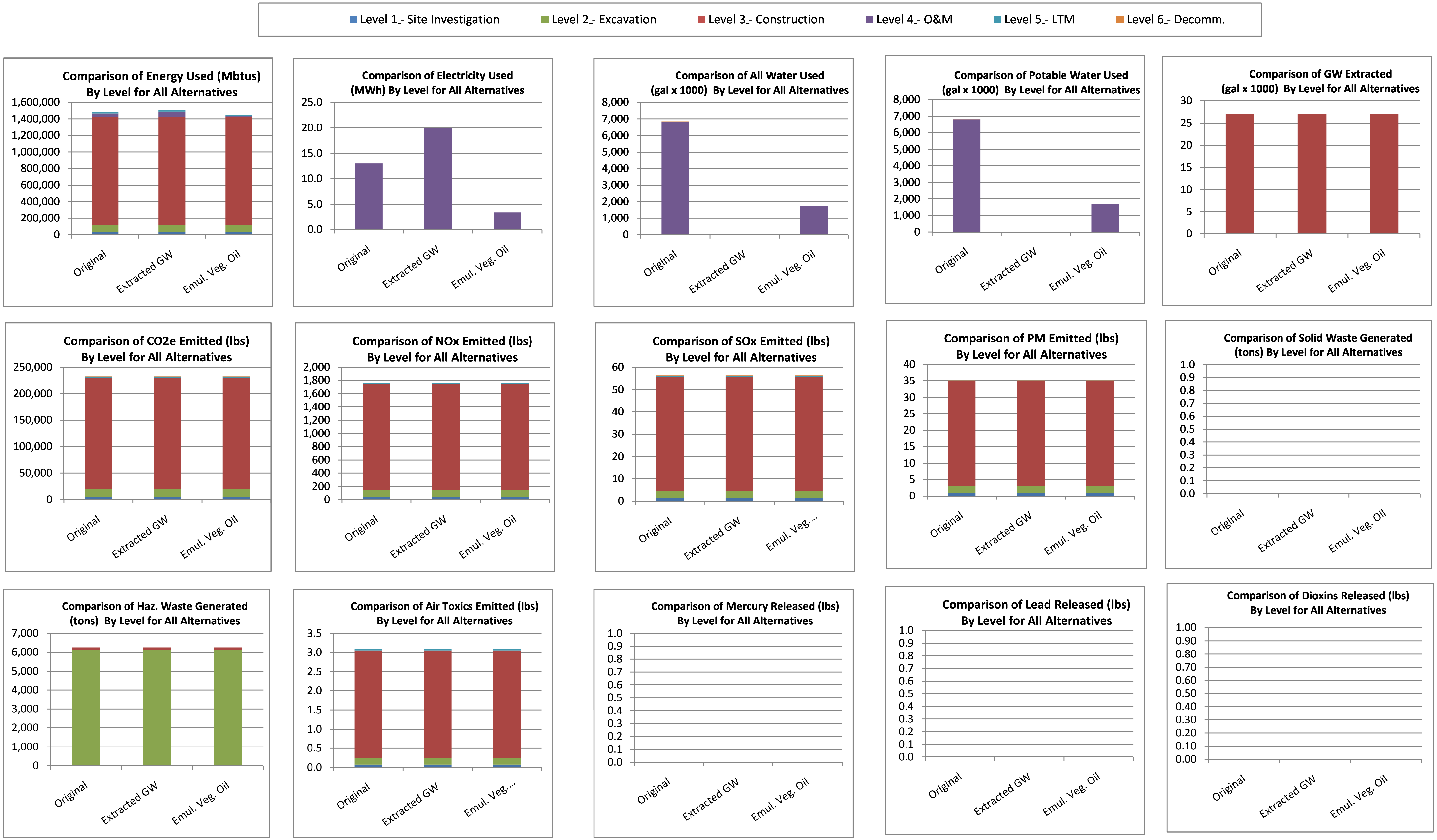
Romic, East Palo Alto, CA - Secondary Analysis - Output by Parameter for Both Remedies - On-Site Footprint



Romic, East Palo Alto, CA - Bioremediation Sensivitiy Analysis - Output by Parameter - Total (On-Site + Off-Site) Footprint

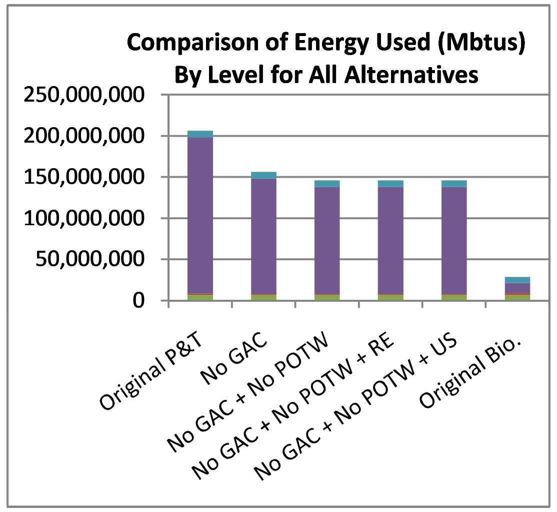


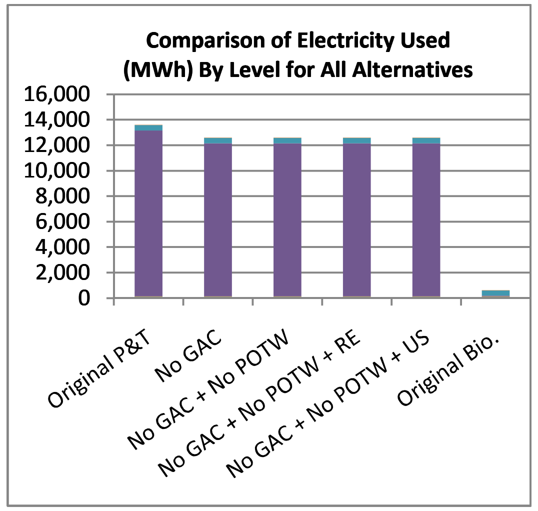
Romic, East Palo Alto, CA - Bioremediation Sensitivity Analysis - Output by Parameter - On-Site Footprint

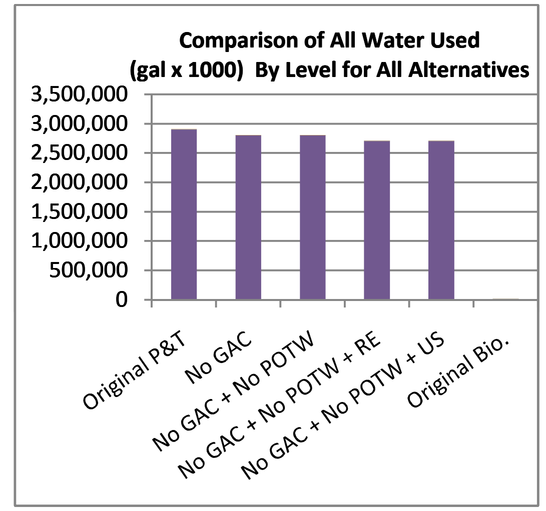


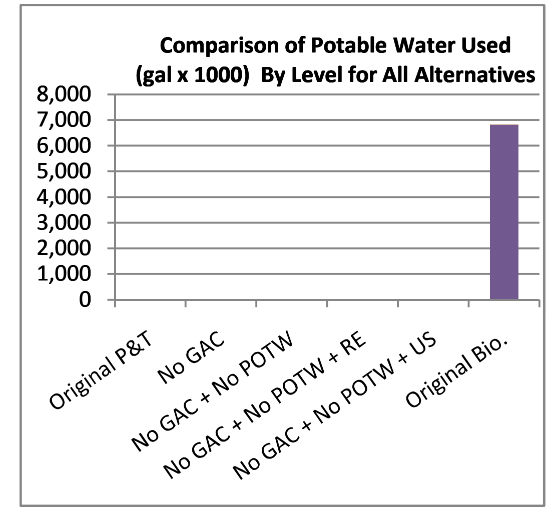
Romic, East Palo Alto, CA - P&T Sensivitiy Analysis - Output by Parameter - Total (On-Site + Off-Site) Footprint

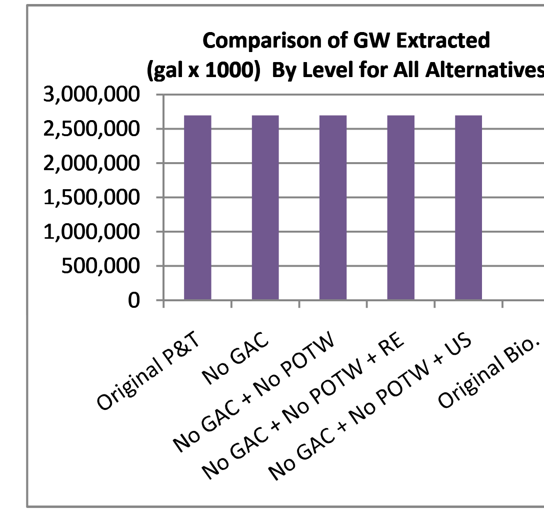
Level 1_- Site Investigation | Level 2_- Excavation | Level 3_- Construction | Level 4_- O&M | Level 5_- LTM | Level 6_- Decomm.

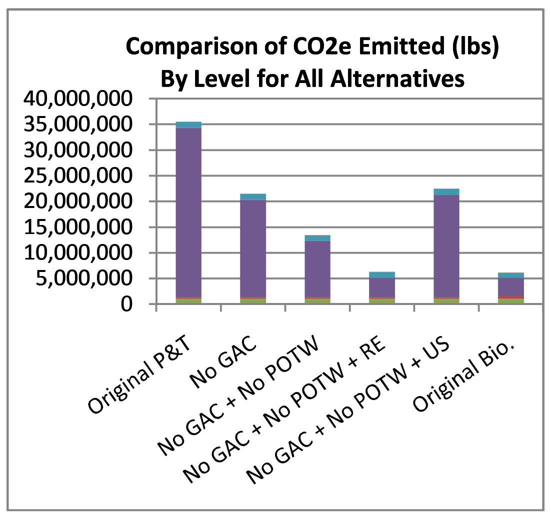


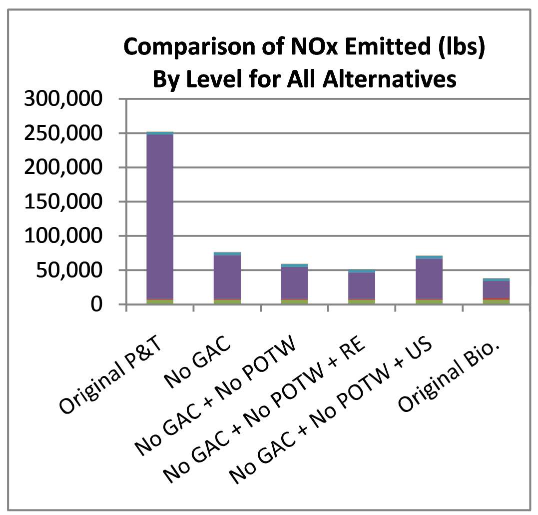


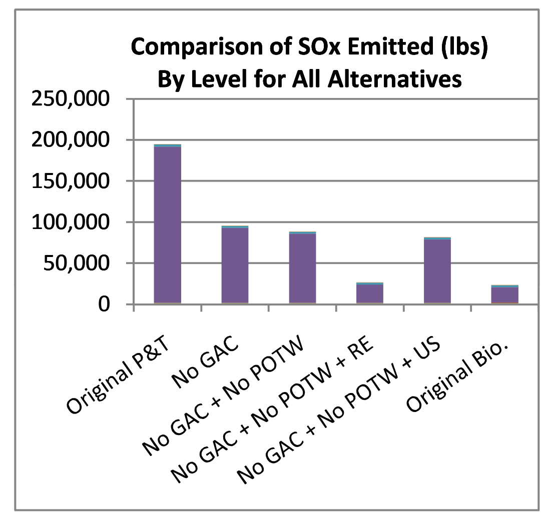


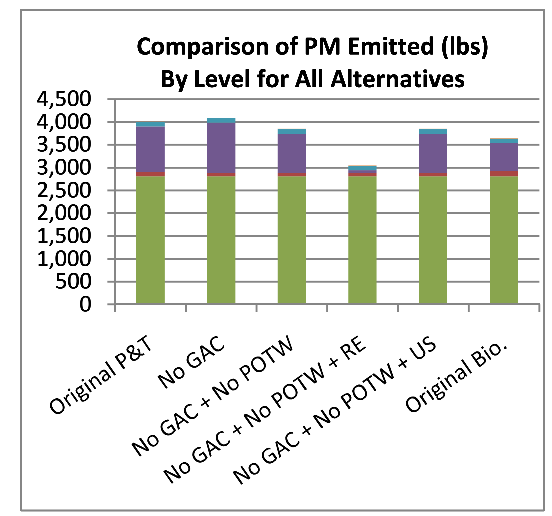


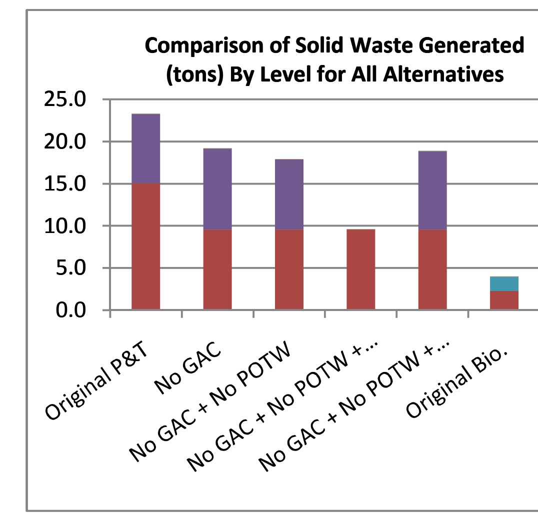


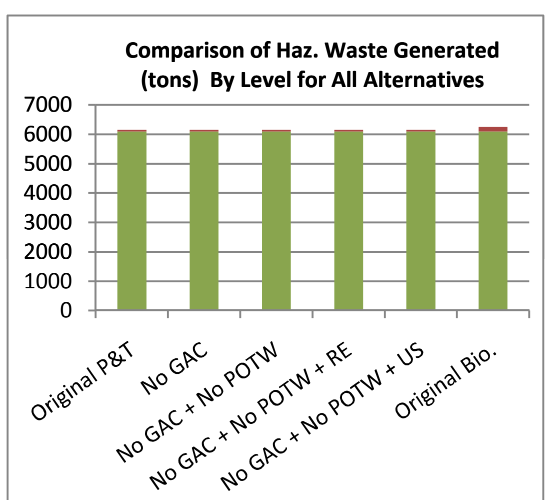


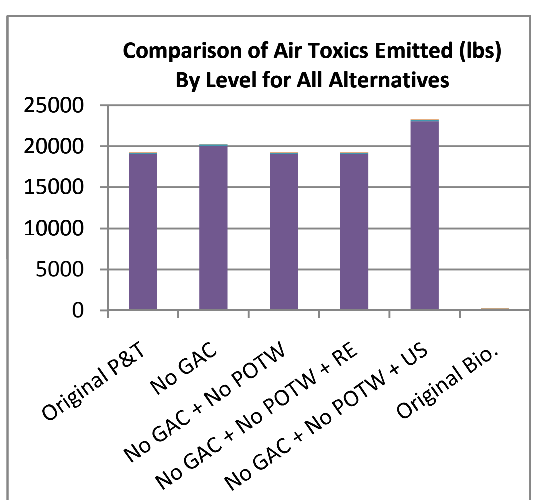


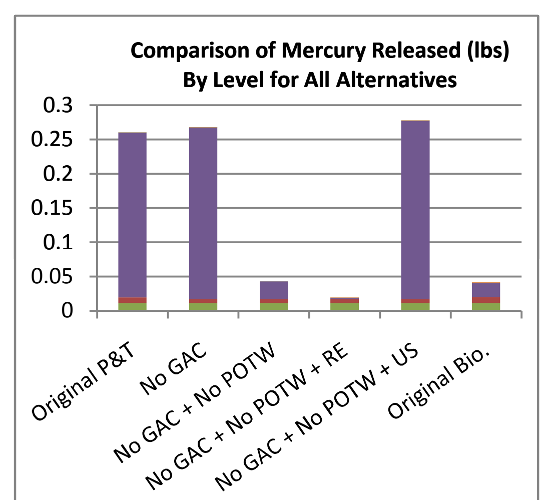


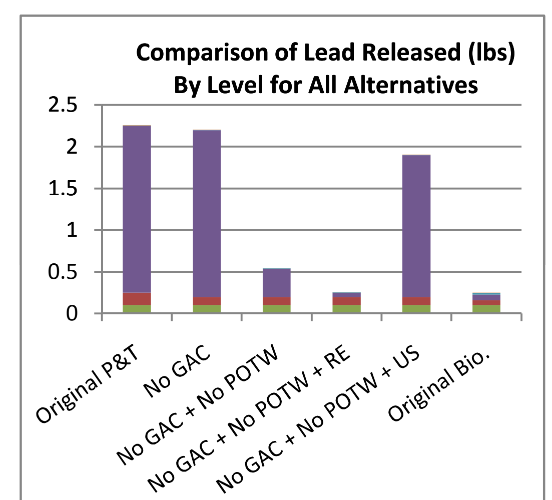


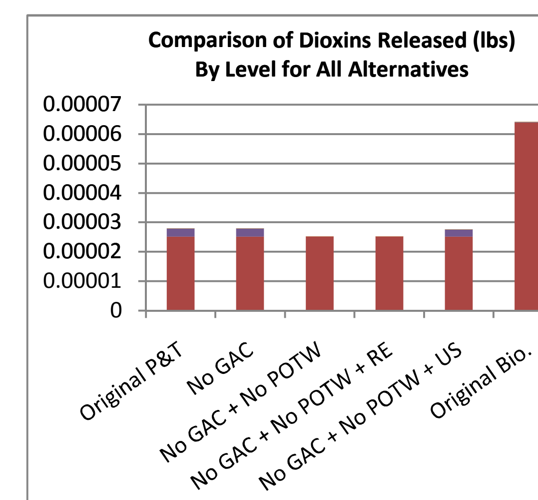












Romic, East Palo Alto, CA - P&T Sensitivity Analysis - Output by Parameter - On-Site Footprint