In-Situ Thermal Remediation: Advances and Lessons Learned at Multiple Sites – 2000 to present

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The business of sustainability

ERM

Lessons Learned Thermal Safety Moment - PPE

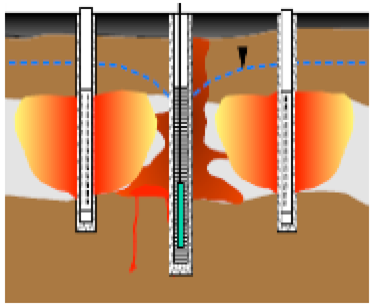
Thermal Remediation PPE Upgrades

- Hard hat with face-shield down
  - **In addition to safety glasses.**
  - **Always in down position when working in active zone.**
- Leather gloves with forearm gauntlets
- Coveralls or long sleeves (no exposed skin)

In Situ Thermal Remediation Application

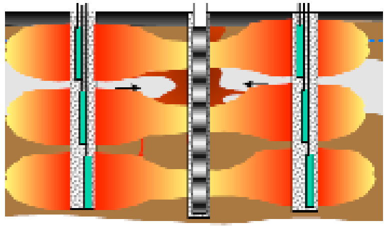
Steam and Hot Air Injection

- Coarse-grained lithology and fractured bedrock
- Chlorinated DNAPLs (dry cleaners, manufacturing, chemical plants)
- Heavy oils and fuels (airports, shipyards, rail yards)



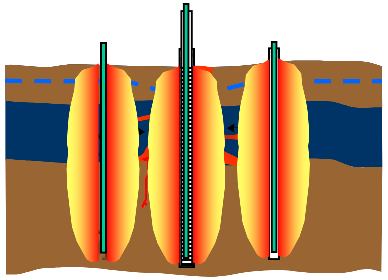
Electric Resistance Heating (ERH)

- Fine-grained lithology
- Chlorinated DNAPLs (dry cleaners, manufacturing, chemical plants)
- Heavy oils and fuels (airports, shipyards, rail yards)



Thermal Conductive Heating (TCH)

- Vadose zone and unsaturated fractured rock
- Recalcitrant compounds (PCBs, Manufactured gas plant [MGP] wastes, dioxins)



From Dr. Bruce McGee,
McMillan McGee, Inc.

“Mistakes are our friends”

- Robust design and safety process
- Well seal materials
- Abandon or re-purpose wells
- Thermal and vapor barriers

Robust design and safety process

Bench Testing

- Evaluate contaminant characteristics at varying temperatures.
- Tar issues:
  - Recognized during site investigation
  - Ambient temperatures evaluated for design;
  - Bench tests provide better evaluation of conditions under heating before project starts

Robust HAZID/HAZOP during the design process

- System construction consistency.
- Connection point failure analysis.
- Temperature capable materials and equipment.
  - Blowers
  - Downhole pumps.

Well seal materials

Problem - Well Seal Failures

- Typical well seal materials
  - Bentonite grout
  - Bentonite cement mixtures
  - Bentonite chip intermediate seals
- Thermal impacts
  - Bentonite loses structural integrity
  - Fractures and failure paths develop
    - Gaps form between borehole wall and seal
    - Gaps form between hot well materials and seal

Solution

- **All seals in contact with high temperature materials are constructed using Type G or H high temperature grout.**
- **No bentonite allowed in seals.**

Abandon or re-purpose monitoring wells.

Problem – Existing PVC monitoring wells

- ❑ Short circuit to surface.
- ❑ Short circuit between lithologic units

Solutions:

- ❑ Abandon by over-drilling and grouting with high temperature grout.
- ❑ Re-purpose wells to temperature monitoring points.

Thermal and vapor barriers

Problem – Ineffective thermal and /or infiltration barrier

- Case 1 – TCH for PCBs in Spain
  - Thin HDPE vapor barrier. Minimal thermal insulation
  - Effective heating to target (300^{o}C), 2 to 3 m bgs.
  - Target temperature not met 1 m bgs.

- Case 2 – Hot air injection for Diluent in Long Beach
  - Thin HDPE vapor barrier. Ineffective well seals.
  - Heat loss to rainfall infiltration.

Solution

- Lightweight concrete as dual purpose thermal and vapor barrier

Innovative heating and low temperature effects

Targeted heating of Interbedded lenses

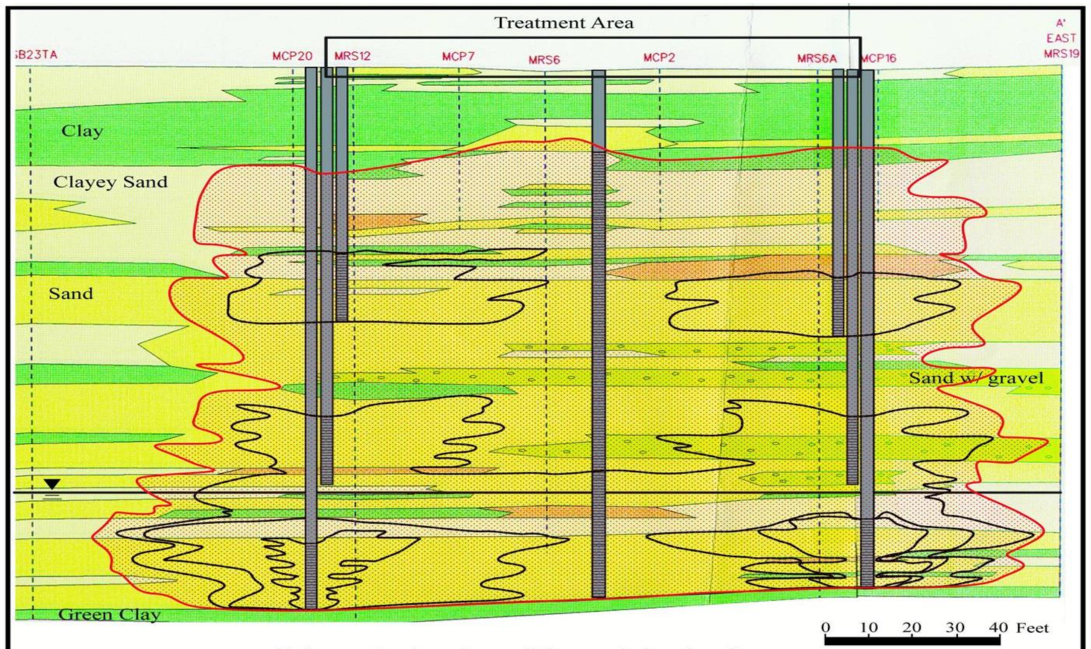
Low temperature mass removal by solubilization.

Low temperature volatilization

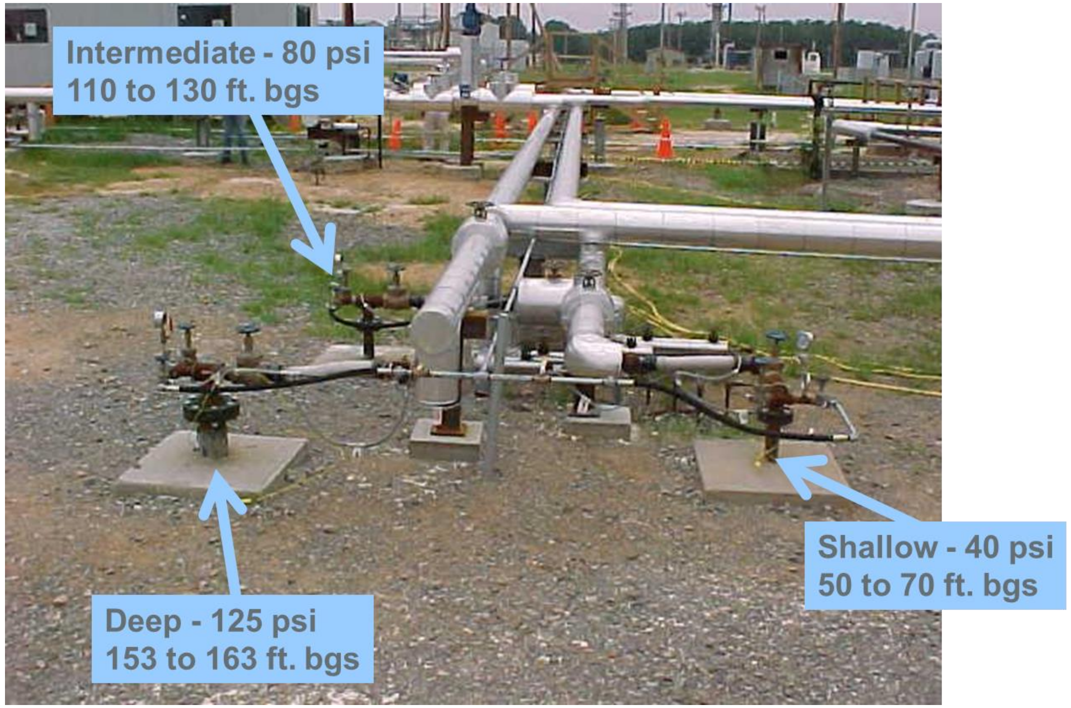
Targeted heating of interbedded lenses

PCE DNAPL at Savanah River DOE Site

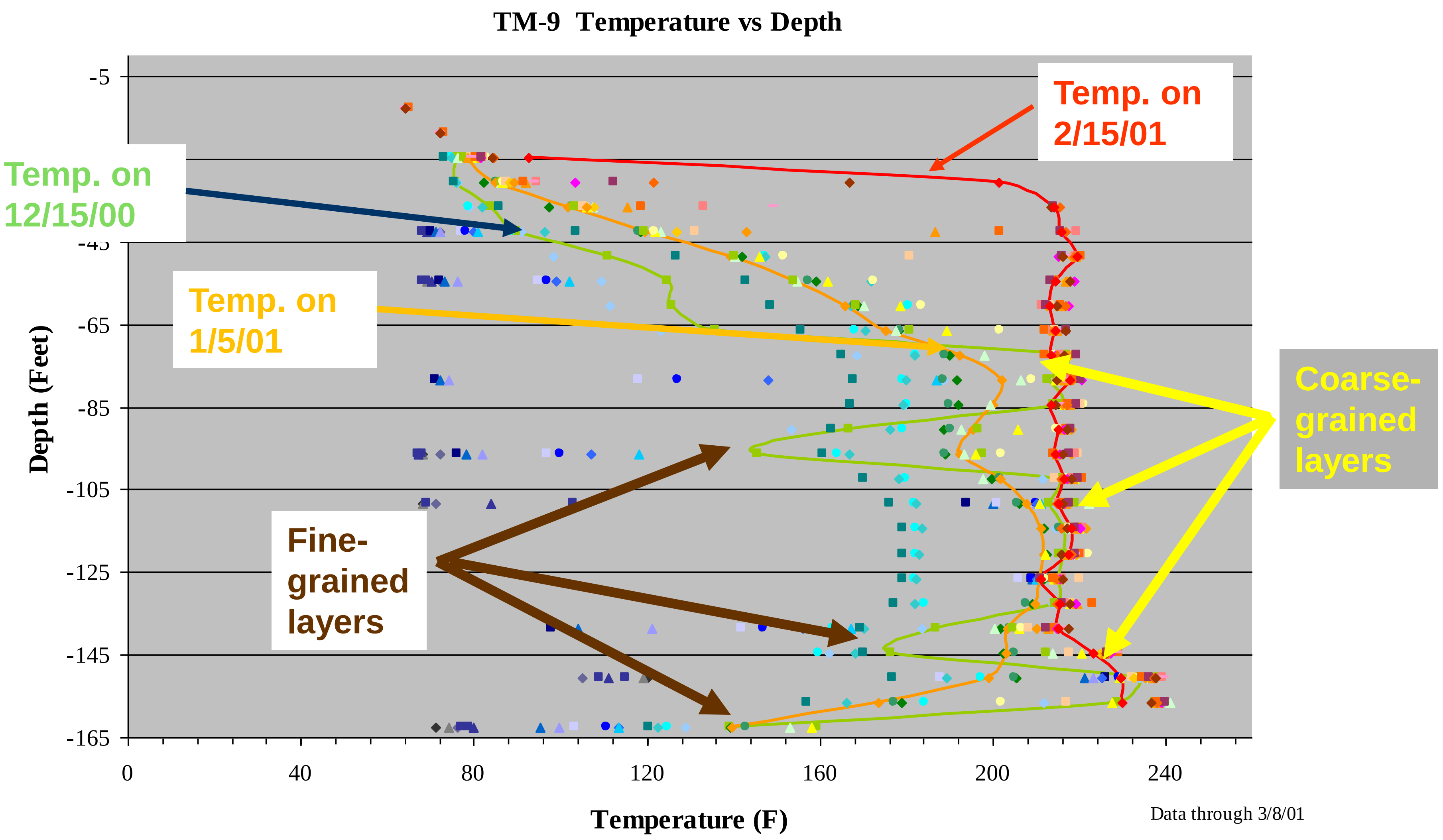
- Steam injection into interbedded sands with clay layers.
- Pulsed "bake in" approach used to achieve even heat distribution and mass removal.



Schematic drawing of Steam Injection Process

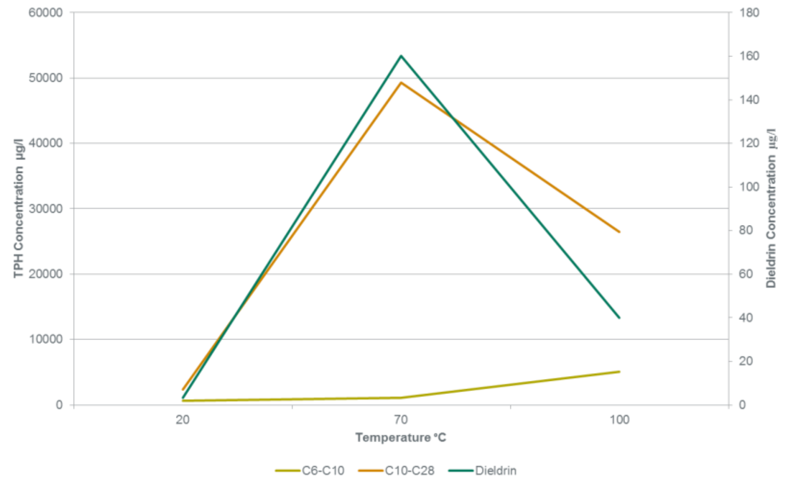


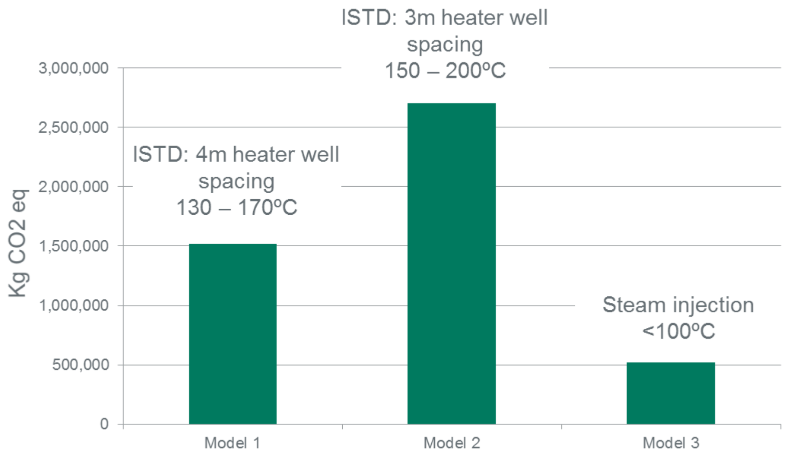
“Bake-In” Heating - Permeability Effects



Low temperature mass removal by solubilization.

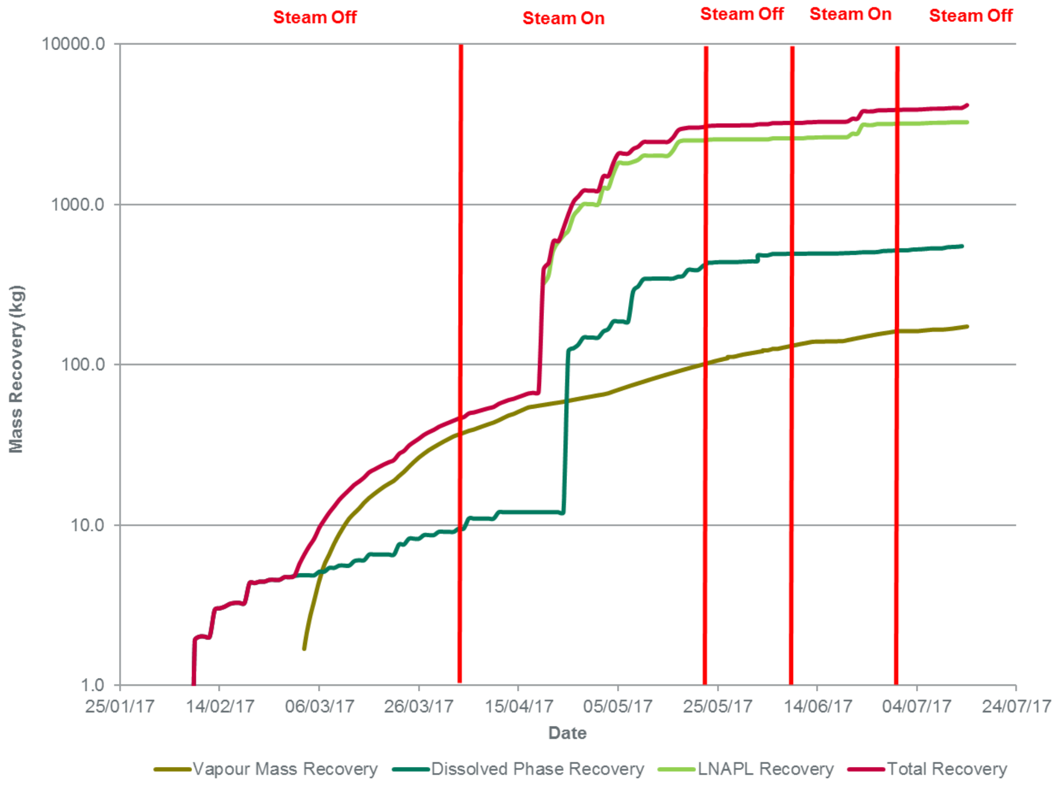
- ❑ Former pesticide manufacturing facility, UK
- ❑ LNAPL (mostly Kerosene).
- ❑ Thermal considered most applicable, but target temperature challenges
  - ❑ **Boiling points:**
    - ❑ Kerosene 150ºC (minimum)
    - ❑ Dieldrin 350ºC!
- ❑ Modelling indicated that dieldrin temperatures may not be achievable.
- ❑ Bench testing indicated that both COCs could be removed with steam at lower temperatures.
- ❑ Significant carbon footprint improvement with low temperature approach.

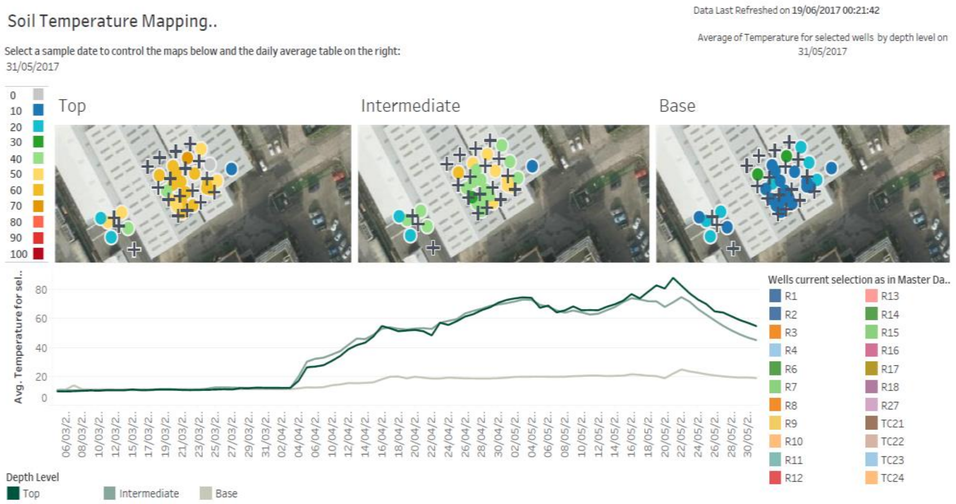




Implementation Results

- Steam injection raised soil temperatures to above modelled mobilization temperature – 70ºC.
- Asymptotic mass recovery achieved.
  - Mainly TPH (kerosene) – 4,160 kg recovery estimated.
  - 7.5kg of pesticides recovered as free, dissolved phase and 'sludge'





Low temperature volatilization

Former electronics manufacturer in Illinois

- Plant closed, site being redeveloped
- Site impacted by 1,1,1-trichloroethane and trichloroethene NAPL
- Remediation Goal:
  - Remove NAPL
  - Reduce groundwater concentrations to < 1% of aqueous solubility
- ERH implemented to volatilize and recover contaminant mass from fine-grained silts and clays.

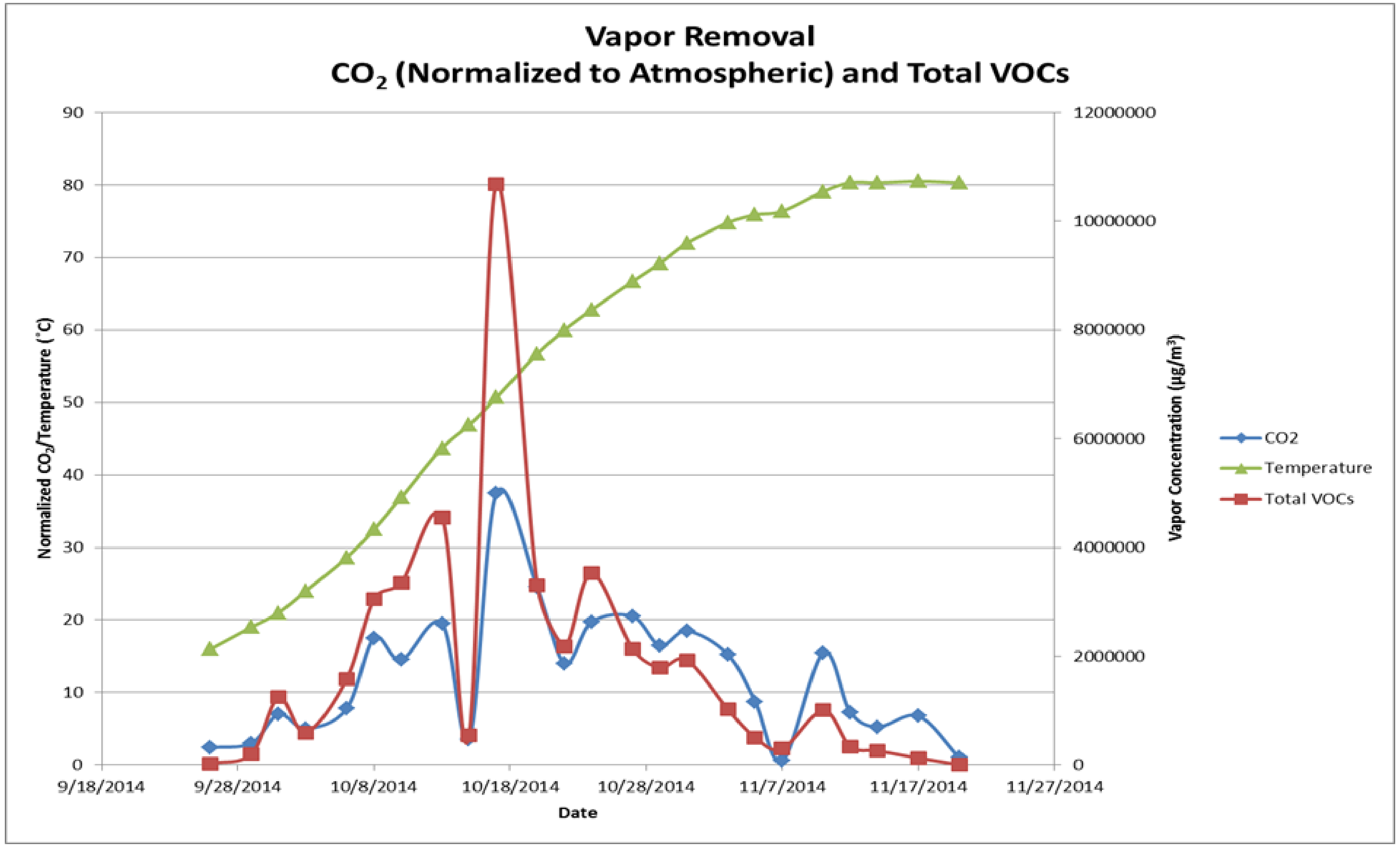
Low Temperature Volatilization Implementation

Start up and initial heating

- Monitored temperature, CO_2 and mass removal
- Ramped up temperature slowly by 10^{o}C increments.
- Asymptotic mass removal reached in 8 weeks.
- Maximum mass removal rates at 50^{o}C, less than co-boiling point of 77^{o}C.

Key Results

- 25% reduction in treatment duration
- 20% reduction in overall cost



Sustainable Remediation

Thermal Conuctive Heating (TCH) as an alternate to “Dig and Haul”

Steam Enhanced Extraction (SEE) as an alternate to “Pump and Treat”

Thermal Conductive Heating as an alternate to "Dig and Haul"

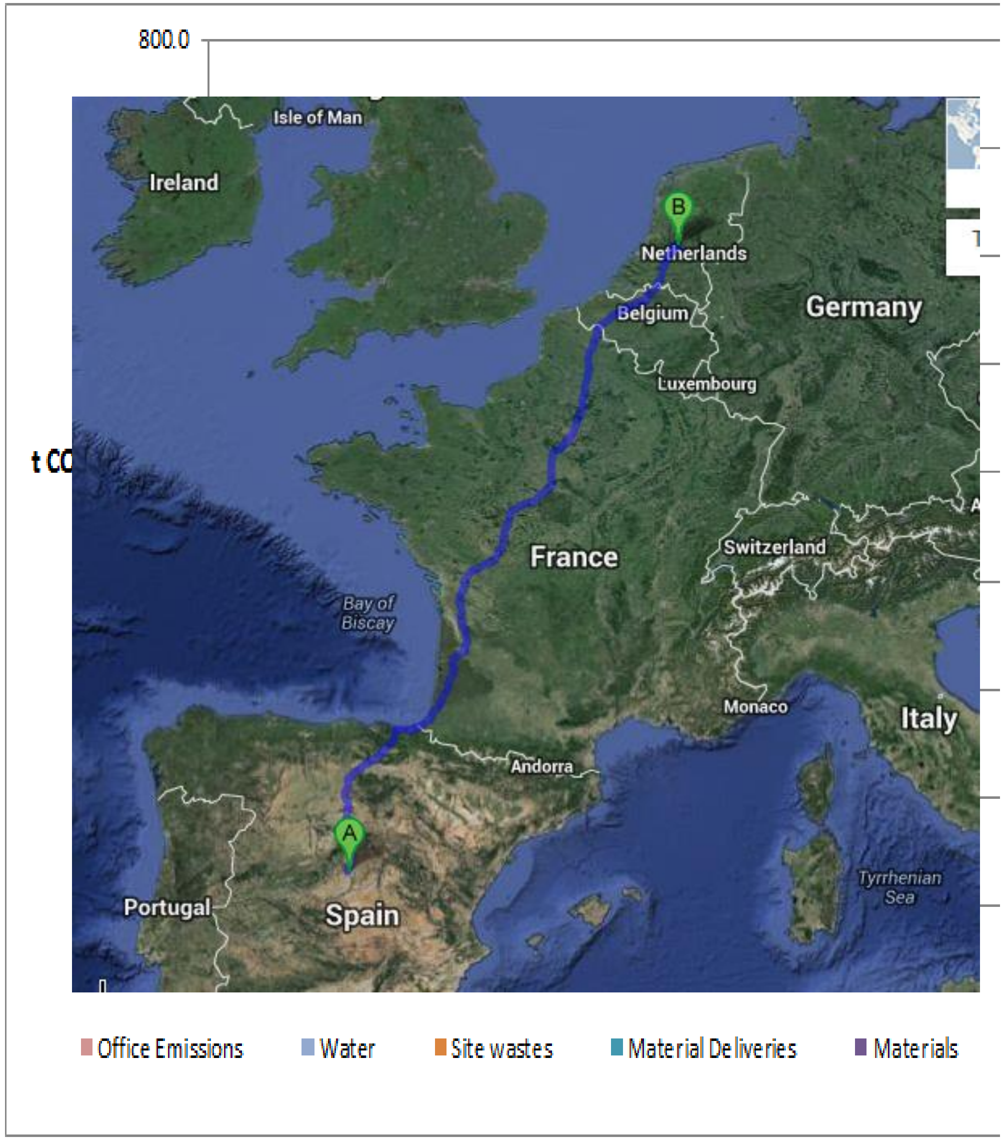
- Site used for servicing of motors and transformers.
- Site investigation identified Polychlorinated Biphenyls (PCBs) at concentrations of up to 27,700mg/kg within underlying low permeability silts and clays.
- Based on the results of a Quantitative Risk Assessment - Site Specific Target Level (SSTL) for PCBs of 4.4mg/kg in soil was set.
- PCBs recovered:
  - Design estimated - 1050 kg of PCBs recovered. 250 kg destroyed in situ.
  - 1550 kg recovered, 390 destroyed in place.

Thermal treatment versus Dig and Haul

Carbon footprint sustainability evaluation

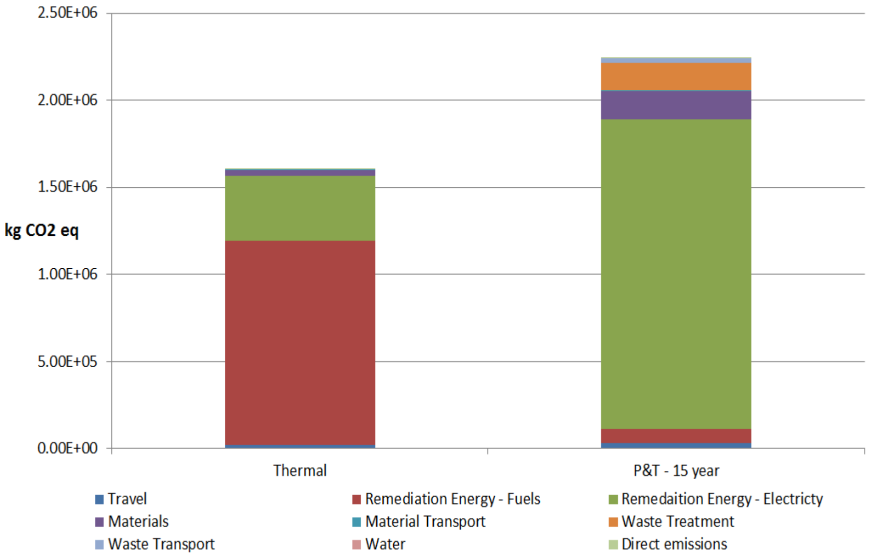
- ❑ Site specific sustainability indicators identified
  - ❑ Predominantly Environmental and Economic – reflecting nature of site
  - ❑ Protection of human health key social metric along 700 km truck route in addition to fuel consumption.

The carbon footprint of thermal treatment was roughly 50% of the traditional dig and haul approach.



Steam Enhanced Extraction (SEE) as an alternate to “Pump and Treat”

- **Background**
  - Former Manufacturing facility in UK
  - Steam enhanced extraction within (confined, fractured rock aquifer)
  - Contaminants of concern: TCE, cis 1,2-DCE and vinyl chloride
- **Results**
  - Over 1,000kg of contaminant mass recovered in less than three months
  - Based on carbon, water, H&S, energy and mass recovery metric in situ thermal approach was more sustainable than pump and treat alternative
  - Financial Outcome: The remediation objectives were met in a sustainable manner at significantly reduced cost.
    - £10million estimated for longer-term pump and treat approach.
    - £2.5million for completed SEE approach.



Thank you

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