REMEDIAL ACTION CONTRACT

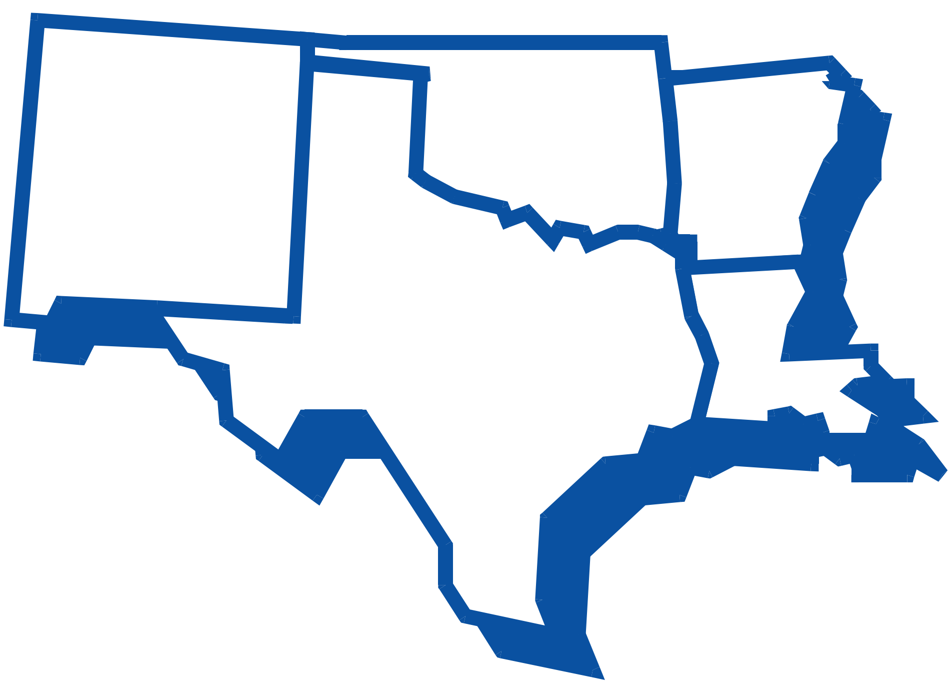
United States Environmental Protection Agency Region 6

Contract No. EP-W-06-021

Evaluation of the Environmental Footprint of the Record of Decision Remedy: Comparison of Four Different Tools

Grants Chlorinated Solvents Plume Site
Grants, Cibola County, New Mexico
Task Order No. 0052-RARA-06HE
Document Control No. 0052-02011

July 2013



Acknowledgements

This report was completed with significant support from representatives of the following organizations who are leaders in the development and application of footprint and life cycle assessment tools:

- Mr. Sai Appaji and Mr. Kirby Biggs (United States Environmental Protection Agency [EPA]) provided the vision for the project and provided overall direction and leadership as well as report review comments.
- Mr. Paul Favara (CH2M HILL) was the overall task manager for the project and lead writer for the report. He also led elements of the project related to the SimaPro and SRT tools. Mr. Favara is a recognized leader in the application of life-cycle assessment (LCA) on remediation projects and was also a contributing member to the Sustainable Remediation Tool (SRT™) development team.
- Dr. Doug Sutton (Tetra Tech) led elements of the project related to the SEFA tool as well as the SiteWise tool. Dr. Sutton was a leader in the development of the Spreadsheets for Environmental Footprint Analysis (SEFA) tool and has worked in deploying SiteWise on USACE projects. Dr. Sutton was also the lead writer for several sections of the report. Dr. Sutton's work on this report was through EPA Contract EP-W-07-078.
- Mr. Russell Sirabian (Battelle) was a leader in the development of the SiteWise tool and provided significant input and recommendations to the report and authored several sections. Mr. Sirabian's work on this report was through EPA Contract EP-C-11-038 Task Order #3, managed by EPA's Office of Research and Development, Engineering Technical Support Center.
- Mr. Doug Downey (CH2M HILL) was a contributing member of the SRT development team and provided comments and input on text and results related to the SRT tool.

The individual tool leads for this report, and their close association with the various tool development or application, provided expert knowledge of each of the tools and the combined individuals worked diligently to present information in an objective and unbiased manner.

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Executive Summary

The topic of sustainable remediation first emerged as a significant industry issue in 2006. Since that time, there has been substantial industry effort to determine how sustainable remediation should be defined and implemented. In 2008, the U.S. Environmental Protection Agency (EPA) introduced the term “green remediation” in the document entitled *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites* (EPA, 2008a).

The EPA defines “green remediation” as the practice of considering all the environmental effects of implementing a remedy, and incorporating options to minimize the environmental footprint of cleanup actions. This definition is a departure from the term “sustainable remediation” because green remediation focuses on the environmental aspect of a project, whereas sustainable remediation addresses environmental, social, and economic aspects of the cleanup activities.

Green remediation strategies may include a detailed analysis in which components of a remedy are closely examined and large contributions to the footprint are identified (*Methodology for Understanding and Reducing a Project’s Environmental Footprint*, [EPA’s Methodology], 2012).

The use of quantification tools to estimate a remediation project footprint has been a key focus area of the remediation industry since sustainable remediation was introduced as an industry focal point in 2006.

As of 2012, the following tools are the most prominent for estimating the potential environmental burdens of remediation projects:

- SiteWise – developed by Battelle, the Naval Facilities Engineering Command, and the U.S. Army Corps of Engineers (USACE) in 2010 (V1) and 2012 (V2)
- Sustainable Remediation Tool (SRT™) – developed by the U.S. Air Force Center for Engineering and the Environment (AFCEE) in 2009 (V1) and 2011 (V2)
- Spreadsheets for Environmental Footprint Analysis (SEFA) – developed by EPA in 2012
- SimaPro® – a commercial life-cycle assessment (LCA) tool

The purpose of this project is to provide a comprehensive comparison of these four tools. This project is the first side-by-side comparison of these tools and shows the primary similarities and differences of the tool input and output for a specific project.

The project selected for the tool comparison was the Grants Chlorinated Solvents Plume (GCSP) Superfund Site, in Grants, New Mexico. The remedy evaluated includes Enhanced Reductive Dechlorination (ERD), and In Situ Chemical Oxidation (ISCO) and In Situ Thermal Treatment (ISTT).

Information from the GCSP remedial design was used as a basis for enumerating the components of the remedy and project-specific input into each of the four tools. The individuals on the project team assessing each of the four tools worked together in developing a consistent basis for tool input to minimize the differences in results that were attributable to interpretation of input parameters from the remedial design. Results from the models were analyzed several different ways:

- An initial comparison of the four tools was completed at the total project level. Results for carbon dioxide equivalents (CO_2e), nitrogen oxides (NO_x), sulfur oxides (SO_x), particulate matter (PM), and energy, were compared, because these five parameters are all reported by each of the five tools. Hazardous air pollutants (HAPs) were also considered as SEFA and SimaPro both report this metric. The results for each tool varied, sometimes significantly.
- The next comparison involved the same six metrics at the individual technology level (ERD, ISTT, and ISCO). As with the comparison at the total project level, some of the differences were minor, while others were more significant.

- The next comparison involved a deeper evaluation and identified the top three contributors for five metrics (HAPs were not considered in this part of the comparison), compared by treatment technology. While there was often reasonable agreement on what the top contributors to each process were, there was not very good agreement on the absolute amounts of emissions for each of these contributors.
- Based on this comparison, a more focused evaluation was made to analyze tool results for key specific inventories on a per-unit basis. As with the previous comparisons, the differences between the different tool results were similar to those reported for the technology level comparison.
- Finally, the results from each tool were assessed to identify commonality and differences in conclusions that can be drawn from the individual tool results. This evaluation showed interpretation of each tool and identified common significant contributors to the footprint for the project. All the tools were reasonably consistent in identifying the largest contributors to the project footprint but differed on the rationale for the impacts. For example, substrate was considered a major contributor and all four tools had a recommendation for optimization of substrate use and sourcing of substrate from suppliers with a lower environmental footprint. Based on SiteWise, SRT, and SEFA, reasons for this recommendation include avoidance of CO_2 emissions, energy, and potable water use. SimaPro encompasses all these observations, but also cites potential for acidification, smog, respiratory impacts, potential carcinogenic impacts, embedded water in soybean growth utilized in substrate manufacturing, eutrophication, land use in agriculture, and scarcity of food. So, while each tool recognizes substrate as a significant contributor to the environmental footprint of the project, the scope of the footprint is represented differently among the tools.

In general, all the tools recommended energy optimization or offsets, substrate optimization, and potassium permanganate optimization to reduce environmental burdens. The context of these recommendations differed. The footprint tools identified benefits, in terms of specific emissions, whereas SimaPro identified the benefits in terms of environmental impact categories. Additional observations are noted below:

- SiteWise and SEFA identified laboratory analysis as a noticeable contributor to CO_2 and energy emissions. SimaPro's footprint for laboratory work was significantly less than SiteWise and SEFF. SRT does not have an inventory for laboratory emissions.
- SiteWise, SEFA, and SimaPro all identified use of potable water as an environmental footprint contributor. In the case of water used for ERD and ISCO injection, none of the tools carry inventory for delivery, but they do allow the flexibility for water to be tracked. SRT does not offer this flexibility.
- SEFA and SimaPro were the only tools to report HAPs.
- SimaPro was the only tool to identify the embedded water related to agricultural activities, which are related to growth of soybean, vegetable, or rapeseed oil used in the substrate inventory. SEFA identified embedded water, but did not specify the activity that represented the embedded water.
- SimaPro was the only tool to address potential impacts associated with eutrophication, acidification, respiratory, carcinogen, and smog.
- SimaPro was the only tool to represent inputs and outputs of the project in terms of impact categories.
- SimaPro was the only tool to place impact categories in context of population equivalents, so as to provide perspective on the relative impact of specific results.

Given that the tool users were all working with the same project assumptions, and given the analysis above, the difference in tool results were attributable to the inventories associated with each remediation process, materials, and activities. The following recommendations are offered to promote better consistency in tool results.

1. Tool users should have greater awareness of the sources of inventory information in the tools they use to make sure the information is applicable to their project and geographic region. Most tools allow the option of

overriding or adding inventory information. Tool users should be familiar with sources of data that can be used to override the values in the tool.

2. Each tool handles transportation differently. When project-specific equipment and logistical information is not available, the tools could use a commonly accepted default approach to address fuel efficiency and truckload factors.
3. Tools should use similar inventories associated with key remediation project components (such as fuel, substrate, and oxidant) for when geographic information is not available or is considered a commodity.
4. Diesel fuel is almost always a significant environmental footprint factor. Tool libraries should include inventories for both road and non-road emissions and represent a range of equipment so users can select the appropriate information to better estimate NO_x, SO_x, and PM.
5. Electricity is almost always a significant environmental footprint factor. Local power supply information should be considered when developing inventories to be used in the project.
6. The significance of tools that do not carry inventory information for NO_x, SO_x, and PM for materials should be considered when conclusions are presented.
7. While each of the four tools provides helpful information in evaluating the environmental footprint of a project, none of the tools should be considered comprehensive and complete for all projects to which they may be applied. Tool users should be aware of potential limitations of a specific tool for a project and consider using other approaches to identify important environmental footprint metrics. For example, with a project that involves air stripping off-gas to the atmosphere, several tools would not capture the emission of HAPs to the atmosphere. However, these emissions could be easily estimated outside of the tool and reported along with the tool results.
8. Users of all remediation assessment tools should be aware of how their tool of choice does or does not consider LCA (such as cradle-to-grave boundary) of project components. This will help them be more aware of the importance of variability in inventory information, the opportunities and impacts associated with recycling and reuse, and the potential strengths and weaknesses of their analyses and conclusions.

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Acronyms and Abbreviations

AFCEE	U.S. Air Force Center for Engineering and the Environment
ARAR	Applicable or Relevant and Appropriate Requirements
bgs	below ground surface
BTU	British thermal unit
CFC	chlorofluorocarbon
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
COC	contaminant of concern
CTUe	comparative toxicity unit—ecotoxicity
CTUh	comparative toxicity unit—human
CVOC	chlorinated volatile organic compound
DNAPL	dense nonaqueous phase liquid
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
ELCD	European Reference Life Cycle Data System
EPA	U.S. Environmental Protection Agency
ERD	enhanced reductive dechlorination
ERH	electrical resistive heating
ES&T	Environmental Science & Technology
ESTCP	Environmental Security Technology Certification Program
EVO	emulsified vegetable oil
FS	feasibility study
GAC	granular activated carbon
GCSP	Grants Chlorinated Solvents Plume Superfund Site
GHG	greenhouse gas
GWP	global warming potential
HAP	hazardous air pollutant
HC	Holiday Cleaners
hp	horsepower
ISCO	in situ chemical oxidation
ISTD	in situ thermal desorption
ISTT	in situ thermal treatment

kg	kilogram
kWh	kilowatt-hour
LCA	life-cycle assessment
LTM	long term monitoring
MBTU	thousand British thermal units
MMBTU	million British thermal units
MCL	maximum contaminant level
MJ	megajoule
mpg	mile per gallon
MT	metric ton(s)
MWhr	megawatt-hour
NO_x	nitrogen oxide
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
PCE	perchloroethylene
PM	particulate matter
$PM_{2.5}$	particulate matter less than 2.5 micrometers in diameter
PM_{10}	particulate matter less than 10 micrometers in diameter
PVC	polyvinyl chloride
RAC	remedial action construction
RAO	remedial action operation
RBCA	Risk-Based Corrective Action
REC	renewable energy certificate
RI	remedial investigation
ROD	Record of Decision
SEFA	spreadsheet for environmental footprint analysis
SO_x	sulfur oxide
SPC	Shallow Plume Core
SRT™	Sustainable Remediation Tool
SVE	soil vapor extraction
TCH	thermal conductive heating
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (EPA)
TTZ	target treatment zone
USACE	U.S. Army Corps of Engineers
USD	U.S. dollar

US-EI	A database created to bridge the current gap in the USLCI database and to apply US electrical conditions to the ecoinvent database
USLCI	U.S. Life Cycle Inventory
VIMS	Vapor Intrusion Mitigation Systems

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SECTION 1

Introduction

1.1 Background and Objectives

The topic of sustainable remediation first emerged as a significant industry issue in 2006. Since that time, there has been substantial industry effort to determine how sustainable remediation should be defined and implemented. In 2008, the U.S. Environmental Protection Agency (EPA) introduced the term “green remediation” in the document entitled *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites* (EPA, 2008a).

The EPA defines “green remediation” as the practice of considering all the environmental effects of implementing a remedy, and incorporating options to minimize the environmental footprint of cleanup actions. This definition is a departure from the term “sustainable remediation” because green remediation focuses on the environmental aspect of a project, whereas sustainable remediation addresses environmental, social, and economic aspects of the cleanup activities.

Green remediation strategies may include a detailed analysis in which components of a remedy are closely examined and large contributions to the footprint are identified (*Methodology for Understanding and Reducing a Project’s Environmental Footprint*, [EPA’s Methodology], 2012).

The use of quantification tools to estimate a remediation project footprint has been a key focus area of the remediation industry since sustainable remediation was introduced as an industry focal point in 2006. The first approach using such tools in estimating green remediation emissions was the quantification of greenhouse gas (GHG) emissions. Subsequently, other pollutants and energy were added to estimating tools. Initially, various consulting companies developed these tools. However, the Department of Defense (DOD) and EPA eventually took the lead in continued development and refinement of the most prominent tools used in the industry today. In parallel with the development of these footprint tools, some site owners and consultants evaluated the use of traditional life-cycle assessment (LCA) tools to assess their potential role in estimating the environmental impacts of cleanup activities.

As of 2012, the following tools are the most prominent for estimating the potential environmental burdens of remediation projects:

- SiteWise – developed by Battelle, the Naval Facilities Engineering Command, and the U.S. Army Corps of Engineers (USACE) in 2010 (V1) and 2012 (V2)
- Sustainable Remediation Tool (SRT™) – developed by the U.S. Air Force Center for Engineering and the Environment (AFCEE) in 2009 (V1) and 2011 (V2)
- Spreadsheets for Environmental Footprint Analysis (SEFA) – developed by EPA in 2012
- SimaPro® – a commercial LCA tool

The first three tools are referred to as footprint tools. The fourth tool is an LCA tool.

For the purposes of this report, the term “environmental footprint” is defined as the quantitative estimate of the environmental impact of a remediation project. A quantitative environmental footprint may be obtained either through a footprint analysis or LCA.

A footprint tool is used to complete a footprint analysis. A footprint analysis is an estimate of an environmental footprint for a remediation phase or activity. The analysis entails the compilation of inputs and outputs to estimate metrics reported by the tool. A footprint analysis may include raw material acquisition, materials manufacturing, and transportation related to the cleanup, in addition to onsite construction, implementation, monitoring, and decommissioning. Results from a footprint analysis are typically reported as emissions such as nitrogen oxides (NO_x), carbon dioxide (CO_2) equivalents (CO_2e), total hazardous air pollutants (HAP]), or resource use (such as water, energy, or materials use). A footprint tool is characterized by the following typical attributes:

- Uses predetermined metrics
- Reports parameters individually, with the exception of GHGs, which are reported as CO_2e based on characterization factors for CO_2, methane, and nitrogen oxides (note that SRT reports CO_2 and not CO_2e)
- Uses an industry-specific software tool
- Carries inventory (the environmental footprint data for each cleanup component in the tool) data on specific emissions estimated by the tool
- Uses a limited inventory and specific emissions, as compared to LCA tools

An LCA is a quantitative estimate of an environmental footprint for a remediation phase or activity. The assessment entails the compilation of inputs and outputs to estimate the potential human health and environmental impacts from a cleanup activity or phase, from raw material acquisition, materials manufacturing and transportation, to onsite construction, implementation, monitoring, and decommissioning. Results from an LCA are reported in impact categories. The LCA tool is characterized by the following attributes:

- Uses an inventory of emissions for raw material inputs and materials, energy, processing, transportation, and waste scenarios, used in the life cycle of the cleanup, which can be used to estimate environmental impacts for a large number of impact categories
- Allows the selection of impact categories that are the most meaningful for the goal and scope of the project
- Employs the characterization of emissions to represent results as potential impacts to different environmental impact categories

There are two fundamental differences between footprint analysis and LCA:

1. An LCA typically considers the full life cycle of the components of a cleanup activity or phase, whereas a footprint analysis may consider the full life cycle of the components, but more commonly selects abbreviated boundaries of the life cycle of the components of the remediation project.
2. Results from an LCA are described in terms of potential relative impacts to human health and ecosystems, whereas results of a footprint analysis are reported in terms of quantities of emissions and resource use, without taking the next step to evaluate the human health and environmental impact from those emissions and resource use. For example, footprint tools will generally report carbon dioxide emissions, whereas LCA tools will represent carbon dioxide emissions as global warming potential.

Appendix A provides an overview of the way cleanup action components are converted into environmental footprint results using footprint and LCA tools.

When the terms “human health” and “ecotoxicity” are used in this report in the context of LCA, the reader should be aware that these terms reflect estimates of total characterization factors that may indicate relative potential life-cycle impacts to human health and the ecosystem, and include impacts at the cleanup site as well as the full life cycle of every project component use to support site cleanup. However, the methodologies used to represent LCA human health and ecotoxicity impacts are not the same as those methodologies traditionally used to estimate human and ecosystem risks at contaminated sites. So while it is noted that these two terms, when used in an LCA context, are similar to terms used in traditional risk assessments, they should not be interpreted to mean the same thing.

1.2 Objectives of Report

Typically, when a project team endeavors to estimate the potential environmental footprint of a remediation project, they use one of the four tools referenced in the previous section. Each tool uses predetermined inventories for specific remediation project components (such as fuel, electricity, or materials) as assumptions in estimating the environmental burden (such as CO_2, NO_x, sulfur oxides [SO_x] emissions) of each component of a remediation project.

The purpose of this project is to provide a comprehensive comparison of these four tools. This project is the first side-by-side comparison of these tools and shows the primary similarities and differences of the tool input and output for a specific project.

The project selected for the tool comparison was the Grants Chlorinated Solvents Plume (GCSP) Superfund Site, in Grants, New Mexico. The remedy evaluated includes In Situ Thermal Treatment (ISTT), Enhanced Reductive Dechlorination (ERD), and In Situ Chemical Oxidation (ISCO). These three technologies were a substantive component of the selected remedy during early phases of the design process. The ISCO remedy was eventually dropped from the selected remedy during a value-engineering workshop because it was determined to be not effective. However, the ISCO remedy was included in this evaluation to better assess the model against a range of remediation technologies. Vapor Intrusion Mitigation Systems (VIMS) are also a component of the final remedy; however, the VIMS remedy was not considered relevant to the project objectives because the impacts of VIMS are considered insignificant compared to the other remedy components.

Information from the GCSP remedial design was used as a basis for enumerating the components of the remedy and project-specific input into each of the four tools. The individuals assessing each of the four tools worked together in developing a consistent basis for tool input to minimize the differences in results that were attributable to interpretation of input parameters from the remedial design. Results from the models were analyzed several different ways, including:

- Overall result comparison
- Results by treatment technology (ISCO, ERD, ISTT)
- Results by sources of emissions or impacts: “onsite,” through electricity generation, through transportation, and “other”
  - “Onsite” refers to all activities within the geographic boundary of the GCSP site and includes primarily construction and operation activities (such as drilling, labor, construction support equipment [for example, pavers, forklifts, and trenching equipment]). When “onsite” is used in this context, it will be presented with quotation marks.
  - Electricity generation refers to all electricity used directly by the project.
  - Transportation includes all personnel transportation (e.g., workers to and from site) and equipment and material transportation to the site via truck or automobiles.
  - “Other” refers to all materials used on the project (chemicals, substrate, construction materials, steel, pipe) and laboratory analysis. The footprint of “other” is typically associated with the life-cycle impacts of the material from manufacturing and occurs at a location where the materials are produced and not consumed. When “other” is used in this context, it will be presented with quotation marks.
- The three biggest impacts by treatment technology and by source of life-cycle impact (for SimaPro) or tool metric (for footprint analysis tools)
- Comparison of the 10 most significant components of the overall remedy, on a unit basis
- Interpretation of results from each tool

This report is organized in the following sections:

Executive Summary

Section 1 – Background and Objectives

Section 2 – Tool Overview

Section 3 – GCSP Background and Designed Remedy

Section 4 – Modeling Results (Inputs/Outputs, and Model Comparisons)

Section 5 – Conclusions and Recommendations

Section 6 – Works Cited

SECTION 2

Tool Overview

2.1 Overview of Tools

Each of the four tools assessed in this report was developed with a specific objective in mind and was designed to quantify specific metrics. SiteWise was designed to support sustainable remediation assessments at Navy sites and sites managed by U.S. Army Corps of Engineers (USACE). The Sustainable Remediation Tool (SRT) was designed to support sustainable remediation assessments for technologies most commonly used for Air Force Cleanup Sites. The spreadsheet for environmental footprint analysis (SEFA) was designed to support EPA's Methodology. SimaPro is a tool designed to support LCAs for a range of projects. SimaPro and other commercial LCA tools are not designed with any specific industry in mind; rather, they are designed to be flexible and applicable to a range of industries and project types.

While the tools have similarities in the metrics they estimate, there are also differences in what is estimated and the inventories used in the estimates. **Table 2-1** provides information on tool structure, method of input, and output results. **Table 2-2** provides information on costs/licensing, training requirements, data references and sources, and the analytical and interpretation features of each tool. The information presented in these tables is representative of the tools at the time the comparisons were completed (March through October 2012). As of the time of production of this report, SiteWise and SRT were undergoing upgrades. Therefore, some of the information presented in **Tables 2-1** and **2-2** may be out of date when the updated tools are released.

The SiteWise tool (SiteWise, 2011) consists of a series of Microsoft Excel-based spreadsheets used to conduct a baseline assessment of sustainability metrics. Each assessment is carried out using a spreadsheet-based, building-block approach, where every remedial alternative is first broken down into modules that mirror the phases of remedial action work. These phases include: remedial investigation (RI), remedial action construction (RAC), remedial action operation (RAO), and long-term monitoring (LTM) (SiteWise, 2011). **Tables 2-1** and **2-2** present metrics reported from the tool and other pertinent information about SiteWise.

The SRT tool focuses on 8 common technologies used for remediating fuel and solvent sites. The SRT tool is built on the Microsoft Excel platform and is structured using analytical "tiers," similarly to the tiered structure of the Risk-Based Corrective Action (RBCA) Tool Kit 2. This tiered structure allows the user to choose the level of effort and detail that is appropriate for the project at hand. Tier 1 (simplest tier) calculations are based on simple design rules that are widely used in the environmental remediation industry. Tier 2 calculations, which are more detailed, incorporate more site-specific factors. Tier 2 is recommended for evaluating existing systems and for projects that have advanced to the feasibility study (FS) stage. At the FS stage, conceptual designs should be available, allowing the user to enter more site-specific inputs. These inputs result in more accurate outputs tailored to the project (AFCEE, 2010). The equivalent of Tier 2 was used for this evaluation (**Section 4.1** for further information). **Tables 2-1** and **2-2** present metrics reported from the tool and other pertinent information about SRT.

SEFA is a collection of Microsoft Excel spreadsheets designed to apply EPA's Methodology. The spreadsheets allow information to be organized into up to six different components that can be defined by the user. Input and output are not constrained by specific technology modules. Input includes materials use, water use, waste disposal, transportation, equipment use, and other items. **Tables 2-1** and **2-2** present metrics reported from the tool and other pertinent information about SEFA.

SimaPro is a commercial LCA tool, which was designed to estimate the environmental footprint of a range of project types. It is flexible in how the project information is entered and allows user discretion in organizing the information in a manner that meets project-specific reporting objectives. In the case of this project, all data were organized around "onsite" activities, "other," transportation, and electricity. **Tables 2-1** and **2-2** present metrics reported from the tool and other pertinent information about SimaPro.

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SECTION 3

Description of Grants Chlorinated Solvents Plume Project

The tool comparison was completed using information from a project site where EPA is currently implementing a remediation action. The following subsections offer an overview of the site.

3.1 Brief Site History of GCSP

The GCSP Superfund Site in Grants, New Mexico, is in a mixed commercial and residential neighborhood; it includes an area of contaminated groundwater that contains chlorinated volatile organic compounds (CVOC) at concentrations four orders of magnitude higher than the remedial goals. The 2,500-foot-long, 100-foot-deep CVOC groundwater plume is associated with historical dry cleaning operations at the active business, Holiday Cleaners (since 1969), and a second business, referred to as “Abandoned Cleaners.” The following RAOs were established based on the nature and extent of contamination, the resources that are currently and potentially threatened, and the potential for human and environmental exposure:

- Restore the groundwater at the GCSP Site such that concentrations of contaminants of concern (COCs) are less than the applicable maximum contaminant levels (MCLs), or applicable or relevant and appropriate requirements (ARARs) in a timely manner.
- Prevent dense non-aqueous phase liquid (DNAPL), if present, from causing concentrations of COCs in groundwater to exceed MCLs or ARARs.
- Reduce the concentration of COCs in groundwater to mitigate vapor intrusion.

Based on the results of the Remedial Investigation Report (EPA, 2005a), FS Report (EPA, 2006), and Baseline Human Health Risk Assessment (EPA, 2005b), EPA established the Record of Decision (ROD) to address five separate components of the GCSP Site:

- Vapor intrusion mitigation
- Source area
- Shallow groundwater plume core and hot spot
- Shallow groundwater plume periphery
- Deep groundwater (between 20 and 100 feet below ground surface [bgs])

The vapor intrusion component of the remedy was not included in the comparison because the footprint of this element of the remedy was considered less than 1 percent of the overall project footprint. Therefore, the VIMS elements of the GCSP remedy will not be further addressed in this report.

3.1.1 Source Area

The source area remedy consists of electrical resistive heating (ERH). ERH uses the subsurface resistance to electrical current applied between subsurface electrodes and extraction wells to heat the subsurface.

In accordance with the design, ISTT using ERH would be installed at the primary source area around the Holiday Cleaners and secondary source area near the Abandoned Cleaners. ERH heater electrodes and collocated vapor extraction wells would be installed on 12- to 20-foot centers. Electricity would then be delivered to the system to raise the subsurface temperature within the target treatment zone (TTZ) high enough to volatilize the perchloroethylene (PCE) and other COCs and generate steam to drive the contaminants from the subsurface. The process typically includes heating, maintenance, and cooling phases, which take less than 1 year (combined) to complete. Vaporized COCs and steam would be collected with an associated soil vapor extraction (SVE) system and treated before the air and condensate are discharged. Treatment would be expected to last 6 to 12 months.

3.1.2 Shallow Groundwater Plume Core and Hot Spot

For treatment of the shallow groundwater plume core (approximately 8 to 20 feet bgs), ISCO would be applied using a network of permanent injection wells within the TTZ. As detailed in the FS (EPA, 2006b) and final GCSP Site ROD (EPA, 2006a), a chemical oxidant solution would be injected to replace one effective pore volume in the TTZ. An initial application would include all of the injection wells; a second, strategic injection would be applied at half of the wells approximately 6 months after the initial event.

After the two ISCO applications, an organic carbon substrate (assumed to be emulsified vegetable oil [EVO]) would be injected into the shallow groundwater plume core to address residual CVOC concentrations via ERD. The ISCO injection well network would be used for EVO injections. The injection volume was based on a 15-foot radius of injection and the replacement of approximately 100 percent of the pore volume within the TTZ. Five rounds of EVO injections, performed once every 15 months to maintain reducing conditions in the TTZ, would be expected to meet the RAOs in the plume core.

Note that while ISCO was part of the remedy described in the ROD, the ROD was developed to be flexible. During a value engineering workshop in 2010, ISCO was determined to not be part of the implemented remedy. However, to represent the ISCO technology in the evaluation, the ISCO component of the remedy was retained for the purpose of the evaluation described in this report.

3.1.3 Shallow Groundwater Plume Periphery

Multiple biobarriers, comprising transects of permanent EVO injection wells, would be installed to address the shallow groundwater plume periphery from 8 to 20 feet bgs. The biobarriers would be created by injecting EVO into injection wells on 20- to 25-foot centers positioned along multiple transects. The injection volume was based on a radius of injection of 15 feet and the replacement of approximately 50 percent of the pore volume along the transects.

The selected remedy in the ROD assumed a total biobarrier length of 2,400 feet, with 200 feet between transects in the direction of groundwater flow. Sixteen rounds of EVO injections were assumed over a 20-year period (one injection every 15 months) to continue reducing conditions along the biobarriers and meet the RAOs.

3.1.4 Deep Groundwater Plume

Multiple biobarriers, comprising transects of permanent nested EVO injection wells, would be installed to address the deep groundwater plume (below 20 feet bgs). The biobarriers would be created by injecting EVO into nested injection wells on 20- to 25-foot centers, positioned along multiple transects. The injection volume was based on a radius of injection of 15 feet and the replacement of approximately 50 percent of the pore volume along the transects.

The selected remedy in the ROD assumed a total biobarrier length of 1,000 feet for the 20- to 60-foot interval and 250 feet for the 60- to 80-foot interval. Sixteen rounds of EVO injections were assumed over a 20-year period (one injection every 15 months) to maintain reducing conditions along the biobarriers and meet the RAOs.

3.1.5 Treatment System Locations

The locations of the ISTT, ISCO, and ERD treatment systems at the GCSP site are presented in **Figure 3-1**.

SECTION 4
Modeling

The design for the remedy described in **Section 3** was completed in 2010 (EPA, 2010a). Quantities of materials and electricity were estimated from the final design for the remedy. As noted previously, because ISCO was not a component of the final design, the project team estimated the size of the ISCO project to represent the technology in this evaluation. In some cases, the quantities for model input were not defined and, therefore, were estimated using the design basis. Examples of quantities estimated included transportation distances for materials, equipment, and personnel.

Table 4-1a provides the model input for the ERD component of the remedy. **Tables 4-1b**, **4-1c**, **4-1d**, and **4-1e** identify how the model input was organized to facilitate input into the SiteWise, SRT, SEFA, and SimaPro models, respectively. **Table 4-1f** provides an overall summary of inputs for the four tools.

Table 4-2a provides the model input for the ERD component of the remedy. **Tables 4-2b**, **4-2c**, **4-2d**, and **4-2e** identify how the model input was organized to facilitate input into the SiteWise, SRT, SEFA, and SimaPro models, respectively. **Table 4-2f** provides an overall summary of inputs for the four tools.

Table 4-3a provides the model input for the ISTT component of the remedy. **Tables 4-3b**, **4-3c**, **4-3d**, and **4-3e** identify how the model input was organized to facilitate input into the SiteWise, SRT, SEFA, and SimaPro models, respectively. **Table 4-3f** provides an overall summary of inputs for the four tools.

4.1 Model Inputs

The remedial design was evaluated to identify and document project components for the ERD, ISCO, and ISTT remedies. These project components were used to estimate the environmental burdens of the remedy, as determined by each of the four tools. Project components for each of the three technologies are presented in **Tables 4-1a**, **4-2a**, and **4-3a**. The model inputs only include project elements to complete the remediation activities. Well decommissioning and recovery/reuse of electrodes for the ISTT element of the project have not been considered in the assessment and evaluation described in this report.

4.1.1 SiteWise Model Inputs

SiteWise model inputs are presented in **Tables 4-1b**, **4-2b**, and **4-3b**.

4.1.2 SRT Model Inputs

SRT model inputs are presented in **Tables 4-1c**, **4-2c**, and **4-3c**. Given the architecture of SRT and the reporting objectives outlined in this report, a tool was prepared to utilize the SRT inventory information and present results in a manner that would map to the reporting objectives. So while the calculation features of SRT were not used for this evaluation, the SRT results presented herein are considered equivalent to what the tool would report if a user were to run multiple iterations of the tool and compile the results in a manner that supports the report objectives. A spreadsheet summarizing the SRT inventory used, input parameters, and output results are summarized in **Appendix B**.

4.1.3 SEFA Model Inputs

EPA SEFA model inputs are presented in **Tables 4-1d**, **4-2d**, and **4-3d**.

4.1.4 SimaPro Model Inputs

SimaPro model inputs are presented in **Tables 4-1e**, **4-2e**, and **4-3e**. A summary of input parameters which provides additional detail on datasets used for the SimaPro model is presented in **Appendix C**.

4.1.5 Comments on Inputs

Inputting project components into the different tools is a data-intensive activity. The project team focused specific attention on consistency of project input to make sure result differences are attributed to how the tools calculate environmental footprint results, rather than differences in interpretation of how inputs should be entered into the tools. Even with the special focus on consistency of project inputs, there were still some differences in how users entered information. For example, for personnel transportation, some users assumed automobile use and others assumed light truck use. In the case of electricity for the ISTT system, three tool users assumed that the 6,000,000 kilo-watt hour (kWh) input included all electricity needs, whereas a fourth user added additional electricity to account for the blower used in the SVE system. Other entry discrepancies can be observed by comparing the "a" tables in **Tables 4-1**, **4-2**, and **4-3** with the tool-specific tables that follow and the summary "f" tables. This comparison underscores a finding that users' input interpretation among the tools vary, and users have the discretion to make any number of decisions of how to enter information into the tool, even with a well-defined set of input parameters.

While some differences existed in how users chose to enter the information, as shown in **Tables 4-1a**, **4-2a**, and **4-3a**, the differences are considered minor in the context of the overall project results.

4.2 Outputs/Comparisons

4.2.1 Overall Footprint Results by Tool

Table 4-4 provides an overall summary of the tool results. The table is organized in the following manner:

- The first two columns of data represent the model output, by metric and units of the metric.
- The next four columns represent a summation of the total footprint of the remedy, as estimated by SiteWise, SRT, EPA SEFA, and SimaPro, respectively. The cells highlighted in yellow in these four columns represent the results reported by each of the four tools.
- The next four columns represent a summation of the "onsite" footprint of the remedy, as estimated by SiteWise, SRT, EPA SEFA, and SimaPro, respectively. "Onsite" refers to all emissions or impacts resulting from onsite operations (e.g., emissions from drilling and construction equipment, water use, waste generation onsite).
- The next four columns represent a summation of the electricity generation footprint of the remedy, as estimated by SiteWise, SRT, EPA SEFA, and SimaPro, respectively. Electricity generation encompasses all the kWhs used for the implementation and operation of the remedy and includes extraction of the fuel used for energy generation, generation of electricity at the power station, line losses associated with transmission of the electricity, and use of the electricity onsite, if this information is represented in the inventory.
- The next four columns represent a summation of the transportation footprint of the remedy, as estimated by SiteWise, SRT, EPA SEFA, and SimaPro, respectively. Transportation includes all personnel, equipment, materials, and waste transportation.
- The final four columns represent a summation of the "other" footprint components of the remedy, as estimated by SiteWise, SRT, EPA SEFA, and SimaPro, respectively. "Other" represents the footprint of the materials used in the remedy (such as chemicals, substrate, polyvinyl chloride [PVC], cement, granular activated carbon [GAC], potable water, lab analysis, and steel).

Figures 4-1 through **4-14** compare tool results for six different metrics. These metrics were selected because they can generally be reported by all four tools (with the exception of HAPs which can only be reported by SEFA and SimaPro).

Figure 4-1 presents the overall summary results in a normalized bar graphic. Normalized results are presented in terms of the tool with the highest result. Normalization allows more results to be presented in the same graphic, thereby making data assessment easier and more consolidated. To illustrate the use of normalization in

Figure 4-1, consider the example metric of CO_2. SEFA reported the highest CO_2 results of all the tools; therefore, it is the reference point by which the other tools are reported. In the case of SRT, the CO_2 emission estimate is 76.77 percent of the SEFA results, so the results are presented as 76.77 percent. Results show that the EPA SEFA tool shows the greatest emissions for CO_2, NO_x, and SO_x, while SimaPro shows the greatest results for PM, Energy, and HAPs.

Table 4-5 provides an overall view of model results for the ERD remedy. **Table 4-5** is organized in the same manner as **Table 4-4**.

Figure 4-2 presents the total footprint for the ERD remedy, as estimated by the four tools. Results indicate that the EPA SEFA tool shows the greatest emissions for CO_2, NO_x, and SO_x, while SimaPro shows the greatest results for particulate matter (PM), energy, and HAPs.

Table 4-6 provides an overall view of model results for the ISCO remedy. **Table 4-6** is organized in the same manner as **Tables 4-4** and **4-5**.

Figure 4-3 presents the total footprint for the ISCO remedy, as estimated by the four tools. Results indicate that the EPA SEFA tool shows the greatest emissions for NO_x, SO_x, and energy, while SimaPro shows the greatest result for PM_{10} and HAPs; SRT show the greatest result for CO_2.

Table 4-7 provides an overall view of model results for the ISTT remedy. **Table 4-7** is organized in the same manner as **Tables 4-4**, **4-5**, and **4-6**.

Figure 4-4 presents the total footprint for the ISTT remedy, as estimated by the four tools.

Compared to the ERD and ISCO remedies, the results for thermal treatment are more consistent among the four tools, although there are significant differences for NO_x, SO_x, and PM.

Figures 4-1 through **4-4** show variation in the reported metrics for each tool. These differences result from different datasets used to estimate the metrics summarized in these figures. The following subsections further explore these differences.

4.2.2 Most Significant Impacts by Contributor and Remedy

The data presented in **Section 4.2.1** represent metric results at the total remedy or total technology level (that is, ERD, ISCO, or ISTT). In an effort to better understand the reasons for the variability in model results, the model results were evaluated to identify the three largest contributors to each treatment technology (ERD, ISCO, and ISTT) and source of emission or impact (“onsite,” energy, transportation, and “other”). **Table 4-8** presents these results.

The comparison was made for CO_2e, energy, NO_x, SO_x, and PM. These parameters were chosen for comparison because they were common model outputs of the four tools evaluated. HAPs are not included in this evaluation.

Evaluation of the results shows a range of consistencies and differences between the most significant contributors and the results reported by the models. Examples of result analysis are:

- There is general agreement among all of the tools that substrate is a primary contributor for the CO_2e footprint for the ERD remedy. In addition, for the tools that calculate the energy, NO_x, SO_x, or PM footprints associated with substrate, there is general agreement that substrate is the primary contributor to these footprints.
- All tools agree that permanganate is the most significant contributor to the CO_2e footprint for the ISCO remedy; SiteWise, SEFA, and SimaPro also agree that permanganate is the largest contributor for the energy footprint for the ISCO remedy. SEFA and SimaPro also agree that permanganate is the largest contributor the NO_x, SO_x, and PM footprints for the ISCO remedy. The current version of SiteWise does not calculate the NO_x, SO_x, and PM footprints for permanganate; and the current version of SRT does not calculate the energy, NO_x, SO_x, and PM footprints for permanganate. As a result, the SiteWise and SRT results do not show that permanganate is a significant contributor for these metrics.

- Electricity is identified as the most significant contributor to all five compared metrics by all tools for ISTT. The only difference among these results is that the version of SiteWise used in this study does not have a mechanism for calculating the PM footprint from electricity; therefore, electricity does not appear as a significant PM contributor for SiteWise.

Many of the observed differences among the ranking of the contributions by each tool are the result of comparing metrics that are defined differently. For example, SiteWise focuses on NO_x and SO_x emissions from fuel use and electricity use only and does not consider the off-site, perhaps distant, emissions of NO_x and SO_x that is associated with materials manufacturing. SRT considers NO_x and SO_x for fuel use, electricity use, and some select materials. By contrast, SEFA and SimaPro consider NO_x and SO_x from fuel use, electricity use, materials, disposal, and other factors.

4.2.3 Comparison of the Ten Most Significant Components of the Overall Remedy, on a Unit Basis

Based on the analysis performed in the previous section, a more granular view of the datasets used by each model was evaluated to show potential differences in the impacts reported by each tool for CO_2e, energy, NO_x, SO_x, and PM. From **Table 4-8**, energy, diesel, substrate, oxidant, GAC, potable water, lab analysis, steel, transportation, and drilling were identified to be the 10 most significant contributors to the footprint or LCA results.

Figure 4-5 shows the emissions and energy reported, per kWh used, for each tool. Emission and energy results for electricity are commonly available and are variable, depending on the source of the data and the location the data represents. EPA SEFA and SimaPro used a dataset representative of the local electricity for the area of the GCSP site. SiteWise used regional emissions (from eGRID), which are representative of a broader geographical area than the local data used by EPA SEFA and SimaPro. SRT has one dataset for electricity based on the USLCI and is based on a U.S. average. SRT and SiteWise do not include HAPs in their inventories; and, because PM is not included in eGRID, SiteWise does not include PM in its inventory. While SEFA and SimaPro used similar local datasets, there is a marked difference in the PM emission. This is because SimaPro used a characterized value that includes not only particular matter but also nitrogen oxides and sulfur oxides in accordance with EPA's impact assessment method (TRACI).

Figure 4-5 shows that users have flexibility in choosing data sources for electricity. Results that are more representative can be obtained by using the most applicable data available, but different parties may have different opinions about which electricity blend (for example, local or regional) is more appropriate for footprint analysis. All of the tools have the ability to substitute or add additional data to allow the tool to be more representative and applicable to the project. Users need to be knowledgeable of electricity datasets to ensure use of the most applicable dataset available.

Figure 4-6 shows the emissions and energy reported, per gallon of diesel fuel, for each tool. The SiteWise data represent an average of all the diesel datasets used in the tool, and include both road and non-road emissions. SRT uses EMFAC 2007, Version 2.3, a model that calculates emissions for vehicles in California for NO_x, SO_x, and PM, and the National Renewable Energy Laboratory (NREL) database for CO_2 emissions (the specific NREL dataset used is not defined). EPA SEFA uses energy and CO_2 emissions from *Direct Emissions from Mobile Combustion Sources* (EPA, 2008b), and NO_x, SO_x, PM, and HAPs from NREL (using the single-unit truck, diesel-powered dataset). SimaPro used the US-EI database, developed by EarthShift. The database was created to bridge the current gap in the US LCI database and to apply US electrical conditions to the ecoinvent database (version 2.2) (Earthshift, 2009). The dataset used represents diesel combusted in industrial equipment.

The difference in the NO_x, SO_x, and PM data among these different sources of data is likely related to the different emission controls used on different equipment, different engines, and variations in handling the processing of diesel. For example, the SRT SO_x value considers emissions based on diesel combustion in vehicles in California. This emission factor does not include the emissions of SO_x resulting from crude oil extraction or refinery operations. By contrast, the other tools consider these life-cycle processes in addition to combustion. EPA SEFA considers diesel emissions based on heavy duty truck usage; the SiteWise value represents a cross-section of diesel combustion scenarios; and SimaPro considers combustion in industrial equipment. The SimaPro results are higher because industrial equipment was assumed, as opposed to road use; the former has less stringent emission controls. It is noted that when transportation is considered, SimaPro uses truck specific emissions.

HAPs are not reported for SiteWise and SRT.

Figure 4-7 shows the emissions and energy reported, per pound of substrate, for each tool. The SiteWise data represent CO_2 and energy representing vegetable oil from USLCI database. The specific dataset used is not defined. SRT uses an Environmental Security Technology Certification Program (ESTCP) reference from 2006 (ESTCP, 2006). EPA SEFA uses rapeseed oil data from a Dutch food database. A unique dataset was created in SimaPro to represent the contents of emulsified oil, using soybean oil (62 percent), molasses (4 percent, a proxy for lactate), soap (10 percent, a proxy for emulsifier), and water (24 percent). The SRT and SiteWise tools do not carry NO_x, SO_x, PM, and HAPs emissions for substrate, and SRT does not carry energy data for substrate. The high SRT results and the low SiteWise and SimaPro emissions for CO_2 represent the differences in using different datasets. The difference between the EPA SEFA and SimaPro results are likely due to uses of different oils and the different emissions from the geographies represented by the dataset – with EPA SEFA representing the Netherlands and SimaPro representing the US.

Figure 4-8 shows the emissions and energy reported, per pound oxidant, for each tool. The SiteWise tool has one oxidant in the material inventory, hydrogen peroxide (Boustead, 1997). The SRT tool assumes oxidants to be representative of sodium permanganate. The reference for the CO_2 emissions associated with the oxidant was provided without a discussion of how the estimate was developed. The SRT and SiteWise tools do not carry NO_x, SO_x, PM, and HAPs emissions for oxidant, and SRT does not carry energy data for oxidant. EPA SEFA does not have an inventory for treatment chemicals; rather, the tool uses an average of several chemicals in the Ecoinvent V2.1 database to represent the footprint of all treatment chemicals; potassium permanganate is represented in the average. The SimaPro database uses potassium permanganate inventory data from the Ecoinvent V2.2 database. The inventory is modeled on data for Europe.

Figure 4-9 shows the emissions and energy reported, per pound of GAC used, for each tool. SiteWise uses a value from a presentation (Goldblum, 2008). The value has two references (NREL and Kirk-Othmer), which are both reputable; however, the references are too general to understand the basis of the estimate. Additionally, the value presented in the reference appears to be half of that represented in the SiteWise inventory table and the basis of the energy for carbon cannot be identified in the reference. SRT uses a value from Vignes (Vignes, 2001) and information from the USLCI. However, the value used in SRT is not represented in either reference and the basis of the calculation is not documented. EPA SEFA documents carbon as:

> *Based on "treatment materials and chemicals" above plus the result of combusting 1.86 pounds of bituminous coal. The additional coal combustion represents the coal that is combusted in the activation process. The 1.86 pounds of bituminous coal assumes that the activated carbon yield is approximately 35 percent of the coal used as a feedstock (e.g., 2.86 pounds of coal yields 1 pound of granular activated carbon), which is consistent with values reported in Pore Develop of Activated Carbon Prepared by Steam Activate Process* (Kim, SC and Hong, IK, 1998).

SimaPro and the associated databases do not contain inventory information for GAC. A literature search was conducted to identify sources of GAC footprints in literature. The inventory used was from *Life Cycle Assessment as a Tool for Green Chemistry: Application to Different Advanced Oxidation Processes for Wastewater Treatment* (Ortiz, 2006).

SiteWise and SRT to not report information for NOx, SOx, PM, and HAPs; additionally, SRT does not report energy information for GAC.

Figure 4-10 shows the emissions and energy reported for water, per gallon of water, for each tool. SiteWise uses a dataset representative of municipal water treatment from the European Reference Life Cycle Data System (ELCD) database for emissions and Environmental Science & Technology (ES&T) Energy Value for Water Treatment (Stokesand Horvath, 2009). The value was converted from megajoules (MJ) per cubic meter to British thermal unit (Btu) per gallon) for energy. SRT does not include an inventory for water. SEFA uses data from ELCD for water treated from surface and groundwater. SimaPro uses Ecoinvent data V2.2, which uses an inventory for potable water in Europe; however, the energy contributions have been substituted with U.S. electricity values to make them more representative of the United States.

SRT does not carry inventory information for potable water. SiteWise does not report HAPs for potable water.

Figure 4-11 shows the emissions and energy reported for laboratory analysis, per 100 U.S. dollars (USD), for each tool. SiteWise uses economic input/output information that translates emissions from economic values. The SiteWise inventory references an EPA 2010 source (EPA, 2010b). However, the value used in SiteWise does not appear to be the same one used in the referenced report. SRT does not have inventory information for laboratory analysis. SEFA also uses *U.S. Carbon Dioxide Emissions and Intensities Over Time: A Detailed Accounting of Industries, Government and Households (*U.S. Department of Commerce, 2010) and assumes that all aspects typically considered in laboratory pricing (such as bottleware and bottle/sample transportation) are included in the footprint values). SimaPro uses a USA Input Output Database System Expansion (CEDA, 2010) with inventory information for research and development services, which includes laboratories.

SRT does not carry inventory information for lab analysis. SiteWise does not address HAPs for lab analysis.

Figure 4-12 shows the emissions and energy reported for steel, per pound, for each tool. SiteWise uses inventory information from “Embodied Energy and Carbon in Construction Materials” (Hammond and Jones, 2008). SiteWise does not carry inventory information for NO_x, SO_x, PM, or HAPs. SRT uses information “derived from EIA.” However, SRT does not document the basis for the derivation. EPA SEFA uses data from the ELCD database. SimaPro uses data from the US-EI database, which uses information from the USLCI database and supplements the missing information. The information is representative of U.S. and Canadian galvanized sheet production. The selection of galvanized steel was a user choice. As compared to the other tools, SimaPro databases offer a number of different inventories to choose from. In the case of steel, there are 435 choices the user has available from 20 life-cycle inventory databases. This highlights a challenge in selecting the correct inventory information when multiple datasets are available.

SRT does not carry emissions for NOx, SOx, PM or HAPs. SiteWise does not carry information for HAPs.

Figure 4-13 shows the emissions and energy reported for transportation of 200 tons of material to a location 100 miles from the GCSP site, for each tool. SiteWise derives the footprint using a calculation that assumes a full load going out and an empty load returning. It also uses an algorithm from *Evaluation of Fuel Consumption Potential of Medium and Heavy Duty Vehicles through Modeling and Simulation* (Argonne National Laboratory, 2009). Variables were determined from interpretation of the fuel economy plot that calculates emissions based on partial loads. An empty load is based on a 7.4 miles per gallon (mpg) and partial loads are a function of weight. For this scenario, a 20-ton load was estimated, resulting in the outbound load having a fuel efficiency of 5.2 mpg. Therefore, the average fuel efficiency for SiteWise was 6.3 mpg.

SRT uses the diesel information in the tool inventory and assumes a fuel efficiency of 5 mpg, round trip. EPA SEFA assumes a fuel efficiency of 6 mpg, round trip.

SimaPro bases transportation footprint on a metric ton (MT) per kilometer basis. The total weight of material to be moved is converted to metric tons and the total distance, round trip, is converted to kilometers. The values are based on the USLCI and consider average emissions on a ton per kilometer basis for a large sample population of truck traffic, which includes full, empty, and partial loads. The resulting number is entered into the SimaPro tool to estimate impacts. For this scenario, the fuel efficiency of diesel used is 4.77 mpg, roundtrip, using the averages in the USLCI database.

SRT and SiteWise do not carry emissions for HAPs.

Figure 4-14 shows the emissions and energy reported, per 100 feet, of a 2-inch-diameter well drilled for each tool. The information reported does not include well materials, construction, or transportation of the drilling equipment to and from the site; it only includes drilling activities. Hollow stem auger drilling is assumed. SiteWise uses inventory information estimates from American Well Technologies (Gigi Marie, 717-919-8515) and assumes a fuel consumption rate of 7.6 gallons per hour of drilling and a production rate of 40 feet per hour. SRT assumes a drilling consumption rate of 4 gallons per hour and a production of 100 feet per day, for a total of 32 gallons of diesel fuel. An assumption used in the SEFA is a production rate of 100 feet per day with a 150-horsepower (hp) drilling rig, for a total of 45 gallons of diesel. An assumption used in SimaPro is a drilling production rate of 40 feet per hour and a total of 20 gallons of diesel fuel.

The information presented in **Figures 4-5** through **4-14** show variation in metrics reported for the ten most significant contributors to the environmental footprint of the GCSP project, based on unit quantities. Given the effort by the project team to ensure consistent interpretation of tool inputs, the reason for the different results reported in **Figures 4-1** through **4-4** can be attributed to the different datasets (inventories) used by each tool to convert project inputs and outputs into metrics for environmental footprints.

4.2.4 Interpretations Can be Made with the Results of Each Tool

The purpose of this section is to provide interpretations from each of the tool results. The previous sections conclude that the tools provide different results. This section determines if different recommendations could be made based on the variable tool results. Most of the tools assessed offer some unique attributes (such as process flow diagrams, Monte Carlo analysis, metric decision weighting, renewable energy optimization, and cost estimating), which can be used to help decisions. However, these attributes were not considered because they were outside the scope of this report.

4.2.4.1 Interpretation from SiteWise

SiteWise results were estimated for CO_2e, SO_x, NO_x, PM, energy, potable water, total water, and embedded water. **Tables 4-4**, **4-5**, **4-6**, and **4-7** present the SiteWise results for the total project, ERD, ISCO, and ISTT, respectively. **Table 4-8** summarizes the three most significant contributions to each metric.

CO_2e – The primary CO_2e emissions are from electricity generation (55 percent) and “other” (36 percent). The top CO_2e-emission-generating components of the alternative are electricity generation for the ISTT technology (3,990 MT), lab analysis for the ERD technology (781 MT), substrate for ERD (714 MT), permanganate for ISCO (513 MT),”onsite” for thermal (255 MT), GAC for thermal (227 MT), and “onsite” for ISCO (216 MT). These contributors represent 94 percent of the CO_2e footprint of the project. The total CO_2e footprint of the project is estimated as 7,110 MT.

NO_x – The primary NO_x emissions are from “onsite” activities (40 percent), electricity generation (39 percent), and “other” (21 percent). The top NO_x-emission-generating components of the alternative are “onsite” activities with drilling for ERD and ISTT phases of work (6 MT), electricity generation for the ISTT technology (6 MT), and lab analysis (2.7 MT). These contributors represent 99 percent of the NO_x footprint of the project. The total NO_x footprint of the project is estimated at 14.8 MT.

SO_x – The primary SO_x emissions are from electricity generation (52 percent), “other” (35 percent), and “onsite” activities (13 percent). The top SO_x-emission-generating components of the alternative are electricity generation for the ISTT technology (3 MT), lab analysis (1.7 MT) and “onsite” activities for ERD, ISTT, and ISCO combined (1.0 MT). These contributors represent 100 percent of the SO_x footprint of the project. The total SO_x footprint of the project is estimated at 5.7 MT.

PM – The primary PM emissions are from “onsite” activities (55 percent) and “other” (32 percent). The total PM footprint of the project is 0.76 MT PM. PM is not carried for inventory for electricity.

Energy – The primary CO_2e emissions are from electricity generation (55 percent) and “other” (36 percent). The primary contributors to energy are electricity generation for ISTT (62,000 million British thermal units [MMBTU]), Substrate for ERD (17,000 MMTBU), lab analysis for ERD (11,700 MMBTU), permanganate for ISCO (7,800 MMBTU), “onsite” activities for ERD (5,950 MMBTU), and “onsite” for ISTT (3,100 MMBTU). These four contributors represent 96 percent of the energy footprint for the project. The total energy footprint of the project is estimated at 112,000 MMBTU.

Potable Water – A total of 15.4 million gallons of potable water is expected to be used with the project. The water is used to deliver substrate for the ERD technology.

All Water – An additional 5 million gallons of water is attributed to the water used in electricity generation, with approximately 40 percent attributed to the "onsite" activities and 60 percent from to electricity generation.

Evaluation – The following text presents observations and recommendations to minimize the footprint of the above referenced metrics:

- The majority of the CO_2e and energy footprint is attributed to electricity generation associated with ISTT treatment. It is impracticable to construct and operate an onsite renewable energy system at Grants for a project with a short operating duration (planned as less than nine months). However, renewable energy certificates (RECs) could be purchased to offset these footprints. RECs could be purchased for approximately $0.85 per megawatt-hour (MWhr).
- Other options to reduce the ISTT footprint include careful monitoring of the system to ensure it does not operate longer than necessary to meet cleanup targets for the technology.
- Laboratory analysis is approximately 10 percent of the CO_2e and energy footprint; optimization of the sampling program to collect only samples necessary for system evaluation and compliance could reduce these footprints.
- Substrate is also a significant contributor to the CO_2e and energy footprint. Because the ERD delivery phase of the project is expected to run for 20 years, periodic evaluation of alternate substrates should be completed to ensure a substrate with the lowest footprint is used while meeting cleanup goals.
- The high sulfate conditions at the site may create a secondary benefit of producing iron sulfide in the barriers, which could support abiotic reduction of chlorinated ethenes, thereby reducing the potential demand of substrate addition.
- The substrate additions should be optimized, based on previous field data, to ensure overdosing is not occurring or substrate application is not occurring at a frequency greater than necessary.
- Potassium permanganate is a noticeable contributor to the CO_2e footprint. Identifying a source of potassium permanganate from a supplier that manufactures their product at a facility operating on hydropower could result in a significant reduction of the CO_2e footprint.
- The ERD phase is projected to use a significant volume of potable water. The site is located in an area with significant water needs. The use of non-potable water (such as site groundwater or effluent from the local wastewater treatment plant) is recommended to reduce the need for potable water.

4.2.4.2 Interpretation of SRT

SRT results were estimated for CO_2e, SO_x, NO_x, PM, energy, and natural resource value. Cost information is also provided with SRT. Cost is not addressed in this section because a construction cost estimate was prepared as part of the remedial design. **Tables 4-4**, **4-5**, **4-6**, and **4-7** present the SRT results for the total project, ERD, ISCO, and thermal treatment components, respectively. **Table 4-8** summarizes the three most significant contributions to each metric.

CO_2e – The primary CO_2e emissions are from electricity generation (32 percent) and "other" (66 percent). The top CO_2e-emission-generating components of the alternative are substrate (6,110 MT), electricity generation for the ISTT technology (3,650 MT), and potassium permanganate (1,390 MT). These contributors represent 97.0 percent of the CO_2e footprint of the project. The total CO_2e footprint of the project is estimated as 11,500 MT.

NO_x – The primary NO_x emissions are from electricity generation (94 percent) and "onsite" activities (4 percent). The top NO_x-emission-generating components of the alternative are electricity generation for the ISTT technology (22 MT), and emissions from drilling activities (0.7 MT). These contributors represent 97 percent of the NO_x footprint of the project. The total NO_x footprint of the project is estimated at 23.4 MT.

SO_x – The primary SO_x emissions are from electricity generation (99 percent). This is all attributable to the ISTT technology and represents 41.3 MT. The total SO_x footprint of the project is estimated at 41.7 MT.

PM – The primary PM emissions are from electricity generation (99 percent). This is all attributable to the ISTT technology and represents 7.74 MT of the total 7.81 MT.

Energy – The primary CO_2e emissions are from electricity generation (93 percent). The primary contributors to energy are electricity generation for ISTT (62,500 MMBTU), "onsite" for ERD (1,100 MMBTU), transport (1,050 MMBTU), and PVC (992 MMBTU). These four contributors represent 98 percent of the energy footprint for the project. The total energy footprint of the project is estimated at 67,000 MMBTU.

Evaluation – The following text presents observations and recommendations to minimize the footprint of the previously referenced metrics:

- Substrate is a significant contributor to the CO_2e and energy footprint. As the ERD delivery phase of the project is expected to run for 20 years, periodic evaluation of alternate substrates should be completed to ensure a substrate with the lowest footprint is used while meeting cleanup goals.
- Electricity generation was also a sizable contributor. It is impracticable to construct and operate an onsite renewable energy system at Grants for a project with a short operating duration (planned as less than 9 months). However, RECs could be purchased to offset these footprints. RECs could be purchased for approximately $0.85/MWhr.
- Other options to reduce the ISTT footprint include careful monitoring of the system to ensure it does not operate longer than necessary to meet cleanup targets for the technology.
- The high sulfate conditions at the site may create a secondary benefit of producing iron sulfide in the barriers, which could support abiotic reduction of chlorinated ethenes, thereby reducing the potential demand of substrate addition.
- The substrate additions should be optimized, based on previous field data, to ensure overdosing is not occurring or delivery of substrate is not occurring at a frequency greater than necessary.
- Potassium permanganate is a noticeable contributor to the CO_2e footprint. Identifying a source of potassium permanganate from a supplier that manufactures their product at a facility operating on hydropower could result in a significant reduction of the CO_2e footprint.

4.2.4.3 Interpretation of EPA SEFA

SEFA results were estimated for CO_2e, SO_x, NO_x, PM, energy, and HAPs. **Tables 4-4**, **4-5**, **4-6**, and **4-7** present the SEFA results for the total project, ERD, ISCO, and thermal treatment components, respectively. **Table 4-8** summarizes the three most significant contributions to each metric.

CO_2e – The primary CO_2e emissions are from electricity generation (52 percent) and "other" (37 percent). The top CO_2e-emission-generating components of the alternative are substrate (7,270 MT), electricity generation (10,260 MT), lab analysis (602 MT), and potassium permanganate (581 MT). These contributors represent 95 percent of the CO_2e footprint of the project. The total CO_2e footprint of the project is estimated as 19,700 MT.

NO_x – The primary NO_x emissions are from electricity generation (56 percent) and "other" (36 percent). The top NO_x-emission-generating components are electricity generation for the ISTT technology (29 MT), and substrate (14 MT). These contributors represent 84 percent of the NO_x footprint of the project. The total NO_x footprint of the project is estimated at 51.5 MT.

SO_x – The primary SO_x emissions are from electricity generation (88 percent) and "other" (12 percent). The top SO_x-emission-generating components of the alternative electricity generation for the ISTT technology (68 MT), and substrate (4 MT), lab analysis (2 MT), and potassium permanganate (2 MT). These contributors represent 99 percent of the SO_x footprint of the project. The total SO_x footprint of the project is estimated at 77 MT.

PM – The primary PM emissions are from "other" (67 percent) and electricity generation (25 percent). The top PM-emission-generating components of the alternative are electricity generation for the ISTT technology (0.26 MT), lab analysis (0.24 MT), and potassium permanganate (0.21 MT). These three contributors, which are part of the “other” category, represent 68 percent of the PM footprint of the project. The total PM footprint of the project is estimated at 1.04 MT.

Energy – The primary energy use is from electricity generation (53 percent), and “other” (40 percent). The primary contributors to energy are electricity generation for ISTT (80,500 MMBTU), substrate (36,800 MMBTU), potassium permanganate (11,500 MMBTU), and “onsite” for ISTT (2,720 MMBTU). These four contributors represent 89.5 percent of the energy footprint for the project. The total energy footprint of the project is estimated at 147,000 MMBTU.

HAPs – The primary HAPs emissions are from electricity generation (6,470 pounds). This represents 96.5 percent of the total HAPs emissions. An additional 229 pounds (or 3.4 percent) is attributable to the manufacturing of materials used in the remedy. The balance, less than 1 percent, is attributable to emissions from transportation.

Evaluation – The following presents observations and recommendations to minimize the footprint of the previously referenced metrics:

- Substrate is a significant contributor to the CO_2e and energy footprint. Because the ERD delivery phase of the project is expected to run for 20 years, periodic evaluation of alternate substrates should be completed to evaluate viable substrate options with lower footprints.
- Electricity generation was also a sizable contributor. It is impracticable to construct and operate an onsite renewable energy system at Grants for a project with a short operating duration (planned as less than nine-months). However, green pricing products (such as renewable energy purchased from the utility for an additional fee) could be purchased from the utility, if available. If green pricing products are not available, then RECs could be purchased to increase amount of renewable energy used in the remedy. It is noted that the EPA footprint methodology, which SEFA was developed to accompany, considers the air emissions from the remedy before considering emission reductions from the purchase of green pricing products or RECS. That is, the purchase of green pricing products or RECs would not reduce the air emission footprints according to the methodology.
- Other options to reduce the ISTT footprint include careful monitoring of the system to ensure it does not operate longer than necessary to meet cleanup targets for the technology.
- The high sulfate conditions at the site may create a secondary benefit of producing iron sulfide in the barriers, which could support abiotic reduction of chlorinated ethenes, thereby reducing the potential demand of substrate addition.
- The substrate additions should be optimized, based on previous field data, to ensure overdosing is not occurring or at a frequency greater than necessary.
- Potassium permanganate is a noticeable contributor to the CO_2e footprint. Identifying a source of potassium permanganate from a supplier that manufactures their product with a lower $CO2_e$ footprint could result in a significant reduction of the CO_2e footprint.

4.2.4.4 Interpretation of SimaPro

While **Tables 4-4** to **4-8** and the figures present SimaPro results for the results presented for the previous models, LCA tools like SimaPro typically report results in terms of impact categories instead of individual emissions. Because the purpose of this section is to show how model results will be interpreted, the SimaPro model results will be interpreted using the more traditional impact assessment method results reported by the model. However, the individual reporting metrics used for the other tools are summarized in **Tables 4-4** through **4-8**. Additionally, the individual HAPs estimated from each component of the remedy are presented in **Appendix D**.

The impact assessment method used for this analysis was primarily TRACI. However, several impact categories (water depletion, fossil fuel depletion, and metal depletion) were not available in TRACI. For these impact categories, the ReCiPe (Goedkoop, 2009) impact assessment was used. ReCiPe is an acronym for the three institutions that contributed to the development of the impact assessment method: RIVM – National Institute for

Public Health and the Environment, Netherlands; CML – Centrum Milieukunde Leiden, Institute of Environmental Sciences, University of Leiden, Netherlands; Pre – PRé Consultants.

One reporting metric used in SimaPro that was not used for SiteWise, SRT, or SERA is population equivalents. The Population equivalent metric is a way to provide context for an impact category result. The population equivalent metric represents the number of population equivalents (number of persons) represented by the impact category results. Population equivalents are based on normalization factors presented by Bare, 2006.

The following sections provide an overview of impact categories and results from the analysis for the GCSP remedy.

Ozone Depletion

Ozone depletion is the reduction of ozone in the stratosphere caused by the release of ozone-depleting chemicals (for example, chlorofluorocarbons [CFCs] and halons). Ozone depletion can increase ultraviolet B radiation to the earth, which can adversely affect human health (leading to skin cancer and cataracts) and other systems (for example, marine life, agricultural crops, and other vegetation). Ozone depletion is characterized relative to CFC-11 equivalents. There are a number of chemicals that contribute to CFC-11 equivalents. For this assessment, the main contributors to this impact category are HCFC-140, Halon 1211, and Halon 1301; and they account for 90 percent of all the project ozone-depletion potential emissions. The biggest contributor to ozone depletion is the emissions from the laboratory operations, which account for 81 percent of the overall project emissions. Another 9 percent of the emissions are related to processing soybeans into oil. The total ozone depletion emissions are estimated as 0.66 kilogram (kg) CFC-11 equivalents. This is comparable to the annual ozone depletion footprint of a population of approximately 4 people in the United States per year. This impact is considered relatively insignificant, given the scale of the project.

Global Warming Potential

This impact category represents the global warming potential (GWP) of gases to change the earth’s climate. A range of chemicals is factored into CO_2e. For this assessment, the main contributors to this impact category are methane, nitrous oxide, and CO_2 which and accounts for 99.9 percent of the CO_2e emissions. The biggest contributors to GWP are electricity generation (62 percent) and “other” for well installation and ERD delivery (22 percent), of which the majority is represented by the substrate (approximately 92 percent of the overall 22 percent). The total GWP footprint is 9,370 MTs of CO_2e. This is comparable to the annual GWP footprint of a population of approximately 396 people in the United States per year.

Smog (Photochemical Oxidant Formation)

Ozone is a reactive gas and is the characterization point associated with photochemical oxidant formation in the troposphere. When present in the troposphere, it can lead to negative impacts to ecosystems and human health. The rate of ozone formation is governed by complex atmospheric chemical reactions involving NO_x, volatile organic chemicals, sunlight, temperatures, and convective flows. Photochemical oxidant formation is expressed in terms of ozone equivalents. A number of chemicals are factored into ozone equivalents. For this assessment, 98 percent of the ozone equivalents come from the generation of NO_x. NO_x come predominantly from electricity generating processes and diesel fuel use, though 16 percent of the smog footprint comes from substrate manufacturing. The total smog footprint is 709 MTs of ozone equivalents. This is comparable to the annual smog footprint of a population of approximately 509 people in the United States per year.

Acidification

Acidification processes increase the acidity of water and soil systems, and acid depositions can result in negative impacts on structures (buildings, monuments) and artifacts. The metric for acidification is hydrogen ion equivalents due to atmospheric emissions of acidic-causing emissions (for example, NO_x and SO_x). A range of chemicals is factored into hydrogen ion equivalents. For this assessment, the main contributors to this impact category are sulfur dioxide (61 percent) and nitrogen dioxide (32 percent). Approximately 75 percent of these emissions come from electricity generation for thermal treatment and another 11 percent of emissions come from the manufacturing of substrate. All other sources of acidification emissions are less than 5 percent. A total of

3,450,000 moles of hydrogen ion equivalent is emitted with the project. This corresponds to an annual acidification footprint equivalent to a United States population of 709 people.

Eutrophication

Eutrophication is the addition of nutrients to surface waters that leads to increased growth of aquatic photosynthetic life. This impact can have adverse impacts on ecosystem quality/diversity and surface water aesthetics. The eutrophication characterization factor is expressed in terms of a chemical's potential to release nitrogen or phosphorus to air or water, per kg of chemical released relative to 1 kg of nitrogen discharged directly to surface water. For this assessment, the main contributors to this impact category are nitrate (72 percent), phosphorous (14 percent), and phosphate (8 percent). These three chemicals comprise 94 percent of the total eutrophication footprint. The production of substrate, an agricultural-intense operation, accounts for 92 percent of the eutrophication footprint. A total of 43,900 kg of nitrogen equivalents is discharged to surface water with the project, the majority of this occurring in areas where soybeans are grown. This corresponds to an annual eutrophication footprint equivalent to a U.S. population of 2,030 people, which is fairly significant. The land requirement to support the growth of soybeans for this project is 5,360 acres. Food scarcity is a global issue and the use of virgin oil in substrate takes food out of the food supply. Typically, less than one acre is able to provide subsidence for one population equivalent.

Carcinogens

Carcinogens have the potential to form cancers in humans. The cancer toxicities of released chemicals are expressed as comparative toxicity units—humans (CTUh). There are numerous compounds that are typically factored into this impact category. For this assessment, the main contributor to this impact category is hexavalent chromium at 86 percent. The majority of the hexavalent chromium is emitted to water through the land disposal of slag that is generated with steel production (65 percent) and another electricity generation for ISTT (14 percent). A total of 0.227 CTUh is emitted with this project. This corresponds to an annual carcinogen footprint equivalent to a U.S. population of 4,470 people. It should be noted that carcinogenic characterization factors, along with non-carcinogenic and ecotoxicity factors, have much greater uncertainties as compared to other impact characterization factors.

Non-carcinogens

Non-carcinogens have the potential to cause non-cancerous adverse impacts to human health. Non-cancer impacts are expressed as CTUh equivalents. There are numerous compounds that are typically factored into this impact category. For this assessment, the main contributors to this impact category are mercury emissions to air and zinc uptake from soil. Because of the heavy agriculture component associated with the growing of soybeans, there is a net uptake of non-carcinogens resulting from zinc uptake in soil during soybean growth. A total of 3.81 CTUhs of noncarcinogens is uptaken from the environment with the project. This corresponds to an offset annualized footprint equivalent to a U.S. population of 3,630 people. As stated previously, non-carcinogenic characterization factors have higher uncertainty compared to those impact categories that estimate impacts where toxicity is not addressed.

Ecotoxicity

Ecotoxicity causes negative impacts to ecological receptors and, indirectly, to human receptors through the impacts to the ecosystem. Ecotoxicity potential has been developed to express a potential ecological harm of a chemical and is presented in terms of Comparative toxicity unit (CTUe). For this assessment, the main contributors to this impact category are hexavalent chromium discharge to water (49 percent) and barium to soil (52 percent). There is a range of other chemicals, such as antimony, aclonifen, and other chemicals, which add to the CTUe footprint. However, there is significant uptake of copper (26 percent) and zinc (52 percent) to offset the ecotoxicity emissions to some degree. The main process contributors include electricity generation (32 percent), "onsite" thermal operations (20 percent), "onsite" well installation and ERD delivery (27 percent), thermal treatment system construction (36 percent), and "other" well installation and ERD delivery (negative 27 percent). A total of 3,980,000 CTUes is discharged to surface water with the project. This corresponds to an annual ecotoxicity footprint equivalent to a U.S. population of 360 people. As compared to other impacts, the ecotoxicity impacts are relatively distributed across the technologies. As stated previously, ecotoxicity characterization factors have higher uncertainty compared to those impact categories that estimate impacts where toxicity is not addressed.

Respiratory Effects

PM concentrations have a strong influence on chronic and acute respiratory symptoms and mortality rates. Respiratory effects are characterized PM less than 2.5 micrometers in diameter ($PM_{2.5}$). There is a range of chemicals factored into PM equivalents. For this assessment, the main contributors to this impact category are SO_x (70 percent), PM_{10} (23 percent), and NO_x (7 percent). These three constituents compose 100 percent of the total respiratory impact footprint. Of this, 72 percent of the footprint comes from electricity generation for ISTT and 19 percent comes from the production of substrate. A total of 9,900 kg of PM equivalents is discharged to the atmosphere with the project. This corresponds to an annual respiratory effects footprint equivalent to a U.S. population of 159 people.

Water Depletion

Water depletion represents all water that goes into the project, including river water, surface water, and potable water. The water footprint for the project is estimated as 128,000 cubic meters (33.8 million gallons) with 59 percent attributable to tap water for distributing the ERD and ISCO reagent and 38 percent attributable to agricultural activities for growing soybeans. The two components account for 97 percent of the project water footprint. This corresponds to an annual water footprint equivalent to a U.S. population of 517 people. The use of local water is significant in a region of the United States where freshwater is less abundant than other parts of the country (EPA, 2002).

Fossil Fuel Depletion

Fossil fuel depletion represents all sources of fossil fuel and is expressed in terms of kg of oil equivalents. A total of 2,630,000 kg of oil equivalents are utilized with the project. An estimated 70 percent of the fossil fuel depletion footprint is attributable to electricity generation for ISTT and 9 percent attributable to substrate production. The balance of footprint is primarily attributable to use of diesel fuel or gasoline. This corresponds to an annual fossil fuel footprint equivalent to a U.S. population of 42 people. This impact is considered relatively insignificant, given the scale of the project.

Metal Depletion

Metal depletion represents the mining of earth minerals for use in processing and manufacturing. An estimated 99 percent of the metal depletion is associated with the mining of manganese and crude ore for potassium permanganate. A total of 130 MTs of material is mined for the permanganate used on the project. This corresponds to an annual metal depletion footprint equivalent to a European population of 17 people (a U.S. normalization factor was not identified). This impact is considered relatively insignificant, given the scale of the project.

Summary

Table 4-9 presents the most significant contributors, by impact category. Electricity generation is the most significant contributor to most of the impact categories assessed. It is impracticable to construct and operate an onsite renewable energy system at Grants for a project with a short operating duration (planned as less than nine months). RECs could be purchased to offset several of the impacts. RECs could be purchased for approximately $0.85/MWhr. Additionally, careful monitoring of the ISTT system promotes the opportunity to turn off the system as early as possible, thereby avoiding impacts associated with electricity generation.

Substrate is also a significant contributor to many of the impact categories. Because the ERD delivery phase of the project is expected to run for 20 years, periodic evaluation of alternate substrates should be completed to ensure a substrate with the lowest footprint is used while meeting cleanup goals. The substrate additions should be optimized, based on previous field data, to ensure overdosing is not occurring or substrate delivery is not occurring at a frequency greater than necessary. The high sulfate conditions at the site may create a secondary benefit of producing iron sulfide in the barriers, which could support abiotic reduction of chlorinated ethenes, thereby reducing the potential demand of substrate addition. Alternative substrates, preferably those that are manufactured using waste oil products, can significantly reduce the footprint associated with substrate addition.

Drilling activities also represent noticeable potential environmental impacts in several impact categories. The main driver of these impacts is the refinement and subsequent use of diesel fuel. Any reductions in project diesel fuel usage will reduce impacts to GWP, acidification, and smog.

The use of steel (primarily in the ISTT system and to some extent in the ERD system) provides the greatest potential carcinogenic impacts. These impacts are associated with the production of steel and do not occur near the site. Maximum use of recycled steel components and recycling of steel after ISTT operations have completed provide an opportunity to reduce impacts to the carcinogens impact category.

Potassium permanganate is a noticeable contributor to the carcinogenic footprint, as well as several other impact categories. The primary reason is attributable to electricity used in the manufacturing process, predominantly associated with potassium hydroxide production (used in the process). Sourcing potassium permanganate from a supplier with a smaller footprint can reduce the carcinogen footprint associated with this oxidant.

The water impacts associated ERD delivery are substantial, in terms of both onsite potable water usage as well as water embedded in the life cycle of the substrate manufacturing process. Use of waste oil as a substrate, as mentioned previously, will eliminate the embedded water component. The onsite potable water footprint can be offset by using local wastewater treatment effluent, or other sources of gray water that may be available. The embedded water footprint of the substrate can be offset by utilizing recycled vegetable oils to manufacture substrate or using other waste products to provide substrate to sulfate reducing bacteria and methanogens required to reduce the chlorinated ethenes in the groundwater.

The eutrophication footprint for the project is equivalent to a U.S. 2,030 people. As with the embedded water footprint discussed in the previous paragraph, the eutrophication footprint can be reduced or avoided by using waste vegetable oils or substrates.

The smog footprint of the project is equivalent to a U.S. population of 509 persons. The main contributors to the smog footprint are NO_x which comes primarily from electricity generation and diesel fuel combustion.

The acidification footprint of the project is equivalent to a U.S. population of 709 persons. The main contributor to the acidification footprint is SO_x from electricity generation. Toxicity, as represented by CTUh for carcinogens and non-carcinogens and CTUe, was reported 4,470, 3,360, and 360 population equivalents respectively. As stated previously there is less confidence in ecotoxicity impact category results as compared to other impact categories.

4.2.4.5 Interpretation Summary for All Four Tools Evaluated

Sections 4.2.4.1 through **4.2.4.4** provide an interpretation of results from each tool and recommendations based on the tool results. These recommendations are summarized in **Table 4-10**. The following observations are offered with review of **Table 4-10**:

- In general, all the tools recommended energy optimization or offsets, substrate optimization, and potassium permanganate optimization to reduce environmental burdens. The context of these recommendations differed. The footprint tools identified benefits, in terms of specific emissions, whereas SimaPro identified the benefits in terms of environmental impact categories.
- SiteWise and SEFA identified laboratory analysis as a noticeable contributor to CO_2 and energy emissions. SimaPro's footprint for laboratory work was significantly less than SiteWise and SEFF. SRT does not have an inventory for laboratory emissions.
- SiteWise, SEFA, and SimaPro all identified use of potable water in the footprint. In the case of water used for ERD and ISCO injection, none of the tools carry inventory for delivery, but they do allow the flexibility for water to be tracked. SRT does not offer this flexibility.
- SEFA and SimaPro were the only tools to report HAPs.

- SimaPro was the only tool to identify the embedded water related to agricultural activities, which are related to growth of soybean, vegetables, or rapeseed oil used in the substrate inventory.
- SimaPro was the only tool to address potential impacts associated with eutrophication, acidification, respiratory, carcinogen, and smog.
- SimaPro was the only tool to represent inputs and outputs of the project in terms of impact categories.
- SimaPro was the only tool to place impact categories in context of population equivalents, so as to provide perspective on the relative impact of specific results.

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SECTION 5

Summary and Conclusions of Tool Comparison

5.1 Summary

This report evaluated the environmental footprint of the remedy designed for the GCSP. The evaluation compared the results of the four tools most commonly used in the remediation industry. The individuals who populated the tools for this report all worked from the same model input assumptions from the remedial design (**Tables 4-1a, 4-2a**, and **4-3a**). This helped minimize any differences related to the interpretation of the remedial design components.

Each of the tools uses a consistent framework for estimating the footprint of a remediation project. This framework includes the following:

- A library of specific remediation processes, materials, and activities (such as Portland cement production, transportation of material or wastes, diesel fuel, and drilling)
- An inventory of specific emissions, energy, and, in some cases, natural resource inputs, per unit of utilization (for example, ton of Portland cement used, truck miles driven, gallons of diesel fuel used, or hours or feet of drilling)
- An entry screen for the user to input the specific quantity of library items used in the remediation project
- An output of results (as tables [graphs with some tools])

An initial comparison of the four tools was completed at the total project level (**Section 4.2.1**). Results for CO_2e, NO_x, SO_x, PM, and energy, were compared, because these five parameters are all reported by each of the five tools. HAPs were also considered as SEFA and SimaPro both report this metric. As presented in **Figure 4-1** and **Table 4-4**, the tool results varied. Some of the differences in results were insignificant, while other differences were greater.

The next comparison (**Section 4.2.2**) involved the same six metrics at the individual technology level (ERD, ISTT, and ISCO). As represented in **Tables 4-5**, **4-6**, and **4-7**, and **Figures 4-2**, **4-3**, and **4-4**, some of the differences were minor, while others were more significant.

The next comparison involved a deeper evaluation (**Table 4-8**) and identified the top three contributors for five metrics (HAPs were not considered in this part of the comparison), compared by treatment technology (**Section 4.2.3**). While there was often reasonable agreement on what the top contributors to each process were, there was not very good agreement on the absolute amounts of emissions for each of these contributors.

Based on this comparison, a more focused evaluation (**Figures 4-5** to **4-14**) was made to analyze tool results for key specific inventories on a per-unit basis (**Section 4.2.4**). As with the comparison noted in **Sections 4.2.1** and **4.2.2**, the differences between the different tool results were similar to those reported for the technology level comparison.

Finally, the results from each tool were assessed to identify commonality and differences in conclusions (**Table 4-10**). This evaluation showed interpretation of each tool and identified common significant contributors to the footprint for the project.

For example, substrate was considered a major contributor and all four tools and a recommendation for optimization of substrate use and sourcing of substrate from suppliers with a lower environmental footprint could be made for all the tools.

Based on SiteWise, SEFA, and SEFA, reasons for this recommendation include avoidance of CO_2 emissions, energy, and potable water use. SimaPro encompasses all these observations, but also cites potential for acidification, smog, respiratory impacts, potential carcinogenic impacts, embedded water in substrate manufacturing, eutrophication, land use in agriculture, and scarcity of food. So, while each tool recognizes substrate as a significant contributor to the environmental footprint of the project, the scope of the footprint is represented differently among the tools.

5.2 Considerations and Recommendations

Given the observations presented in this report, several questions could arise when considering the different tools:

1. **How important are metrics?** Will the number of metrics quantified by each tool be a factor in decision making? If one tool has a limited set of metrics and another tool has a much greater number of metrics, would a project team reach different conclusions based on the different metrics evaluated? For example, one interpretation of the conclusions from the four tools is they were similar. Yet SimaPro provided more context (how emissions translate to environmental impact) and analysis (expressing as population equivalents). Does this extra level of context and analysis provide more weight of evidence for decision making?
2. **How important are different results between the tools?** Given the differences in results of the tools evaluated, would the absolute value from one tool drive a decision, where it might not drive that decision when the result from another tool is considered?

Given that the tool users were all working with the same project assumptions, and given the analysis above, the difference in tool results are attributable to the inventories associated with each remediation process, material, and activity. An additional factor in the differences was the interpretation of input information by each of the tool users – even though additional effort was focused removing this variable from the assessment. Following is a list of recommendations and considerations for tool use and development to provide improved results and consistency between tools.

- Tool users should have greater awareness of the sources of inventory information in the tools they use to make sure the information is applicable to their project and geographic region. Most tools allow the option of overriding or adding inventory information. Tool users should be familiar with sources of data that can be used to override the values in the tool.
- Each tool handles transportation differently. When project-specific equipment and logistical information is not available, the tools could use a commonly accepted default approach to address fuel efficiency and truckload factors.
- Tools should use similar inventories associated with key remediation project components (such as fuel, substrate, and oxidant) for when geographic information is not available or is considered a commodity.
- Diesel fuel is almost always a significant environmental footprint factor. Tool libraries should include inventories for both road and non-road emissions and represent a range of equipment so users can select the appropriate information to better estimate NO_x, SO_x, and PM.
- Electricity is almost always a significant environmental footprint factor. Local power supply information should be considered when developing inventories to be used in the project.
- The significance of tools that do not carry inventory information for NO_x, SO_x, and PM should be considered when conclusions are presented.
- While each of the four tools provides helpful information in evaluating the environmental footprint of a project, none of the tools should be considered comprehensive and complete for all projects to which they may be applied. Tool users should be aware of potential limitations of a specific tool for a project and consider using other approaches to identify important environmental footprint metrics. For example, with a project that involves air stripping off-gas to the atmosphere, several tools would not capture the emission of HAPs to the atmosphere. However, these emissions could be easily estimated outside of the tool and reported along with the tool results.

- Users of all remediation assessment tools should be aware of how their tool of choice does or does not consider LCA of project fuels and materials. This will help them be more aware of the importance of variability in inventory information, the opportunities and impacts associated with recycling and reuse, and the potential strengths and weaknesses of their analyses and conclusions.

5.3 How Footprinting and LCA Tools Can Improve Remedy Development and Optimization

The evaluation of the GCSP sustainability evaluation remedy was performed after the remedy was designed. Also, the evaluation was not initiated until the remedy was being implemented. Given this, the only viable options for reducing the footprint of the GCSP remedy are in the future operations and maintenance (O&M) phases of work. Estimating the footprint of a remediation project is still a relatively new practice within the remediation industry. The state of the practice of footprint methodologies was not fully developed at the time the GCSP remedy was selected and designed.

Going forward, the site cleanup life-cycle provides several opportunities to use footprinting and LCA tools to reduce the footprint of a project, as described below.

5.3.1 Development of Feasibility Study Alternatives

The development of a footprint assessment for FS alternatives is a current practice in the remediation industry. However, the assessment is generally performed on alternatives that have been developed with traditional approaches. Footprint reduction is not considered in the development of alternatives. If emphasis on footprint reduction is considered in the development of alternatives (that is, considering all the footprint metrics that are applicable), alternatives with lower footprints may be developed for the FS. This provides the opportunity to evaluate greener alternatives in the FS. Additionally, FS alternatives can also be improved once they are identified, and prior to estimating the alternative footprint, to reduce the projected environmental footprint. These improvements are based on professional judgment and do not warrant detailed analysis.

5.3.2 Evaluation of Feasibility Study Alternatives

Once the alternatives have been identified, a footprint assessment can be completed as part of the FS. The results of this assessment can be used to better understand the environmental impacts associated with each alternative. Some of these results may be used in the evaluation criteria used in the FS. In some cases, it may be possible to develop a new alternative, or revise existing alternatives, for FS evaluation that provides environmental footprint benefits that may not have been considered during development of the original alternatives. For example, one alternative may rely heavily on use of recycled material, whereas another has not. Seeing the environmental footprint benefits of using recycled materials in one alternative may warrant consideration of using recycled material for other alternatives as well.

5.3.3 Evaluation of Design Options

Once the remedy is selected, the baseline configuration of the design can be assessed using footprint tools to evaluate the environmental footprint of the remedy. Evaluation of the baseline configuration can help to identify potential target areas for footprint reduction. The options for footprint reduction can be evaluated with footprint tools, along with their associated costs, to allow cost and benefit for implementing footprint reduction ideas into the design.

5.3.4 Ongoing Evaluation of Operating Remedies

The ongoing operations of remedies allows a project team to estimate the environmental footprint of the remedy using known quantities (rather than estimated quantities, as is the case with the opportunities identified in **Sections 5.3.2** and **5.3.3**). With this information, there is more confidence in the footprint results for the existing operations. This information, like **Section 5.3.3**, allows greener options to be considered. The main difference between optimization in this phase, compared to the design phase, is there is more confidence in estimates because they are based on existing operations.

SECTION 6

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Tables

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TABLE 2-1
Tool Comparison: Tool Structure, Method of Input, Reference Information, Tool Output

SiteWise	SRT	EPA SEFA	SimaPro
Tool Structure			
- Tool evaluates up to 12 remedy alternatives and separate output information into the following categories: o Materials production o Transportation for personnel o Transportation for materials/equipment o Equipment use and miscellaneous - Residual handling breaks out the input and output by four phases of remediation: investigation, construction, operation, and long-term monitoring - Flexible framework allows the tool to be used to model a variety of remedial scenarios and is well suited to model treatment train scenarios. - Documentation of footprint factors and assumptions provides transparency.	- Evaluates three different soil technologies (excavation, SVE, ITTS). Evaluates five different groundwater technologies (P/T, Enhanced Bio, PRB, ISCO, and LTM/MNA) - Provides two tiers for input: Tier 1 = rules of thumb; Tier 2 = more site-specific - Has two significant features: embedded cost estimating and design functionality - Has ability to model time of remediation - Results can be normalized against cost - Results can be weighted for decision-making purposes - Has a user-friendly interface and sequentially walks the user through inputs - Technologies represent the "typical" technologies in the industry; however, other technologies (e.g., capping) cannot be used - Summarizes all key input factors in allocated areas of the workbook, allowing simple QC review of the input	- Evaluates one remedy alternative. Automatically breaks output information into the following categories to be generally consistent with climate registries: o Onsite o Electricity generation o Transportation o Offsite activities - Allows for division of input and output for each remedy alternative into six levels representing phases (e.g., construction, operations and maintenance, monitoring), different operable units) - Provides up to 15 different tabs to input information, where each input tab can be assigned a level (Input for a given tab can be toggled off by changing the level to 0, allowing variations of various remedies to be readily evaluated.)	- Evaluates an unlimited number of alternatives - Uses reference databases (the configuration for the tool used in this assessment had access to 17 databases) - Assimilates input from material, energy, transport, processing, use, waste treatment, and waste scenario libraries - Based on manner of input, allows output to be consistent with climate registries, project phases, or other reporting basis for comparison - Converts all input into life-cycle raw materials (256), energy, and emissions to air (315)/soil (73)/water(268)/final waste flows (20) [numbers in parentheses represent the number of individual inventories in available databases] - Converts raw material inputs, energy flows, and emissions to specific impacts using an available library of impact assessment methods - Models both system and unit processes - Offers toggle on/off infrastructure inclusion - Offers toggle on/off long-term impacts - Addresses uncertainty in parameters with use of internal Monte Carlo analysis - Requires user input of processes and assemblies to represent remediation activities (SiteWise, SRT, and SEFA have pre-determined remediation activities designed into the tool); assumptions used to build the remediation processes and assemblies often draw from SiteWise and SEFA guidance; reference databases are not the same. - Allows remediation process and assembly development to be a one-time effort, able to be used repeatedly
Input sheets can be generated for a scenario and be opened at the same time as other input sheets. Input sheets can also be re-loaded into other project folders to serve as a starting point. Input sheets can be emailed to others, allowing recipients to load it.	A single workbook could be used for a project as long as the alternatives have technologies in SRT. If a project uses alternatives with multiple technologies, additional workbooks will be required. The additional workbooks are not integrated and the results from each workbook would need to be manually totaled in a separate worksheet.	All spreadsheets have individual names and can be opened simultaneously to facilitate data entry.	Multiple input and output windows can be open at the same time. Input changes require reprocessing of new/different inputs (no real time updating).
Spreadsheets for a given alternative can be opened as needed. Not all spreadsheets need to be opened for values to update.		The main spreadsheet, reference spreadsheet, input spreadsheet, and calculation spreadsheet for a given alternative all need to be open to see output.	
There is no convenient place to include notes on the input sheets.	There is no convenient place to include notes on the input sheets. However, input results can be easily cut and pasted in other worksheets where notes can be added. This involves some duplication of effort.	Limited space is available to provide notes on the input sheets.	The tool allows for extensive documentation of assumptions next to input. A command to export inputs is available and the notes are exported with other library input information.
Method of Input			
Individual input sheets are available for different phases of the site cleanup process. The user navigates through each applicable worksheet and enters quantities and types of specific project components through data entry and selecting from drop down menus. Input sheets are organized around material production, transportation, equipment use, residual handling, and resource consumption.	User-friendly interface allows guided step-by-step instruction. Interface allows selection of technologies that will be considered in the analysis and walks the user through these inputs, bypassing technologies that will not be considered in the analysis. A checklist is provided to help the user identify important input values that should be considered.	All materials are input based on mass (weight) required. This provides flexibility for input but requires additional references to help convert materials used into mass (weight). EPA's Methodology provides many of these conversion factors to be used in conjunction with SEFA.	All inputs can be based on a variety of inputs (such as energy, volume, and mass). Input basis, however, needs to be consistent for the datasets used. In addition, calculation setups (through numbers of variable names) can be included to simplify input and allow cascading changes if input parameters are changed. Variable values can be added on a project or library basis to allow for consistent conversions. Careful review of formulas is required to assure correct operators are used (as is the case with Excel).

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TABLE 2-1
Tool Comparison: Tool Structure, Method of Input, Reference Information, Tool Output

SiteWise	SRT	EPA SEFA	SimaPro
Other calculations or assumptions that are used to simplify input include the following: - Heavy equipment use is based on volume of material to be used. - Option for electricity use is based on pump head and flow rate. - Thermal oxidizers energy use based on energy content of influent gas, efficiency of heat exchanger, operating temperature, and any additional necessary fuel requirements *Note: When using the rules of thumb, some of the assumptions result in very poor estimates for some of the heavy equipment use. The user can easily overcome this by directly inputting the fuel use under the headings of Internal Combustion Engines or Other Fueled Equipment.*	The tool is structured into RBCA Tool Kit-type tiers. This allows the user to choose the level of effort and detail appropriate for the project at hand. Tier 1 (simplest tier) calculations are based on standard rules that are widely used in the environmental remediation industry. Tier 2 calculations are more detailed and incorporate site-specific factors. A user might choose Tier 1 rather than Tier 2 if a quick evaluation is required, if detailed site data are lacking, or if an extremely site-specific evaluation is not required. Tier 1 is more appropriate for making general comparisons between remediation technologies. Conversely, a user might choose a Tier 2 evaluation if adequate time in which to complete the Tier 2 evaluation is available or if very detailed site data are available.	All input is based on known quantities. For example, for heavy equipment operation, the size of heavy equipment and hours of operation need to be known. For electricity use, electricity can be input directly or based on the horsepower, load, efficiency, and operational hours.	All input is based on known quantities. Input must be compatible with the units of the reference data. For example, pounds, tons, and kg can be used interchangeably, but volume could not be used without appropriate unit adjustments. Assembly structure allows input of simple updates to address sensitivity and uncertainty in results to a baseline scenario and alternate input scenario; alternate input scenarios can be directly compared. With significant datasets available for input, users need to be able to discern appropriate datasets for analysis.
Output			
The following parameters are calculated: - CO_2e - Energy - NO_x* - SO_x* - PM* - Injury risk - Fatality risk - Lost hours * Values are for direct fuel combustion and electricity generation only. Values for raw material extraction and material processing are not included (they are not life-cycle based). However, V3 will be modified to include these factors and will report these as off-site emissions. Direct water usage can be tracked.	The following parameters are calculated: - Carbon dioxide emissions (not CO_2e)* - NO_x emissions* - SO_x emissions* - PM10* - Total energy consumed - Change in resource service - Technology cost - Safety/accident risk - Resource value * Values are for direct fuel combustion and electricity generation only. Values for raw material extraction and material processing are not included (i.e., not life-cycle based) Direct water usage is not easily tracked. Output results are not intended to be life cycle. NREL data were used, where available. It is unclear if the input parameters included additional datasets for emissions that would go further up in the life cycle of the parameter (e.g., CO_2 emissions from fuel could be tailpipe but could also include extraction and refining; documentation is unclear on this). As of this writing, SRT is currently being updated with new conversion factors to represent the above parameters.	The following parameters are calculated: - CO_2e - Energy - NO_x - SO_x - PM - Air toxics Output is intended to be a close approximation to life-cycle usage (for example, resource extraction and refining of fuels is considered). SEFA also helps organize materials use, waste generation, and water use consistent with the green remediation metrics defined in EPA's Methodology.	Output can be on an individual chemical basis or in terms of impact assessment results. Result output basis is significant and offers flexibility for reporting needs. Tables and graphs are prepared within the tool but the data can be easily cut and pasted into Excel for additional analysis, manipulation, and presentation formatting. All results are life-cycle based. With significant data output, more data are available for documentation and analysis. Data results in tools allow for easily drilling down into results to find basis for impacts. Sankey diagrams provide same in visual format. Interpretation of results is sometimes challenging because of all the data that are available and the competing attributes this creates in the decision-making process (for example, how to balance the release of carcinogens in the life cycle of the project with global warming potential). Communication is also sometimes challenging. LCA is relatively new in the remediation industry. Many people are predominantly concerned with CO_2 emissions, and the addition of so many results (discrete chemicals or impact assessment results) can be overwhelming. Direct water usage can be tracked. Embedded water can be tracked.
Results are summarized in tables and charts.	Results are summarized in tables.	Results are summarized in tables.	Results are summarized in tables and charts.

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TABLE 2-2
Tool Comparison: Cost and Licensing, Training, Reference Information, and Analytical and Interpretative Capabilities

SiteWise	SRT	EPA SEFA	SimaPro
Costs and Licensing			
Freeware	Freeware	Freeware	Approximately $5,000 to $10,000 (depending on version purchased) and approximately $2,000 per year in maintenance; maintenance is only required if user desires software and database updates.
No license is required.	No license is required.	No license is required.	License is required.
			Typically, software is sold along with LCA databases. The LCA databases also have a license. For users who only want to use software and not pay for a LCA database, the software can still be used with public domain LCA databases (such as US LCI, EUROPA).
Training Requirements			
User's manual is available.	User's manual is available.		User's manual is available.
65-minute instruction available online at http://www.ert2.org/t2gsrportal/tutorials/SitewiseTraining2/default.html		Internet seminars and training sessions for EPA's Methodology now include a brief section on the use of SEFA.	Comprehensive instructional/training problem is available.
Training has been periodically offered at technical conferences; training courses typically require a fee.	Training has been periodically offered at technical conferences; training courses typically require a fee.		Training is offered regularly and can occur at onsite or offsite training locations, or via virtual meetings.
User can become conversant and functional in tool by reading the user's manual, watching instructional video, and practicing with the tool.	User can become conversant and functional in tool by the reading user's manual and practicing with the tool.	User can become conversant and functional in tool by reading EPA's Methodology and practicing with the tool.	Significant practice with the tool is required to be conversant and functional. Select external training typically required (these can sometimes be completed via webinar) and training fee is typically required. Significant background reading on published LCAs is recommended to gain a better understanding of the various methods and approaches practitioners have used. Familiarity with ISO 14040 and 14044 is recommended. Collaboration with other LCA practitioners is helpful in discussion approaches and options to completing discrete elements of LCA.
Time needed to be conversant and functional in tool is typically 8 hours, provided the user has background in environmental sciences and engineering.	Time needed to be conversant and functional in tool is typically 8 hours, provided the user has background in environmental sciences and engineering.	Time to be conversant and functional in tool is typically 8 hours, provided the user has background in environmental sciences, engineering, and spreadsheets.	Time to be conversant and functional in tool is typically 200 hours, provided the user has a background in environmental sciences and engineering, understanding of human/ecological risks, and understanding of environmental systems and system dynamics.
Reference Information			
Limited footprint conversion footprint information (not necessarily life-cycle) is provided for 27 materials. User can modify footprint conversion factors and can add up to six additional materials, provided they load conversion factors for the materials.	Limited footprint conversion footprint information (not necessarily life-cycle) is provided for 11 materials and four energy/fuel sources. User can modify footprint conversion factors but cannot easily add materials. As of this writing, SRT is being updated to increase the number of materials and energy sources.	Footprint information (generally life-cycle or a close approximation) is provided for 12 materials, and generic footprint information is provided for other materials for which footprint information is not readily available. User can specify site-specific conversion factors and can add up to 20 additional materials or activities. Estimated conversion factors are also provided for various services including landfill disposal, waste water disposal, and laboratory analysis.	Footprint information is full life cycle for all raw materials (256), energy, and emissions to air (315), soil (73), water (268), and final waste flows (20) [numbers in parentheses represent the number of individual inventories in available databases]. Also includes infrastructure considerations. Library structure allows assembly of new input from unit process library or system basis input.
Electricity conversion factors are based on eGRID. Renewable energy or specific generation mixes cannot be used. Allows the user to input factors.	Extensive documentation of conversion factors is provided in the user manual.	Electricity conversion factors are constructed by the user based on an appropriate generation mix. Resulting conversion factors include impacts from resource extraction and transmission losses.	Extensive documentation is provided in built in library of references as well as documentation of individual dataset.
Tool allows for consideration of retrofitted diesel engines.	Tool only considers one type of diesel source.	Tool only considers one type of diesel engine.	A large number of fuel types and energy sources are available. User needs to have knowledge of different types of information available to make sure most correct datasets are utilized.

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TABLE 2-2
Tool Comparison: Cost and Licensing, Training, Reference Information, and Analytical and Interpretative Capabilities

SiteWise	SRT	EPA SEFA	SimaPro
Analytical and Interpretation Capabilities			
Tabular output of results	Tabular output of results	Tabular output of results	Tabular output of results
Graphical outputs of results	Individual results can be normalized in terms of U.S. dollars; therefore, the individual metrics calculated by the tool can be expressed as total U.S. dollars.	Data can be extracted from the output tables to prepare project-specific charts.	Graphical output of results. Multiple alternatives can be normalized to show relative differences by impact category.
Results can be presented by phase of work (investigation, construction, operation, long-term monitoring) and type of metric (such as transportation or consumable).		Results can be presented in categories defined by the user and type of metric	Results can be grouped by an unlimited range of analysis groupings (such as those described for SiteWise and EPA SEFA, plus others at the discretion of the user).
Tool allows for the evaluation of the impacts of optimization opportunities through use of renewable energy, alternative fuels, energy efficient devices, and footprint reduction practices.			Extensive library of data allows the selection of the most applicable dataset inputs for analysis.
Results are presented in a manner that shows individual contributions of each component to impact assessment results.			Results can be presented in a manner that shows individual contributions of each component to impact assessment results.
			Allows modification of datasets to yield local results (for example, substation of local power mix from supplier).
			Produces Sankey Diagram that shows contributions to individual categories.
			Provides ability to evaluate different cut-off values (percent of input that is considered relevant to the conclusions) before final cut-off rule finalized.
			Fully document life-cycle inventory of all inputs into analysis, and specifying individual and discrete chemical emissions to soil, water, and air as well as raw material inputs.
			Discrete process contributions fully delineated with results.
			Ability to input probability distributions for uncertain parameters and run Monte Carlo analysis, which allows results to be reported as probability distribution rather than deterministic values.
			Impact assessment results can be represented as population equivalents to provide better context of results (provided impact assessment method supports population normalization).

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TABLE 4-1A
Components of ERD Remedy – Construction and Operations and Management

ERD Construction Scope of Work	
Injection well installation	736 2-inch-diameter SCH 40 PVC injection wells installed in 560 borings Total drilling depth of 18,977 feet Total casing length of 23,735 feet
PVC monitoring well installation	89 2-inch-diameter SCH 40 PVC monitoring wells installed in 43 borings Total drilling depth of 1,919 feet Total casing length of 2,797 feet
Steel monitoring well installation	16 2-inch-diameter SCH 40 steel monitoring wells installed in 8 borings Total drilling depth 460 feet Total casing length of 700 feet
Drilling*	345 locations 6.5 hours per location for biobarrier 25 locations at 16.6 hours per location for Holiday Cleaners 190 locations at 3.7 hours per location for shallow plume core 51 locations at 8.3 hours per location for monitoring wells
Concrete pads for wells	283 total well locations 3-foot x 3-foot x 4-inch concrete pad per location
Grout and bentonite for wells	9.1 cubic yard (246 $feet^3$) of grout 72.6 cubic yard (1,960 $feet^3$) of bentonite
Sand for wells	38.1 cubic yard of sand for biobarrier injection wells 5.2 cubic yard of sand for Holiday Cleaners injection wells 4.1 cubic yard of sand for shallow plume core injection wells 5.3 cubic yard of sand for monitoring wells
Personnel transport	21,400 person-miles to and from site
Equipment transport	Sand transport (79 tons) is 20 miles each way Grout transport (11.5 tons) is 100 miles each way Bentonite transport (66.8 tons) is 100 miles each way Other materials transport (3 tons) is 100 miles each way Return trips for all equipment transportation

TABLE 4-1A
Components of ERD Remedy – Construction and Operations and Management

ERD Construction Scope of Work	
Pavement	Roller 6,000 $feet^2$ Paver 6,000 $feet^2$
Residual handling	8 trips, 80 miles per trip, 29 tons per trip Return trips required
Input water	220,000 gallons for well construction
Vegetable oil	340,046 pounds per event for 13 events for biobarrier 50,894 pounds per event for 3 events for Holiday Cleaners 66,225 pounds per event for 3 events for shallow plume core
Personnel transport	24,760 miles, 1 person via car for operations and maintenance 20,400 miles, 1 person via car for monitoring
Equipment transport	96 trips at 100 miles per each way per trip 28 tons total Return trips required
Generator operation	9,904 hours for 3 to 6-hp diesel generator
Laboratory analysis	1 baseline event for $44,300 4 quarterly events for $36,350 each 2 semiannual events for $36,350 each 18 annual events for $59,050 each
Input water	14,280,305 gallons (biobarriers) 491,619 gallons (Holiday Cleaners site) 639,711 gallons (shallow plume core)

SCH = schedule
*Drilling estimates based on number of days specified in Final Design and assumption of 10-hour days.

TABLE 4-1B

Input of ERD Components into SiteWise – Construction and Operations and Maintenance

SiteWise Input for ERD Construction

	Well Materials				
Well casing	Injection wells 1 well 23,735 feet[a] Sch 40 PVC 2-inch diameter	Monitoring wells 1 well 2,797 feet[a] Sch 40 PVC 2-inch diameter	Monitoring wells 1 well 700 feet[a] Sch 40 steel 2-inch diameter		19,103 lbs of PVC 2,555 pounds of steel
	Drilling				
Drilling*	Biobarrier Diesel HSA 345 locations 6.5 hours each	HC Diesel HSA 25 locations 1.6 hours each	SPC Diesel HSA 190 locations 3.7 hours each	Monitoring Diesel HSA 51 locations 8.3 hours each	3,783.8 hours of drilling 28,567.8 gallons of diesel
	Construction Materials				
Concrete pads for wells	General concrete 2,547 feet^2 0.33 foot				125,403 pounds of concrete
Grout and bentonite for wells	**Construction Materials** Typical C\cement (grout) 246 feet^2 area 1 foot thick		**Bulk Materials** Bentonite Cubic feet 1,960 feet^3		23,080 pounds of cement 219,784 pounds of bentonite
	Well Decommissioning (surrogate entry for sand pack)				
Sand for wells	Biobarrier Sand 1,310 feet[a] 12-inch[b]	HC Sand 179 feet[a] 12-inch[b]	SPC Sand 141 feet[a] 12-inch[b]	Monitoring Sand 182 feet[a] 12-inch[b]	164,017 pounds of sand

TABLE 4-1B

Input of ERD Components into SiteWise – Construction and Operations and Maintenance

Personnel transport	**Personnel Transportation- Road** No diesel retrofit Car Gasoline 19,760 miles per trip 1 trip, 1 traveler per trip	19,760 miles by car 681.4 gallons of gasoline
Equipment transport	**Equipment Transportation – Road** Sand: Diesel, 120 miles, 14 tons Grout: Diesel, 100 miles, 9 tons Bentonite: Diesel, 800 miles, 6 tons Other: Diesel, 700 miles, 3 tons Return trip: Diesel, 1,720 miles, 0 tons	484 gallons of diesel
Pavement	**Capping Equipment** Roller: Diesel, 6,000 $feet^2$, 2 days Paver: Diesel, 6,000 $feet^2$, 2 days	2 gallons of diesel
Residual handling	**Residual Disposal/Recycling** Disposal trip: No diesel retrofit, 29 tons, Gasoline, 8 trips, 80 miles per trip Empty return trip: No diesel retrofit, 0 tons, Gasoline, 8 trips, 80 miles per trip **Landfill Operations:** 29 tons, non-hazardous landfill	231 gallons of gasoline
Input water	**Water Consumption:** 220,000 gallons	220,000 gallons

TABLE 4-1B
Input of ERD Components into SiteWise – Construction and Operations and Maintenance

SiteWise Input for ERD Operations and Maintenance and Monitoring

Vegetable oil	**Treatment Chemicals & Materials** Biobarrier: 340,046 pounds/event; 13 points (events) HC: 50,894 pounds /event; 3 points (events) SPC: 66,225 pounds /event; 3 points (events)	4,771,955 pounds of vegetable oil
Personnel transport	**Personnel Transportation – Road** Monitoring: No diesel retrofit; Car; Gasoline; 20,400 miles per trip; 1 trip; 1 traveler per trip Operations and maintenance: No diesel retrofit; Car; Gasoline; 26,360 miles per trip; 1 trip; 1 traveler per trip	46,760 miles traveled by car 1,612.4 gallons of gasoline
Equipment transport	**Equipment Transportation – Road** Delivery: No diesel retrofit; Diesel; 9,600 miles; 28 tons total Empty return trip: No diesel retrofit; Diesel; 9,600 miles; 0 tons total	3,415 gallons of diesel
Equipment Operation	**Generators** Diesel 3 to 6 hp 9,904 hrs	7,926.2 gallons of diesel
Laboratory Analysis	$1,325,300 of laboratory analytical costs for one baseline event, four quarterly events, two semiannual events, and 18 annual events	$1,325,300 of laboratory analytical costs
Input water	**Water Consumption** Biobarrier: 14,280,305 gallons HC site: 491,619 gallons SPC: 639,711 gallons	15,411,635 gallons of water

HC = Holiday Cleaners, SPC = Shallow Plume Core; HSA = Hollow Stem Auger
[a] Length refers to depth of well.
[b] Refers to well diameter.

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TABLE 4-1C
Input of ERD Components into SRT – Construction and Operations and Maintenance

SRT Input for ERD Construction

Well casing	**Enhanced Bioremediation** Length of Piping Per Well = 32.25 feet Injection well spacing = 13.56 (results in 736 wells) User override values to match total length of wells input into SiteWise **LTM_MNA** Number of monitoring wells = 105 Length of piping per well = 33.3 User override values to match total length of wells input into SiteWise	55,100 pounds of PVC
Drilling	**Enhanced Bioremediation and LTM_MNA** Drilling rate = 100 feet/day Drilling fuel consumption rate = 32 gallon/day SRT default values	272.32 days of drilling 8,714 gallons of diesel
Concrete pads for wells	NA	NA
Grout and bentonite for wells	NA	NA
Sand for wells	NA	NA
Personnel transport	**Enhanced Bioremediation and LTM_MNA** Average distance traveled by workers each way = 10 miles Trips by workers during construction = 988 (enhanced bioremediation) Trips by workers during construction = 8 (LTM_MNA) User specified values to match total distance input into SiteWise	19,920 miles traveled 1,328 gallons of gasoline
Equipment transport	NA	NA
Pavement	NA	NA

TABLE 4-1C
Input of ERD Components into SRT – Construction and Operations and Maintenance

SRT Input for ERD Construction		
Residual handling	NA	NA
Vegetable oil	**Enhanced Bioremediation** Volume for treatment = 7,918,533 gallons (user specified) Percent of pore space for donor = 0.01 (default value) Donor conversion factor = 8.172 pounds/gallon (user specified) Values are intended to match SiteWise input of approximately 4,800,000 pounds of vegetable oil	4,800,000 pounds of vegetable oil
Personnel transport	**Enhanced Bioremediation and LTM_MNA** Average distance traveled each way = 10 miles Trips by site workers after construction = 1,318 (enhanced bioremediation) Trips by site works after construction = 1,012 (LTM_MNA) *User specified values to match total distance input into SiteWise*	46,600 miles traveled 3,107 gallons of gasoline
Equipment transport	NA	NA
Generator operation	NA	NA
Laboratory analysis	NA	NA
Input water	NA	NA

LTM_MNA = Long-Term Monitoring/Monitored Natural Attenuation

TABLE 4-1D
Input of ERD Components into EPA SEFA – Construction and Operations and Maintenance

SEFA Input for ERD Construction

Well casing	18,043 pounds of PVC (26,534 feet of 2-inch Sch 40 PVC, 0.68 pounds per foot) 2,555 pounds of steel (700 feet of 2-inch Sch 40 steel at 3.65 pounds per foot)	18,043 pounds of PVC 2,555 pounds of steel
Drilling	3,783.8 hours of drilling (set to match SiteWise input) with a medium-sized rig (150 hp) selected at 0.75 load 756 hours of forklift operation (60 hp) to assist with drilling	3,783.8 hours of drilling 756 hours for forklift 22,985 gallons of diesel
Concrete pads for wells	62.9 tons of concrete (849 $feet^3$ of concrete, 2 tons per cubic yard)	125,800 pounds of concrete
Grout and bentonite for wells	66.8 tons of bentonite (1,960 $feet^3$ of bentonite, 0.92 tons per cubic yard) 11.6 tons of cement (246 $feet^3$ of grout, 1.27 tons per cubic yard)	133,600 pounds of bentonite 23,200 pounds of cement
Sand for wells	79.2 tons of sand (1,426 $feet^3$ of sand, 1.5 tons per cubic yard)	158,400 pounds of sand
Personnel transport	Total of 21,400 miles traveled by light truck	21,400 miles by light truck 1,259 gallons of gasoline
Equipment transport	Various trips and distances with diesel trucks for drill rig, forklift, paver, and roller mobilization Transportation of well construction materials with diesel trucks including empty return trips	931.7 gallons of diesel used
Pavement	150-hp asphalt paver and 100-hp roller operating two 10-hour days	187.5 gallons of diesel
Residual handling	Transport: Diesel truck 8 trips, 80 miles per trip (640 total one-way miles) for disposal route and same mileage for empty return Non-hazardous landfill: 29 tons of waste	213.4 gallons of diesel 29 tons of non-hazardous waste disposal

TABLE 4-1D
Input of ERD Components into EPA SEFA – Construction and Operations and Maintenance

SEFA Input for ERD Construction		
Input water	220,000 gallons of public water	220,000 gallons of public water
Vegetable oil	4,771,995 pounds of vegetable oil for all events set to match SiteWise input	4,771,955 pounds of vegetable oil
Personnel transport	**Operations and Maintenance** 24,760 miles traveled by light truck **Monitoring** 20,400 miles traveled by light truck	45,160 miles traveled by light truck 2,657 gallons of gasoline
Equipment transport	100 miles one way (delivery) 4,771,995 pounds delivered in 96 trips with diesel truck (mpg) 100 miles one way (empty return trip) 96 trips with diesel truck (mpg)	3,200 gallons of diesel
Generator operation	**Bioremediation Injections** Gasoline 4 hp at 75 percent electricity load 9,904 hours **Monitoring** Gasoline 2 hp at 75 percent electricity load 10,200 hours	2,521 gallons of gasoline
Laboratory analysis	$1,325,300 of laboratory analytical costs for one baseline event, four quarterly events, two semiannual events, and 18 annual events	$1,325,300 of laboratory analytical costs
Input water	15,411,635 gallons of potable water reinjected into the aquifer	15,411,635 gallons of water

TABLE 4-1E
Input of ERD Components into SimaPro– Construction and Operations and Maintenance

SimaPro Input for ERD Construction		
Well casing	18,043 pounds of PVC (26,534 feet of 2-inch Sch 40 PVC, 0.68 pound per foot) 2,555 pounds of steel (700 feet of 2-inch Sch 40 steel at 3.65 pounds per foot)	18,491 lbs of PVC 2,556 lbs of steel
Drilling	3,784 hours of drilling (set to match SiteWise input) at about 8 gallons per hour 500 hours of forklift operation (30 hp) to assist with drilling	3,784 hours of drilling 500 hours for forklift 30,834 gallons of diesel
Concrete pads for wells	62.2 tons of concrete (SG of 2.37)	124,400 pounds of concrete
Grout and bentonite for wells	66.8 tons of bentonite (1,960 $feet^3$ of bentonite, 0.92 tons per cubic yard) 11.6 tons of cement (246 $feet^3$ of grout, 1.27 tons per cubic yard)	119,677 pounds of bentonite 23,142 pounds of cement
Sand for wells	79.2 tons of sand (1,426 $feet^3$ of sand, 1.5 tons per cubic yard)	135,000 pounds of sand
Personnel transport	Total of 21,400 miles traveled by auto	21,400 miles by auto 1,097 gallons of gasoline
Equipment transport	Various trips and distances (see input sheets) for drill rig, forklift, paver, and roller mobilization Transportation of well construction materials (see input sheet), including empty return trips	526 gal of diesel used for materials and well construction equipment (assumed 100 tons of equipment)
Pavement	100 hp asphalt paver and roller operating two 10-hour days	179.5 gallons of diesel
Residual handling	Disposal: 8 trips, 80 miles per trip for 640 total one-way miles Diesel truck carrying 5 to 10 tons Empty return trip: 8 trips, 80 miles per trip for 640 total one-way miles Diesel truck carrying < 5 tons	389.5 gallons of diesel

TABLE 4-1E
Input of ERD Components into SimaPro– Construction and Operations and Maintenance

SimaPro Input for ERD Operations and Maintenance and Monitoring

Emulsified vegetable oil	4,760,640 lbs of EVO for all events	4,760,640 pounds of EVO; inventory built up based on constituents including vegetable oil, emulsifier, lactate, and tap water
Personnel transport	**Operations and Maintenance** 24,760 miles traveled by auto, 2 persons **Monitoring** 20,400 miles traveled by auto, 2 persons	45,160 miles traveled by 2 persons 2,480 gallons of gasoline Calculated on person-kilometer basis
Equipment transport	100 miles one way (delivery) 4,760,640 pounds delivered	5,002 gallons of diesel Based on ton-kilometer basis
Generator operation	**Bioremediation Injections** Gasoline 5 hp at 75 percent electricity load 9,904 hours **Monitoring** 2 hp at 75 percent electricity load 7,200 hours	1,860 gallons of diesel 540 gallons of diesel
Laboratory analysis		Considered minimal
Input water	15,411,635 gallons of potable water reinjected into the aquifer	15,411,635 gallons of water

TABLE 4-1F
ERD Summary Table of Input into Four Tools

	SiteWise	SRT	SEFA	SimaPro
Well installation	19,103 pounds of PVC 2,555 pounds of steel	55,100 pounds of PVC 0 pounds of Steel	18,043 pounds of PVC 2,555 pounds of steel	18,491 pounds of PVC 2,556 pounds of steel
Drilling	3,783.8 hours of drilling 28,567.8 gallons of diesel	272.32 days of drilling 8,714 gallons of diesel	3,783.8 hours of drilling 756 hours of forklift 22,985 gallons of diesel	3,784 hours of drilling 500 hours of Forklift Time 30,834 gallons of diesel
Concrete pads for wells	125,403 pounds of concrete	NA	125,800 pounds of concrete	124,400 pounds of concrete
Grout and bentonite for wells	219,784 pounds of bentonite 23,080 pounds of cement	NA	133,600 pounds of bentonite 23,200 pounds of cement	119,677 pounds of bentonite 23,142 lbs of cement
Sand for wells	164,017 pounds of sand	NA	158,400 pounds of sand	135,500 pounds of sand
Personnel transport	19,760 miles by car 681.4 gallons of gasoline	19,920 miles traveled 1,328 gallons of gasoline	21,400 miles by light truck 1,259 gallons of gasoline	21,400 miles in auto 1,097 gallons of gasoline
Equipment transport	484 gallons of diesel	NA	931.7 gallons of diesel	526 gallons of diesel
Pavement	2 gallons of diesel	NA	187.5 gallons of diesel	179.5 gallons of diesel
Residual handling	231 gallons of gasoline 29 tons non-hazardous waste	NA	213.4 gallons of diesel 29 tons non- hazardous waste	389.5 gallons of diesel
Vegetable oil	4,771,955 pounds of oil	4,800,000 pounds of oil	4,771,955 pounds of oil	4,760,640 pounds of EVO
Personnel transport	46,760 miles by car 1,612.4 gallons of gasoline	46,600 miles 3,107 gallons of gasoline	45,160 miles by light truck 2,657 gallons of gasoline	45,160 miles by auto 2,480 gallons of gasoline
Equipment transport	3,415 gallons of diesel	NA	3,200 gallons of diesel	5,002 gallons of diesel
Generator operation	7,926.2 gallons of diesel	NA	2,521 gallons of gasoline	2,400 gallons of diesel
Laboratory analysis	$1,325,300 of laboratory analytical costs	NA	$1,325,300 of laboratory analytical costs	NA
Input water	220,000 gallons (well construction) 15,411,635 gallons (substrate del)	NA	220,000 gallons (well construction) 15,411,635 gallons (substrate del)	15,411,635 gallons (substrate del)

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TABLE 4-2A

Components of ISCO – Construction and Operations and Maintenance

ISCO Construction Scope of Work	
Not applicable. Well installation and construction associated with ERD remedy.	
ISCO Operations and Maintenance, and Monitoring Scope of Work	
Potassium permanganate	Inject 9,000 gallons of 4.6% solution potassium permanganate per well (765,000 pounds total) 221 wells for first event one injection event only 6 gpm injection rate per well, assume injection at 10 wells simultaneously
Personnel transport	140 trips at 20 miles roundtrip per trip Crew of three Two trucks per trip
Equipment transport	Transport potassium permanganate by truck a distance of 100 miles Assume approximately 10 trips are required Plus empty return trips
Generator operation	One injection assuming 70 8-hour days of 10-hp generator operation
Laboratory analysis	None.
Input water	1,989,000 gallons of potable water (9,000 gallons per well multiplied by 221 wells)

gpm = gallons per minute

TABLE 4-2B
Input of ISCO Components into SiteWise – Construction and Operations and Maintenance

SiteWise Input for ISCO Construction

Not applicable. Well installation and construction associated with ERD remedy.

SiteWise Input for ISCO Operations and Maintenance, and Monitoring

Potassium permanganate	**Treatment Chemicals & Materials** 1 injection point Sodium Hypochlorite (surrogate for potassium permanganate) 765,000 pounds 1 injection per injection point		765,000 pounds of potassium permanganate
Personnel transport	**Personnel Transportation – Road** Operations and maintenance No diesel retrofit Car Gasoline 20 miles per trip 152 trips 3 travelers per trip		2,800 miles by car 97 gallons of gasoline
Equipment transport	**Equipment Transportation – Road** Delivery No diesel retrofit Diesel 1,900 miles 20 tons per truckload	Empty return trip No diesel retrofit Diesel 1,900 miles 0 tons per truckload	612 gallons of diesel
Equipment operation	Generators Diesel 6 to 11-hpgenerator 608 hours		565.1 gallons of diesel
Laboratory analysis	None		None
Input water	Water consumption 1,989,000 gallons of potable water		1,989,000 gallons of potable water

TABLE 4-2C
Input of ISCO Components into SRT– Construction and Operations and Maintenance

SRT Input for ISCO Construction		
Not applicable. Well installation and construction associated with ERD remedy.		
SRT Input for ISCO Operations and Maintenance, and Monitoring		
Potassium permanganate	**Enhanced Bioremediation** Total mass of oxidant = 765,000 pounds (override value)	765,000 pounds of oxidant
Personnel transport	**Enhanced Bioremediation and LTM_MNA** Average distance traveled each way = 10 miles Trips by site workers after construction = 140 *User-specified values to match total distance input into other models*	2,800 miles traveled 187 gallons of gasoline
Equipment transport	Oxidant load delivery capacity = 40,000 pounds Number of loads for oxidant = 19 load Distance to oxidant supplier = 100 miles Total miles driven for oxidant = 1,900 Vehicle mileage = 17.6 mpg (default) *User specified values to match total distance input into other models*	1,900 miles 108 gallons of diesel
Generator operation	NA	NA
Laboratory analysis	NA	NA
Input water	NA	NA

LTM_MNA = Long-Term Monitoring/Monitored Natural Attenuation; mpg = mile per gallon

TABLE 4-2D

Input of ISCO Components into EPA SEFA– Construction and Operations and Maintenance

SEFA Input for ISCO Construction

Not applicable. Well installation and construction associated with ERD remedy.

SEFA Input for ISCO Operations and Maintenance, and Monitoring

Potassium permanganate	765,000 pounds of potassium permanganate	765,000 pounds
Personnel transport	O&M 140 trips (two vehicles per day for 70 days) 20 miles per trip by light-duty truck	2,800 miles traveled by light truck 140 gallons of gasoline
Equipment transport	Delivery 100 miles one way 765,000 pounds delivered in 19 trips, diesel truck (mpg) Return Trip 100 miles one way 19 empty truck trips, diesel truck (mpg)	633.4 gallons of diesel
Generator operation	Injections Diesel 10 HP at electricity load of 75 percent 560 hours	210 gallons of diesel
Laboratory analysis	None	None
Input water	1,989,000 gallons of potable water used for blending and injecting	1,989,000 gallons

mpg = mile per gallon

TABLE 4-2E
Input of ISCO Components into SimaPro– Construction and Operations and Maintenance

SimaPro Input for ISCO Operations and Maintenance, and Monitoring		
Potassium permanganate	765,000 pounds of potassium permanganate	765,000 pounds
Personnel transport	**O&M** 140 trips (two vehicles per day for 70 days) 20 miles per trip by light-duty truck Total of 13,534 person-km or 8,406 person-miles	2,800 miles traveled by passenger car 143 gallons of gasoline
Equipment transport	**Delivery** 100 miles one way 765,000 pounds delivered in 10 round trips Return Trip Calculation uses USLCI Ton-Kilometer basis, which factors in both full and empty loads	798.2 gallons of diesel
Generator operation	**Injections** Gasoline Assume 2 pumps using 2.5 gallons per day, each, for 70 days	348 gallons of diesel
Laboratory analysis	None	None
Input water	1,989,000 gallons of potable water used for blending and injecting	1,989,000 gallons

O&M = Operations and Maintenance

TABLE 4-2F
ISCO Summary Table of Input into Four Tools

	SiteWise	SRT	SEFA	SimaPro
Potassium permanganate	765,000 pounds	765,000 pounds	765,000 pounds	765,000 pounds
Personnel transport	97 gallons of gasoline	187 gallons of gasoline	140 gallons of gasoline	143 gallons of fuel
Equipment transport	612 gallons of diesel	108 gallons of diesel	633.4 gallons of diesel	789 gallons of diesel
Generator operation	565.1 gallons of diesel	NA	210 gallons of diesel	348 gallons of gasoline
Laboratory analysis	None	NA	None	None
Potable water input	1,989,000 gallons	NA	1,989,000 gallons	1,989,000 gallons

TABLE 4-3A
Components of ISTT – Construction and Operations and Maintenance

ISTT Construction Scope of Work	
Electrode, probe, well materials, and piping	8,575 feet of 2-inch SCH 40 PVC SVE wells 8,000 feet of 3-inch carbon steel pipe for heater boring, temperature probes, and vapor recovery 1,000 feet of 1.5-inch carbon steel pipe for heater boring, temperature probes, and vapor recovery 4,000 feet of 2-inch fiberglass for SVE laterals
Drilling	275 wells with total drilling depth of 8,575 feet over 3,000 hours (average of 10.9 hours per well and 31.2 feet per well)
Grout for wells	20 cubic yards of grout (540 $feet^3$) of grout for well construction
Sand for wells	80 cubic yards (2,160 $feet^3$) of sand for well construction
Trenching	1,000 feet (assume 100 cubic yards) with 14,000 square feet of asphalt surface finishing
Pavement	14,000 square feet of surface refinishing after trenching
Equipment transport	2 trips with 8.6 tons each for grout plus empty return trips – 100 miles each way 8 trips with 13.7 tons each for sand plus empty return trips – 20 miles each way 3 trips with 3 tons each for fiberglass and steel plus empty return trips – 100 miles each way
Personnel transport	10,000 person-miles total to and from site (500 individual visits, 20 miles round trip)
Waste disposal	Assume four 10-ton trips, 80 miles each way with empty return trips
Input water	220,000 gallons of public water

TABLE 4-3A
Components of ISTT – Construction and Operations and Maintenance

ISTT Operations and Maintenance and Monitoring Scope of Work	
Electricity	6,000,000 kWh of electricity
Vapor phase GAC	20,000 lbs of virgin GAC
Equipment transport	One 1,300-mile trip with 10 tons of GAC, round-trip One 100-mile trip with 8-ton transformer for electrical power plus empty return trip
Personnel transport	2,000 person-miles total to and from site (100 individual visits, 20 miles round trip)
Laboratory Analysis	Quarterly sampling at 8 locations for 10 years for VOCs (320 samples)
Water disposal	1,000,000 gallons of water extracted with disposal to a waste water treatment facility

SCH = schedule; VOC = volatile organic compound

TABLE 4-3B

Input of ISTT Components into SiteWise – Construction and Operations and Maintenance

SiteWise Input for ISTT Construction

Electrode, probe, and well materials	**Well Materials** SVE wells 1 well 8,575 feet SCH 40 PVC 2 inch	Piping 1 well 4,000 feet SCH 40 PVC 2 inch	Heater Borings 1 well 9,000 feet SCH 40 steel 2 inch	9,054 pounds of PVC 32,850 pounds of steel
Drilling	**Drilling** Diesel HSA 275 locations 10.9 hours each			2997.5 hours of drilling 22,631.1 gallons of diesel
Grout for wells	**Construction Materials** Typical Cement (grout) 540 feet^2 area 1 foot thick			50,662.48 pounds of cement
Sand for wells	**Well Decommissioning (surrogate entry for sand pack)** Sand 2,750 feet 12-inch *Dimensions set to equal 80 cubic yards (2,160 feet^3) of sand*			248,939.02 pounds of sand
Trenching	**Earthwork** Excavator Diesel 100 cubic yards Not retrofitted with particulate reduction technology			4.6 gallons of diesel

TABLE 4-3B
Input of ISTT Components into SiteWise – Construction and Operations and Maintenance

Pavement	**Capping Equipment** Roller: Diesel; 14,000 $feet^2$; 4 days Paver: Diesel; 14,000 $feet^2$; 4 days	4.6 gallons of diesel
Equipment transport	**Equipment Transportation – Road** Other: Diesel; 300 miles; 3 tons Sand: Diesel; 160 miles; 13.7 tons Grout: Diesel; 200 miles; 8.6 tons Return trip: Diesel; 660 miles; 0 tons **No refers to no diesel retrofit.*	189 gallons of diesel
Personnel transport	**Personnel Transportation – Road** No diesel retrofit Car Gasoline 10,000 miles per trip 1 trip 1 traveler per trip	10,000 miles by car 344.8 gallons of gasoline
Residual handling	**Residual Disposal/Recycling** Disposal trip: No diesel retrofit; 10 tons; Diesel; 4 trips; 80 miles per trip Empty return trip: No diesel retrofit; 0 tons; Diesel; 4 trips; 80 miles per trip **Landfill Operations:** 10 tons, non-hazardous landfill	93.4 gallons of gasoline 10 tons non-hazardous waste
Input water	220,000 gallons of public water	220,000 gallons of public water

TABLE 4-3B
Input of ISTT Components into SiteWise – Construction and Operations and Maintenance

SiteWise Input for ISTT Operations and Maintenance, **and Monitoring**

Electricity	**Blower, Compressor, Mixer, and Other Equipment** Method 1 6,000,000 kWh	6,000,000 kWh
Vapor phase GAC	**Treatment Chemicals & Materials** 20,000 pounds Virgin GAC	20,000 pounds of virgin GAC
Equipment transport	**Equipment Transportation - Road** Transformer / No diesel retrofit / Diesel / 100 miles / 8 tons GAC / No diesel retrofit / Diesel / 1,300 miles / 10 tons Empty return trip / No diesel retrofit / Diesel / 100 miles / 0 tons total *GAC is roundtrip. Empty return trip is for transformer truck.*	233 gallons of diesel
Personnel transport	**Personnel Transportation – Road** No diesel retrofit Car Gasoline 2,000 miles per trip 1 trip, 1 traveler per trip	2,000 miles traveled by car 69 gallons of gasoline
Laboratory analysis	Quarterly sampling for VOCs at 8 locations for 10 years at $90 per sample	$28,800
Water disposal	Resource consumption (condensate from thermal operations) 1,000,000 gallons disposed to wastewater treatment facility	1,000,000 gallons of water to wastewater treatment

VOC = volatile organic compound

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TABLE 4-3C
Input of ISTT Components into SRT – Construction

SRT Input for ISTT Construction		
Electrode, probe, and well materials	Default values • Well diameter (4-inch) • Manifold diameter (6-inch) • Well spacing (7 feet) • Area heated per well (43 $feet^2$) • 180 heater wells (user override) • Weight of steel per length of well (4.76 pounds/foot) • Weight of steel per length of manifold (7.28 pounds/foot) User override values to match SiteWise inputs • Heater wells (180 wells) • Heater-vacuum wells (65 wells) • Length of manifold (1,260 feet)	74,000 pounds of steel
Drilling	Default values Drilling rate (100 feet/day) • Drilling fuel consumption (32 gallons/day) User override values Linear feet for drilling (10,290 feet)	3,293 gallons of diesel
Grout for wells	NA	NA
Sand for wells	NA	NA
Trenching	Default values Trenching rate (300 feet/hour) • Trenching fuel consumption rate (6.25 gallons/hour) User override values to match SiteWise input Linear feet for trenching (1,000 feet)	21 gallons of diesel

TABLE 4-3C
Input of ISTT Components into SRT – Construction

Equipment transport	NA	NA
Personnel transport	15 miles per gallon (default) 200 trips, 10 miles each way Combined construction and O&M trips; and distance set to equal 12,000 miles to equal SiteWise input	4,000 miles traveled 267 gallons of gasoline
Residual handling	NA	NA
Input water	NA	NA
SRT Input for ISTT Operations and Maintenance, and Monitoring		
Electricity	6,000,000 kWh (user override to match SiteWise input)	6,000,000 kWh
Vapor phase GAC	20,000 pounds (user override to match SiteWise input)	20,000 pounds of GAC
Equipment transport	Default values Miles traveled for GAC disposal (400 miles) Vehicle mileage for GAC disposal (5 mpg)	80 gallons of diesel
Personnel transport	400 trips, 10 miles each way 15 miles per gallons (default)	8,000 miles traveled 533 gallons of gasoline
Laboratory analysis	NA	NA
Water disposal	NA	NA

mpg = mile per gallon

TABLE 4-3D
Input of ISTT Components into EPA SEFA– Construction and Operations and Maintenance

SEFA Input for ISTT Construction		
Electrode, probe, and well materials	8,551 pounds of PVC (12,575 feet of 2-inch Sch 40 PVC, 0.68 pounds per foot) 32,850 pounds of steel (9,000 feet of 2-inch Sch 40 steel at 3.65 pounds per foot) *Values set to be consistent with SiteWise input.*	8,551 pounds of PVC 32,850 pounds of steel
Drilling	3,000 hours of drilling (set to match SiteWise input) with a medium-sized rig (150 hp) selected at 0.75 load	3,000 hours of drilling 16,875 gallons of diesel
Grout for wells	25 tons of cement (20 cubic yards at 1.27 tons per cubic yard) *Values set to be consistent with SiteWise input*	50,000 pounds of cement
Sand for wells	120 tons of sand (80 cubic yards of sand, 1.5 tons per cubic yard) *Values set to be consistent with SiteWise input.*	240,000 pounds of sand
Trenching	Medium excavator (150 hp) at load of 0.75 for 16 hours	105 gallons of diesel
Pavement	Asphalt paver (150 hp) and roller (100 hp) used for four 8-hour days each at 0.75 load	300 gallons of diesel
Equipment transport	Various trips and distances (see input sheets) for drill rig, excavator, and transformer delivery Transportation of well construction materials (see input sheet), including empty return trips. Distances consistent with SiteWise input.	410 gallons of diesel used
Personnel transport	10,000 miles traveled by light duty truck	588 gallons of gasoline
Residual handling	Disposal: 4 trips, 80 miles per trip for 320 total one-way miles by diesel truck Empty return trip: 4 trips, 80 miles per trip for 320 total one-way miles by diesel truck	106.6 gallons of diesel plus landfill activities
Input water	220,000 gallons of public water	220,000 gallons of public water
Electricity	6,000,000 kWh for all equipment	6,000,000 kWh

TABLE 4-3D
Input of ISTT Components into EPA SEFA– Construction and Operations and Maintenance

Vapor phase GAC	20,000 lbs of virgin GAC	20,000 pounds of virgin GAC
Equipment transport	650 miles one way for GAC 650 miles one way for empty GAC return trip 100 miles one way for transformer 100 miles one way for empty transformer return trip	249.9 gallons of diesel
Personnel transport	2,000 miles by light duty truck	2,000 miles traveled 100 gallons of gasoline
Laboratory Analysis	Quarterly sampling for VOCs at 8 locations for 10 years at $90 per sample	$28,800
Water disposal	1,000,000 discharged to POTW by pipe	1,000,000 gallons of water discharge to POTW

POTW = publicly owned treatment works; SCH = scheduled; VOC = volatile organic compound

TABLE 4-3E
Input of ISTT Components into SimaPro – Construction and Operations and Maintenance

SimaPro Input for ISTT Construction		
Electrode, probe, and well materials	8,551 pounds of PVC (12,575 feet of 2-inch SCH 40 PVC, 0.68 pounds per foot) 32,850 pounds of steel (9,000 feet of 2-inch SCH 40 steel at 3.65 pounds per foot) *Values set to be consistent with SiteWise input.*	8,551 pounds of PVC 32,840 pounds of steel
Drilling	3,000 hours of drilling (set to match SiteWise input) with a medium-sized rig (150 hp) selected at 0.75 load	3,000 hours of drilling 24,000 gallons of diesel
Grout for wells	25 tons of cement (20 cubic yards at 1.27 tons per cubic yard) *Values set to be consistent with SiteWise input.*	50,692 pounds of cement
Sand for wells	120 tons of sand (80 cubic yards of sand, 1.5 tons per cubic yard) *Values set to be consistent with SiteWise input.*	240,000 pounds of sand
Trenching	Hydraulic Digger, 100 cubic meters estimated	13 gallons of diesel
Pavement	Assume 100-hp Paver and 100-hp roller for 24 hours each	180 gallons of diesel
Equipment transport	Total distances times weight converted to ton-kilometer unit Includes sand, cement, PVC, stainless steel and 8-ton transformer	143 gallons of diesel used
Personnel transport	10,000 miles traveled by passenger car 2 persons in car Converted into person-kilometer unit	352 gallons of gasoline
Residual handling	Disposal: 4 trips, 80 miles per trip for 640 total one-way miles by diesel truck, 10 short tons per load Converted to ton-kilometer basis	67 gallons of diesel

TABLE 4-3E
Input of ISTT Components into SimaPro – Construction and Operations and Maintenance

SimaPro for ISTT Operations and Maintenance, and Monitoring		
Electricity	6,272,871 kWh for all equipment	6,000,000 kWh for thermal energy and balance for vacuum blower
Vapor phase GAC	20,000 pounds of virgin GAC Assume one reactivation phase to simulate disposal	20,000 pounds of virgin GAC And one cycle of reactivation
Equipment transport	650 miles one way for GAC (assumed dry) 650 miles one way for empty GAC return trip (assumed wet) 100 miles one way for transformer 100 miles one way for empty transformer return trip All estimates use ton-kilometer basis	244 gallons of diesel
Personnel transport	2,000 miles by passenger car assume 2 persons All estimates use person-kilometer basis	2,000 miles traveled 68 gallons of gasoline
Laboratory analysis	Quarterly sampling for VOCs at 8 locations for 10 years at $90 per sample	$28,200
Water disposal	1,000,000 discharged to POTW by pipe	1,000,000 gallons of water discharge to POTW

VOC = volatile organic compound

TABLE 4-3F
ISTT Summary Table of Input into Four Tools

	SiteWise	SRT	SEFA	SimaPro
Electrode, probe, and well materials	9,054 pounds of PVC 32,850 pounds of steel	74,000 pounds of steel	8,551 pounds of PVC 32,850 pounds of steel	8,551 pounds of PVC 32,840 pounds of steel
Drilling	2997.5 hours of drilling 22,631.1 gallons of diesel	3,293 gallons of diesel	3,000 hours of drilling 16,875 gallons of diesel	3,000 hours of drilling 24,000 gallons of diesel
Grout for wells	50,662.48 pounds of cement	NA	50,000 pounds of cement	50,692 pounds of cement
Sand for wells	248,939.02 pounds of sand	NA	240,000 pounds of sand	240,000 pounds of sand
Trenching	4.6 gallons of diesel	21 gallons of diesel	105 gallons of diesel	13 gallons of diesel
Pavement	4.6 gallons of diesel	NA	300 gallons of diesel	180 gallons of diesel
Equipment transport	189 gallons of diesel	NA	410 gallons of diesel used	143 gallons of diesel
Personnel transport	10,000 miles by car 344.8 gallons of gasoline	4,000 miles traveled 267 gallons of gasoline	10,000 miles by truck 588 gallons of gasoline	10,000 miles driven, with 2 people 352 gallons
Residual handling	93.4 gallons of gasoline 10 tons of non-hazardous waste	NA	106.6 gallons of diesel 10 tons of non-hazardous waste	67 gallons of diesel
Input water	220,000 gallons	NA	220,000 gallons	NA
Electricity	6,000,000 kWh	6,000,000 kWh	6,000,000 kWh	6,272,871 kWh for all equipment
Vapor phase GAC	20,000 pounds of virgin GAC	20,000 pounds of GAC	20,000 pounds of virgin GAC	20,000 lbs of virgin GAC with one cycle of reactivation
Equipment transport	233 gallons of diesel	80 gallons of diesel	249.9 gallons of diesel	244 gallons of diesel
Personnel transport	2,000 miles traveled by car 69 gallons of gasoline	8,000 miles traveled 533. gallons of gasoline	2,000 miles traveled 100 gallons of gasoline	2,000 miles traveled 68 gallons of gasoline
Laboratory analysis	$28,800	NA	$28,800	$28,200
Water disposal	1,000,000 gallons of water to wastewater treatment	NA	1,000,000 gallons of water to wastewater treatment	1,000,000 gallons of water to wastewater treatment

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TABLE 4-4

Summary of Total of ERD, ISCO, and ISTT Environmetnal Footprint and Subdivided Contributions for "Onsite", Electricity Generation, Transportation, and "Other"

Total

Metric	Units	SiteWise Calculation Total	SRT Calculation Total	SEFA Calculation Total	SimaPro Calculation Total	SiteWise Onsite	SRT Onsite	SEFA Onsite	SimaPro Onsite	SiteWise Electricity Generation	SRT Electricity Generation	SEFA Electricity Generation	SimaPro Electricity Generation
CO2e (tons)	MT	1.48E+01	2.34E+01	3.85E+01	2.79E+01	6.00E+00	9.09E-01	3.40E+00	5.44E+00	5.75E+00	2.20E+01	1.57E+01	1.61E+01
Nox (tons)	MT	5.69E+00	4.17E+01	4.50E+01	4.16E+01	7.59E-01	8.72E-04	3.67E-01	3.68E-01	2.94E+00	4.13E+01	3.54E+01	3.67E+01
SOx (tons)	MT	7.63E-01	7.81E+00	1.04E+00	9.90E+00	5.64E-01	4.33E-02	7.04E-02	3.20E-01		7.74E+00	2.64E-01	7.09E+00
PM (tons) 2.5 um EQ	MT	1.12E+05	6.70E+04	1.47E+05	1.74E+05	8.12E+03	1.54E+03	6.77E+03	9.72E+03	6.20E+04	6.25E+04	8.05E+04	7.74E+04
Energy (MMBTU)	MMBTU	1.83E+00	5.86E+01			1.25E+00	2.53E+00						
Lost Hours	Hours												
Cost	USD	7.10E-01	Not Calculated		1.00E+00	6.37E-01	5.30E-02		9.01E-01				
Injury Risk	Count	1.53E-03			3.40E-03	6.21E-04			1.65E-03				
Fatality Risk	Count												
Nat Resource Value	m2a		Not Calculated				6.00E+06						
Potable Water (onsite 1,000's of gal)	Gal (1000's)	5.06E+06			3.38E+07	2.00E+06			4.67E+03	3.06E+06			2.44E+05
All Water (on and offsite)	Gal (1000's)				2.90E+01								
Solid Waste (lbs)	MT												
Hazardous Waste (tons)	MT			6.70E+03	4.45E+03			5.59E+00	2.06E+01			6.47E+03	3.46E+03
Hazardous Air Pollutants (lbs)	Variable				2.47E+02				9.52E+00				2.27E+02
Lead released to air or water (lbs)	lbs				1.42E+00				2.74E-02				8.42E-01
Hg released to air or water (lbs)	lbs				1.27E-05				4.30E-08				3.67E-06
Dioxins released to air or water	lbs												
Ozone depletion	kg CFC-11 eq				9.37E+06				7.48E+05				5.83E+06
Global warming	kg CO2 eq				7.09E+05				1.36E+05				4.02E+05
Smog	kg O3 eq				3.45E+06				2.72E+05				2.59E+06
Acidification	mol H+ eq				4.39E+04				3.25E+02				2.15E+03
Eutrophication	kg N eq				2.27E-01				1.04E-02				3.21E-02
Carcinogenics	CTUh				-3.81E+00				9.88E-02				1.63E-01
Non carcinogenics	CTUh				9.90E+03				3.20E+02				7.09E+03
Respiratory effects	kg PM10 eq				1.28E+05				1.77E+01				9.23E+02
Water depletion	m3				1.00E+07				2.68E+02				6.80E+04
Metal depletion	kg Fe eq				2.63E+06				2.43E+05				1.83E+06
Fossil depletion	kg oil eq				1.00E+00				9.01E-01				
Social Impacts Injury	Count				3.40E-03				1.65E-03				
Social Impacts Fatality	Count				3.98E+06				1.89E+06				1.27E+06
Ecotoxicity	CTUe				1.84E+08				1.03E+07				8.18E+07
Energy, Total	MJ				4.16E+04				3.68E+02				3.67E+04
Sulfur Oxides	kg SOX				2.79E+04				5.44E+03				1.61E+04
Nitrogen Oxides	kg NOX				1.12E+02				4.32E+00				1.03E+02
Lead to Air and Water	kg Pb				6.45E-01				1.24E-02				3.82E-01
Mercury to Air and Water	kg Hg				5.78E-06				1.95E-08				1.67E-06
2378TCDD to Air and Water	kg 2378TCDD				2.02E+03				9.33E+00				1.57E+03

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TABLE 4-4

Summary of Total of ERD, ISCO, and ISTT Environmetnal Footprint and Subdivided Contributions for "Onsite", Electricity Generation, Transportation, and "Other"

Total									
		SiteWise	SRT	SEFA	SimaPro	SiteWise	SRT	SEFA	SimaPro
Metric	**Units**	**Transportation**	**Transportation**	**Transportation**	**Transportation**	**Other**	**Other**	**Other**	**Other**
CO2e (tons)	MT	2.74E-02	3.76E-01	7.21E-01	7.33E-01	3.06E+00	1.44E-01	1.87E+01	5.70E+00
Nox (tons)	MT	7.06E-04	7.18E-04	9.79E-02	9.27E-02	1.99E+00	3.85E-01	9.11E+00	4.41E+00
SOx (tons)	MT	3.72E-03	1.93E-02	1.20E-02	5.94E-02	1.95E-01	6.69E-03	6.99E-01	2.44E+00
PM (tons) 2.5 um EQ	MT	1.06E+03	1.34E+03	1.60E+03	1.81E+03	4.12E+04	1.58E+03	5.84E+04	8.50E+04
Energy (MMBTU)	MMBTU	5.84E-01	2.35E+01			3.10E-03	3.25E+01		
Lost Hours	Hours								
Cost	USD	7.32E-02	4.93E-01		1.01E-01		6.84E-01		
Injury Risk	Count	9.08E-04			1.76E-03				
Fatality Risk	Count								
Nat Resource Value	m2a								
Potable Water (onsite 1,000's of gal)	Gal (1000's)				9.91E+03				3.35E+07
All Water (on and offsite)	Gal (1000's)								2.90E+01
Solid Waste (lbs)	MT								
Hazardous Waste (tons)	MT			1.65E+00	2.60E+01			2.29E+02	9.50E+02
Hazardous Air Pollutants (lbs)	Variable				1.22E+00				9.04E+00
Lead released to air or water (lbs)	lbs				3.87E-03				5.48E-01
Hg released to air or water (lbs)	lbs				6.32E-09				9.01E-06
Dioxins released to air or water	lbs								
Ozone depletion	kg CFC-11 eq				1.38E+05				2.66E+06
Global warming	kg CO2 eq				1.84E+04				1.52E+05
Smog	kg O3 eq				3.89E+04				5.48E+05
Acidification	mol H+ eq				5.63E+01				4.13E+04
Eutrophication	kg N eq				1.35E-03				1.83E-01
Carcinogenics	CTUh				1.34E-02				-4.09E+00
Non carcinogenics	CTUh				5.94E+01				2.44E+03
Respiratory effects	kg PM10 eq				3.75E+01				1.27E+05
Water depletion	m3				4.27E+01				9.95E+06
Metal depletion	kg Fe eq				4.52E+04				5.13E+05
Fossil depletion	kg oil eq				1.01E-01				
Social Impacts Injury	Count				1.76E-03				
Social Impacts Fatality	Count				2.43E+05				5.82E+05
Ecotoxicity	CTUe				1.91E+06				8.97E+07
Energy, Total	MJ				9.27E+01				4.41E+03
Sulfur Oxides	kg SOX				7.33E+02				5.70E+03
Nitrogen Oxides	kg NOX				5.53E-01				4.10E+00
Lead to Air and Water	kg Pb				1.76E-03				2.49E-01
Mercury to Air and Water	kg Hg				2.87E-09				4.09E-06
2378TCDD to Air and Water	kg 2378TCDD				1.18E+01				4.31E+02

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Table Notes:
MT - Metric Tons
MMBTU - Million British Thermal Units
USD - US Dollars
KWhr - Kilowatt Hours
lbs - pounds
kg CFC-11 eq - kilograms chlorofluorocarbon 11 equivalents
kg CO2 eq - kilogram carbon dioxide equivalents
kg O3 eq - kilogram ozone equivalents
moe H+ eq - moles hyrogen ions equivalents
kg N eq - kilogram nitrogen equivalents
CTUh - comparative toxicity units humans
kg PM10 eq - kilogram particulate matter less than 10 micros equivalent
m3 - cubic meter
kg Fe eq - kilogram iron equivalent
kg oil eq - kilogram oil equivalent
CTUe - comparative toxicity unit ecotoxicity
MJ - million joules
kg SOX - kilogram sulfur oxides
kg NOX - kilogram nitrogen oxides
kg Pb - kilogram lead
kg Hg - kilogram mercury
kg 2378TCDD - kilogram 2,3,7,8-tetrachloro-dibenzo-paradioxin

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TABLE 4-5

Summary of ERD Environmetnal Footprint and Subdivided Contributions for "Onsite", Electricity Generation, Transportation, and "Other"

Metric	Units	SiteWise Calculation Total	SRT Calculation Total	SEFA Calculation Total	SimaPro Calculation Total	SiteWise Onsite	SRT Onsite	SEFA Onsite	SimaPro Onsite	SiteWise Electricity Generation	SRT Electricity Generation	SEFA Electricity Generation	SimaPro Electricity Generation
CO2e (tons)	MT	2.02E+03	6.29E+03	8.53E+03	2.48E+03	3.50E+02	8.00E+01	2.93E+02	4.30E+02				
Nox (tons)	MT	6.21E+00	9.75E-01	1.99E+01	8.08E+00	3.42E+00	6.48E-01	1.99E+00	3.25E+00				
SOx (tons)	MT	2.28E+00	2.61E-01	6.72E+00	2.94E+00	4.35E-01	6.22E-04	2.21E-01	2.02E-01				
PM (tons)	MT	5.01E-01	4.83E-02	4.92E-01	2.20E+00	3.23E-01	3.09E-02	4.05E-02	1.90E-01				
Energy (MMBTU)	MMBTU	3.69E+04	3.11E+03	5.13E+04	8.04E+04	4.96E+03	1.10E+03	4.02E+03	5.59E+03				
Lost Hours	Hours	1.15E+00	6.04E+00			6.97E-01	2.00E+00						
Cost	USD		Not Calculated										
Injury Risk	Count	1.44E-01	1.27E-01		6.73E-01	8.71E-02	4.20E-02		5.94E-01				
Fatality Risk	Count	1.05E-03			2.46E-03	3.46E-04			1.09E-03				
Nat Resource Value	m2a		Not Calculated										
Potable Water (onsite 1,000's of gal)	Gal	1.54E+07			1.54E+04	1.54E+07							
All Water (on and offsite)	Gal				3.07E+07				1.18E+03				
Solid Waste (lbs)	MT				2.90E+01								
Hazardous Air Pollutants (lbs)	Variable			1.87E+02	8.25E+02			3.40E+00	1.13E+01				
Lead released to air or water (lbs)	lbs				8.62E+00				5.50E+00				
Hg released to air or water (lbs)	lbs				4.29E-01				1.58E-02				
Dioxins released to air or water	lbs				6.21E-06				2.23E-08				
Ozone depletion	kg CFC-11 eq				5.63E-01				7.10E-03				
Global warming	kg CO2 eq				2.48E+06				4.30E+05				
Smog	kg O3 eq				2.12E+05				8.14E+04				
Acidification	mol H+ eq				5.84E+05				1.61E+05				
Eutrophication	kg N eq				4.04E+04				1.93E+02				
Carcinogenics	CTUh				3.39E-02				6.01E-03				
Non carcinogenics	CTUh				-4.07E+00				5.70E-02				
Respiratory effects	kg PM10 eq				2.20E+03				1.90E+02				
Water depletion	m3				1.16E+05				4.46E+00				
Metal depletion	kg Fe eq				1.15E+03				1.53E+02				
Fossil depletion	kg oil eq				4.52E+05				1.40E+05				
Social Impacts Injury	P				6.73E-01				5.94E-01				
Social Impacts Fatality	P				2.46E-03				1.09E-03				
Ecotoxicity	CTUe				2.18E+05				1.09E+06				
Energy, Total	MJ				8.49E+07				5.90E+06				
Sulfur Oxides	kg SOX				2.94E+03				2.02E+02				
Nitrogen Oxides	kg NOX				8.08E+03				3.25E+03				
Lead to Air and Water	kg Pb				3.91E+00				2.50E+00				
Mercury to Air and Water	kg Hg				1.95E-01				7.15E-03				
2378TCDD to Air and Water	kg 2378TCDD				2.82E-06				1.01E-08				

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TABLE 4-5

Summary of ERD Environmetnal Footprint and Subdivided Contributions for "Onsite", Electricity Generation, Transportation, and "Other"

Metric	Units	SiteWise Transportation	SRT Transportation	SEFA Transportation	SimaPro Transportation	SiteWise Other	SRT Other	SEFA Other	SimaPro Other
CO2e (tons)	MT	6.83E+01	6.72E+01	9.25E+01	1.14E+02	1.60E+03	6.14E+03	8.14E+03	1.94E+03
Nox (tons)	MT	2.28E-02	2.46E-01	5.58E-01	6.03E-01	2.77E+00	8.03E-02	1.74E+01	4.22E+00
SOx (tons)	MT	5.87E-04	5.29E-04	7.81E-02	7.68E-02	1.84E+00	2.60E-01	6.42E+00	2.66E+00
PM (tons)	MT	3.06E-03	1.29E-02	8.87E-03	4.91E-02	1.75E-01	4.46E-03	4.43E-01	1.96E+00
Energy (MMBTU)	MMBTU	8.81E+02	9.96E+02	1.25E+03	1.49E+03	3.11E+04	1.01E+03	4.60E+04	7.33E+04
Lost Hours	Hours	4.54E-01	2.02E+00				2.02E+00		
Cost	USD								
Injury Risk	Count	5.68E-02	4.24E-02		7.95E-02		4.30E-02		
Fatality Risk	Count	7.05E-04			1.37E-03				
Nat Resource Value	m2a								
Potable Water (onsite 1,000's of gal)	Gal								1.54E+04
All Water (on and offsite)	Gal				8.28E+03				3.06E+07
Solid Waste (lbs)	MT								2.90E+01
Hazardous Air Pollutants (lbs)	Variable			1.33E+00	2.17E+01			1.83E+02	7.92E+02
Lead released to air or water (lbs)	lbs				1.00E+00				2.12E+00
Hg released to air or water (lbs)	lbs				3.18E-03				4.10E-01
Dioxins released to air or water	lbs				5.21E-09				6.18E-06
Ozone depletion	kg CFC-11 eq				8.14E-03				5.47E-01
Global warming	kg CO2 eq				1.14E+05				1.94E+06
Smog	kg O3 eq				1.51E+04				1.15E+05
Acidification	mol H+ eq				3.20E+04				3.91E+05
Eutrophication	kg N eq				4.64E+01				4.02E+04
Carcinogenics	CTUh				1.10E-03				2.68E-02
Non carcinogenics	CTUh				1.10E-02				-4.14E+00
Respiratory effects	kg PM10 eq				4.91E+01				1.96E+03
Water depletion	m3				3.13E+01				1.16E+05
Metal depletion	kg Fe eq				3.52E+01				9.66E+02
Fossil depletion	kg oil eq				3.73E+04				2.74E+05
Social Impacts Injury	P				7.95E-02				
Social Impacts Fatality	P				1.37E-03				
Ecotoxicity	CTUe				1.99E+05				-1.07E+06
Energy, Total	MJ				1.57E+06				7.74E+07
Sulfur Oxides	kg SOX				7.68E+01				2.66E+03
Nitrogen Oxides	kg NOX				6.03E+02				4.22E+03
Lead to Air and Water	kg Pb				4.54E-01				9.61E-01
Mercury to Air and Water	kg Hg				1.44E-03				1.86E-01
2378TCDD to Air and Water	kg 2378TCDD				2.36E-09				2.81E-06

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Table Notes:
MT - Metric Tons
MMBTU - Million British Thermal Units
USD - US Dollars
KWhr - Kilowatt Hours
lbs - pounds
kg CFC-11 eq - kilograms chlorofluorocarbon 11 equivalents
kg CO2 eq - kilogram carbon dioxide equivalents
kg O3 eq - kilogram ozone equivalents
moe H+ eq - moles hyrogen ions equivalents
kg N eq - kilogram nitrogen equivalents
CTUh - comparative toxicity units humans
kg PM10 eq - kilogram particulate matter less than 10 micros equivalent
m3 - cubic meter
kg Fe eq - kilogram iron equivalent
kg oil eq - kilogram oil equivalent
CTUe - comparative toxicity unit ecotoxicity
MJ - million joules
kg SOX - kilogram sulfur oxides
kg NOX - kilogram nitrogen oxides
kg Pb - kilogram lead
kg Hg - kilogram mercury
kg 2378TCDD - kilogram 2,3,7,8-tetrachloro-dibenzo-paradioxin

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TABLE 4-6

Summary of ISCO Environmetnal Footprint and Subdivided Contributions for "Onsite", Electricity Generation, Transportation, and "Other"

Metric	Units	SiteWise Calculation Total	SRT Calculation Total	SEFA Calculation Total	SimaPro Calculation Total	SiteWise Onsite	SRT Onsite	SEFA Onsite	SimaPro Onsite	SiteWise Electricity Generation	SRT Electricity Generation	SEFA Electricity Generation	SimaPro Electricity Generation
CO2e (tons)	MT	5.24E+02	1.40E+03	5.96E+02	4.22E+02	2.49E+00		2.41E+00	1.58E+00				
Nox (tons)	MT	2.62E-02	4.87E-02	1.13E+00	8.87E-01	1.64E-02		1.70E-02	2.77E-02				
SOx (tons)	MT	7.01E-03	5.91E-05	2.27E+00	1.40E+00	2.43E-03		1.75E-03	7.98E-04				
PM (tons)	MT	1.49E-02	2.37E-03	2.29E-01	3.74E-01	1.82E-03		3.57E-04	1.72E-03				
Energy (MMBTU)	MMBTU	8.02E+03	1.07E+02	1.16E+04	7.19E+03	8.34E+01		3.29E+01	2.21E+01				
Lost Hours	Hours	5.28E-02	5.10E+01										
Cost	USD		Not Calculated										
Injury Risk	Count	6.60E-03	1.07E+00		6.10E-02				5.38E-02				
Fatality Risk	Count	8.21E-05			2.31E-04				9.85E-05				
Nat Resource Value	m2a		Not Calculated										
Potable Water (onsite 1,000's of gal)	Gal				4.76E+00								
All Water (on and offsite)	Gal	2.00E+06			2.82E+06	2.00E+06			4.76E+00				
Solid Waste (lbs)	MT												
Hazardous Air Pollutants (lbs)	Variable			1.20E+01	1.18E+02			2.62E-02	1.05E-01				
Lead released to air or water (lbs)	lbs				1.18E+00				2.18E-02				
Hg released to air or water (lbs)	lbs				1.04E-01				6.24E-05				
Dioxins released to air or water	lbs				2.04E-07				8.84E-11				
Ozone depletion	kg CFC-11 eq	5.45E-04			3.23E-02				2.97E-05				
Global warming	kg CO2 eq	1.24E+04			4.22E+05				1.58E+03				
Smog	kg O3 eq	1.84E+03			2.24E+04				6.90E+02				
Acidification	mol H+ eq	3.81E+03			1.11E+05				1.23E+03				
Eutrophication	kg N eq	5.03E+00			1.22E+03				1.42E+00				
Carcinogenics	CTUh	1.47E-04			1.33E-02				2.39E-05				
Non carcinogenics	CTUh	1.42E-03			3.87E-02				2.26E-04				
Respiratory effects	kg PM10 eq	4.97E+00			3.74E+02				1.72E+00				
Water depletion	m3	1.77E+00			1.07E+04				1.80E-02				
Metal depletion	kg Fe eq	4.12E+00			9.95E+06				6.04E-01				
Fossil depletion	kg oil eq	4.06E+03			1.29E+05				5.55E+02				
Social Impacts Injury	P	7.24E-03			6.10E-02				5.38E-02				
Social Impacts Fatality	P	1.32E-04			2.31E-04				9.85E-05				
Ecotoxicity	CTUe	2.66E+04			2.68E+05				4.32E+03				
Energy, Total	MJ	1.71E+05			7.60E+06				2.34E+04				
Sulfur Oxides	kg SOX	7.09E+00			1.40E+03				7.98E-01				
Nitrogen Oxides	kg NOX	7.34E+01			8.87E+02				2.77E+01				
Lead to Air and Water	kg Pb	6.08E-02			5.33E-01				9.88E-03				
Mercury to Air and Water	kg Hg	1.82E-04			4.73E-02				2.83E-05				
2378TCDD to Air and Water	kg 2378TCDD	2.75E-10			9.26E-08				4.01E-11				

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TABLE 4-6

Summary of ISCO Environmetnal Footprint and Subdivided Contributions for "Onsite", Electricity Generation, Transportation, and "Other"

Metric	Units	SiteWise	SRT	SEFA	SimaPro	SiteWise	SRT	SEFA	SimaPro
		Transportation	Transportation	Transportation	Transportation	Other	Other	Other	Other
CO2e (tons)	MT	3.88E+00	7.56E+00	8.86E+00	1.24E+01	5.18E+02	1.39E+03	5.85E+02	4.08E+02
Nox (tons)	MT	1.28E-03	4.87E-02	6.18E-02	7.34E-02	8.46E-03		1.05E+00	7.86E-01
SOx (tons)	MT	3.02E-05	5.91E-05	6.39E-03	7.09E-03	4.55E-03		2.27E+00	1.40E+00
PM (tons)	MT	1.63E-04	2.37E-03	1.48E-03	4.97E-03	1.29E-02		2.27E-01	3.68E-01
Energy (MMBTU)	MMBTU	5.01E+01	1.07E+02	1.22E+02	1.62E+02	7.89E+03		1.15E+04	7.01E+03
Lost Hours	Hours	5.28E-02	2.10E+01				3.00E+01		
Cost	USD								
Injury Risk	Count	6.60E-03	4.40E-01		7.24E-03		6.30E-01		
Fatality Risk	Count	8.21E-05			1.32E-04				
Nat Resource Value	m2a								
Potable Water (onsite 1,000's of gal)	Gal								
All Water (on and offsite)	Gal				4.67E+02				2.82E+06
Solid Waste (lbs)	MT								
Hazardous Air Pollutants (lbs)	Variable			9.68E-02	1.33E+00			1.19E+01	1.17E+02
Lead released to air or water (lbs)	lbs				1.34E-01				1.02E+00
Hg released to air or water (lbs)	lbs				4.01E-04				1.04E-01
Dioxins released to air or water	lbs				6.06E-10				2.03E-07
Ozone depletion	kg CFC-11 eq				5.45E-04				3.17E-02
Global warming	kg CO2 eq				1.24E+04				4.08E+05
Smog	kg O3 eq				1.84E+03				1.99E+04
Acidification	mol H+ eq				3.81E+03				1.06E+05
Eutrophication	kg N eq				5.03E+00				1.22E+03
Carcinogenics	CTUh				1.47E-04				1.32E-02
Non carcinogenics	CTUh				1.42E-03				3.71E-02
Respiratory effects	kg PM10 eq				4.97E+00				3.68E+02
Water depletion	m3				1.77E+00				1.07E+04
Metal depletion	kg Fe eq				4.12E+00				9.95E+06
Fossil depletion	kg oil eq				4.06E+03				1.25E+05
Social Impacts Injury	P				7.24E-03				
Social Impacts Fatality	P				1.32E-04				
Ecotoxicity	CTUe				2.66E+04				2.37E+05
Energy, Total	MJ				1.71E+05				7.40E+06
Sulfur Oxides	kg SOX				7.09E+00				1.40E+03
Nitrogen Oxides	kg NOX				7.34E+01				7.86E+02
Lead to Air and Water	kg Pb				6.08E-02				4.62E-01
Mercury to Air and Water	kg Hg				1.82E-04				4.71E-02
2378TCDD to Air and Water	kg 2378TCDD				2.75E-10				9.23E-08

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Table Notes:

MT - Metric Tons
MMBTU - Million British Thermal Units
USD - US Dollars
KWhr - Kilowatt Hours
lbs - pounds
kg CFC-11 eq - kilograms chlorofluorocarbon 11 equivalents
kg CO2 eq - kilogram carbon dioxide equivalents
kg O3 eq - kilogram ozone equivalents
moe H+ eq - moles hyrogen ions equivalents
kg N eq - kilogram nitrogen equivalents
CTUh - comparative toxicity units humans
kg PM10 eq - kilogram particulate matter less than 10 micros equivalent
m3 - cubic meter
kg Fe eq - kilogram iron equivalent
kg oil eq - kilogram oil equivalent
CTUe - comparative toxicity unit ecotoxicity
MJ - million joules
kg SOX - kilogram sulfur oxides
kg NOX - kilogram nitrogen oxides
kg Pb - kilogram lead
kg Hg - kilogram mercury
kg 2378TCDD - kilogram 2,3,7,8-tetrachloro-dibenzo-paradioxin

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TABLE 4-7

Summary of ISTT Environmetnal Footprint and Subdivided Contributions for "Onsite", Electricity Generation, Transportation, and "Other"

Metric	Units	SiteWise Calculation Total	SRT Calculation Total	SEFA Calculation Total	SimaPro Calculation Total	SiteWise Onsite	SRT Onsite	SEFA Onsite	SimaPro Onsite	SiteWise Electricity Generation	SRT Electricity Generation	SEFA Electricity Generation	SimaPro Electricity Generation
CO2e (tons)	MT	4.57E+03	3.79E+03	5.82E+03	6.47E+03	2.55E+02	3.21E+01	1.98E+02	3.17E+02	3.88E+03	3.65E+03	5.52E+03	5.83E+03
Nox (tons)	MT	8.60E+00	2.24E+01	1.75E+01	1.90E+01	2.57E+00	2.60E-01	1.39E+00	2.16E+00	5.75E+00	2.20E+01	1.57E+01	1.61E+01
SOx (tons)	MT	3.41E+00	4.15E+01	3.60E+01	3.72E+01	3.21E-01	2.50E-04	1.44E-01	1.66E-01	2.94E+00	4.13E+01	3.54E+01	3.67E+01
PM (tons)	MT	2.48E-01	7.76E+00	3.24E-01	7.33E+00	2.40E-01	1.24E-02	2.95E-02	1.28E-01		7.74E+00	2.64E-01	7.09E+00
Energy (MMBTU)	MMBTU	6.74E+04	6.38E+04	8.43E+04	8.64E+04	3.07E+03	4.42E+02	2.72E+03	4.11E+03	6.20E+04	6.25E+04	8.05E+04	7.74E+04
Lost Hours	Hours	6.31E-01	1.59E+00			5.50E-01	5.30E-01						
Cost	USD		Not Calculated										
Injury Risk	Count	5.60E-01	3.30E-02		2.68E-01	5.50E-01	1.10E-02		2.54E-01				
Fatality Risk	Count	3.96E-04			7.18E-04	2.75E-04			4.64E-04				
Nat Resource Value	m2a		Not Calculated										
Potable Water (onsite 1,000's of gal)	Gal												
All Water (on and offsite)	Gal	3.06E+06			3.30E+05				3.49E+03	3.06E+06			2.44E+05
Solid Waste (lbs)	MT												
Hazardous Air Pollutants (lbs)	Variable			6.50E+03	3.51E+03			2.16E+00	9.14E+00			6.47E+03	3.46E+03
Lead released to air or water (lbs)	lbs				2.37E+02				3.99E+00				2.27E+02
Hg released to air or water (lbs)	lbs				8.88E-01				1.16E-02				8.42E-01
Dioxins released to air or water	lbs				6.32E-06				2.06E-08				3.67E-06
Ozone depletion	kg CFC-11 eq				6.61E-02				5.29E-03				1.58E-02
Global warming	kg CO2 eq				6.47E+06				3.17E+05				5.83E+06
Smog	kg O3 eq				4.75E+05				5.41E+04				4.02E+05
Acidification	mol H+ eq				2.76E+06				1.10E+05				2.59E+06
Eutrophication	kg N eq				2.22E+03				1.31E+02				2.15E+03
Carcinogenics	CTUh				1.80E-01				4.39E-03				3.21E-02
Non carcinogenics	CTUh				2.22E-01				4.15E-02				1.63E-01
Respiratory effects	kg PM10 eq				7.33E+03				1.28E+02				7.09E+03
Water depletion	m3				1.25E+03				1.32E+01				9.23E+02
Metal depletion	kg Fe eq				6.83E+04				1.15E+02				6.80E+04
Fossil depletion	kg oil eq				2.05E+06				1.03E+05				1.83E+06
Social Impacts Injury	P				2.68E-01				2.54E-01				
Social Impacts Fatality	P				7.18E-04				4.64E-04				
Ecotoxicity	CTUe				3.49E+06				7.91E+05				1.27E+06
Energy, Total	MJ				9.12E+07				4.34E+06				8.18E+07
Sulfur Oxides	kg SOX				3.72E+04				1.66E+02				3.67E+04
Nitrogen Oxides	kg NOX				1.90E+04				2.16E+03				1.61E+04
Lead to Air and Water	kg Pb				1.07E+02				1.81E+00				1.03E+02
Mercury to Air and Water	kg Hg				4.03E-01				5.26E-03				3.82E-01
2378TCDD to Air and Water	kg 2378TCDD				2.87E-06				9.33E-09				1.67E-06

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TABLE 4-7

Summary of ISTT Environmetnal Footprint and Subdivided Contribut
Electricity Generation, Transportation, and "Other"

Metric	Units	SiteWise	SRT	SEFA	SimaPro	SiteWise	SRT	SEFA	SimaPro
		Transportation	Transportation	Transportation	Transportation	Other	Other	Other	Other
CO2e (tons)	MT	9.93E+00	1.66E+01	1.63E+01	1.17E+01	4.25E+02	9.55E+01	9.46E+01	3.13E+02
Nox (tons)	MT	3.37E-03	8.08E-02	1.01E-01	5.67E-02	2.81E-01	6.39E-02	2.40E-01	6.94E-01
SOx (tons)	MT	8.93E-05	1.30E-04	1.34E-02	8.84E-03	1.44E-01	1.25E-01	4.22E-01	3.59E-01
PM (tons)	MT	4.97E-04	4.06E-03	1.64E-03	5.34E-03	7.15E-03	2.23E-03	2.91E-02	1.07E-01
Energy (MMBTU)	MMBTU	1.29E+02	2.41E+02	2.21E+02	1.54E+02	2.19E+03	5.71E+02	8.39E+02	4.67E+03
Lost Hours	Hours	7.74E-02	5.30E-01			3.10E-03	5.30E-01		
Cost	USD								
Injury Risk	Count	9.77E-03	1.10E-02		1.45E-02		1.10E-02		
Fatality Risk	Count	1.21E-04			2.54E-04				
Nat Resource Value	m2a								
Potable Water (onsite 1,000's of gal)	Gal								
All Water (on and offsite)	Gal				1.17E+03				8.18E+04
Solid Waste (lbs)	MT								
Hazardous Air Pollutants (lbs)	Variable			2.26E-01	2.99E+00			3.45E+01	4.12E+01
Lead released to air or water (lbs)	lbs				8.53E-02				5.91E+00
Hg released to air or water (lbs)	lbs				2.89E-04				3.40E-02
Dioxins released to air or water	lbs				5.10E-10				2.62E-06
Ozone depletion	kg CFC-11 eq				1.09E-03				4.39E-02
Global warming	kg CO2 eq				1.17E+04				3.13E+05
Smog	kg O3 eq				1.42E+03				1.73E+04
Acidification	mol H+ eq				3.07E+03				5.16E+04
Eutrophication	kg N eq				4.82E+00				-6.43E+01
Carcinogenics	CTUh				9.49E-05				1.43E-01
Non carcinogenics	CTUh				9.73E-04				1.68E-02
Respiratory effects	kg PM10 eq				5.34E+00				1.07E+02
Water depletion	m3				4.41E+00				3.10E+02
Metal depletion	kg Fe eq				3.43E+00				1.66E+02
Fossil depletion	kg oil eq				3.86E+03				1.14E+05
Social Impacts Injury	P				1.45E-02				
Social Impacts Fatality	P				2.54E-04				
Ecotoxicity	CTUe				1.70E+04				1.42E+06
Energy, Total	MJ				1.63E+05				4.93E+06
Sulfur Oxides	kg SOX				8.84E+00				3.59E+02
Nitrogen Oxides	kg NOX				5.67E+01				6.94E+02
Lead to Air and Water	kg Pb				3.87E-02				2.68E+00
Mercury to Air and Water	kg Hg				1.31E-04				1.54E-02
2378TCDD to Air and Water	kg 2378TCDD				2.31E-10				1.19E-06

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Table Notes:
MT - Metric Tons
MMBTU - Million British Thermal Units
USD - US Dollars
KWhr - Kilowatt Hours
lbs - pounds
kg CFC-11 eq - kilograms chlorofluorocarbon 11 equivalents
kg CO2 eq - kilogram carbon dioxide equivalents
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moe H+ eq - moles hyrogen ions equivalents
kg N eq - kilogram nitrogen equivalents
CTUh - comparative toxicity units humans
kg PM10 eq - kilogram particulate matter less than 10 micros equivalent
m3 - cubic meter
kg Fe eq - kilogram iron equivalent
kg oil eq - kilogram oil equivalent
CTUe - comparative toxicity unit ecotoxicity
MJ - million joules
kg SOX - kilogram sulfur oxides
kg NOX - kilogram nitrogen oxides
kg Pb - kilogram lead
kg Hg - kilogram mercury
kg 2378TCDD - kilogram 2,3,7,8-tetrachloro-dibenzo-paradioxin

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TABLE 4-8
Summary of Top 3 Environmental Footprint Contributors to Each Remediation Component

ERD

CO2e (metric tons)								
Rank	SiteWise		SRT		SEFA		SimaPro	
1	Lab Analysis	781	Substrate	6100	Substrate	7273	Substrate	1770
2	Substrate	714	Onsite	80	Lab Analysis	602	Onsite	430
3	On-Site	351	Transport	67.2	On-Site	293	Transportation	114

Energy (MMBTU)								
Rank	SiteWise		SRT		SEFA		SimaPro	
1	Substrate	17000	Onsite	1100	Substrate	36744	Substrate	74000
2	Lab Analysis	11700	PVC	992	Lab Analysis	8614	Onsite	5590
3	On-Site	5953	Transport	996	On-Site	4020	Transportation	1490

NOx (metric tons)								
Rank	SiteWise		SRT		SEFA		SimaPro	
1	On-Site	3.5	Onsite	0.65	Substrate	14	Substrate	4.05
2	Lab Analysis	2.7	Transport	0.246	Lab Analysis	2.9	Onsite	3.25
3	Potable Water	0.066	PVC	0.077	On-Site	2.0	Transportation	0.63

SOx (metric tons)								
Rank	SiteWise		SRT		SEFA		SimaPro	
1	Lab Analysis	1.80	PVC	0.256	Substrate	4.1	Substrate	2.26
2	On-Site	0.47	Steel	0.0037	Lab Analysis	2.2	Onsite	0.2
3	Potable Water	0.035	Onsite	0.0006	On-Site	0.22	Transportation	0.077

PM10 (metric tons)								
Rank	SiteWise		SRT		SEFA		SimaPro	
1	On-Site	0.42	Onsite	0.031	Lab Analysis	0.24	Substrate	1.87
2	Lab Analysis	0.069	Transportation	0.013	Substrate	0.071	Onsite	0.19
3	Disposal	0.005	Steel	0.0044	On-Site	0.041	Transportation	0.049

ISTT

CO2e (metric tons)								
Rank	SiteWise		SRT		SEFA		SimaPro	
1	Electricity	3989	Electricity	3650	Electricity	10260	Electricity	5830
2	On-Site	255	Steel	60.6	On-Site	198	Onsite	317
3	GAC	227	Onsite	32.1	GAC	77	GAC	160

Energy (MMBTU)								
Rank	SiteWise		SRT		SEFA		SimaPro	
1	Electricity	62000	Electricity	62500	Electricity	80500	Electricity	77400
2	On-Site	3100	Onsite	442	On-Site	2720	GAC	2560
3	GAC	1000	Steel	339	GAC	300	Onsite	4110

NOx (metric tons)								
Rank	SiteWise		SRT		SEFA		SimaPro	
1	Electricity	6.0	Electricity	22	Electricity	29	Electricity	16.1
2	On-Site	2.57	Onsite	0.26	On-Site	1.39	Onsite	2.16
3	POTW	0.22	Transport	0.081	GAC	0.13	GAC	0.417

SOx (metric tons)								
Rank	SiteWise		SRT		SEFA		SimaPro	
1	Electricity	3.0	Electricity	41.3	Electricity	67.6	Electricity	36.7
2	On-Site	0.32	PVC	0.06	GAC	0.31	GAC	0.22
3	POTW	0.1	Steel	0.0037	Lab Analysis	0.047	Onsite	0.166

PM10 (metric tons)								
Rank	SiteWise		SRT		SEFA		SimaPro	
1	On-Site	0.24	Electricity	7.74	Electricity	0.26	Electricity	7.09
2	POTW	0.0024	Onsite	0.0124	On-Site	0.027	Onsite	0.128
3	Disposal	0.0018	Steel	0.0046	Steel	0.008	GAC	0.06

ISCO

CO2e (metric tons)								
Rank	SiteWise		SRT		SEFA		SimaPro	
1	Permanganate	513	Permanganate	1390	Permanganate	581	Permanganate	406
2	On-Site	216	Transportation	7.56	Transportation	8.9	Transportation	12.4
3	Transportation	3.8	N/A	N/A	Public Water	4.5	Onsite	1.58

Energy (MMBTU)								
Rank	SiteWise		SRT		SEFA		SimaPro	
1	Permanganate	7800	Transport	107	Permanganate	11475	Permanganate	6977
2	On-Site	110	N/A	N/A	Transportation	122	Onsite	162
3	Transportation	51	N/A	N/A	On-Site	29	Transportation	177

NOx (metric tons)								
Rank	SiteWise		SRT		SEFA		SimaPro	
1	On-Site	0.45	Transportation	0.049	Permanganate	1.041289	Permanganate	0.782
2	Transportation	0.0013	N/A	N/A	Transportation	0.062	Transportation	0.0734
3	NA		N/A	N/A	On-Site	0.016	Onsite	0.0277

SOx (metric tons)								
Rank	SiteWise		SRT		SEFA		SimaPro	
1	On-Site	0.21	Transportation	0.00006	Permanganate	2.256352	Permanganate	1.4
2	Transportation	3E-05	N/A	N/A	Transportation	0.0064	Transportation	0.0071
3	NA		N/A	N/A	Public Water	0.0053	Onsite	0.0002

PM10 (metric tons)								
Rank	SiteWise		SRT		SEFA		SimaPro	
1	On-Site	0.0066	Transportation	0.0024	Permanganate	0.211887	Permanganate	0.368
2	Transportation	0.0002	N/A	N/A	Transportation	0.0015	Transportation	0.005
3	NA		N/A	N/A	Public Water	0.014	Onsite	0.0017

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TABLE 4-9
Most Significant Contributors, by Impact Category - SimaPro

Impact Category	Notable Contributor 1	Notable Contributor 2	Notable Contributor 3	Balance
GWP	Electricity for ISTT 62%	Substrate production 19%	Drilling 5%	14%
Acidification	Electricity for ISTT 75%	Substrate production 11%	Drilling 7%	7%
Smog	Electricity for ISTT 57%	Drilling 17%	Substrate production 16%	10%
Eutrophication	Substrate production – 92%			8%
Respiratory Impacts	Electricity for ISTT – 72%	Substrate production – 19%		9%
Carcinogens	Steel – 67%	Electricity for ISTT – 14%	Potassium permanganate – 6%	87%
Water depletion	“Onsite” water for ERD delivery – 59%	Water for soybean production - 38%		3%

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TABLE 4-10

Recommendations to Reduce the GSCP Project Footprint, Based on Tool Result

Item No.	Recommendation Narrative	SiteWise	SRT	EPA SEFA	SimaPro
1	The majority of the CO2e, NOx, SOx, PM, and energy footprint is attributable electricity generation associated with ISTT treatment. It is impracticable to construct and operate an onsite renewable energy system at Grants for a project with a short operating duration (planned as less than nine-months). However, Renewable Energy Certificates (RECs) could be purchased to offset these footprints. RECs could be purchased for approximately $0.85/MWhr.	x	x	x	x
1a	Other options to reduce the ISTT footprint include careful monitoring of the system to assure it doesn't operate longer than necessary to meet cleanup targets for the technology.	x	x	x	x
2	Laboratory analysis is a noticeable contributor of the CO2e and energy footprint; optimization of the sampling program to only collect samples necessary for system evaluation and compliance could reduce these footprints. *In the case of SimaPro, laboratory analysis was evalauted but was considered a minor environmental footprint.*	x		x	
3	Substrate is also a significant contributor to the CO2e and energy footprint. As the ERD delivery phase of the project is expected to run for 10 years, periodic evaluation of alternate substrates should be completed to assure a substrate with the lowest footprint is used while meeting cleanup goals.	x	x	x	x
3a	Substrate also is a noticeable contributor to GWP, acidification, smog, and respiratory impacts categories. Decreasing substrate demand will reduce the footprint of these impact categories.				x
3b	The high sulfate conditions at the site may create a secondary benefit of producing iron sulfide in the barriers that could support abiotic reduction of chlorinated ethenes, thusly reducing the potential demand of substrate addition and the environmental impacts of substrate production.	x	x	x	x
3c	The substrate additions should be optimized, based on previous field data, to assure overdosing is not occurring or at a frequency greater than necessary. Additionally, consideration could be given to sourcing substrate with a lower environmental footprint.	x	x	x	x
3d	The life cycle of soybeans used in the emulsified substrate indicates a high water footprint associated vegetable oil productoin. Alternate source of vegetable oil may reduce the embedded water footprint.			x	x
3e	The life cycle of soybeans used in the emulsified substrate indicates has a substantive impact on eutrophication, due to the runoff associated with soybean growth. The use of recylced oil in the substrate formulation may reduce the embedded water associated with soybean growth				x
4	Potassium permanganate is a noticeable contributor to the CO2e footprint. Identifying a source of potassium permanganate from a supplier that manufactures their product with a smaller environmental footprint may result in a significant reduction of the CO2e footprint. Additionally, evaluation of other oxidants might lead the identification of a lower footprint oxidant that meets treatment objectives. *In the case of SimaPro, the optimization of sourcing an oxidant avoids impacts in a number of environmental impact categories.*	x	x	x	x
5	The ERD phase is projected to utilize a significant volume of potable water. The site is located in an area with significant water needs. The use of non-potable water (e.g., site groundwater, effluent from the local wastewater treatment plant) could reduce the requirement for potable water.	x		x	x
6	Onsite activities and transportation activities that utilize diesel fuel impact CO2 emissions. Reductions in fuel use results in commensurate reduction of CO2 emissions. *In the case of SimaPro, diesel fuel reduction results in commensurate footprint reductions in GWP, acidification, smog, respiratory impacts, and carcinogen impact categories.*	x	x	x	x
7	Hazardous air pollutant emissions are primarily from electricity generation. (The specific emissions are not reported as a model output for SEFA; specific emissions are available for SimaPro).			x	x

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Figures

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FIGURE 3-1
ISTT, ISCO, and ERD Treatment Locations

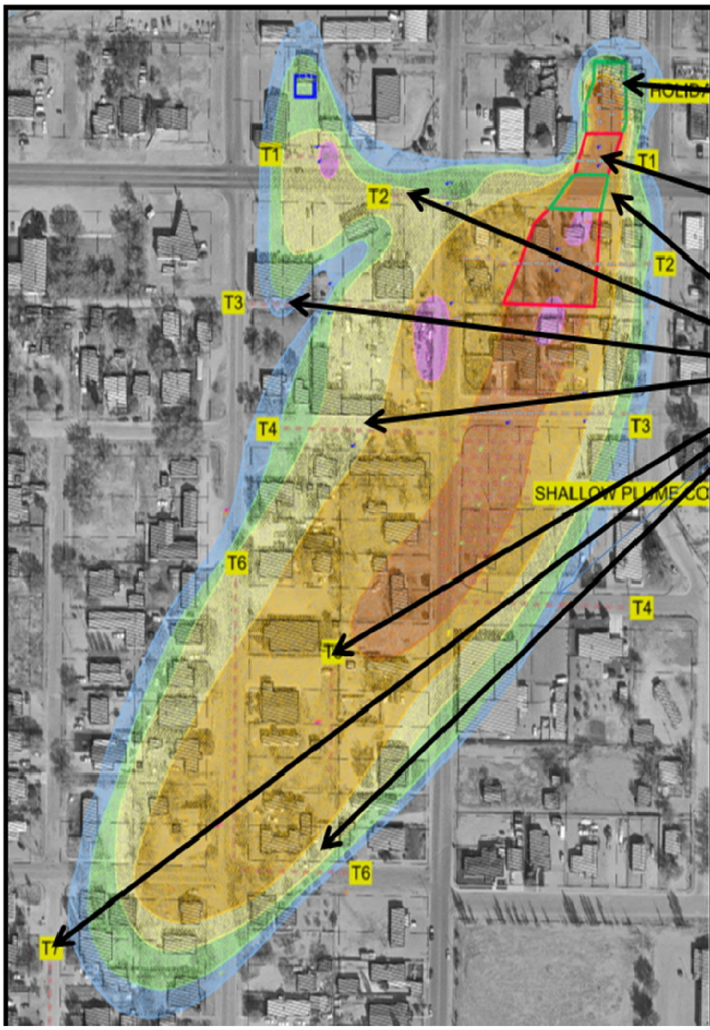
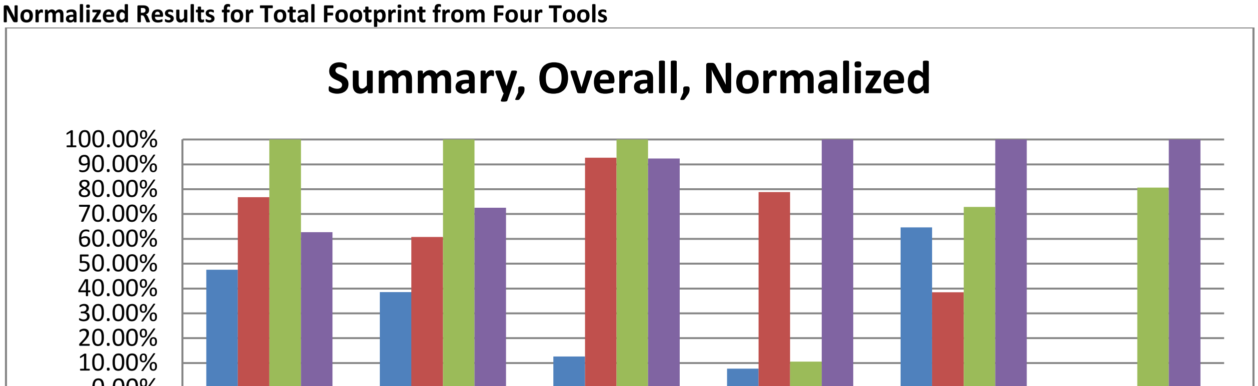


FIGURE 4-1
Normalized Results for Total Footprint from Four Tools

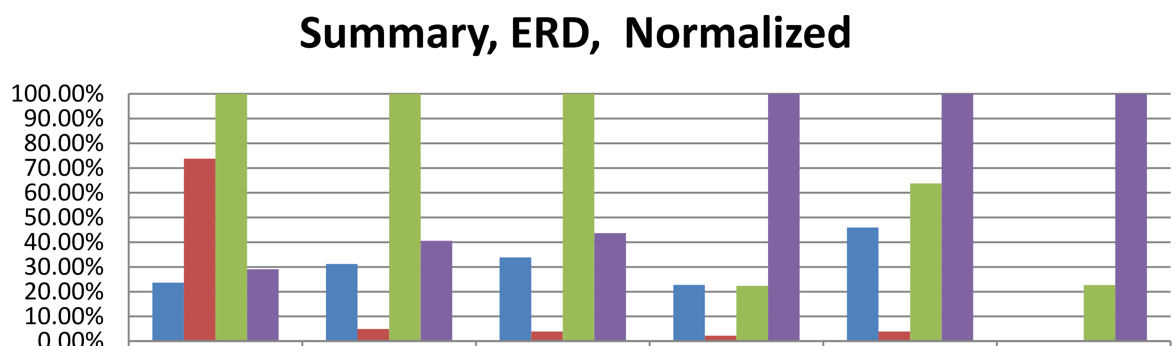


	CO2	NOX	SOX	PM	MBTU	HAPS
SiteWise	47.59%	38.55%	12.65%	7.71%	64.61%	0.00%
SRT	76.77%	60.75%	92.71%	78.83%	38.50%	0.00%
SEFA	100.00%	100.00%	100.00%	10.55%	72.86%	80.67%
SimaPro	62.71%	72.56%	92.39%	100.00%	100.00%	100.00%

Note - All graphical results are normalized against the highest result for the specific reporting metric.

FIGURE 4-2

Normalized Results for ERD Remedy from Four Tools

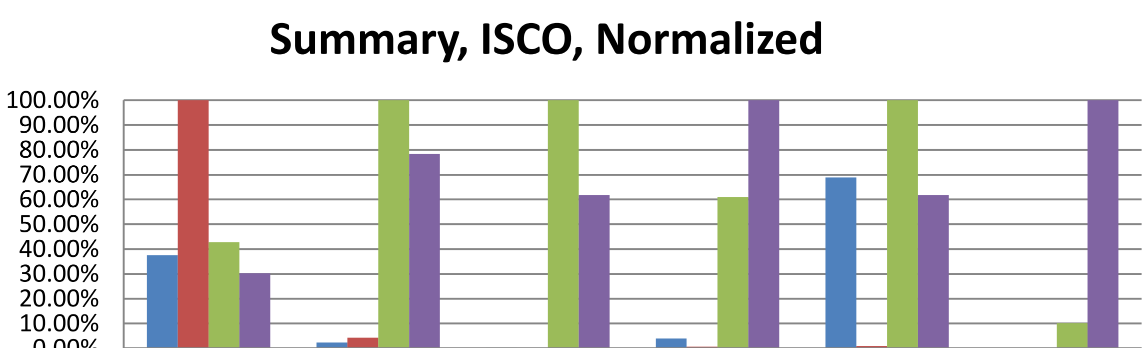


	CO2	NOX	SOX	PM	MBTU	HAPS
SiteWise	23.65%	31.20%	33.86%	22.74%	45.95%	0.00%
SRT	73.76%	4.90%	3.89%	2.19%	3.87%	0.00%
SEFA	100.00%	100.00%	100.00%	22.35%	63.81%	22.71%
SimaPro	29.09%	40.57%	43.71%	100.00%	100.00%	100.00%

Note - All graphical results are normalized against the highest result for the specific reporting metric.

FIGURE 4-3

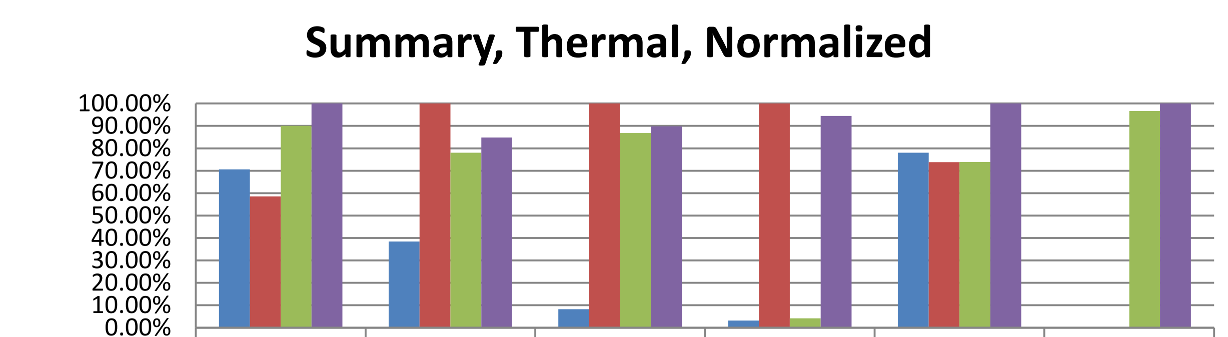
Normalized Results for ISCO Remedy from Four Tools



	CO2	NOX	SOX	PM	MBTU	HAPS
SiteWise	37.57%	2.31%	0.31%	3.98%	68.89%	0.00%
SRT	100.00%	4.31%	0.00%	0.63%	0.92%	0.00%
EPA R9 WS	42.75%	100.00%	100.00%	61.02%	100.00%	10.15%
SimaPro	30.27%	78.45%	61.75%	100.00%	61.76%	100.00%

Note - All graphical results are normalized against the highest result for the specific reporting metric.

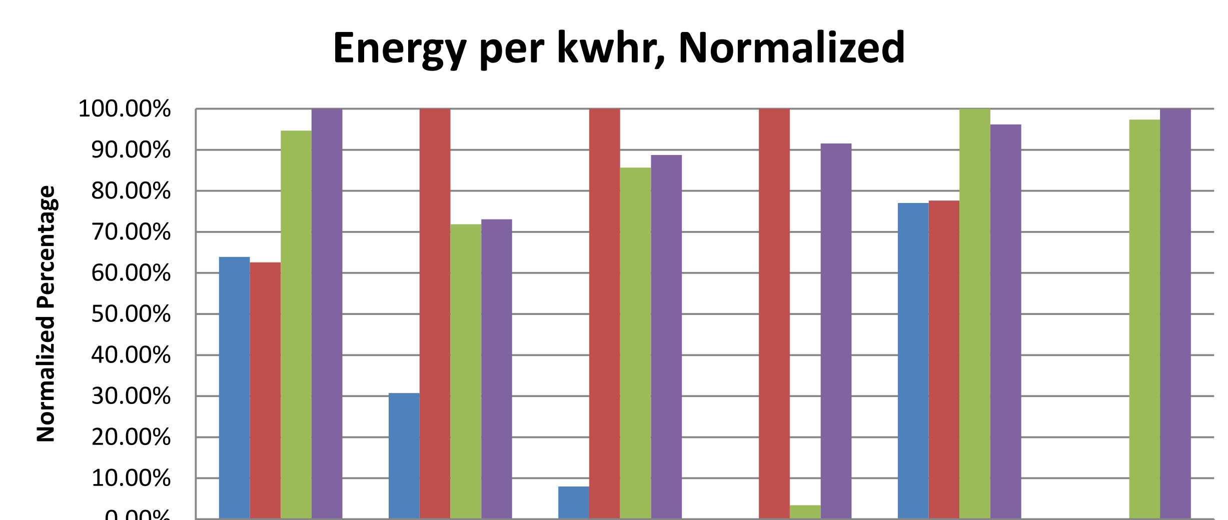
FIGURE 4-4
Normalized Results for ISTT Remedy from Four Tools



	CO2	NOX	SOX	PM	MBTU	HAPS
SiteWise	70.65%	38.46%	8.22%	3.19%	78.07%	0.00%
SRT	58.58%	100.00%	100.00%	100.00%	73.82%	0.00%
EPA R9 WS	90.01%	78.05%	86.84%	4.18%	73.87%	96.66%
SimaPro	100.00%	84.81%	89.80%	94.46%	100.00%	100.00%

Note - All graphical results are normalized against the highest result for the specific reporting metric.

FIGURE 4-5
Emissions and Energy Reported, per KWh Used, for Each Tool

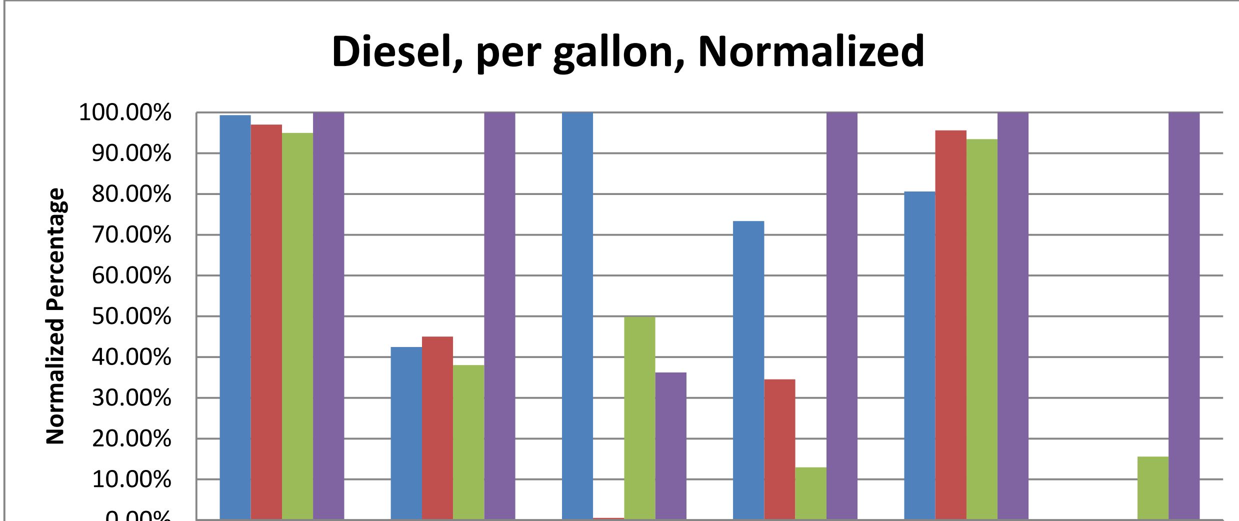


	CO2e	NOX	SOX	PM	MBTU	HAPS
SiteWise	63.93%	30.73%	7.99%	0.00%	77.06%	0.00%
SRT	62.58%	100.00%	100.00%	100.00%	77.64%	0.00%
EPA R9 WS	94.66%	71.87%	85.69%	3.43%	100.00%	97.37%
SimaPro	100.00%	73.08%	88.74%	91.53%	96.21%	100.00%

Note - All graphical results are normalized against the highest result for the specific reporting metric.

FIGURE 4-6

Emissions and Energy Reported, per Gallon of Diesel Fuel Used, for Each Tool

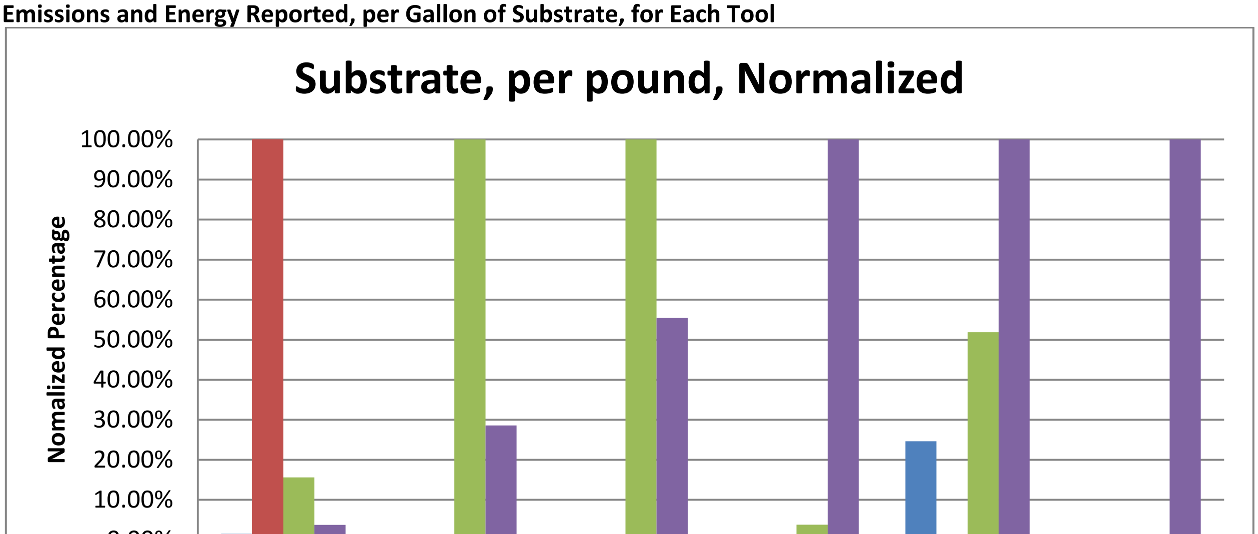


	CO2e	NOX	SOX	PM	MBTU	HAPS
SiteWise	99.36%	42.47%	100.00%	73.36%	80.62%	0.00%
SRT	97.04%	45.02%	0.54%	34.53%	95.61%	0.00%
SEFA	95.00%	38.04%	49.84%	12.97%	93.47%	15.59%
SimaPro	100.00%	100.00%	36.24%	100.00%	100.00%	100.00%

Note - All graphical results are normalized against the highest result for the specific reporting metric.

FIGURE 4-7

Emissions and Energy Reported, per Gallon of Substrate, for Each Tool

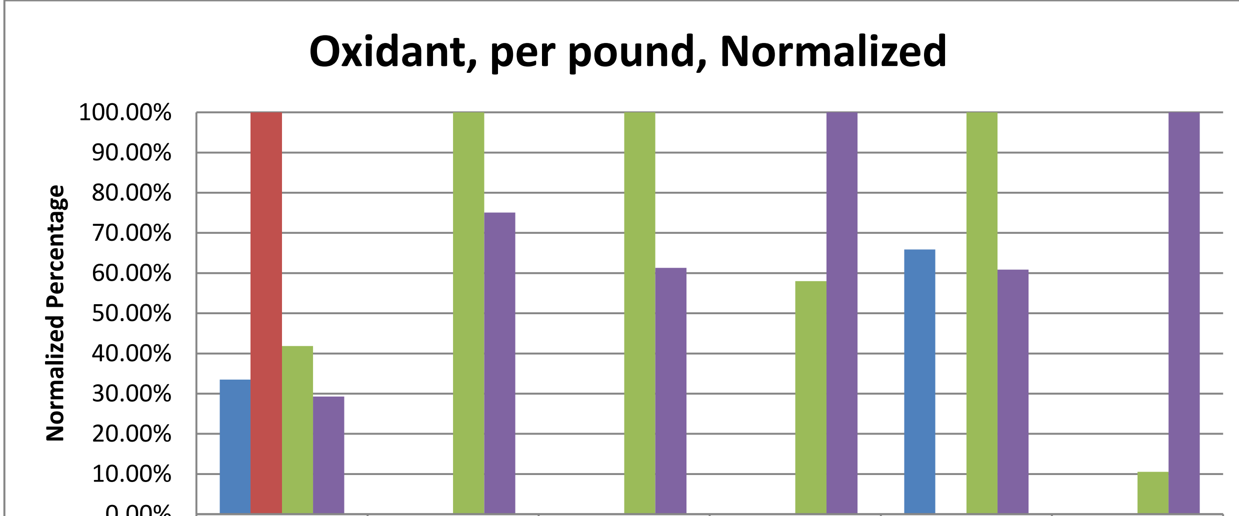


	CO2e	NOX	SOX	PM	MBTU	HAPS
SiteWise	1.49%	0.00%	0.00%	0.00%	24.63%	0.00%
SRT	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%
SEFA	15.61%	100.00%	100.00%	3.79%	51.88%	0.00%
SimaPro	3.74%	28.57%	55.45%	100.00%	100.00%	100.00%

Note - All graphical results are normalized against the highest result for the specific reporting metric.

FIGURE 4-8

Emissions and Energy Reported, per Pound Oxidant, for Each Tool

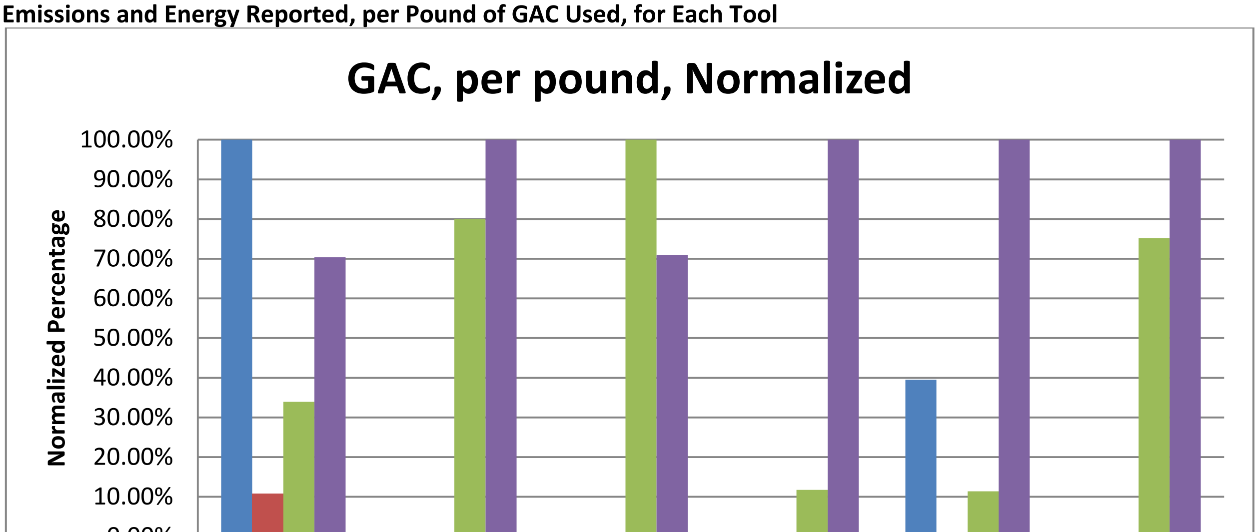


	CO2e	NOX	SOX	PM	MBTU	HAPS
SiteWise	33.50%	0.00%	0.00%	0.00%	65.87%	0.00%
SRT	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%
SEFA	41.84%	100.00%	100.00%	58.00%	100.00%	10.56%
SimaPro	29.30%	75.06%	61.30%	100.00%	60.87%	100.00%

Note - All graphical results are normalized against the highest result for the specific reporting metric.

FIGURE 4-9

Emissions and Energy Reported, per Pound of GAC Used, for Each Tool

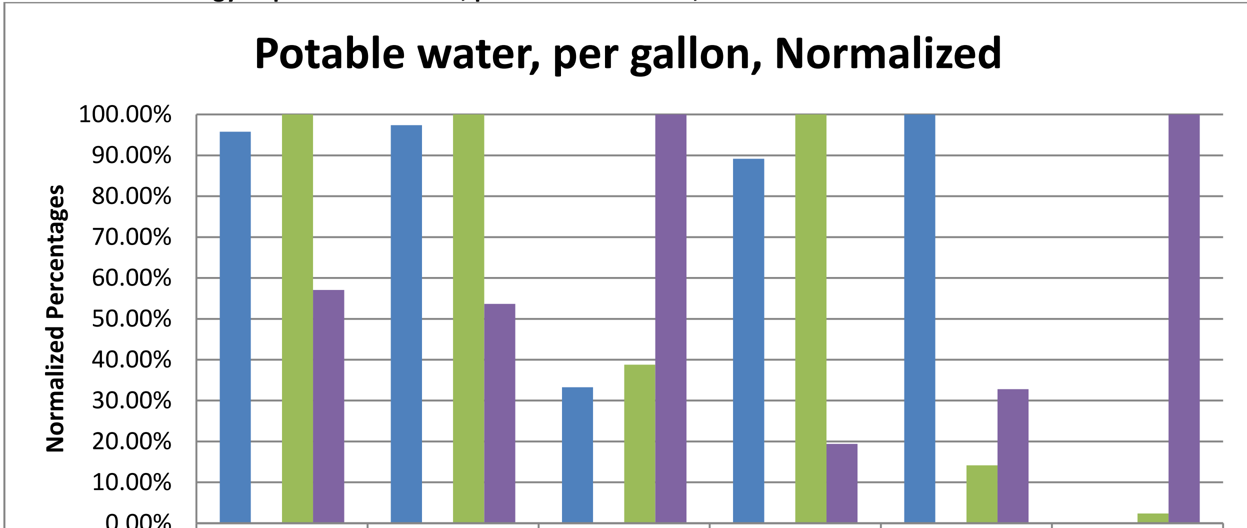


	CO2e	NOX	SOX	PM	MBTU	HAPS
SiteWise	100.00%	0.00%	0.00%	0.00%	39.48%	0.00%
SRT	10.76%	0.00%	0.00%	0.00%	0.00%	0.00%
SEFA	33.94%	80.03%	100.00%	11.76%	11.38%	75.17%
SimaPro	70.36%	100.00%	70.97%	100.00%	100.00%	100.00%

Note - All graphical results are normalized against the highest result for the specific reporting metric.

FIGURE 4-10

Emissions and Energy Reported for Water, per Gallon of Water, for Each Tool

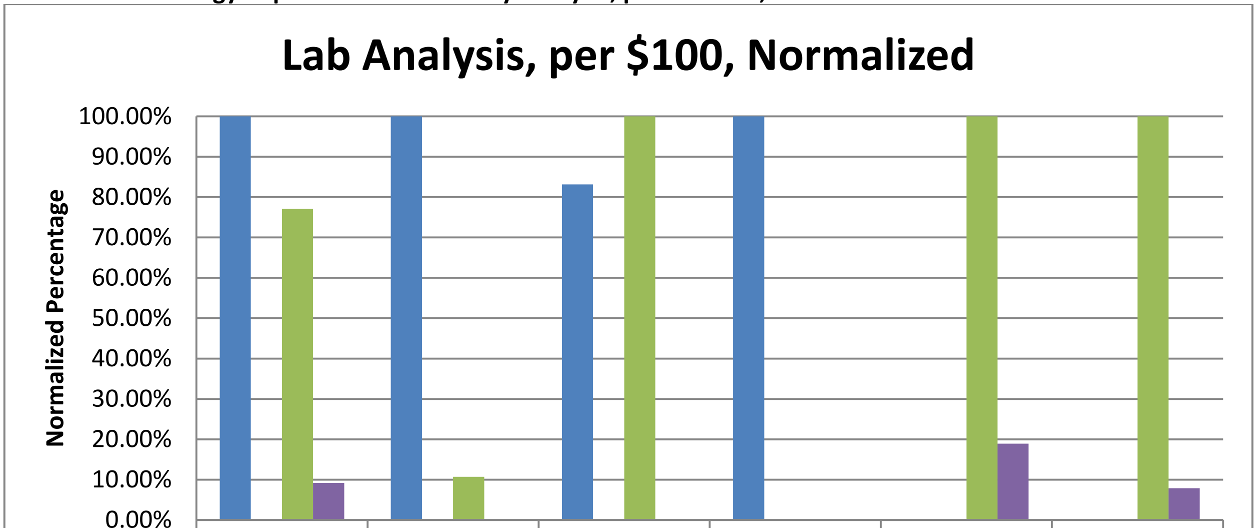


	CO2e	NOX	SOX	PM	MBTU	HAPS
SiteWise	95.78%	97.41%	33.27%	89.17%	100.00%	0.00%
SRT	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
SEFA	100.00%	100.00%	38.80%	100.00%	14.15%	2.39%
SimaPro	57.05%	53.65%	100.00%	19.43%	32.79%	100.00%

Note - All graphical results are normalized against the highest result for the specific reporting metric.

FIGURE 4-11

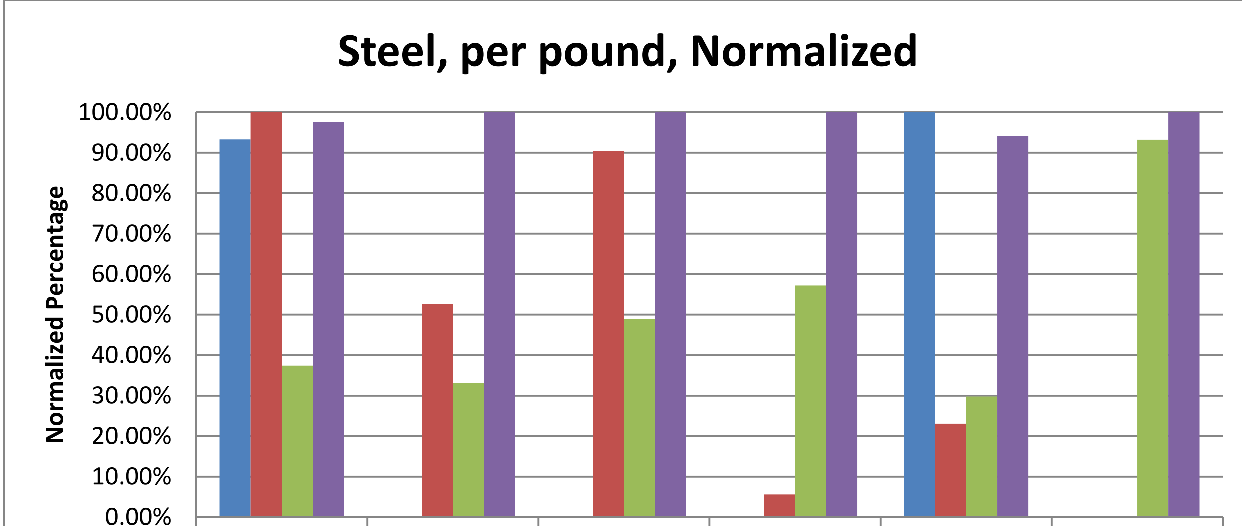
Emissions and Energy Reported for Laboratory Analysis, per 100 USD, for Each Tool



	CO2e	NOX	SOX	PM	MBTU	HAPS
SiteWise	100.00%	100.00%	83.14%	100.00%	0.00%	0.00%
SRT	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
SEFA	77.10%	10.69%	100.00%	0.00%	100.00%	100.00%
SimaPro	9.18%	0.00%	0.13%	0.00%	18.90%	7.88%

Note - All graphical results are normalized against the highest result for the specific reporting metric.

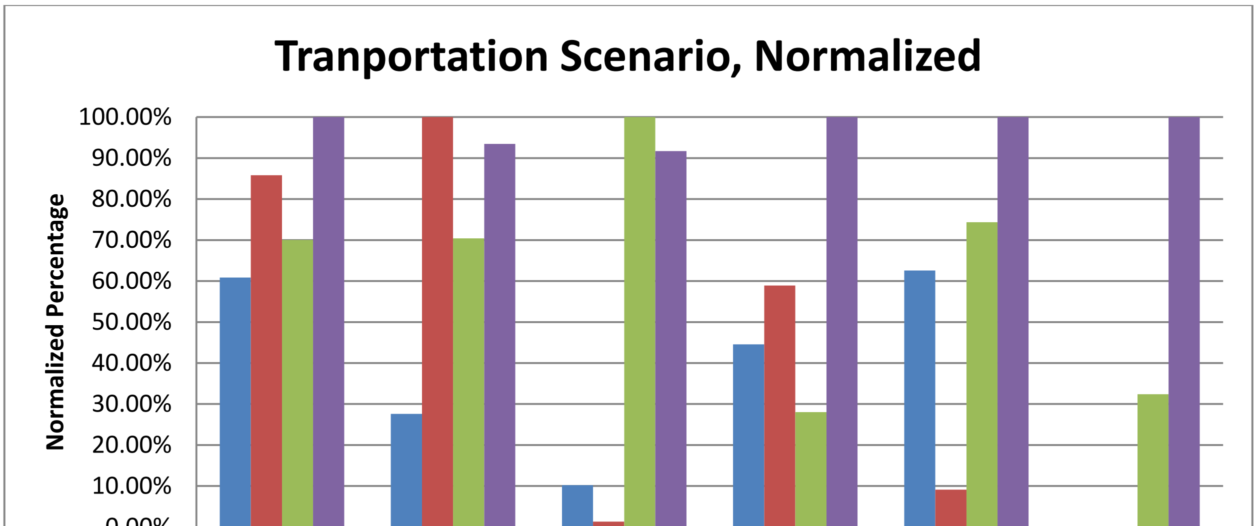
FIGURE 4-12
Emissions and Energy Reported for Steel, per Pound, for Each Tool



	CO2	NOX	SOX	PM	MBTU	HAPS
SiteWise	93.28%	0.00%	0.00%	0.00%	100.00%	0.00%
SRT	100.00%	52.65%	90.43%	5.59%	23.09%	0.00%
SEFA	37.40%	33.17%	48.87%	57.22%	29.77%	93.23%
SimaPro	97.61%	100.00%	100.00%	100.00%	94.11%	100.00%

Note - All graphical results are normalized against the highest result for the specific reporting metric.

FIGURE 4-13
Emissions and Energy Reported for Transportation of 200 Tons of Material to a Location 100 Miles from the Grants Site, for Each Tool

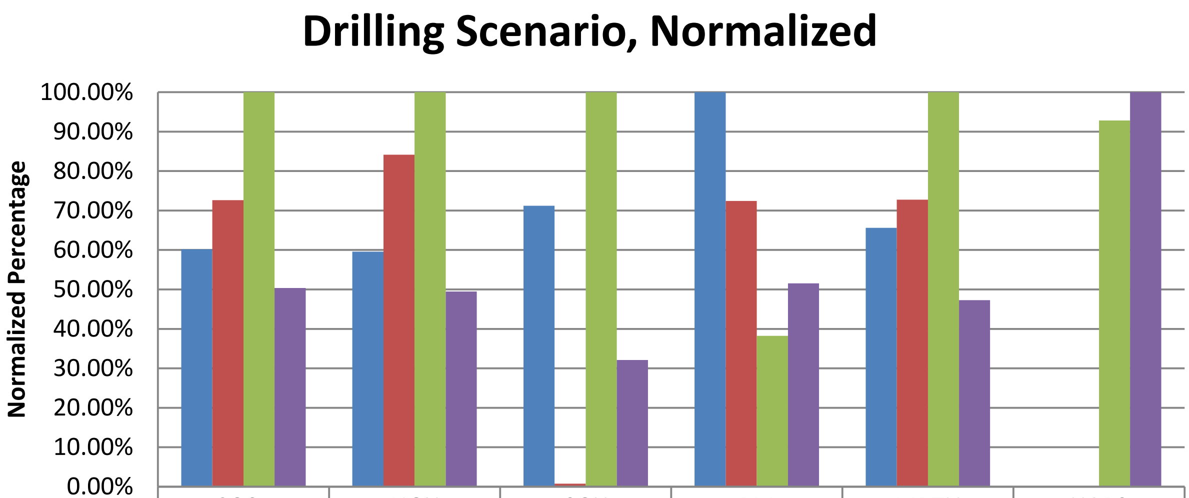


	CO2e	NOX	SOX	PM	MBTU	HAPS
SiteWise	60.87%	27.60%	10.22%	44.58%	62.59%	0.00%
SRT	85.82%	100.00%	1.30%	58.92%	9.13%	0.00%
SEFA	70.01%	70.42%	100.00%	28.03%	74.34%	32.41%
SimaPro	100.00%	93.46%	91.71%	100.00%	100.00%	100.00%

Note - All graphical results are normalized against the highest result for the specific reporting metric.

FIGURE 4-14

Emissions and Energy Reported, per 100 Feet of a 2-Inch-Diameter Well Drilled, for Each Tool



	CO2e	NOX	SOX	PM	MBTU	HAPS
SiteWise	60.18%	59.58%	71.20%	100.00%	65.61%	0.00%
SRT	72.64%	84.15%	0.77%	72.42%	72.74%	0.00%
SEFA	100.00%	100.00%	100.00%	38.25%	100.00%	92.85%
SimaPro	50.35%	49.46%	32.11%	51.52%	47.28%	100.00%

Note - All graphical results are normalized against the highest result for the specific reporting metric.

Appendixes

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Appendix A
Overview of Converting Project Components to Environmental Footprint Results Using Footprint Analysis and LCA

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APPENDIX A

Overview of Footprint Analysis and Life Cycle Assessment

The topic of footprint analysis and life cycle assessment (LCA) is vast and complex and cannot be adequately addressed in this appendix. The references provided at the end of this appendix provide users with additional resources for further reading. The purpose of this appendix is to provide a general overview of the key attributes *of a footprint analysis and LCA.*

Examples of tools that may be used for estimating the environmental footprint of a cleanup include, but are not limited to: SRT™, SiteWise™, and Spreadsheets for Environmental Footprint Evaluation (SEFA). Examples of LCA tools include SimaPro® and GaBi®. LCA tools can also be adapted to replicate output of footprint analysis tools. The use of a pre-designed tool is not required to complete a footprint analysis or LCA.

A footprint analysis is characterized by the typical attributes listed below:

- Possibly considers the full life cycle of the components of a cleanup project, but more commonly selects abbreviated boundaries.
- Reports tool environmental footprint contributors individually, with the exception of greenhouse gases, which are generally reported as carbon dioxide equivalents based on characterization factors for carbon dioxide, methane, and nitrous oxide.
- Possibly uses an industry-specific software tool, a commercial software tool, and/or a specific spreadsheet-based tool developed for the cleanup project. A footprint analysis may also be conducted in a more informal fashion without use of pre-designed tool.
- Carries only inventory data (that is, the environmental footprint data for each cleanup component in the tool) on the specific metric estimated by the tool. The user should be aware of the data resource quality (such as transparency of assumptions, data integrity, and applicable boundaries) of a specific footprint tool and associated inventory data to ensure it can achieve the goal and scope of the assessment.

An LCA is characterized by the typical attributes listed below:

- Considers the full life cycle of the components *of a cleanup* project.
- Uses an inventory of emissions for raw material inputs and materials, energy, processing, transportation, and waste scenarios used in the life cycle of the cleanup which can be used to determine environmental footprint contributors for a large number of impact categories. The user should be aware of the data resources (such as transparency of assumptions, data integrity, and applicable boundaries) of a specific LCA tool and associated inventory data to ensure it can achieve the goal and scope of the assessment.
- Allows the selection of impact categories that are the most meaningful for the goal and scope of the project.
- Employs the characterization of emissions to represent results as potential impacts to different categories.
- Generally requires the use of commercial tools needing specific training and investment. In some limited circumstances, an LCA may be able to be completed without commercial software, depending on the goal and scope defined for the assessment.

Both footprint analysis and LCA start with identifying all the key components of the cleanup. This is accomplished by assembling a list of materials, energy, natural resources, transportation, and waste-generating processes associated with the cleanup activities). Footprint analysis and LCA tools have inventories of data for a range of cleanup components that define the emissions (emissions to air, water, and soil), energy, and water associated with the production and use of the cleanup component.

One of the main differences between footprint analysis and LCA tools is the depth of the inventories available for consideration, the number of emissions and energy types reported in an inventory, and the media to which the emission is released. Another main difference between the two is how the tools aggregate the inventory emissions and report the results.

Footprint Tool Overview

Footprint tool inventories generally include information on the following core element contributors and flows for each cleanup component in the tool library:

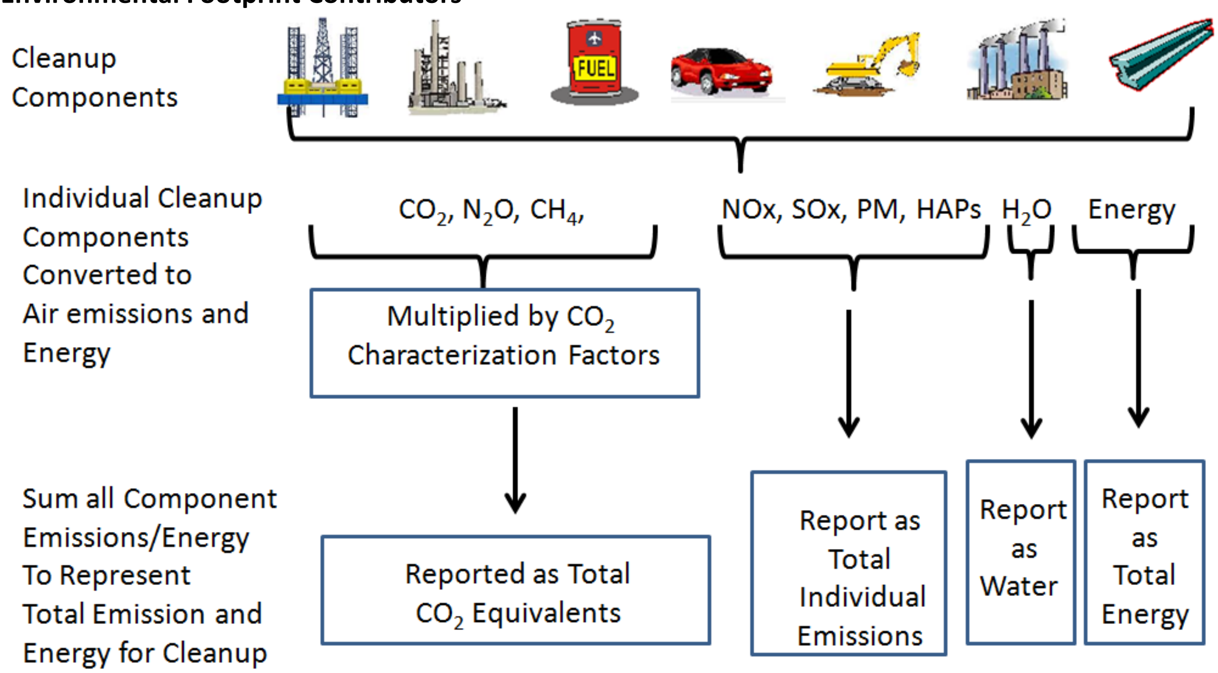
- Carbon dioxide equivalents (based on carbon dioxide, nitrous oxide, and methane emissions, as well as characterization factors used to convert each emission into a carbon dioxide equivalent unit)
- Nitrogen oxides
- Sulfur oxides
- Particulate matter
- Water
- Energy

Depending on the footprinting tool, more information can also be quantified. For example, some tools may contain unique emissions (such as hazardous air pollutants)that other tools do not. Additionally, there are other important items, such as solid and hazardous waste produced, which can be tracked with footprint tools. However, because the tools do not actually calculate use or generation of these substances, and only track what a user enters, discussion of these project components is not included in this section.

Characterization factors for carbon dioxide, nitrous oxide, and methane are multiplied and totaled to represent total carbon dioxide equivalents. All environmental footprint contributors are totaled and reported.

Figure App New -1 summarizes the process of identifying cleanup components through reporting results. Note that this is an example that applies to several footprint tools. Some tools may not conform to this example.

Figure App New 1. Footprint Analysis - Overview of Approach to Converting Cleanup Components to Environmental Footprint Contributors



LCA Overview

LCA includes information on the following emissions and flows (processes, transportation, energy, and waste) for each cleanup component in the tool library:

- Emissions to air
- Emissions to soil
- Emissions to water
- Raw materials utilized
- All processes and transportation used to convert raw material to component used in cleanup
- Energy inputted
- Wastes produced

While the number of datasets for the above items vary depending on the LCA library employed in the analysis, the number of the flows (described above) are typically much greater than those carried by footprint analysis tools. Given the depth of data typically available in LCA datasets, users have more flexibility in addressing broader project goals and scopes in their assessments.

As with footprint analysis, cleanup components are converted to raw materials and chemicals, which are collectively referred to as the Life Cycle Inventory (LCI). Each LCI component is assigned to one or more different impact categories, depending on the impact assessment method used for the LCA. For example, the U.S. Environmental Protection Agency's (EPA) Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) has the following nine impact categories (from TRACI V2.1):

- **Global Warming–**the potential of climate change potential gases to change the earth's climate; reported as carbon dioxide equivalents.
- **Acidification –** processes that increase the acidity of water and soil systems; reported as hydrogen ion equivalents.
- **Euthrophication –**addition of nutrients to surface waters, which leads to increased growth of aquatic photosynthetic life and can affect both ecosystem quality/diversity and aesthetics; reported as nitrogen equivalents.
- **Ozone depletion –**reduction of ozone in the stratosphere caused by the release of ozone-depleting chemicals. Ozone depletion can increase ultraviolet B radiation to the earth, which can adversely affect human health (in the forms of skin cancer and cataracts) and other systems (such as marine life, agricultural crops, and other vegetation). Reported as chloroflurocarbon-11.
- **Smog–**a reactive gas that is the characterization point associated with photochemical oxidant formation (smog) in the troposphere. When present in the troposphere, it can lead to negative impacts to ecosystems and human health. Reported as ozone equivalents.
- **Respiratory Effects –**particulate matter concentrations have a strong influence on chronic and acute respiratory effects symptoms and mortality rates. Reported as particulate matter equivalents.
- **Carcinogens –**have the potential to form cancers in humans. Reported as comparative toxicity unit-human-equivalents.
- **Non-carcinogens–** have the potential to cause non-cancerous adverse impacts to human health. Reported as comparative toxicity unit-human-equivalents.
- **Ecotoxicity–** causes negative impacts to ecological receptors and, indirectly, to human receptors through the impacts to the ecosystem. Reported as comparative toxicity unit-ecological-equivalents.
- **Fossil Fuel Depletion** – represents use of non-renewable fossil fuel, reported a megajoule surplus.

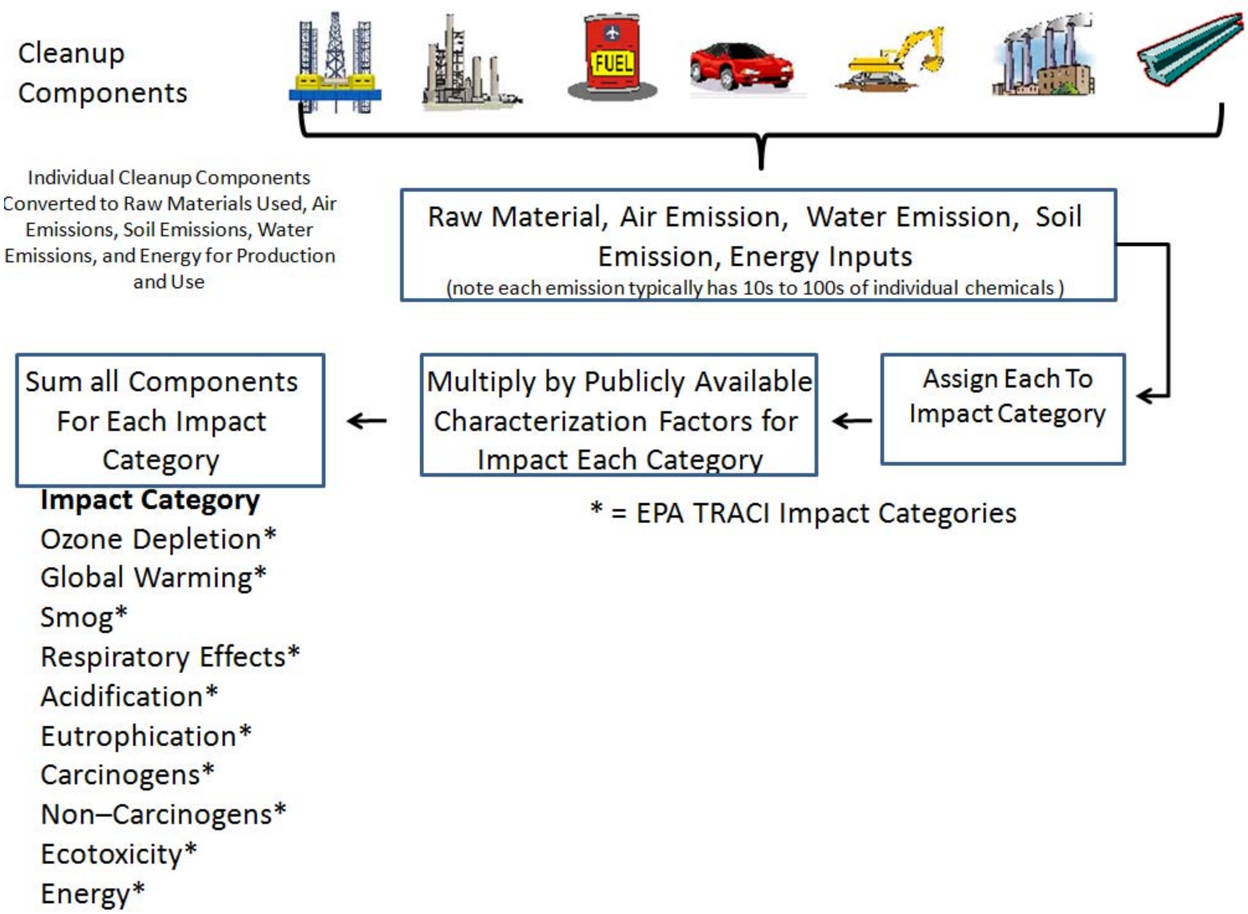
Each of the raw materials and chemicals in the LCA's for the cleanup components is assigned to one or more impact categories. Much like the approach used to convert methane and nitrous oxides into carbon dioxide equivalents, described above for footprint analysis, each raw material and chemical in an inventory is multiplied by an appropriate characterization factor to convert the chemical concentration into a concentration of an indicator chemical that represents the impact category.

The indicator chemicals for the TRACI impact categories are described above. The characterization factors for TRACI, and other impact assessment methods, are publicly available and typically receive significant review before being released.

After characterization, each of the contributors to each impact category is summed up and results are presented in terms of indicator equivalents for each impact category.

Figure App New -1 summarizes the process of identifying cleanup components through mapping of results to core elements for LCAs.

Figure App New 2. LCA - Overview of Approach to Converting Cleanup Components to Impacts



Recommendations for Further Reading on Life Cycle Assessment and Footprint Analysis:

Favara, P., Krieger, T., Boughton, B., Fisher, A., & Bhargava, M. 2011. "Guidance for Performing Footprint Analyses and Life-cycle Assessments for the Environmental Remediation Industry." *Remediation*, 21(3), 39–79.

EPA. 2012. "Methodology for Understanding and Reducing a Project's Environmental Footprint." EPA 542-R-12-002.February.

EPA. 2006. "Life Cycle Assessment: Principles and Practice." EPA/600/R-06/060. May.

Appendix B
SRT Project Inputs

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							Nox	SOx	PM	
Gasoline	20.17	lb-CO2/Gallon	nrel.gov	150	MJ/Gallon	nrel.gov, converted to MJ/gal	0.0150777	0.0001599	0.00129015	lb/gal
Diesel	25.8	lb-CO2/Gallon	nrel.gov	170	MJ/Gallon	nrel.gov, converted to MJ/gal	0.2092296	0.00020065	0.0099786	lb/gal
Electricity	1.34	lb-CO2/kWh	Energy Information Administration, 2002, Updated State-level Greenhouse Gas Emission Coefficients for Electricity Generation 1998-2000 http://tonto.eia.doe.gov/ftproot/environment/e-supdoc-u.pdf (US Average CO2)	11	MJ/kWh	*Electricity generation is 32% efficient (see MV spreadsheet). So, for every 1 kWh used, 3.125 kWh total were expended. Conversion 1 kWh = 3.6 MJ.*	0.0080688	0.015189594	0.002843915	lb/kWh
Natural gas	122	lb-CO2/mcf	nrel.gov/lci (Natural Gas Combustion in Industrial Equipment)	1000	MJ/mcf		0	0	0	lb/mcf
Default Steel Pipe	2.948	lb-CO2/lb	Assumes the only CO2 is from energy consumption	2.2	kWh/lb	upper end of range from Energy Information Administration (metal casting)	0.002227	0.003153	0.00005843	lb/lb
Steel Sch 40 (2-inch)	2.948	lb-CO2/lb	Assumes the only CO2 is from energy consumption	2.2	kWh/lb	upper end of range from Energy Information Administration (metal casting)	0.002227	0.003153	0.00005843	lb/lb
Steel Sch 40 (4-inch)	2.948	lb-CO2/lb	Assumes the only CO2 is from energy consumption	2.2	kWh/lb	upper end of range from Energy Information Administration (metal casting)	0.002227	0.003153	0.00005843	lb/lb
Default PVC Pipe	1.824	lb-CO2/lb	NREL CO2 outputs to nature from PVC cradle to resin	5.4	kWh/lb	NREL PVC cradle to resin natural gas input, btu converted to kwh	0.00318	0.0105	0.00018	lb/lb
PVC Sch 40 (2-inch)	1.824	lb-CO2/lb	NREL CO2 outputs to nature from PVC cradle to resin	5.4	kwh/lb	NREL PVC cradle to resin natural gas input, btu converted to kwh	0.00318	0.0105	0.00018	lb/lb
PVC Sch 40 (4-inch)	1.824	lb-CO2/lb	NREL CO2 outputs to nature from PVC cradle to resin	5.4	kwh/lb	NREL PVC cradle to resin natural gas input, btu converted to kwh	0.00318	0.0105	0.00018	lb/lb
Default Activated Carbon	2.7	lb-CO2/lb	Derived from Vignes, 2001 and EIA Electricity	0			0	0	0	
Substrate	2.8	lb-CO2/lb	Design Team (DTA)	0			0	0	0	
Oxygen Additive		lb-CO2/lb	Design Team (DTA)	0			0	0	0	
Oxidant	4	lb-CO2/lb		0			0	0	0	
ZVI (Iron)	1.21	lb-CO2/lb		0			0	0	0	

Model Inputs	**ERD**	**Thermal**	**ISCO**
PVC (lbs)	53859.96	12575	0
Steel (lbs)	2555	45360	0
Oxidant (lbs)	0	0	765000
Activated Carbon (lbs)	0	20000	0
Substrate/Donor (if CVOCs)	4800000	0	0
Diesel Onsite (gal)	6834	2744	0
Diesel Eq Txp (gal)	2273	794	500
Gasoline (gal)	4437	800	187
Electricity (kwh)	0	6000000	0

Model Output by Technology and Metric

CO2(MT)	ERD	ISTT	ISCO
PVC (lbs)	4.46E+01	1.04E+01	0.00E+00
Steel (lbs)	3.42E+00	6.06E+01	0.00E+00
Oxidant (lbs)	0.00E+00	0.00E+00	1.39E+03
Activated Carbon (lbs)	0.00E+00	2.45E+01	0.00E+00
Substrate/Donor (if CVOCs)	6.10E+03	0.00E+00	0.00E+00
Diesel Onsite (gal)	8.00E+01	3.21E+01	0.00E+00
Diesel Eq Txp (gal)	2.66E+01	9.29E+00	5.85E+00
Gasoline (gal)	4.06E+01	7.32E+00	1.71E+00
Electricity (kwh)	0.00E+00	3.65E+03	0.00E+00
SUM	6.29E+03	3.79E+03	1.40E+03

	ERD	ISTT	ISCO	Overall Total
Onsite	8.00E+01	3.21E+01	0.00E+00	
Elect	0.00E+00	3.65E+03	0.00E+00	
Transport	6.72E+01	1.66E+01	7.56E+00	
Other	6.14E+03	9.55E+01	1.39E+03	
SUM	6.29E+03	3.79E+03	1.40E+03	1.15E+04

Energy MMBTU	ERD	ISTT	ISCO
PVC (lbs)	9.92E+02	2.32E+02	0.00E+00
Steel (lbs)	1.91E+01	3.39E+02	0.00E+00
Oxidant (lbs)	0.00E+00	0.00E+00	0.00E+00
Activated Carbon (lbs)	0.00E+00	0.00E+00	0.00E+00
Substrate/Donor (if CVOCs)	0.00E+00	0.00E+00	0.00E+00
Diesel Onsite (gal)	1.10E+03	4.42E+02	0.00E+00
Diesel Eq Txp (gal)	3.66E+02	1.28E+02	8.05E+01
Gasoline (gal)	6.30E+02	1.14E+02	2.66E+01
Electricity (kwh)	0.00E+00	6.25E+04	0.00E+00
SUM	3.11E+03	6.38E+04	1.07E+02

	ERD	ISTT	ISCO	Overall Total
Onsite	1.10E+03	4.42E+02	0.00E+00	
Elect	0.00E+00	6.25E+04	0.00E+00	
Transport	9.96E+02	2.41E+02	1.07E+02	
Other	1.01E+03	5.71E+02	0.00E+00	
SUM	3.11E+03	6.38E+04	1.07E+02	6.70E+04

NOX (MT)	ERD	ISTT	ISCO
PVC (lbs)	7.77E-02	1.81E-02	0.00E+00
Steel (lbs)	2.58E-03	4.58E-02	0.00E+00
Oxidant (lbs)	0.00E+00	0.00E+00	0.00E+00
Activated Carbon (lbs)	0.00E+00	0.00E+00	0.00E+00
Substrate/Donor (if CVOCs)	0.00E+00	0.00E+00	0.00E+00
Diesel Onsite (gal)	6.48E-01	2.60E-01	0.00E+00
Diesel Eq Txp (gal)	2.16E-01	7.53E-02	4.74E-02
Gasoline (gal)	3.03E-02	5.47E-03	1.28E-03
Electricity (kwh)	0.00E+00	2.20E+01	0.00E+00
SUM	9.75E-01	2.24E+01	4.87E-02

	ERD	ISTT	ISCO	Overall Total
Onsite	6.48E-01	2.60E-01	0.00E+00	
Elect	0.00E+00	2.20E+01	0.00E+00	
Transport	2.46E-01	8.08E-02	4.87E-02	
Other	8.03E-02	6.39E-02	0.00E+00	
SUM	9.75E-01	2.24E+01	4.87E-02	2.34E+01

SOX (MT)	ERD	ISTT	ISCO
PVC (lbs)	2.56E-01	5.99E-02	0.00E+00
Steel (lbs)	3.65E-03	6.49E-02	0.00E+00
Oxidant (lbs)	0.00E+00	0.00E+00	0.00E+00
Activated Carbon (lbs)	0.00E+00	0.00E+00	0.00E+00
Substrate/Donor (if CVOCs)	0.00E+00	0.00E+00	0.00E+00
Diesel Onsite (gal)	6.22E-04	2.50E-04	0.00E+00
Diesel Eq Txp (gal)	2.07E-04	7.23E-05	4.55E-05
Gasoline (gal)	3.22E-04	5.80E-05	1.36E-05
Electricity (kwh)	0.00E+00	4.13E+01	0.00E+00
SUM	2.61E-01	4.15E+01	5.91E-05

	ERD	ISTT	ISCO	Overall Total
Onsite	6.22E-04	2.50E-04	0.00E+00	
Elect	0.00E+00	4.13E+01	0.00E+00	
Transport	5.29E-04	1.30E-04	5.91E-05	
Other	2.60E-01	1.25E-01	0.00E+00	
SUM	2.61E-01	4.15E+01	5.91E-05	4.17E+01

PM (MT)			
PVC (lbs)	4.40E-03	1.03E-03	0.00E+00
Steel (lbs)	6.77E-05	1.20E-03	0.00E+00
Oxidant (lbs)	0.00E+00	0.00E+00	0.00E+00
Activated Carbon (lbs)	0.00E+00	0.00E+00	0.00E+00
Substrate/Donor (if CVOCs)	0.00E+00	0.00E+00	0.00E+00
Diesel Onsite (gal)	3.09E-02	1.24E-02	0.00E+00
Diesel Eq Txp (gal)	1.03E-02	3.59E-03	2.26E-03
Gasoline (gal)	2.60E-03	4.68E-04	1.09E-04
Electricity (kwh)	0.00E+00	7.74E+00	0.00E+00
SUM	4.83E-02	7.76E+00	2.37E-03

	ERD	**ISTT**	**ISCO**	**Overall Total**
Onsite	3.09E-02	1.24E-02	0.00E+00	
Elect	0.00E+00	7.74E+00	0.00E+00	
Transport	1.29E-02	4.06E-03	2.37E-03	
Other	4.46E-03	2.23E-03	0.00E+00	
SUM	4.83E-02	7.76E+00	2.37E-03	7.81E+00

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Appendix C
SimaPro Project Inputs

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SimaPro 7#3	product stage	Column1	1/18/2013	Time:	8:30 AM	F7	Column2
Onsite Well Installation and ERD Delivery							
Processes	Input or Calculation Setup						
Worker Injury and Fatality	8790	hr	Undefined				Delivery: 53 days X 10 hr days * 3 staff = 1590 hours; Sampling: 360 days of sampling * 10 hr day * 2 pple = 7200 hrs
Diesel, combusted in industrial equipment NREL /US	9904*5*0.05*.75	gal*	Undefined				9904 hour at 5 HP
Diesel, combusted in industrial equipment NREL /US	7200*2*0.05*.75	gal*	Undefined				7200 hours at 2 HP
30 HP Forklift	500	hr	Undefined				From EPA Methodology Ex 3.10B, assume 500 hours
100 HP asphalt paver	24	hr	Undefined				From EPA Methodology Ex 3.10B, assume 24
							hours
100 HP Roller	24	hr	Undefined				From EPA Methodology Ex 3.10B, assume 24
							hours
Drill Rig, HSA, 8 gal/hour	3784	hr	Undefined				345 locations 6.5 hours per location for biobarrier
							25 locations at 16.6 hours per location for Holiday Cleaners
							190 locations at 3.7 hours per location for Shallow Plume Core
							51 locations at 8.3 hours per location for monitoring wells
Worker Injury and Fatality	11340	hr	Undefined				3780 hours * 3 workers (hrs from Battelle drilling worksheet and 3 workers assumed per rig hour)

SimaPro 7#3	product stage	Column1	1/18/2013	Time:	8:30 AM	F7	Column2
SimaPro 7#3	product stage	Column1	1/18/2013	Time:	8:31 AM	F7	Column2
Other Well Installation and ERD Delivery							
Materials/Assemblies	Input or Calculation Setup						
Galvanized steel sheet, at plant NREL /RNA copy	SS_kg	kg	Undefined				Parameter
PVC pipe E	PVC_kg	kg	Undefined				Parameter
Sand, at mine/CH with US electricity U	Sand_kg	kg	Undefined				Parameter
Bentonite, at processing/DE with US electricity U	Bentonite_kg	kg	Undefined				Parameter
Concrete, normal, at plant/CH with US electricity U	31.13*0.765	m3	Undefined				283 total well locations
							3-ft x 3-ft x 4-inch concrete pad per location
Portland cement, strength class Z 42.5, at plant/CH with US electricity U	10500	kg	Undefined				
ERD Substrate Emulsified Soybean Oil	583855*3.7	kg	Undefined				583855 gal * 3.7 kg/gal = 2160263.5 kg EOS
Tap water, at user/RER with US electricity U	58318074	kg	Undefined				14,280,305 gallons
							491,619 gallons
							639,711 gallons
Scientific research and development services SE	1325300	USD2002	Undefined				
Processes							
Input parameters							
SS_lbft	3.65					No	lb/ft3 of SS, engineers toolbox
SS_ft	700					No	ft, length of SS pipe from Battelle estimate - 2"

SimaPro 7#3	product stage	Column1	1/18/2013	Time:	8:30 AM	F7	Column2
PVC_lbft	0.68					No	lb/ft3 of PVC, engineers toolbox, http://www.engineeringtoolbox.com/pvc-cpvc-pipes-dimensions-d_795.htm
PVC_ft	27200					No	ft, length of PVC pipe from Battelle Estimate
Sand_vol	50					No	cy, volume of sand, from Mike Perlmutter
Sand_lbft3	100					No	book value
cy_cf	27					No	cubic yards per cubic foot conversion
Bentonite_vol	66.8					No	cy, volume of bentonite, from Mike Perlmutter
Bentonite_kgm3	593					No	593 kg/m3
							http://www.simetric.co.uk/si_materials.htm
Concrete_kgm3	2403					No	2403 kg/m3 http://www.simetric.co.uk/si_materials.htm
Concrete_vol_cy	31.4					No	
Concrete_USTperCY	2					No	
Calculated parameters							
SS_kg	SS_lbft*SS_ft/lb_kg						
PVC_kg	PVC_lbft*PVC_ft/lb_kg						
Sand_kg	Sand_vol*Sand_lbft3*cy_cf/lb_kg						
Bentonite_kg	Bentonite_vol*cy_m3*Bentonite_kgm3						
Concrete_vol_m3	Concrete_vol_cy/cy_m3						
Concrete_m3	concrete_vol_cy*concrete_USTperCY*0.765						

SimaPro 7#3	product stage	Column1	1/18/2013	Time:	8:31 AM	F7	Column2
Transport Well Installation and ERD Delivery							
Processes	Input or Calculation Setup						
Transport, combination truck, diesel powered NREL /US	(ss_kg+PVC_kg+sand_kg+bentonite_kg+concrete_vol_m3+10.5)/1000*100*1.61*2	tkm	Undefined				Well: Transport of material to site
							assume 100 mile * 1.61 km *2 roundtrip

SimaPro 7#3	product stage	Column1	1/18/2013	Time:	8:30 AM	F7	Column2
Transport, combination truck, diesel powered NREL /US	8*29*0.9074*80*1.61*2	tkm	Undefined				Well: waste generation from drilling: 29 tons X 2000 lbs/2.204 lb/kg / 1000 kg/tonnes = 26.31 tonnes. 80 miles * 1.61
Transport, combination truck, diesel powered NREL /US	100*100*1.61*2	tkm	Undefined				Well: Assume 100 tons of transport 100 miles one way *2 roundtrip
Community, Injury and Fatality, Passenger Car Miles Driven	21400	mile	Undefined				Well: 21400 miles driven
Community, Injury and Fatality, Truck Miles Driven	4240	mile	Undefined				Well: From Battelle Construction Worksheet (3440) plus residual hauling (80 miles)
Transport, passenger car/RER with US electricity U	21400*1.61*3	personkm	Undefined				Well: ERD Inject: 21400 mi * 1.61 km/mi*3 staff
Transport, combination truck, diesel powered NREL /US	100*1.61*2*2160	tkm	Undefined				ERD: Assume 100 mi transport *1.61 km * 2 roundtrip *2160 tons substrate
Transport, passenger car/RER with US electricity U	(24760+20400)*1.61*2	personkm	Undefined				ERD:24,760 miles, 2 person via car for O&M
							20,400 miles, 2 person via car for monitoring
Community, Injury and Fatality, Passenger Car Miles Driven	46760	mile	Undefined				ERD: 20400 for sampling + 26360 for ERD Delivery = 46760
Community, Injury and Fatality, Truck Miles Driven	19200	mile	Undefined				ERD: 100 mi * 96 EOS trips * 2 trips
Input parameters							
SS_lbft	3.65					No	lb/ft3 of SS, engineers toolbox
SS_ft	700					No	ft, length of SS pipe from Battelle estimate - 2"

SimaPro 7#3	product stage	Column1	1/18/2013	Time:	8:30 AM	F7	Column2
PVC_lbft	0.68					No	lb/ft3 of PVC, engineers toolbox, http://www.engineeringtoolbox.com/pvc-cpvc-pipes-dimensions-d_795.htm
PVC_ft	27200					No	ft, length of PVC pipe from Battelle Estimate
Sand_vol	50					No	cy, volume of sand, from Mike Perlmutter
Sand_lbft3	100					No	book value
cy_cf	27					No	cubic yards per cubic foot conversion
Bentonite_vol	66.8					No	cy, volume of bentonite, from Mike Perlmutter
Bentonite_kgm3	593					No	593 kg/m3
							http://www.simetric.co.uk/si_materials.htm
Concrete_kgm3	2403					No	2403 kg/m3 http://www.simetric.co.uk/si_materials.htm
Concrete_vol_cy	31.4					No	
Concrete_USTperCY	2					No	
Calculated parameters							
SS_kg	SS_lbft*SS_ft/lb_kg						
PVC_kg	PVC_lbft*PVC_ft/lb_kg						
Sand_kg	Sand_vol*Sand_lbft3*cy_cf/lb_kg						
Bentonite_kg	Bentonite_vol*cy_m3*Bentonite_kgm3						
Concrete_vol_m3	Concrete_vol_cy/cy_m3						
Concrete_m3	concrete_vol_cy*concrete_USTperCY*0.765						

SimaPro 7#3	product stage	Column1	Column3
Onsite ISCO Delivery			
Processes	Input or Calculation Setup		
Worker Injury and Fatality	((221*9000)/(60*60))*3*1.1	hr	221 wells * 9000 gal delivered per well/60 gpm delivery/60 min per hour
			* 3 staff*1.1 for daily setup and takedown
Diesel, combusted in industrial equipment NREL /US	70*10*5*0.05*0.75	gal*	5 HP * 70 days * 10 hr/day * 75% PLF *0.05 gal/hp-hr
Input parameters			
KMnO4_frac	0.046	Undefined	
Water_frac	0.954	Undefined	
Mass_Del	7526438	Undefined	221 wells at 9000 gal per well * 8.34 lb/gal * kg/2.204 lb = 7526438 kg
kg_load	36298	Undefined	kg, represents 40 US tons material transported

SimaPro 7#3	product stage	Column2	Column1
Other ISCO Delivery			
Materials/Assemblies	Input or Calculation Setup		
Potassium permanganate, at plant/RER U Grants	KMnO4_del	kg	Parameter
Tap water, at user/RER with US electricity U	Water_del	kg	Parameter
Processes			
Input parameters			
KMnO4_frac	0.046		
Water_frac	0.954		
Mass_Del	7526438		221 wells at 9000 gal per well * 8.34 lb/gal * kg/2.204 lb = 7526438 kg
kg_load	36298		kg, represents 40 US tons material transported
Calculated parameters			
KMnO4_del	KMnO4_frac*Mass_Del		
Water_del	Water_frac*Mass_Del		
Load	KMnO4_frac*Mass_Del/kg_load		

SimaPro 7#3	product stage	Column1	Column2
Transport ISCO Delivery			
Processes	Input or Calculation Setup		
Transport, combination truck, diesel powered NREL /US	KMnO4_del/1000*100*1.61*2	tkm	KMnO4 ships from 100 mi from site *2 roundtrip
Transport, passenger car/RER with US electricity U	13524	personkm	2800 miles * 1.61 km/mile * 3 pers =
Community, Injury and Fatality, Passenger Car Miles Driven	5600	mile	140 trips x 20 miles each * 2 vehicles
Community, Injury and Fatality, Truck Miles Driven	Load*100*1.61*2	mile	Load Parameter times 100 miles * 1.61 km/mi * 2 roundtrip
Input parameters			
KMnO4_frac	0.046		
Water_frac	0.954		
Mass_Del	7526438		221 wells at 9000 gal per well * 8.34 lb/gal * kg/2.204 lb = 7526438 kg
kg_load	36298		kg, represents 40 US tons material transported
Calculated parameters			
KMnO4_del	KMnO4_frac*Mass_Del		
Water_del	Water_frac*Mass_Del		
Load	KMnO4_frac*Mass_Del/kg_load		

SimaPro 7#3	product stage	Column1	Column2
Project	EPA Grants Site Chlorinated Solvent Plume		
Elect Gen Thermal Treatment Operations			
Processes	Input or calculation setup		
Grants Energy Mix	6000000	kWh	See Energy Mix Module

SimaPro 7#3	product stage	Column1	Column2
Onsite Therm Treat & Const and Operations			
Materials/Assemblies	Input or calculation setup		
Condensation for SVE	1000000*3.785	kg	1 million gallons of condensate produced; operations
Processes	Input or calculation setup		
Drill Rig, HSA, 8 gal/hour	3000	hr	From Battelle ISTT input; construction
Excavation, hydraulic digger/RER with US electricity U	100	m3	Assumption for buried conveyance pipes; construction
Worker Injury and Fatality	5000	hr	500 days * 2 staff * 10 hr/day; construction
100 HP asphalt paver	24	hr	assumption; construction
100 HP Roller	24	hr	assumption; construction
Worker Injury and Fatality	180*10*2	hr	180 days * 10 hr/day * 2 staff = 2000 hrs; operations
Compressed air, average generation, >30kW, 6 bar gauge, at compressor/RER with US electricity U	32471	m3	0.119 kWhr per m3; 272871 kWhr used; operations

SimaPro 7#3	product stage	Column1	Column2
Other Therm Treat & Const and Operations			
Materials/Assemblies	Input or Calculation Setup		
Galvanized steel sheet, at plant NREL /RNA copy	SS_kg	kg	Parameter
PVC pipe E	PVC_kg	kg	Parameter
Sand, at mine/CH with US electricity U	sand_kg	kg	Parameter
Portland cement, strength class Z 42.5, at plant/CH with US electricity U	cement_kg	kg	Parameter
Activated Carbon Meier 1997 as cited by Ortiz 2006 (A)	20000/2.204	kg	
Regneration of GAC Meier 1997 (A)	20000/2.204	kg	
Processes			
Scientific research and development services SE Grants	28200	USD2002	
Input parameters			
SS_lbft	3.65		lb/ft3 of SS, engineers toolbox
SS_ft	9000		ft, length of SS pipe from Battelle estimate

SimaPro 7#3	product stage	Column1	Column2
PVC_lbft	0.68		lb/ft3 of PVC, engineers toolbox, http://www.engineeringtoolbox.com/pvc-cpvc-pipes-dimensions-d_795.htm
PVC_ft	12575		ft, length of PVC pipe from Battelle Estimate, SVE laterals (4000 ft) and SVE wells (8575 ft)
Sand_vol	80		cy, volume of sand, from Mike Perlmutter
Sand_lbft3	111.11		book value
cy_cf	27		cubic yards per cubic foot conversion
Bentonite_vol	70		cy, volume of bentonite, from Mike Perlmutter
Bentonite_kgm3	593		593 kg/m3
			http://www.simetric.co.uk/si_materials.htm
Cement_kgm3	1506		2403 kg/m3 http://www.simetric.co.uk/si_materials.htm
Cement_vol_cy	20		cy, volume of concrete, from Mike Perlmutter
Calculated parameters			
SS_kg	SS_lbft*SS_ft/lb_kg		
PVC_kg	PVC_lbft*PVC_ft/lb_kg		
Sand_kg	Sand_vol*Sand_lbft3*cy_cf/lb_kg		
Bentonite_kg	Bentonite_vol*cy_m3*Bentonite_kgm3		
Cement_vol_m3	Cement_vol_cy/cy_m3		
Cement_kg	Cement_vol_m3*cement_kgm3		
TranspTonnes_SS_PVC_Cement	(SS_kg+PVC_kg+cement_kg)/1000		

SimaPro 7#3	product stage	Column1	Column2
UPD Transport Therm Treat & Const and Ops			
	27200 ft of Schd 40 PVC and 700 ft of SS 304		
Materials/Assemblies			
Processes	Input or Calculation Setup		
Transport, combination truck, diesel powered NREL /US	((TranspTonnes_SS_PVC_Cement)*100*1.61*2)+((Sand_kg/1000)*20*2*1.61)	tkm	const: Parameters +sand
Transport, combination truck, diesel powered NREL /US	8*0.9074*100*1.61*2	tkm	const: 8 tons * 2000 lb/2204 lb * 100 mi * 1.61 km *2 roundrip transformer
Transport, combination truck, diesel powered NREL /US	10*4*0.9074*80*1.61*2	tkm	const: 10 short tons * 4 oneway trips *
			0.9074* 80 miles to LF *1.61 km *2 roundtrip
Community, Injury and Fatality, Passenger Car Miles Driven	10000	mile	Const: From Battelle ISTT worksheet
Community, Injury and Fatality, Truck Miles Driven	(1260*2)+(320*2)	mile	1260 miles *2 roundtrip for materials + 80 miles * 4 const: trips *2 roundtrip for landfill
Transport, passenger car/RER with US electricity U	32200	personkm	const: 500 days * 2 people * 20 miles * 1.61 km/mile
Community, Injury and Fatality, Passenger Car Miles Driven	2000	mile	ops: 100 mile roundtrip for personal transpor
Community, Injury and Fatality, Truck Miles Driven	1700	mile	ops: Total truck miles driven
Transport, passenger car/RER with US electricity U	2000*1.61	personkm	ops: 2000 total miles with 2 persons
Transport, combination truck, diesel powered NREL /US	200*1.61*10*0.9074	tkm	ops: Virgin GAC transport 200 mile round trip * 1.61 km * 10 tons * 0.9074 short ton per metric ton
Transport, combination truck, diesel powered NREL /US	(650*1.61*10*0.9074)+(650*1.61*10*0.9074*70/30)+(7.25*100*1.61*2)	tkm	ops: dry: 650 miles * 1.61(10 tons * 0.9074; wet same as dry *7
			0/30 to represent entrained water

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Appendix D
HAPs Emissions Reported from SimaPro

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SimaPro 7.3 Inventory Date: 1/15/2013 Time: 2:42 PM
Project EPA Grants Site Chlorinated Solvent Plume

Calculation: Analyze
Results: Inventory
Product: 1 p UPD Grants Overall Sept 2012 (of project EPA Grants Site Chlorinated Solvent Plume)
Method: TRACI 2 Grants Apr 2012Rev1 V4.00
Indicator: Characterization
Unit: kg HAPs
Compartment: All compartments
Per sub-compartme No
Skip unused: No
Category: HAPs to Air
Cut-off: 0.001%
Exclude infrastructu Yes
Exclude long-term e No
Sorted on item: Substance
Sort order: Ascending

No	Substance	Compartment	Unit	Total	Elect Gen Thermal Treatment Operations	Onsite ISCO Delivery	Onsite Therm Treat & Const and Operations	Onsite Well Installation and ERD Delivery	Other ISCO Delivery	Other Therm Treat & Const and Operations	Other Well Installation and ERD Delivery	Transport ISCO Delivery	Transport Therm Treat & Const and Ops	Transport Well Installation and ERD Delivery
	Total of all compart		kg HAPs	2.02E+03	1.57E+03	4.78E-02	4.15E+00	5.13E+00	5.30E+01	1.87E+01	3.59E+02	6.02E-01	1.35E+00	9.85E+00
	Remaining substanc		kg HAPs	4.73E-02	3.90E-03	3.23E-04	4.54E-05	5.96E-03	7.12E-03	1.05E-03	2.89E-02	2.03E-06	2.37E-06	2.11E-05
1	Acetaldehyde	Air	kg HAPs	3.59E+01	4.69E-02	6.34E-03	1.34E-03	1.17E-01	5.69E-02	9.91E-03	3.52E+01	2.33E-02	6.09E-02	4.28E-01
2	Acetonitrile	Air	kg HAPs	9.16E+00	5.91E-06	6.47E-11	2.17E-08	1.62E-08	1.09E-05	5.01E-04	9.16E+00	6.39E-08	1.67E-07	1.17E-06
3	Acrolein	Air	kg HAPs	3.69E-01	3.34E-01	7.68E-04	8.68E-04	1.49E-02	6.39E-03	5.04E-04	1.11E-02	2.56E-05	2.01E-05	2.12E-04
4	Antimony	Air	kg HAPs	2.51E-02	2.07E-02	2.12E-07	5.12E-05	5.35E-05	1.77E-03	5.83E-04	1.91E-03	1.66E-06	1.77E-06	1.63E-05
5	Arsenic	Air	kg HAPs	5.53E-01	4.78E-01	6.74E-06	1.48E-03	1.70E-03	3.01E-02	8.76E-03	3.31E-02	5.70E-05	6.71E-05	5.95E-04
6	Benzene	Air	kg HAPs	3.79E+01	2.24E+00	7.75E-03	3.13E-02	1.53E-01	2.01E+00	1.37E+00	2.65E+01	2.52E-01	6.61E-01	4.64E+00
7	Beryllium	Air	kg HAPs	2.81E-02	2.51E-02	3.27E-07	7.16E-05	8.25E-05	9.09E-04	4.82E-04	1.38E-03	2.14E-06	1.63E-06	1.75E-05
8	Cadmium	Air	kg HAPs	8.39E-02	6.28E-02	1.65E-06	3.46E-04	4.18E-04	3.94E-03	1.73E-03	1.39E-02	4.35E-05	9.37E-05	6.88E-04
9	Chlorine	Air	kg HAPs	1.10E+01	1.31E-01	1.34E-06	3.68E-04	3.38E-04	7.22E-02	8.33E-01	9.98E+00	8.02E-05	1.94E-04	1.39E-03
10	Chromium	Air	kg HAPs	4.97E-01	3.16E-01	4.96E-06	1.14E-03	1.25E-03	1.12E-01	1.59E-02	4.91E-02	1.18E-04	2.49E-04	1.84E-03
11	Chromium VI	Air	kg HAPs	1.02E-01	9.05E-02	9.17E-07	2.13E-04	2.31E-04	6.09E-03	9.49E-04	4.32E-03	6.34E-06	5.44E-06	5.50E-05
12	Cobalt	Air	kg HAPs	1.74E-01	1.29E-01	9.48E-06	1.86E-03	2.40E-03	1.62E-02	2.22E-03	2.10E-02	8.62E-05	1.10E-04	9.48E-04
13	Cyanide	Air	kg HAPs	1.55E+01	1.58E-01	4.13E-06	2.12E-03	1.03E-03	5.58E-02	4.00E-03	1.53E+01	4.25E-05	6.17E-05	5.08E-04
14	Ethane, 1,1,1-trichl	Air	kg HAPs	3.75E+00	1.87E-04	5.66E-08	2.13E-05	1.42E-05	4.25E-04	7.82E-02	3.67E+00	4.81E-07	5.73E-07	5.06E-06
15	Ethane, 1,2-dichlor	Air	kg HAPs	6.99E-01	1.05E-03	3.38E-08	2.94E-05	8.31E-06	1.26E-03	1.88E-01	5.09E-01	2.08E-06	5.05E-06	3.61E-05
16	Ethene, tetrachloro	Air	kg HAPs	4.89E-01	4.94E-02	6.00E-07	1.33E-04	1.51E-04	9.17E-04	9.26E-03	4.30E-01	3.96E-06	3.04E-06	3.24E-05
17	Formaldehyde	Air	kg HAPs	6.15E+01	5.54E-01	9.83E-03	1.78E-02	2.00E-01	5.53E-01	3.61E-01	5.87E+01	5.06E-02	1.31E-01	9.24E-01
18	Hydrogen chloride	Air	kg HAPs	1.51E+03	1.38E+03	1.52E-02	3.46E+00	3.85E+00	4.27E+01	1.43E+01	6.45E+01	1.03E-01	8.39E-02	8.70E-01
19	Hydrogen fluoride	Air	kg HAPs	1.88E+02	1.73E+02	1.84E-03	4.22E-01	4.65E-01	5.50E+00	6.66E-01	7.48E+00	1.25E-02	1.02E-02	1.05E-01
20	Lead	Air	kg HAPs	9.45E-01	7.10E-01	9.35E-06	2.04E-03	2.36E-03	6.16E-02	3.42E-02	1.27E-01	3.30E-04	7.51E-04	5.45E-03
21	m-Xylene	Air	kg HAPs	3.71E-01	2.81E-03	8.00E-08	7.66E-05	1.96E-05	6.55E-03	3.05E-03	3.58E-01	1.26E-06	2.35E-06	1.80E-05
22	Mercury	Air	kg HAPs	2.28E-01	1.02E-01	1.38E-06	3.19E-04	3.47E-04	8.08E-03	1.34E-02	1.04E-01	1.72E-05	2.83E-05	2.24E-04
23	Methane, dichloro-	Air	kg HAPs	6.51E-01	3.46E-01	1.03E-05	2.04E-03	2.60E-03	6.17E-03	7.83E-03	2.86E-01	6.49E-05	4.42E-05	5.00E-04
24	Methane, monochl	Air	kg HAPs	3.56E-02	4.84E-03	3.37E-07	3.50E-04	8.24E-05	1.13E-02	6.62E-04	1.83E-02	5.63E-06	1.08E-05	8.17E-05
25	Methanol	Air	kg HAPs	1.09E+02	6.66E-02	1.56E-06	1.22E-03	3.83E-04	1.21E-01	1.77E-02	1.09E+02	4.23E-03	1.10E-02	7.76E-02
26	Naphthalene	Air	kg HAPs	3.06E-02	1.63E-02	1.91E-06	3.50E-04	4.83E-04	x	2.91E-04	1.31E-02	1.17E-05	7.24E-06	8.60E-05
27	PAH, polycyclic aror	Air	kg HAPs	3.24E-01	4.15E-02	1.39E-03	9.33E-04	2.58E-02	3.94E-02	3.21E-02	1.82E-01	3.10E-05	5.92E-05	4.49E-04
28	Phenol	Air	kg HAPs	3.14E-01	9.43E-03	9.30E-08	2.67E-05	2.34E-05	4.43E-04	6.13E-04	3.04E-01	6.97E-07	6.96E-07	6.59E-06
29	Phenols, unspecifie	Air	kg HAPs	3.13E-02	2.86E-02	5.41E-06	9.91E-04	1.37E-03	x	1.81E-05	x	3.30E-05	2.05E-05	2.43E-04
30	Phosphorus	Air	kg HAPs	7.10E-01	5.26E-02	9.68E-07	3.37E-04	2.43E-04	3.04E-02	1.83E-02	6.08E-01	8.03E-06	9.29E-06	8.30E-05
31	Radionuclides (Inclu	Air	kg HAPs	6.66E+00	6.24E+00	8.44E-04	1.55E-01	2.13E-01	x	2.82E-03	x	5.15E-03	3.19E-03	3.80E-02
32	Selenium	Air	kg HAPs	1.61E+00	1.49E+00	1.62E-05	3.70E-03	4.09E-03	4.33E-02	5.51E-03	5.54E-02	1.26E-04	1.31E-04	1.22E-03
33	Styrene	Air	kg HAPs	2.30E-02	3.03E-04	1.65E-08	1.66E-05	4.05E-06	5.47E-04	4.51E-04	2.17E-02	3.18E-07	6.37E-07	4.77E-06
34	t-Butyl methyl ethe	Air	kg HAPs	1.88E-01	9.00E-04	8.05E-09	1.56E-06	2.03E-06	1.07E-05	4.85E-05	4.11E-03	8.31E-03	2.18E-02	1.53E-01
35	Toluene	Air	kg HAPs	2.31E+01	6.34E-01	3.42E-03	3.71E-02	7.13E-02	1.60E+00	6.98E-01	1.69E+01	1.41E-01	3.70E-01	2.60E+00

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