Organization of Presentation

- National Perspective on In Situ Thermal Treatment
- Applications and some Lessons Learned
- ‘Bonus’ Discussion
  - ‘New Kids on the Block’
  - Combining Thermal with...
Nationwide

- Trend toward use of on-site, in situ remedies
  - In situ Thermal
  - In situ Chemical Oxidation/Reduction (ISCO/R)
  - In situ Bioremediation

- Trend toward flexible, adaptive use of combinations of technologies to address different contaminant compartments
  - ISCO vendors ‘morphing’ into Chem+Bio companies

Brief Sermon...

- “Remedy Implementation is just the next phase of site characterization” – e.g.:
  - Typical site characterization occurs on 100-150’ centers
  - In situ heating elements installed on 10-15’ centers...

- “Sources begin to reveal themselves as the remedy progresses”
  - Pay attention to what the site is trying to tell you...

- The smart guys are using flexible, adaptive iterative approaches
In Situ Thermal Treatment in a Nutshell

- +/- 100 of completed projects* domestically and internationally (*# growing rapidly)

- All vendors report being very busy**
  - ‘Over the Hump?’ - i.e., potential clients asking ‘Why Not?’ as often as ‘Why?’

** May result in fewer bids in response to RFPs
(Grants, NM dry cleaner project had one bidder)

Over the Hump...

- Clients willing to pay a (modest) premium* for the greater performance confidence** offered by ISTT

  - * May still be the most cost effective option from a total life cycle cost standpoint

  - ** Particularly attractive for schedule-driven redevelopment projects with stipulated penalties
Nutshell...(cont.)

- **Variety of contaminants**
  - Low boiling point solvents
  - Petroleum hydrocarbons
  - High boiling point coal tars and PCB's

- **Variety of unconsolidated and consolidated lithologies** *(Fractured rock, the Last Frontier...)*

- **Variety of conditions/situations**
  - Beneath (inhabited) buildings
  - Considerable depth (c. 130’)
  - Below the water table

Positive Attributes

- Effective across a wide range of permeabilities
- Thermal conductive varies +/− 2 over 10^6 permeability contrast
- Significant shortening of remedial timeframes
- Susceptible of In Situ Process Control
- Possible beneficial impacts on downgradient contamination
- No evidence of (dreaded) ‘rebound’
Applications

‘Sampler’ of Completed In Situ Thermal Projects at NPL and NPL-caliber sites

- Visalia, Ca NPL wood treater - SEE
- Pemaco, Ca Solvent NPL Site - ERH+
- Camelot Cleaners, Fargo ND - ERH
  - Tight clays
- Groveland Wells, Ma - ERH+SEE
- Silresim, Ma - ERH
‘Sampler’ – On-Going/Prospective NPL caliber In Situ Thermal Projects

- Grants, NM Drycleaner – ERH+
- Frontier Fertilizer, Ca (pesticides) – ERH
- SRSNE, Conn – TCH
- S Muni Water Supply Well site, Peterborough, NH – ERH+
- Carter Carburetor, Mo. – PCB - TCH(?)
- Wyckoff, Wa., wood treater - SEE(?)

Steam Enhanced Extraction (SEE)

Visalia, Ca Former Wood Treater NPL Site

**Poster Child for Shortening Remedial Timeframes**

Site Delisted from NPL (**‘Holy Grail of Remediation’**)
Hydrocarbon Removed ~ 1,330,000 Lbs
May 1997 to June 2000

Yield Equivalent of 3500 Years of Pump and Treat

- 660,000,000 lbs Steam Injected
- 239,400 lbs Vapor Phase
- 212,200 lbs In Situ Oxidation (HPO)
- 678,000 lbs Free Phase
- 199,500 lbs Aqueous Phase
- 3500 Years of Pump and Treat

In-Situ Reactions (It’s not just ‘Volatilize and Recover’)

Pyrolysis
- Benzo(a)pyrene: \( C_{20}H_{12} \rightarrow 20 \text{C (coke)} + 6H_2 \)
- TCE: \( C_2HCl_3 + 4H_2O \rightarrow 2CO_2 + 3HCl + 3H_2 \)

Oxidation
- Benzo(a)pyrene: \( C_{20}H_{12} + 23 O_2 \rightarrow 20 CO_2 + 6 H_2O \)
- Coke: \( C + O_2 \rightarrow CO_2 \)

Hydrolysis
- Benzo(a)pyrene: \( C_{20}H_{12} + 40 H_2O \rightarrow 20CO_2 + 46H_2 \)
- Coke: \( C + 2H_2O \rightarrow CO_2 + 2H_2 \)
- Methylene Chloride: \( CH_2Cl_2 + 2H_2O \rightarrow CO_2 + 3H_2 + 2Cl^- \)

Hydrous Pyrolysis Oxidation
- TCE: \( C_2HCl_3 + H_2O + 1.5O_2 \rightarrow 2CO_2 + 3HCl \)

AND Subsurface Surfactant Generation (LLNL patents)
Electrical Resistance Heating (ERH)

Seattle Dry Cleaner – One of Earliest ERH Applications
Seattle Dry Cleaner - Remediation to MCLs

99.9% clean-up (to MCLs)

ERH Innovations
Angled Electrode Boring – AF Plant 4

Sheet Pile Electrodes
Horizontal Electrodes

McMillan-McGee Electro-Thermal Dynamic Stripping Process (ET-DSP)

ERH Variant Used for Petroleum Hydrocarbon Contamination Beneath Apartment Building
In the Apartment

In Tight Spaces
...And on the Front Lawn

In Situ Thermal Desorption (aka TCH)
Dunn Field, Memphis, Tn
Selective/(Semi-) Surgical Intervention
Better than Req’d Performance
Dunn Field, Memphis Depot, TN

8 DNAPL source areas, CVOCs

49,800 cubic yards

Surgical remediation (Heron et al. 2009)

Aerial View of Memphis Site (During Demob)

Central Treatment Equipment

367 heaters

68 extraction wells
Contaminants of Concern and Remedial Target Concentrations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Remedial target concentration (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.2150</td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.9170</td>
</tr>
<tr>
<td>Dichloroethane, 1,2-</td>
<td>0.0329</td>
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<tr>
<td>Dichloroethene, 1,1-</td>
<td>0.1500</td>
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<tr>
<td>Dichloroethene, cis-1,2-</td>
<td>0.7550</td>
</tr>
<tr>
<td>Dichloroethene, trans-1,2-</td>
<td>1.5200</td>
</tr>
<tr>
<td>Methylene Chloride</td>
<td>0.0305</td>
</tr>
<tr>
<td>Tetrachloroethane, 1,1,2,2-</td>
<td>0.0112</td>
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<tr>
<td>Tetrachloroethene</td>
<td>0.1806</td>
</tr>
<tr>
<td>Trichloroethane, 1,1,2</td>
<td>0.0627</td>
</tr>
<tr>
<td>Trichloroethene</td>
<td>0.1820</td>
</tr>
<tr>
<td>Vinyl Chloride</td>
<td>0.0294</td>
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</tbody>
</table>

CVOC Concentrations in Soils before and after ISTD

<table>
<thead>
<tr>
<th>DNAPL source area</th>
<th>Governing contaminant</th>
<th>Max soil concentration before (mg/kg)</th>
<th>Max soil concentration after (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>Carbon tetrachloride</td>
<td>9.8</td>
<td>0.009</td>
</tr>
<tr>
<td></td>
<td>Chloroform</td>
<td>14.0</td>
<td>0.053</td>
</tr>
<tr>
<td>1B</td>
<td>cis-1,2-Dichloroethene</td>
<td>133.9</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>Tetrachloroethene</td>
<td>20.8</td>
<td>0.010</td>
</tr>
<tr>
<td></td>
<td>Trichloroethane</td>
<td>21.5</td>
<td>0.009</td>
</tr>
<tr>
<td>1C</td>
<td>1,1,2,2-Tetrachloroethane</td>
<td>2.850</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>cis-1,2-Dichloroethene</td>
<td>199</td>
<td>0.132</td>
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<tr>
<td></td>
<td>Trichloroethane</td>
<td>671</td>
<td>0.017</td>
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<tr>
<td>1D</td>
<td>1,1,2,2-Tetrachloroethane</td>
<td>0.93</td>
<td>&lt;0.000</td>
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<tr>
<td>1E</td>
<td>1,2-Dichloroethane</td>
<td>17.6</td>
<td>&lt;0.003</td>
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<tr>
<td></td>
<td>Trichloroethane</td>
<td>2.42</td>
<td>&lt;0.005</td>
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<tr>
<td>2</td>
<td>1,1,2,2-Tetrachloroethane</td>
<td>163</td>
<td>&lt;0.003</td>
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<tr>
<td></td>
<td>Tetrachloroethene</td>
<td>9.85</td>
<td>&lt;0.005</td>
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<tr>
<td></td>
<td>Trichloroethane</td>
<td>23.6</td>
<td>0.008</td>
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<tr>
<td>3</td>
<td>1,1,2,2-Tetrachloroethane</td>
<td>3.11</td>
<td>&lt;0.003</td>
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<tr>
<td></td>
<td>cis-1,2-Dichloroethene</td>
<td>3.35</td>
<td>0.006</td>
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<td></td>
<td>Trichloroethane</td>
<td>1.56</td>
<td>0.041</td>
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<tr>
<td>4</td>
<td>Carbon tetrachloride</td>
<td>0.53</td>
<td>&lt;0.006</td>
</tr>
<tr>
<td></td>
<td>Chloroform</td>
<td>3.18</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>Trichloroethane</td>
<td>0.97</td>
<td>0.040</td>
</tr>
</tbody>
</table>

Average reduction: 99.996%
Lessons Learned

- Actual performance often exceeds cleanup goals

- For ERH, need to add water adjacent to electrodes to prevent soil drying and ensure current flow

- Media conductivity (e.g., fill) may affect ERH applicability/performance

- For SEE, ensure proper closure of existing monitoring wells, etc. in treatment volume (NOT hypothetical)

Lessons Learned

- Investment in additional Site Characterization to reduce volumes requiring aggressive treatment can pay BIG dividends (e.g. SRSNE)

- Possible to heat discrete zones – horizontally and vertically

- Pilot-scale studies can provide valuable site-specific engineering design insights to support full-scale deployment
  - Enough experience that may not be needed at ‘simple(r)’ sites

- Systems can be installed entirely below grade
  - No conflict w/ facility operations or pedestrian/vehicular traffic
Lessons Learned

- **Insulating covers** may be needed to prevent heat losses and/or water infiltration
  - Check existing pads for integrity

- Subsidence rarely a problem
  - But see Fargo, ND dry cleaner as main/only(?) exception

Lessons Learned

- **Materials of Construction**
  - (Very) High concentrations of chlorinated solvents may result in high temp/low pH corrosive waste streams

- **Phase Changes in the ground and in above ground capture/treatment units**
  - Coal tar and creosote can result in crystallization and plugging in non heat-traced piping and heat exchangers (NOT hypothetical)
Naphthalene Pipe Clogging

Lessons Learned

- High subsurface GW flow regimes
  - May hamper achieving requisite temperature and prevent achieving cleanup goals
  - Additional cost to divert and/or dewater

- Temperature serves as an important metric for in-situ process control
  - Only recently have other in situ technologies - e.g., ISCO - made strides in this area

- Fractured Rock is Doable
Lessons Learned

• ‘Step 1…’ – Check with local utility regarding power and equipment availability (and KEEP checking)
  • Especially in areas undergoing development

• If there is a lot of contamination in the ground, you will recover it
  • Have the (big) catcher’s mitt ready
  • Cummings’ rule of remediation – mass 2-5X estimated

Lessons Learned

• ‘Hot sampling’ allows discontinuing heating of zones which have met cleanup goals
  • Concentrate power in zones not cleaning up as quickly
  • Don’t have to wait 12-18 months for site to cool before demobilizing treatment equipment

• A point about sustainability:
  • Carbon footprint for electrically heating 1 yd$^3$ of contaminated soil ≈ digging and hauling it 65 miles
    (source: Terratherm)
New Kids on the Block

STAR – Self-Sustaining Technology for Active Remediation?

- **In Situ Combustion**
  - Exothermic reaction converting carbon compounds $\text{CO}_2 + \text{H}_2\text{O}$
  - Take advantage of BTU content of wastes

- **Smoldering**
  - Flameless
  - Occurs in porous materials
  - Temperatures typically 400 – 800 °C
  - Propagation typically 5 ft/day
  - Oxygen-limited, thus controllable
### Pilot Results – Pitt Consol DuPont Facility in NJ

#### Post-pilot Soil Sampling

**Before**

![Before Image]

**After**

![After Image]

**Average Concentration Reduction = 99.72%**

Approximately 10,000 # of coal tar destroyed in situ

Proceeding to full-scale

#### TPH-DRO soil C10-C28*

<table>
<thead>
<tr>
<th>Compound</th>
<th>Average Concentration (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before STA Treatment</td>
<td>118,000</td>
</tr>
</tbody>
</table>

#### TPH-GRO soil C6-C10

<table>
<thead>
<tr>
<th>Compound</th>
<th>Average Concentration (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before STA Treatment</td>
<td>1,300</td>
</tr>
</tbody>
</table>

*TPH-DRO soil C10-C28*
**How it Works**

Closed-loop in-situ thermal conductive heating system;

Co-located vapor extraction and heating wells;

Treatment temperatures from ~100°C to >400°C

More information at: [www.tpsthermal.com](http://www.tpsthermal.com)
### Attributes of Gas Thermal Remediation

1. **Scalable**
   - Can be applied to very large and very small projects
   - Smallest commercial project performed = 300 cubic yards

2. **Vertical Control**
   - Target heat to different depths

3. **Pollution → Energy**
   - Uses off-gas as supplemental fuel

4. **No Electricity Required**
   - Propane or natural gas

### ISTR Operations – Former MGP Site

PAHs and BTEXs to 21 ft.

ISTR Mobilized in Less Than One Month

Target Treatment Temperature Reached in Three Weeks

3 areas of heating at various temps for $615M dev project
‘Bonus’ Discussion

‘Brave(r) New World’

Combining Remedies/Treatment Trains to Address All Components of Site Contamination

Large Hammers Most Suitable For Strong(er) Source(s)

- Other, hopefully complementary, tools can be brought to bear to address other components
  - Downgradient ‘warm spots’
  - Core(s) of dissolved phase plumes**

- Small(er) sites may be particularly suitable for combining tools

** Buzz in Monterey: Few plumes are ‘blobs’ – 90% of plume mass in 10% of cross-section (Parker et al)
Pemaco Solvent Site, Maywood, Ca
Fund-lead NPL Site

Pemaco Tank Removal
**Pemaco Remedy Components**

- Dual Phase Extraction (DPE) for shallow zone
- **Electrical Resistance Heating (ERH)** for >10ppm contour at 35-100’
  - Flameless Thermal Oxidizer (FTO) for off-gas treatment
- Vacuum Enhanced Pump and Treat for GW zone outside 10ppm contour
- Enhanced In Situ Bio (EISB) for down/cross-gradient zones

**Pemaco Site - Status**

- ERH phase completed
- Lactate injection to stimulate reductive dechlorination in downgradient zones
- Groundwater concentration trends are encouraging (*MCLs in sight...*)
Science Notes

- Dechlorinating bacteria appear to thrive at 30-35 C
- In situ thermal (and ISCO) liberate dissolved organic carbon which facilitates biodegradation

![Graph showing the effect of ERH on groundwater dissolved organic carbon. The graph indicates a significant decrease in dissolved organic carbon levels, with one monitoring well showing a 41 times higher concentration post-ERH.]
S Municipal Water Supply Well Site, Peterborough NH

- In Situ Thermal Treatment of Identified Source Areas + Additional DNAPL areas as/if identified during RD
- In situ Bioremediation for soil and GW following ISTT
- Permeable Reactive Barrier for GW in TI Waiver Area
Regulatory Acceptance

- (Some/many/most (?)) Regulators accepting contingent (‘If..., Then...’) – as distinct from prescriptive – decision documents

- See ROD’s:
  - Pemaco
  - Grants, NM
  - S Muni Water Supply Well

Desired End States/ Cost-Effective Solutions

- **Adequate** Use of Robust Source Term Removal Technologies
- **Timely transition** to cost-effective ‘polishing’ step(s)
- **Reduce/Eliminate** Need for Pump and Treat
- **Appropriate** Reliance on Monitored Natural Attenuation (MNA)
Resources
Resources/Contact Information

- Jim Cummings
  - cummings.james@epa.gov
  - 703-603-7197
- Web-based resources
  - www.cluin.org
  - www.frtr.gov
- In Situ Thermal Treatment of Chlorinated Solvents: Fundamentals and Field Applications – EPA 540-R-04-010 Mar 2004
- In Situ Thermal Treatment – Lessons Learned – In preparation

Vendor Contact Information – Additional Case Studies

- Terratherm
  - terratherm.com
  - Ralph Baker – 978-343-0300
- Thermal Remediation Services
  - thermalrs.com
  - David Fleming – 425-396-4266
- Current Environmental Solutions
  - Cesiweb.com
  - Joe Pezzullo – 215-262-7855
- McMillan-McGee
  - Mcmillan-Mcgee.com
  - Bruce McGee – 403-569-5101
Vendor Contact Information (cont.)

- STAR Technology
  - Gavin Grant, Geosyntec
    - ggrant@geosyntec.com
    - 919-822-2230
- Gas Thermal Remediation
  - TPS Tech America
    - Grant Geckeler
      - grant@tpsthermal.com
      - 858-608-1838