Why In Situ Thermal Desorption Can Be the Most Cost-Effective Remediation Method for Many Sites

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ABSTRACT: Three case studies are presented, showing that thermal remediation utilizing In Situ Thermal Desorption (ISTD) is often less expensive than alternatives. The life-cycle costs of implementing ISTD compare favorably with those for alternative remediation technologies such as excavation, pump-and-treat, soil vapor extraction, multiphase extraction, bioremediation and in situ chemical oxidation. With respect to excavation, ISTD is not only less expensive and less obtrusive, but also much more community friendly. The most significant cost of an ISTD project is the capital cost associated with the installation, while the operation and maintenance (O&M) cost is a less significant component. On the other hand, O&M is typically the most significant cost for non-thermal remediation technologies. Too often, however, feasibility studies for non-thermal in situ alternatives adopt unsubstantiated, short O&M timeframes for the achievement of cleanup criteria. As a result, the less effective technology may appear to be less expensive. However, when technologies are compared realistically, and have to achieve the same endpoint (e.g., remediation and removal of >99% of the contaminant mass), thermal methods often compare very favorably.

INTRODUCTION AND METHODOLOGY

Over the past 10 years, developments in the design and implementation of ISTD for treatment of source areas contaminated with organic compounds have resulted in significant cost reductions. These include utilization of less expensive materials and methods for installation of thermal wells; development of simpler approaches for recovering off-gas; reliance on off-the-shelf off-gas treatment equipment; efficiencies in use of manpower; and economies of scale.

Meanwhile the effectiveness of the ISTD technology in reliably achieving cleanup goals in soil and groundwater has been proven at full scale for a wide variety of contaminant types (e.g., chlorinated volatile organic compounds [CVOCs], semivolatile organic compounds [SVOCs], coal tar, polychlorinated biphenyls [PCBs]) and hydrogeologic settings (above and below the water table, in sandy, silty and clayey soil, and in fractured rock).

ISTD projects are frequently completed and sites closed, after less than one year of heating. By contrast, projections of the required duration of treatment for other in situ technologies have frequently proven to be overly optimistic. Mass removal is often seen initially, but due to subsurface heterogeneity and associated mass transport limitations, the required treatment and monitoring period often persists for many years. ISTD is fundamentally different because thermal conductivity is nearly invariant even within heterogeneous sites. Thus source zones targeted for treatment are fully heated and treated. Further rounds of treatment are not required.

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The evaluation of remedial costs is an important component of the remedy selection process, which is often performed during the Feasibility Study (FS). Specifically, cost estimates are among the data that are considered during the development and screening of remedial action alternatives, and during the subsequent more detailed comparison of those alternatives that are carried forward through the selection process. EPA (2000) provides guidance on developing and documenting costs during this process.

In the detailed analysis of remedial alternatives, cost estimates need to include the total resource costs over time (i.e., "life cycle costs") associated with any given alternative. The EPA (2000) guidance specifies how Present Value Analysis must be incorporated into remedy cost estimates of capital costs, annual O&M costs, and periodic costs provided during an FS so that they are presented on a common yardstick.

Properly comparing alternative costs and benefits is hardly the unique domain of remediation, having been developed and used for decades for many purposes. Guidance specific to remediation has been issued, however. For example, Volkwein (2000) describes how the Life Cycle Cost (LCC) assessment framework can be applied in soil remediation planning. Schultz and Weber (2003) further apply the principles of LCC analysis to the special requirements of site investigation and remediation projects.

According to EPA (2000), "the total estimated cost of a project is primarily dependent on how well, or to what degree, the project is defined (i.e., 'scope' or completeness of design)." Accordingly, LCC analysis requires that when alternatives employing different remediation methods are selected, "they must all be designed to achieve the same level of environmental performance (Schultz and Weber 2003)." Comparing the costs of remedies with different endpoints is like comparing apples to oranges.

Often the true life cycle costs of long-term remedies are not factored in properly during the remedy selection process. For example, overly optimistic timeframes for achieving the desired endpoints are often adopted, or the effectiveness of a remedy is not properly represented. For example, Bost and Perry (2006) adopted an estimate of only 5 percent mass removal for thermally-enhanced soil vapor extraction (TESVE), and as a result selected mechanical auger mixing of a clayey soil with a chemical oxidant. Our experience with TESVE utilizing the ISTD method of heating is that when properly designed and implemented, it has consistently produced a >95 percent mass removal, even in clayey soil. Had they used a more accurate estimate, TESVE would have been judged the more cost-effective remedy.

Another frequent problem is that the remedy selection process is undertaken with an incomplete accounting or understanding of the actual life cycle costs of effective source remediation. For example, Hatton and co-workers (2006) concluded that "Source remediation can reduce the overall life-cycle cost for a site only under near ideal circumstances, requiring some combination of rapid and substantial reduction of annual cost, and very low implementation cost." Our experience, as illustrated by the analysis in Example 3 below is that source remediation using ISTD often results in overall lower life cycle costs.

In this paper, guidelines for computing the life cycle costs of environmental projects are reviewed. Examples are provided of cost comparisons that led to the award of ISTD projects. In addition, LCC estimates of ISTD and competing in situ alternatives are presented.

RESULTS AND DISCUSSION

Example 1. Terminal One, Richmond CA. TerraTherm employed ISTD to successfully remediate a portion of the 14-acre (5.7-hectare) Terminal One Site in Richmond, California to enable its owner, the City of Richmond, to redevelop the parcel into a combined multi-family residential and recreational complex. High-end single and multi-family residences and a marina are located adjacent to the property, which is located on the shore of San Francisco Bay with open views across the bay to the cities of San Francisco, Oakland and Berkeley. Terminal One had been a port facility used for shipping and bulk storage of industrial chemicals and petroleum products from 1915 until the late 1980s. Remediation in the southwestern portion of the parcel, formerly the site of large aboveground tanks, was required to prevent exposure of potential receptors to vapors, particularly tetrachloroethene (PCE), which was found at concentrations of up to 2,700,000 μg/kg in soil and up to 96,000 μg/L in groundwater, and vinyl chloride (VC). Related contaminants were also present, including trichloroethene (TCE) and *cis*-1,2-dichloroethene (*cis*-1,2-DCE). Goals for the contaminants of concern (COCs) were 2,000 μg/kg for PCE and TCE, 17,000 μg/kg for *cis*-1,2-DCE, and 230 μg/kg for VC.

In their Updated Proposed Remedial Action Plan (RAP), Geomatrix (2004a,b) selected the following alternatives for the case of a 33,000 cubic yards (cy) (25,000 m^3) Target Treatment Zone (TTZ), 35 ft (10.7 m) in depth, with associated costs including Geomatrix-applied contingencies:

Alternative 1 – No Action	$0
Alternative 2 – Subsurface Vertical Vapor Barrier and Capping	$4.0M
Alternative 3 – In Situ Thermal Treatment: Thermal Desorption (ISTD)	$5.6M
Alternative 4 – In Situ Thermal Treatment: Electrical Resistance Heating (ERH)	$7.2M
Alternative 6 – Excavation and Off-Site Disposal	$11.4M

Geomatrix judged that Alternatives 1 and 2 would not meet the remedial goals to the same degree as Alternatives 3, 4 and 6.

Geomatrix also considered the following alternatives for the case of a TTZ of 7,000 cy (5,350 m^3), 20 ft (6.1 m) in depth, with associated costs including Geomatrix-applied contingencies:

Alternative 5 – Subsurface Vertical Vapor Barrier and ISTD	$2.7M
Alternative 7 – Subsurface Vertical Vapor Barrier and Excavation	$2.8M

Alternative 5 – ISTD was judged to be preferable to Alternative 7 – Excavation because the cost of Alternative 7 was thought to be more uncertain, as it depended on how much of the excavated soil would be subject to various soil classifications.

Under a performance-based contract, TerraTherm designed the ISTD system to treat soil and groundwater to a depth of 20 feet (6.1 m) over an area of 0.2 acres (0.08 ha), both inside and outside a large warehouse building, comprising a TTZ volume of 7,000 cy (5,350 m^3). The subsurface consisted of a 3-ft (0.9-m) deep unsaturated zone (granular fill) over saturated Bay Mud (low permeability clay). In June 2005, after completing the installation of 126 vertical heaters and an associated vapor collection and air quality control system, TerraTherm heated the TTZ to the boiling point of water for a period of 100 days, while collecting and treating the resulting steam and vapors. TerraTherm completed ISTD operation in October 2005, after 110 days of heating. Post-treatment soil sampling showed all remedial goals were achieved (Table 1). The project was completed on schedule and budget (LaChance et al. 2006).

The actual cost of the completed ISTD remedy was $1.96M, plus $0.35M for electric power, for a total cost to the City of Richmond of $2.31M. The City of Richmond Redevelopment Agency reported that TerraTherm's achievement of residential cleanup standards at this site would enable the City to derive ~$5M more during the sale of the property than had they opted for less-stringent industrial cleanup standards.

TABLE 1. Results of Full-Scale ISTD Treatment at the Terminal 1 Site in Richmond, CA.

		PCE	**TCE**	***cis*-1,2-DCE**	**VC**
		µg/kg	µg/kg	µg/kg	µg/kg
Remedial Goal		2,000	2,000	17,000	230
Average Soil Concentration	Avg. Pre-Treatment	34,222	1,055	6,650	932
	Avg. Post-Treatment	12.4	< RL	65	4.7
	No. of Samples < RL (i.e., ND)	54	64	41	63
	% Reduction Avg. Pre- to Post-	99.96%	> 99.6%	99.02%	99.49%
Maximum Soil Concentration	Max. Pre-Treatment	510,000	6,500	57,000	6,500
	Max. Post-Treatment	44	< RL	1,500	24
	% Reduction Max. Pre- to Post-	99.99%	> 99.3%	97.37%	99.63%

RL = Reporting Limit; ND = non-detect

Example 2. Former Manufactured Gas Plant, North Adams, MA. At a former manufactured gas plant (MGP) site in North Adams, Massachusetts, TerraTherm employed ISTD at full scale to remediate a 62-ft (18.9-m) diameter, 18-ft (5.5-m) deep gasholder containing residual coal tar. The owner, Massachusetts Electric Company, a subsidiary of National Grid, actively uses the property as an electric power distribution service facility, and has no plans to do otherwise. A risk characterization (Brown and Caldwell 2002) concluded that under the conditions at that time, the gasholder did not pose significant risk of harm to human health, safety, public welfare or the environment. A condition of no significant risk to human health had not been attained, however, because of the future potential for worker exposure to soil contaminants exceeding Massachusetts Upper Concentration Limits (UCLs). It was also concluded that the gas holder may be considered an uncontrolled source in that the possibility of a future release to surrounding soil and groundwater would exist if the integrity of the gas holder were to deteriorate with time or if the structure were to become damaged. While the remedial action alternative selected for the gasholder in the earlier Phase III RAP had been DNAPL recovery and capping, efforts to recover the viscous coal tar DNAPL had been only minimally successful. The RAP Addendum (Brown and Caldwell 2002) therefore assessed the feasibility of using technologies which could destroy or treat the COCs to minimize the need for long-term management of contaminated media.

Therefore, even though the gasholder structure was believed to be tight, elimination of the risk of future DNAPL migration was a major goal within the entire gasholder. Within its mid-section only (depths shallower than 12 ft [3.7 m] below ground surface

[bgs]), a construction worker scenario identified in a subsequent human health risk assessment called for achievement of the UCLs.

In their RAP Addendum, Brown and Caldwell (2002) selected four alternatives for detailed evaluation, with estimated costs on a total present worth basis as follows:

- Alternative 1 – No Further Action $0
- Alternative 2 – ISTD $0.76M
- Alternative 3 – Excavation and Offsite Thermal Treatment $0.78M
- Alternative 4 – DNAPL Recovery and Capping $0.43M

Alternative 1 was not considered viable. Alternative 4 ranked lower than Alternatives 2 or 3 because it did not entail destruction or treatment of the hazardous materials so as to minimize the need for their long-term management. Alternatives 2 and 3 were both ranked similarly in terms of meeting the prescribed decision criteria and had similar costs; however, it was concluded that ISTD had the advantage of lower possible risk of exposure to emissions because it would not require excavation, and would cause less disruption to the site. Therefore Alternative 2 – ISTD was selected.

The performance-based contract awarded to TerraTherm had a value of $0.625M. During site mobilization, it was discovered that the gasholder's diameter was actually 62 ft (18.9 m), 27% larger in area and volume than the original estimate of 55 ft (16.8 m) that had served as the basis for the above cost estimates, each of which would have scaled up accordingly.

After completing the installation of 25 vertical thermal wells, 2 recovery wells, and associated fluid recovery/treatment equipment, TerraTherm dewatered the gasholder and heated it in a step-wise fashion. First, by applying low-temperature heating to achieve 80°C within the DNAPL zone, and thus reducing the coal tar viscosity by about 20-fold, >16,000 gallons (>60,000 l) of coal tar DNAPL and emulsion were recovered. Then more heat was added to achieve moderate (~100°C) and higher (325°C) soil temperatures within the bottom and the mid-section of the gasholder, respectively. In doing so, >166,000 lb (>75,000 kg) expressed as naphthalene were extracted and treated as vapor.

The following reductions in pre- versus post-treatment soil concentrations (mg/kg), were achieved: (a) Bottom of gasholder (12-18 ft [3.7-5.5 m] bgs, heating to ~100°C): benzene from 3,400 to 0.95, naphthalene from 14,000 to 70, and benzo(a)pyrene from 650 to 100; furthermore, the coal tar residuals in the bottom of the gasholder had the appearance of asphalt, consistent with the laboratory-based findings of Hayes (2002); (b) Mid-section of gasholder (6-12 ft [1.8-3.7 m] bgs, heating to 325°C): benzene from 2,068 to 0.35, naphthalene from 679 to 5.7, and benzo(a)pyrene from 20 to 0.33. No DNAPL remained within the gasholder, and all constituents were below the remedial goals. The actual turn-key cost for ISTD was $852,000. National Grid also spent $55,000 for electricity and $86,000 on disposal of the coal tar liquids, for an overall cost of $991,000. It was National Grid's judgment that the overall cost remained less than that of excavation.

Example 3. Confidential S. CA Site. An LCC analysis was prepared in accordance with Schultz and Weber (2003) and is presented to demonstrate the cost effectiveness of thermally enhanced remediation versus conventional multiphase extraction system (MPE) methods for a site at which TerraTherm was contracted to perform services.

A large-scale MPE system had been in operation for 9 years. Interim soil samples were collected, the results of which indicated essentially no change in 1,2-dichloroethane (1,2-DCA) concentrations, which were as high as 27,000 mg/kg within a dense silty clay unit below the water table. Subsequently TerraTherm conducted a pilot test to evaluate the effectiveness and cost of TESVE utilizing the ISTD method of heating. The pilot system used much of the existing MPE equipment and was designed to treat 6,700 cy (5,100 m^3) of the dense silty clay unit, from a depth of 17 to 37 ft (5.2 to 11.3 m) bgs. Heater wells were installed at 22-ft (6.7-m) spacing within the existing MPE well field. After low-power thermal treatment for 14 months, the mean 1,2-DCA concentration (24 soil samples) was 0.2 mg/kg within the fully heated interval and a mean of 35 mg/kg within the interval of partial heating. 1,2-DCA source removal of the fully heated zone was >99.9% relative to pre-treatment levels.

Based on results of the TESVE pilot, TerraTherm estimated that the remaining MPE treatment area of 226,000 cy (173,000 m^3) could be treated for a unit cost of $44/cy ($58/m^3). The treatment goal was to reduce 1,2-DCA concentrations by 99% in 14 months. In contrast, the capital and O&M costs incurred for 9 years of MPE operation was ~ $82/cy ($107/m^3). Further evaluation indicated that if TESVE had been deployed in lieu of MPE, the 226,000 cy (173,000 m^3) could have been treated for an estimated turnkey cost of ~$53/cy ($69/m^3), including capital, O&M costs, and electricity.

An LCC analysis compares the cost of the two technologies on a present value basis (Figure 1). Curves indicate the total cost of MPE and its major cost components, electricity and O&M, versus TESVE. For ease of comparison, the cost of each alternative is normalized to 2006 dollars (MPE operation began in 1998).

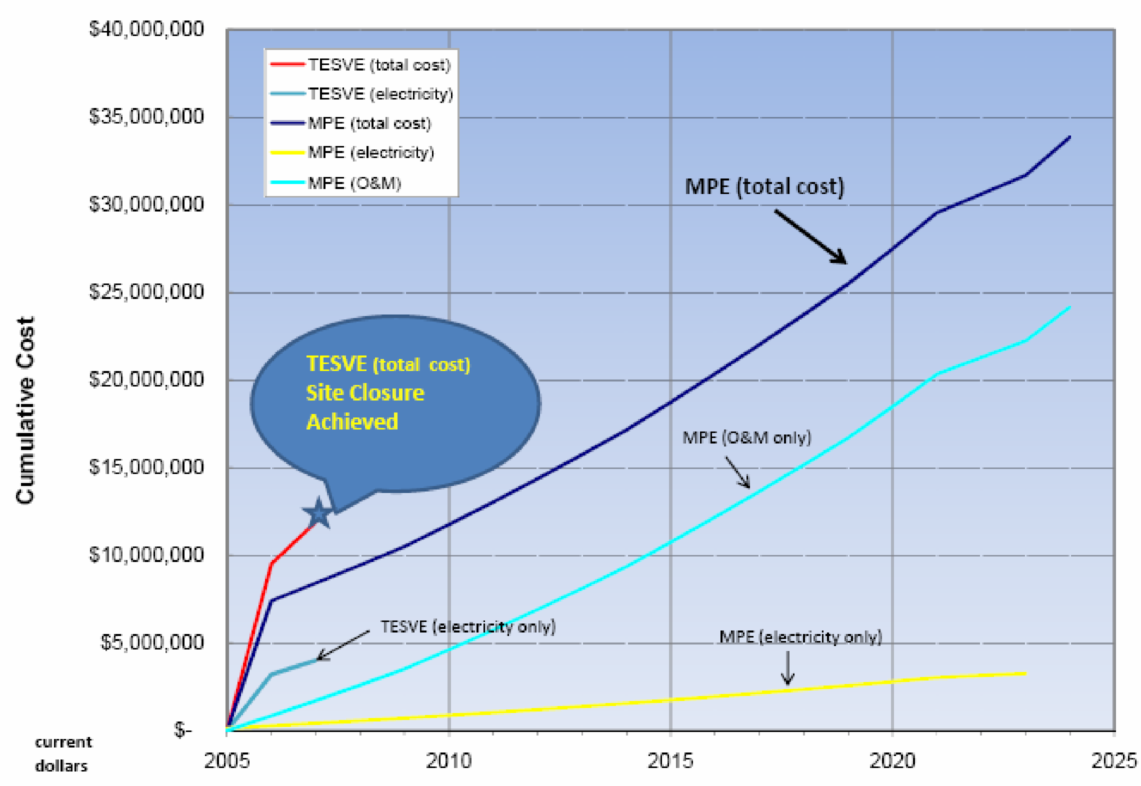

FIGURE 1. Comparison of MPE and TESVE Life Cycle Costs.

Note that after nearly 9 years of operation, the MPE system: (a) had not effectively removed any significant portion of the 1,2-DCA, although mass removal of other constituents had continued throughout operation; and (b) had cost more than $17M (2006 dollars). Had TESVE been utilized in lieu of MPE from the start, its total cost would have been < $12M. Furthermore, the site could have been fully treated in 14 months.

When comparing the LCC of two alternatives, a difference in the length of the remediation method can be quantified, and additional years of property use subtracted from the cost of the alternative as a benefit (Schultz and Weber 2003). A credit of $2.9M was estimated based on a review of local real estate (Multiple Listing Service) values in the area. It should be considered a low value considering the real estate market in southern California and the fact that the parcel is larger than comparable listings.

The LCC for each alternative is provided in Tables 2 and 3, while Table 4 provides a summary of LCC along with the credit applied. A period of comparison of 18 years was used for MPE, although it is highly uncertain if achievement of remedial goals could be accomplished in that period of time, given its observed performance.

TABLE 2. Multiphase Extraction (MPE).

COST TYPE	YEAR	TOTAL COST	PRESENT VALUE
Capital Cost	0	$ 6,434,988	$ 6,434,988
Annual O&M Cost	1-18	$ 26,455,993	$ 17,556,394
Periodic Cost	5	$ 225,224.58	$ 214,704
Periodic Cost	10	$ 257,399.52	$ 245,376
Periodic Cost	15	$ 321,749.40	$ 306,720
		$ 33,695,355	**$ 24,758,182**

TABLE 3. Thermally Enhanced Multiphase Extraction (TESVE).

COST TYPE	MONTHS	TOTAL COST	PRESENT VALUE
Capital Cost	0	$ 7,589,000	$ 7,589,000
Annual O&M Cost	14	$ 4,300,000	$ 4,189,201
		$ 11,889,000	**$ 11,778,201**

TABLE 4. Summary of Life-Cycle Costs by Alternative.

Alternative	Total LCC	Credit	Adjusted Total LCC
MPE	$ 24,758,182	$ 1,225,855	$ 23,532,327
TESVE	$ 11,778,201	$ 2,742,584	$ 9,035,617

On a LCC basis, the TESVE alternative utilizing the ISTD method of heating presents the lowest cost and shortest time frame, while providing certainty that the remediation would successfully achieve the remedial goals and site closure.

CONCLUSIONS

These three examples of the implementation of ISTD show that despite the inaccurate perception that thermal remediation is expensive, it can be the least costly solution for many contaminated sites. When life cycle costs and the duration and limitations of competing technologies are properly accounted for, this method of in situ thermal treatment is cost competitive and proven to achieve remedial goals and site closure.

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