ELECTRICAL RESISTANCE HEATING AS A SUSTAINABLE REMEDIATION TECHNIQUE

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Traditional evaluations of remedial technologies have followed feasibility criteria outlined in the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental, Response, Compensation and Recovery Act (CERCLA). However, more recent legislation has created an emphasis on considering "sustainability" as part of the remediation evaluation process.[1] A sustainability evaluation of a remediation technology involves analysis of environmental, social and economic issues as depicted in Figure 1below (Ellis, 2009).

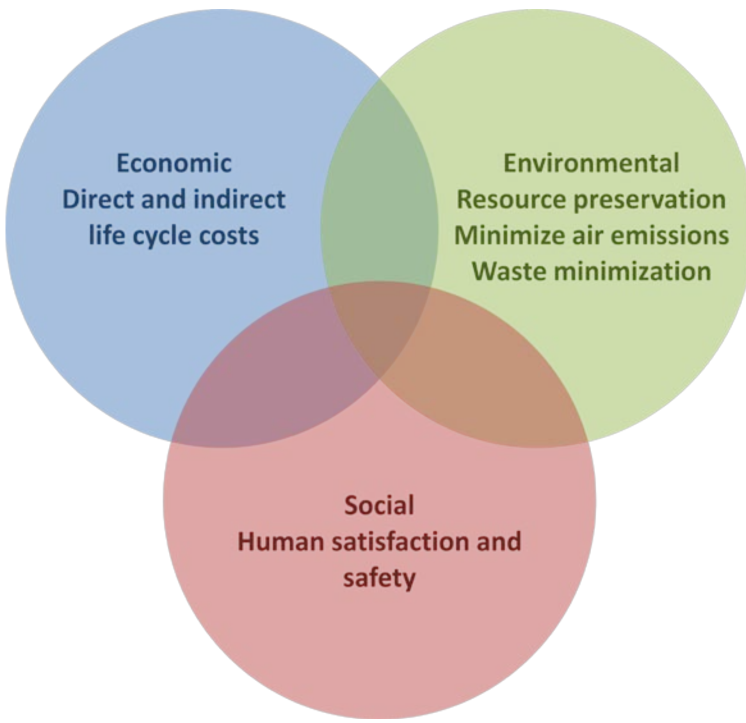


FIGURE 1: SUSTAINABILITY VENN DIAGRAM

As the concept of sustainability gains in strength, the relative value for each existing treatment technology must be reassessed. Looking beyond the immediate cost impact of a particular technology, and assessing its impact on sustainability, greatly improves the selection process of remedial methods. The recent changes in perspective, relative to remedial value, have increased the value of in-situ technologies once thought to be niche methods like Electrical Resistive Heating (ERH).

[1] Public Law 109-58 - Energy Policy Act of 2005; 42 U.S.C. 17081 - Energy Independence and Security Act of 2007; Executive Order 13423 – Strengthening Federal Environmental Energy and Transportation Management, January 24, 2007.

ERH ECONOMIC ASSESSMENT

Economic assessment is a key component of the feasibility analyses performed under RCRA and CERCLA. It is also a key component in a sustainable remediation analysis as avoiding economic waste is a component of sustainability. A proper remedial cost evaluation involves a comparison of technologies on the basis of cost per pound ($/lb) of contaminant removed and/or an evaluation on cost per cubic yard ($\$/yd^3$) of treated soil (USEPA, 1998). These costs will vary from site to site depending on the mass of contaminant in the soil and the soil volume at each particular site. Using existing remedial methods, for sites having more than 2,000 pounds of contaminants, remediation costs tend to normalize into the range of $20/lb to $200/lb of contaminant mass removed (Boulding 1996; Freeman, 1995; Hyman, 2001; Lehr, 2002; Lehr 2004; Noris, 1993; Rast, 1997; Saske, 2003; USEPA, 1997; Vanek, 2003).[2] An analysis of 13 ERH sites (contaminant mass ranging from 2,000 to 100,000 lbs) showed that the average cost per pound of contaminant removed was $78/lb. The median cost was $48/lb with the 25% to 75% probability values falling into the range of $28/lb to $142/lb. These values are well in line with the costs observed for traditional remediation approaches. The very high removal efficiency observed for VOCs during ERH remediation tends to decrease the cost per pound of contaminant recovery in ERH remediation to make it even more efficient.

Technologies like air sparging, excavation, soil vapor extraction, soil mixing, phytoremediation, composting and bioremediation are often evaluated in terms of $\$/yd^3$. This value fluctuates from site to site depending on site volume, but the costs tend to normalize into the range of $40 to $250 per cubic yard of soil for remediation when the sites have more than 5,000 cubic yards of impacted soil (Boulding 1996; Freeman, 1995; Hyman, 2001; Lehr, 2002; Lehr 2004; Noris, 1993; Rast, 1997; Saske, 2003; USEPA, 1997; Vanek, 2003).[2] In an evaluation of 20 ERH projects with soil treatment volumes greater than 5,000 yd^3, the average cost for treatment was $\$133/yd^3$. The median cost was $\$115/yd^3$ with the 25% to 75% probability values in the range of $83 to $\$174/yd^3$. These values show that on a $\$/yd^3$ basis, ERH also falls into the cost range of other remedial technologies.

ERH ENVIRONMENTAL ASSESSMENT

The amount of greenhouse gases produced by a remediation effort carries heavy weight in the environmental assessment portion of a sustainability analysis. These analyses involve calculations of specific work activities and the amounts of greenhouse gases associated with the performance of the activities. It is probably simplest to illustrate this environmental analyses using the following example comparing ERH to two commonly used alternative technologies:

> A consultant was evaluating technologies for a remedial project having 25,000 cubic yards of soil impacted with trichloroethylene (TCE). During her evaluation of ERH, she determined that an estimated 3 million kWh of energy would be required to heat the soil to achieve clean-up objectives while also operating the vapor recovery and treatment system. In addition, it was estimated that 2,200 gallons of diesel fuel would be burned as a result of drilling and trucking activities. The estimated mass of carbon dioxide (CO_2) produced by ERH treatment of 25,000 cubic yards of soil was estimated at 4,000,000 pounds. At first this seemed like a phenomenal amount of energy usage that would ultimately contribute to green house gas production.

[2] Costs adjusted for inflation based on the date of publication.

However, upon closer evaluation, she learned that these costs were actually in-line with other commonly employed remedial technologies. For example, one remedial option for the site in question involved excavation and transportation to a treatment, storage and disposal (TSD) facility located 2 hours from the site. The consultant performed the following evaluation:

Greenhouse gas production for excavation and TSD of 25,000 cubic yards

- Excavation and loading of soils requires 0.2 gallons of diesel per cubic yard (Loeffler, 2008)
- Trucking expends 145 ton-miles per gallon of diesel (Brown, 2002)
- The TSD is located 120 miles from the site
- 25,000 cubic yards of silty sand at 1.5 tons per cubic yard
- Thermal desorption pre-treatment is required at the TSD for land-banned wastes
- The soil heat capacity at 15% moisture is 0.0004 kWh/kg ^{o} C
- 1 kWh produces approximately 1.3 pounds of carbon dioxide (CO_2) emissions
- Diesel has an energy value of 41 kWh/gallon (Perry, 1984)
- Clean fill will be provided by the TSD for use as backfill

Energy Calculations:
Excavation = (25,000 cy)(0.2 gal/cy)(41 kWh/gal)x2 ~ 410,000 kWh
TSD Trucking = (37,500 tons)(240 miles)(1 gal/145 ton-miles)(41 kWh/gal) ~ 2,545,000 kWh
Land-ban treatment = (37,500 tons)(0.0004 kWh/kg ^{o} C)(60 ^{o} C)(909 kg/ton) ~ 818,000 kWh.

The total energy expenditure for excavation and disposal was estimated at 3,773,000 kWh, or the equivalent of 4,900,000 pounds of CO_2. The dig-and-haul operations would actually produce nearly 1 million more pounds of CO_2 than remediation by ERH. In addition, the consultant noted that excavation would also emit significant VOCs and particulate matter (PM_{10}) to the atmosphere.

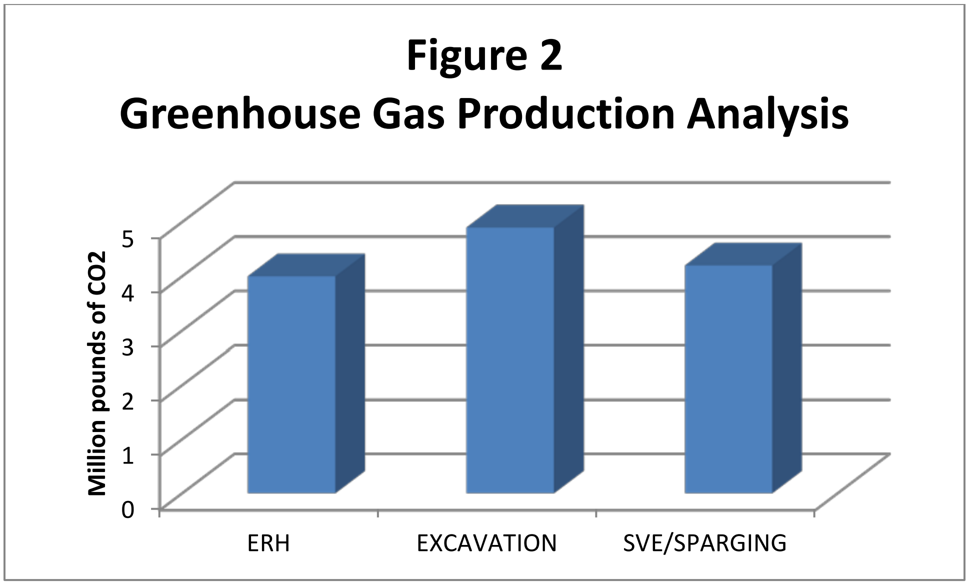
In an alternative analysis, the consultant evaluated a combined groundwater sparging and soil vapor extraction (SVE) system for remediation using the following assumptions:

Energy calculation for sparging and soil vapor extraction

- The design requires 50 sparging wells and 25 SVE wells.
- Each sparging well operates at 8 scfm and each SVE well recovers 30 scfm of air flow.
- The energy to generate compressed air is 0.2 kW per scfm (Perry, 1984).
- A 50-HP (38 kW) blower will be used for SVE.
- Diesel for drilling and trucking were estimated to consume 2,200 gallons of diesel.
- Remediation activities will last 3 years.

Energy Calculations:
Sparging energy = (50 wells)(8 scfm/well)(0.2 kW/scfm)(26,280 hours) ~ 2,100,000 kWh
SVE energy = (38 kW)(26,280 hours) ~1,000,000 kWh
Diesel consumption = (2,200 gallons)(41 kWh/gallon) = 90,200 kWh

The energy expended for sparging and SVE is nearly the same as the energy expended for ERH, producing an estimated 4,147,000 lbs of CO_2. In a sustainability evaluation, ERH has a similar amount of CO_2 production as other remedial technologies, the energy is simply expended over a shorter time-frame. Compared to standard remediation methods, the shorter treatment time and the higher clean-up efficiency of ERH does generally produce less CO_2 emissions per pound of contaminant mass removed as illustrated below in Figure 2.



Waste minimization and resource preservation are also considered important aspects of the environmental assessment. In-situ technologies are favored in comparison to ex-situ technologies because they conserve the natural resources of soil and groundwater. For example, large volumes of groundwater have to be pumped and removed from sites where excavation occurs at or below the water table.

ERH SOCIAL ASSESSMENT

The social aspect of sustainability involves improvement of life style as well as the health and safety of site workers and surrounding residents. Improvement of life style can be measured by the obtrusiveness of the remediation approach to the surrounding community. For example, the Record of Decision (ROD) for a large Superfund project in Florida directed the Potentially Responsible Parties (PRPs) to excavate the site and dispose of the materials off-site. The community objected to the ROD over concerns of dangers produced by hundreds of trucks transporting waste through their community and objections to odors and dust produced by excavation. The noise and emissions from heavy equipment were also a concern. The ROD was eventually amended as a result of community concern.

Health and safety is another consideration when evaluating the social implications of remedy selection. For example, excavation exposes workers and the community to contaminants that would not be released by an in-situ technology. The equipment and working environment involved in excavation and trucking activities pose a significant health and safety risk (Suarez, 1999). The average fatality rate for workers in the United States is approximately 0.03 fatalities per million hours worked (Bureau of Labor Statistics), but the rate of fatalities for heavy construction work and truck driving is significantly higher. Truck driver fatalities occur at a rate of approximately 1.45 fatalities per billion ton-miles (Brown, 2002). If 25,000 cubic yards (37,500 tons) of soil were excavated and transported to a TDF 120 miles away, with 25,000 cubic yards of backfill soil supplied for the return trip, then the project would involve 9 million ton-miles of soil transport. The statistical probably for a trucking fatality with this volume of trucking is $\frac{(1.45)(9E6)}{1E9} =$ 0.013 or 1.3%. The probability for a fatality during excavation activities is significantly lower. Heavy construction has approximately 0.12 fatalities per billion man-hours worked (Bureau of Labor Statistics). Assuming 600 hours of construction activities with a 5-man excavation crew, the probability of a fatality during excavation is $(5\ men)(600\ hours)\left(\frac{0.12 fatalities}{1E9\ man\ hours}\right) =$ 0.00036 or 0.036%. With excavation and trucking combined, a dig and haul scenario presents a 1.34% statistical probability for a fatality.

ERH activities are classified as light construction. Light construction activities are reported to have a 0.03 fatality rate per million hours worked (Bureau of Labor Statistics) while drilling operations have a rate of 0.07 fatalities per million hours worked (Drilling Contractor, 2009). Man hours for ERH installation, operation and decommissioning might total 2,000 hours with approximately 600 hours of drilling activities and shipment of 60 tons of drill cuttings and equipment. The statistics for this scenario indicates that the probably for a fatality for under this scenario is (2,000 hrs)(0.03/1E6) + (600 hrs)(0.07/1E6) + (80)(0.12 /1E9) = 0.00001 or 0.001%. These statistical values show that dig-and-haul is 1,340 times more likely to result in a fatality when compared to other light construction remedial technologies like ERH.

CONCLUSIONS

The novelty and upfront cost of an ERH remediation might make it a daunting technology to pursue, however, with further evaluation it becomes apparent that ERH is highly competitive in all aspects of sustainable remediation. The utilization of similar amounts of energy and the similar production of greenhouse gases match well with all conventional remediation technologies. ERH offers a cost-effective, sustainable remedy and a safe work environment that protects remedial construction workers and the community.

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