SUMMARY

The U.S. Environmental Protection Agency's (EPA) strategic plan calls for increased research and application of sustainable systems that promote environmental stewardship, reduce greenhouse gas (GHG) emissions, and improve energy efficiency. One area of this research is green remediation. Green remediation is a relatively new approach to environmental cleanup; expanded from the traditional perspective through the addition of best management practices (BMPs) and a series of new criteria for consideration. EPA's Office of Solid Waste and Emergency Response (OSWER) is working with private and public partners to promote the use of BMPs for green remediation at contaminated sites throughout the United States.

At the request of Adventus Americas, Inc. (Adventus), Maul Foster & Alongi, Inc. (MFA) completed a review of four potential green remediation technologies (EHC®, emulsified oil, electrical resistive heating, and pump and treat) for an active cleanup site where groundwater is contaminated with trichloroethene (TCE). The technologies reviewed for potential use at this site were evaluated using federal requirements for green acquisition as defined by Executive Order 13423-2007 and EPA's *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites.*

Table S-1

	BIOBASED	RENEWABLE ENERGY	ALTERNATIVE FUEL	RECYCLED CONTENT
EHC	✓	NA	✓	✓
EMULSIFIED OILS	✓	NA	✓	
ERH		✓		
PUMP & TREAT		✓	✓	

The evaluation includes a review of qualitative and quantitative data for the selected technologies. Qualitative information, such as material content, potential for renewable energy or alternative fuel use, is provided in Table S-1. The quantitative comparison (Figure S-2) evaluates resource efficiency onsite and includes a ranked score to determine best overall performance of each technology across the parameters. A carbon footprint (i.e. metric tons of carbon dioxide equivalents) for onsite fuel and electricity use for each technology is provided in Figure S-3. A detailed evaluation of each technology is provided in the following report.

Based on this comparison for the defined site, MFA finds that EHC® meets EPA's criteria for sustainable product procurement and green remediation more effectively than the other technologies evaluated in this document.

Figure S-3. Metric Tons of CO2e

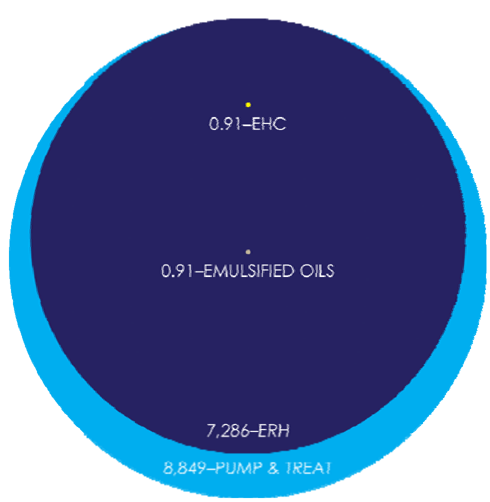
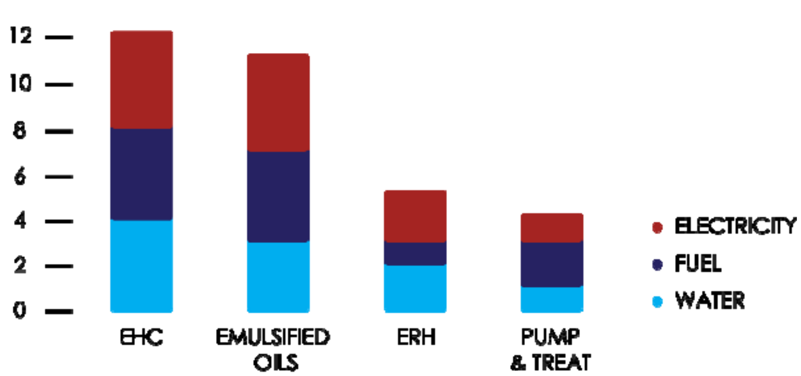


Figure S-2. EFFICIENCY RANKINGS



1 PROJECT DATA

For the purposes of providing a quantitative and qualitative comparison of the different technologies as applied, MFA used data from a typical site. This site is described further in this section, including the size, location and contaminants present.

1.1 SITE DESCRIPTION

The 80-acre site consists of an operating facility in Portland, Oregon, adjacent to the Willamette River. Operations at the facility began in 1980, after the site had been developed by filling during the 1970s. Prior to development, portions of the property were used for waste disposal from a manufactured gas plant (MGP). The MGP waste stream included petroleum hydrocarbon dense non-aqueous phase liquid (DNAPL), which was incorporated into the fill, along with spent oxide waste, dredged sediment, and quarry spoils.

1.2 CONTAMINANT INFORMATION

Operations at the facility included the use of TCE from approximately 1980 to 1989. TCE and/or TCE-containing wastewater were released to the subsurface in the early 1980s, roughly between 1980 and 1984. The releases likely occurred immediately upgradient of the primary manufacturing building, which covers most of the groundwater plume between the source area and the riverbank. Groundwater flows from the upland under the river, with a small portion of the impacted plume intersecting transition zone water.

1.2.1 NATURE AND EXTENT

Concentrations of TCE and 1,1-dichloroethene (DCE) in the release area ranged as high as 592,000 and 90,000 ug/L (respectively) at depths ranging from approximately 50 to 110 ft below ground surface (bgs). The concentrations and depth of the impacts suggested the presence of TCE DNAPL. The soil in the source area consists of fill (from 0 to 25 ft bgs), underlain by silt (about 25-50 ft bgs), silty sand (to about 170 ft bgs), gravels and cobbles (to about 200 ft bgs), underlain by basalt characteristic of the Columbia River Basalt deposits. Significant soil and groundwater legacy impacts including MGP DNAPL are present throughout the fill and alluvial units, and are being addressed by other responsible parties. Groundwater flow velocities in the source area have been estimated to be on the order of 0.1 to 0.2 ft/day.

Investigation at the riverbank showed that concentrations of TCE, DCE and vinyl chloride (VC) ranged as high as 2,000; 34,000; and 5,000 ug/L (respectively), at depths ranging from approximately 80-130 ft bgs. The soil in the zone impacted by TCE consists of alluvial sands, with occasional thin silt layers. Legacy impacts have been observed in riverbank wells screened from 109-124 ft bgs. Groundwater flow velocities at the riverbank have been estimated to be on the order of 1 to 10 ft/day.

1.2.2 SIZE

Two treatment areas were identified for the purposes of this evaluation. The upland source area (south of the production building) treatment dimensions of have been assumed to be 100 feet (north-south) by 300 feet (east-west) and to extend from 20 to 100 feet below ground surface (bgs). The treatment area at the riverbank is assumed to be 80 feet (north-south) by 300 feet (east-west) and to extend from 70 to 130 feet bgs. The footprints and volumes of these treatment areas are similar regardless of the technologies compared – i.e., each technology would be required to address similar volumes.

2 REMEDIATION TECHNOLOGIES REVIEW

Four technologies were selected for potential use at the site as appropriate remedies for the TCE-related impacts.[1] The technologies were evaluated using federal requirements for green acquisition as defined by Executive Order 13423-2007 and EPA's *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites.* A brief description of each technology as well as quantitative and qualitative information that may be used in sustainable project planning, design and management is included.

This review focuses primarily on sustainability criteria identified and does not address parameters used for technology screens that are consistent with EPA guidance for feasibility studies, such as long-term reliability, effectiveness, implementation and cost. These parameters are important for sustainable site remediation and long-term site use, but are well-understood by project managers and do not warrant further consideration here. However, it should be noted that a robust technology screen for a green remediation project should include both sets of parameters.

2.1 EHC®

EHC® technology is a group of remediation products used for the *in situ* treatment of groundwater and soil impacted by heavy metals and persistent organic compounds such as chlorinated solvents (Seech, 2006).

EHC® combines physical, chemical and biological treatment methods into an injectable material composed of micro-scale zero-valent iron (ZVI) and food-grade organic carbon. Following injection, EHC® slowly ferments to release fatty acids and nutrients. This process supports reductive dechlorination of chlorinated solvents, explosives, pesticides, without accumulation of metabolites and is less disrupting of natural habitats; minimizes production of fermentation end-products, such as methane. EHC® injection usually promotes three to five years of treatment.

Sustainability criteria for EHC® were evaluated by reviewing product information and project application case studies. This evaluation assumes that EHC is not reapplied.

- Life Cycle Impacts

[1] Remediation of the MGP-related impacts is to be completed by other responsible parties.

  - Provides pH buffering capacity; does not lead to acidification of the aquifer or alter its natural attenuation mechanisms as opposed to other commercially available organic substrates.
  - Produces less greenhouse gases (GHG) upstream by using biobased and recycled content.
  - No waste is produced, eliminating the impacts and emissions from transport and disposal.
  - Short-term effectiveness, limiting need for long-term operational maintenance.
- Recycled Content
  - Potential to use recycled materials, such as industrial (for the micro-scale ZVI) or agricultural waste (for the organic carbon component).
- Biobased
  - Yes.
- Alternative Fuels
  - Alternative fuels may be used in onsite equipment such as drill operations, but are not included in the evaluation of this technology for this site.
- Non-ozone Depleting Substances
  - Yes.
- Renewable Energy
  - No significant amount of electricity required.
- Water
  - 515,000 gallons potable water for the total project.
  - Groundwater use restricted for 3-5 years during remediation.
- Fuel
  - 90 gallons of diesel for the total project.
- Electricity
  - No significant amount of electricity required.

2.2 ELECTRICAL RESISTIVE HEATING

Thermal treatment, such as electrical resistive heating (ERH), reduces site contamination by introducing an electrical current into the contaminated zone which increases the subsurface temperature based on the electrical resistance of the soil and groundwater to volatilize, mobilize, or degrade contaminants.

ERH is an aggressive remediation technology. It has to be actively managed and maintained. It typically is used to remediate heavily contaminated source areas, and because of cost and infrastructure, it is not a good technology for light to moderate groundwater contamination, but could be appropriate for the test case (Mc-Millan, 2008). ERH treatment is often completed within one year – the assumed treatment period for this evaluation.

Sustainability criteria for ERH were evaluated by reviewing product information and project application case studies.

- Life Cycle Impacts
  - Short-term effectiveness, limiting needs for long-term operational maintenance.
  - Remediation process can be monitored offsite reducing impacts from operational maintenance.
  - No waste is produced, eliminating transportation and disposal impacts.
- Recycled Content
  - No.
- Biobased
  - No.
- Alternative Fuels
  - Alternative fuels may be used in onsite equipment such as drill operations, but are not included in the evaluation of this technology for this site.
- Non-ozone Depleting Substances
  - Yes.
- Renewable Energy
  - It is possible to combine the use of renewable energy with this technology, but would be purchased separately from the technology package.
- Water
  - 150,000 gallons potable water is needed for system operation for the total project.
  - Removal and disposal of approximately 5.4 million gallons of groundwater during the total project.
- Fuel
  - 3,000 gallons diesel for the total project.
- Electricity
  - 16 million kwh for the total project.

2.3 EMULSIFIED OIL

Emulsified oil is a remediation product composed of biodegradable substrates combined with micronutrients that enhance anaerobic biodegradation of the contaminant. According to the one provider, contaminants that may be treated with emulsified oil include chlorinated solvents, energetic materials, nitrates, heavy metals, radionucleides, and acid rock drainage (EOS, 2008).

Emulsified oil remediation products are delivered to the site as a concentrate and must be diluted prior to injection. Treatment duration varies and re-injections are sometimes needed (EOS, 2008). Sustainability criteria for emulsified oil were evaluated by reviewing product information and project application case studies. This evaluation assumes that the emulsified oil is not reapplied.

- Life Cycle Impacts
  - Biobase reduces upstream emissions and impacts of the product manufacture.
  - May result in a total organic carbon (TOC) plume and/or mobilize heavy metals.
- Recycled Content
  - The product evaluated does not currently contain recycled content.
- Biobased
  - Yes.
- Alternative Fuels
  - Alternative fuels may be used in onsite equipment such as drill operations, but are not included in the evaluation of this technology for this site.
- Non-ozone Depleting Substances
  - Yes.
- Renewable Energy
  - No significant amount of electricity required.
- Water
  - 3.05 million gallons of potable water for the total project.
  - Possible acidification of groundwater.
  - Groundwater use restricted for 3-5 years during remediation.
- Fuel
  - 90 gallons for the total project.
- Electricity
  - No significant amount of electricity required.

2.4 PUMP & TREAT

Pump and treat is a common method for cleaning up groundwater. Pumps are used to bring polluted groundwater to the surface where it can be treated more easily. In general, a pump and treat cleanup is a relatively slow process. It will usually require at least five to ten years, but can last for up to 30 years. For the site evaluated in this document, a 30 year timeframe would be required for treatment and is used in all total project calculations.

Pump and treat systems in general have a relatively high implementability. Extraction wells and treatment system components are based on well-established and readily available technologies. There are many vendors and contractors experienced with the components of pump and treat systems. Pump and treat systems have been installed at many chlorinated solvent sites (EPA, 1990).

- Life Cycle Impacts
  - Is a well-established technology.
  - Requires a relatively long implementation timeframe.
  - Process residuals will require treatment and disposal.
- Recycled Content
  - None.
- Biobased
  - No.
- Alternative Fuels
  - Alternative fuels may be used in onsite equipment such as drill operations, but is not included in the evaluation of this technology for this site.
- Non-ozone Depleting Substances
  - None.
- Renewable Energy
  - It is possible to combine the use of renewable energy with this technology, but would be purchased separately from the technology package.
- Water
  - No potable water required.
  - Removal and disposal of 52.6 million gallons per year of groundwater, 1.6 billion gallons for the total project.
- Fuel
  - 600 gallons for the total project.
- Electricity

– 650,000 kwh/year, 19.5 million kwh for the total project.

2.5 SUSTAINABILITY ASPECTS COMPARISON

The information provided in this section is a summary of the details described in Sections 3.1-3.4 for the four remediation technologies. The technologies are evaluated against EPA's green procurement guidelines and green remediation BMPs, and are rated using a simple credit scoring method as an adaptation of a rating system used by EPA in a pilot study (EPA, 2007).

The rating system functions as follows:

- For yes/no categories, each technology receives one credit
- For relative resource consumption categories, the technologies are ranked, with a score of 4 being the efficiency highest or the least amount of resource consumed.
- Higher total scores represent higher levels of sustainability over all parameters for the use of that technology at the defined site.
- Given the project parameters or clients' interest, this ranking scale could be adjusted to emphasize upstream impacts, site characteristics or specific site goals by applying a multiplier to individual parameters.

COMPARISON: GREEN PRODUCT ACQUISITION METRICS

Table 2-1

Product	Recycled Content	Biobased	Water	Fuel	Electricity	Total
EHC	1	1	4	4	4	14
Emulsified Oils		1	3	4	4	12
Electrical Resistive Heating (ERH)			2	1	2	5
Pump & Treat			1	2	1	4

Alternative fuel and/or renewable energy could be used at this site, but is not included in Table 2-1 as the use of such practices may be out of the direct control of the remediation technology manufacturer and/or is not included in the standard technology packages. An 'x' in Table 2-2 indicates where the potential use of alternative fuels and/or renewable energy could be considered for each of the four technologies.

Table 2-2

PRODUCT	ALTERNATIVE FUELS	RENEWABLE ENERGY
EHC	x	NA
Emulsified Oils	x	NA
Electrical Resistive Heating (ERH)		x
Pump & Treat	x	x

Table 2-3 describes the carbon dioxide equivalents (CO_2e) of the technologies reviewed, including electricity use and fuel consumption on site. The CO_2e consumption assumes the carbon intensity of the local electricity grid mix in the identified site location.

Table 2-3

PRODUCT	METRIC TONS OF CO_2e
EHC	.91[2]
Emulsified Oils	.91[3]
Electrical Resistive Heating (ERH)	7,286
Pump & Treat	8,849

EHC PRODUCT EVALUATION-SUSTAINABLE SITE REMEDIATION

The table below provides a brief snapshot of how EHC meets various criteria for whole-site green remediation. A mark in the each box below represents a positive contribution from the use of EHC to green remediation goals throughout the cleanup process. This information should be used to guide clients or project managers in understanding and developing green remediation plans.

[2] This calculation includes electricity and fuel use onsite and does not include upstream or downstream impacts of production and manufacture of the technology. Further study may show positive CO_2e impacts from the use of recycled input products.

[3] The calculation includes electricity and fuel use onsite and does not include upstream or downstream impacts of production, harvesting and/or disposal of soybeans or soybean oil. Some studies suggest that soybean production emits nitrous oxide (N_2O), a relatively powerful global warming gas-310 times that of CO_2 (Yan, 2005) (IPCC, 1996).

Table 2-4

ASPECT	EXTRACTION OF MATERIALS	PRODUCTION/MANUFACTURE OF TECHNOLOGY	SITE INVESTIGATION & TREATMENT	DISPOSAL	SITE END-USE
ECONOMIC					
Direct cost of product			X	X	
Life cycle cost	X	X			
Economic benefit from reuse of site					X
Economic benefit to local economy		X*	X	X	X
Cost savings resulting from efficiency, reductions in materials use or reuse			X	X	X
ENVIRONMENTAL					
Reduction of toxicity, mobility or volume	X		X	X	
Energy Impacts	X	X	X	X	
Air Emissions	X	X	X		
Water Impacts	X	X	X	X	
Land/Ecosystem Impacts	X	X	X		
Material Consumption	X	X	X	X	
Waste Generation	X	X	X	X	
COMMUNITY					
Acceptance/ perception			X		
Societal Impacts	X	X	X		X
Local and national issues		X	X	X	

* Will provide an advantage if produced locally.

3 CONCLUSION

3.1 SUMMARY

Based on the comparison, MFA finds that EHC meets EPA's criteria for sustainable product procurement and green remediation more effectively than traditional technologies (groundwater extraction and treatment), other in-situ technologies (e.g., emulsified oil) or emerging/developing technologies (e.g., electrical resistive heating) evaluated in this document.

3.2 ADDITIONAL DATA NEEDS

For green remediation technologies to be robustly evaluated, more data regarding the resources, manufacturing processes, and transportation of the various technologies products and by-products is required. EPA would likely need to provide incentives to technology providers to disclose this information, or mandate disclosure.

Likewise, a ranking system to more completely evaluate relative impacts of the various criteria upstream, at the site, and downstream is required. The current method does not allow the users to give weight to parameters that may be of significant relevance in this area (e.g. water or air critical).

3.3 FUTURE CONSIDERATIONS

Adventus may consider the following future implications or next steps associated with this work:

- Consider utilizing additional sustainability metrics or tools as they are developed to compare results (e.g. AFCEE sustainability protocol).
- Explore opportunities to encourage certification standards for 'green remediation' products; with varying degrees of product achievement.
- Provide sustainability or green remediation information to clients as part of bid proposals.
- Develop a more comprehensive greenhouse gas baseline that illuminates upstream and downstream advantages of the product in addition to onsite use.

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Yan, Lanfang. Cai, Zucong. Soil Biology and Biochemistry, Volume 37, Issue 6, June 2005, Pages 1205-1209.

APPENDIX A

RESOURCE USE & EMISSIONS CALCULATIONS

ADVENTUS SUSTAINABILITY EVALUATION
RESOURCE USE AND EMISSIONS CALCULATIONS

ITEM	DESCRIPTION	COMMENT	CALCULATION
SITE CHARACTERISTICS			
Source area (cf)	2,400,000	Based on site information	100 ft x 300 ft x 80 ft
Tons of Soil	88,900	Based on site information	
Porosity	0.3	Based on site information	
Source Volume	2,400,000	Based on site information	
Pore Volume	720,000	Based on site information	
Effective Porosity	0.17	Based on site information	
Groundwater Volume within Source (million gallons)	3.05	Based on site information	
REMEDIAL ACTIONS			
EHC			
Water Use (gallons)	515,000	Potable water use: approximate for entire project, assumes an application rate of 1% and 128,900 tons of soil	tons of EHC * 2000 lb/ton * 30 gal water/150 lbs EHC
	0	Groundwater use restricted 3-5 years.	
Energy Use (kwh)	0	Based on product information.	
Fuel Use (gallons diesel)	90	Approximate for total project, based on site information.	3 gallons of fuel/day * 30 days
Carbon Dioxide Equivalents (metric tons)	0.91	Includes fuel and electricity use.	gallons fuel oil * lbs CO2/gallon + kwh of electricity * ton of CO2/kwh
EMULSIFIED OIL			
Water Use (gallons)	3,050,000	Potable water use; approximate for total project.	Based on site information; groundwater volume.
	0	Likely acidification of groundwater. Groundwater use restricted for 3-5 years during remediation.	
Energy Use (kwh)	0	Based on product information.	
Fuel Use (gallons diesel)	90	Approximate for total project.	3 gallons of fuel/day * 30 days

ADVENTUS SUSTAINABILITY EVALUATION
RESOURCE USE AND EMISSIONS CALCULATIONS

ITEM	DESCRIPTION	COMMENT	CALCULATION
Carbon Dioxide Equivalents (metric tons)	0.91	Includes fuel and electricity use.	gallons fuel oil * lbs CO2/gallon + kwh of electricity * ton of CO2/kwh
ERH			
Water Use (gallons)	150,000	Potable water use, approximate for total project.	vendor supplied
	5,400,000	Quantity of groundwater extracted and disposed.	
Energy Use (kwh)	16,000,000	Based on product information.	vendor supplied
Fuel Use (gallons diesel)	3,000	Approximate for total project.	30 gallons/day * 1day/boring * 100 borings (electrode or extraction well)
Carbon Dioxide Equivalents (metric tons)	7,286	Includes fuel and electricity use.	(gallons distillate fuel oil consumed * lbs CO2/gallon) + (kwh of electricity * ton of CO2/kwh)
PUMP & TREAT			
Water Use (gallons)	0	Potable water use.	Based on product information.
	1,578,000,000	Groundwater extraction and disposal for the total project.	
Energy Use (kwh)	19,500,000	Based on site information	Estimated for pumps and equipment.
Fuel Use (gallons diesel)	600	Approximate for entire project	30 gallons/day * 2 days/well * 10 wells
Carbon Dioxide Equivalents (metric tons)	8,849	Includes fuel and electricity use.	gallons fuel oil * lbs CO2/gallon + kwh of electricity * ton of CO2/kwh
REFERENCES			
lbs of CO2 produced/gallon diesel fuel		For reference, see http://www.eia.doe.gov/oiaf/1605/forms.html, then click on Form EIA-1605 long form instructions. Scroll down to Appendix B.	
lbs of CO2 produced/kwh of electricity used		1 lb. of CO2/ kwh. PGE reference.	