Life Cycle Assessment of ISTD and Improving the Sustainability of Source Removal

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Overview

- Reerslev Site Description
- Life Cycle Assessment
- Remedy Selection
- ISTD Design and Implementation
- Results
- Conclusions
Reerslev – near Copenhagen, Denmark
Reerslev – Locus

Well Field

Plume – primary aquifer

Plume – secondary aquifer

Source
Solhøj Municipal Well Field
Supplied 50,000 homes
Conceptual Site Model

Clayey till: 0-8 m
Hot spot area
Sand: 8-23 m
Secondary aquifer
Clay: 23-25 m
Chalk
Primary aquifer
<1 µg/l
13 µg/l
400 µg/l
Well Field
Reerslev – Site Description

Legend:
- Red: Risk of DNAPL
- Purple: High soil concentrations
- Yellow: Diffuse contamination - not to be treated

Houses
Technology Evaluation

• Excavation and off site treatment

• In Situ Thermal Desorption (ISTD)

• Cutting off hotspot by Soil Vapor Extraction (SVE)
# Life Cycle Assessment (LCA)
(Pfeilschifter et al. 2007)

## Evaluation parameters

<table>
<thead>
<tr>
<th>Setting-up</th>
<th>Transport</th>
<th>Excavation</th>
<th>Drilling</th>
<th>Building equipment</th>
<th>Commissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Consumables</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Power</td>
<td>Fuel/gas</td>
<td>Plastic</td>
<td>Concrete</td>
<td>Iron/steel</td>
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<td></td>
<td>Activated carbon</td>
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<tr>
<td></td>
<td>Resources</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Inadequate raw materials</td>
<td>Metals</td>
<td>Sand/gravel</td>
<td>Water</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Operation</th>
<th>Operation period</th>
<th>Electrical effect</th>
<th>Supervision</th>
<th>Service</th>
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<tbody>
<tr>
<td></td>
<td>Consumables</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>CO₂, CO, NOₓ, SO₄</td>
<td>VOC’s</td>
<td>Noise and vibrations</td>
<td>Dust or odor</td>
</tr>
<tr>
<td></td>
<td>Environment</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Global warming</td>
<td>Acidification</td>
<td>Toxicity</td>
<td>Landfill</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dismantling</th>
<th>Transport</th>
<th>Waste</th>
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</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>Risk of fire or explosions</td>
<td>Dangerous work</td>
</tr>
<tr>
<td></td>
<td>Inconvenience/disturbance of neighbors</td>
<td></td>
</tr>
<tr>
<td>Human</td>
<td>Working environment</td>
<td>Inconvenience/disturbance of neighbors</td>
</tr>
</tbody>
</table>
LCA, cont.
(Pfeilschifter et al. 2007)

Carbon footprint – ton CO₂ equivalents

- Excavation 80 km
- SVE 30 years
- SVE 100 years
- ISTD 8 months
- ISTD 12 months
LCA, adjusted for:
Actual ISTD Duration; Transport Distance

Carbon footprint — ton CO₂ equivalents

- Excavation 140 km
- SVE 30 years
- SVE 100 years
- ISTD 5.5 months
- ISTD 12 months
LCA, cont. (Pfeilschifter et al. 2007)

Environmental Impacts

- Emissions
- Toxicity
- Waste

Environmental impacts (PE)

- Acidification
- Global warming
- Nutrient enrichment
- Ozone depletion
- Photochemical oxidant potential
- Ecotoxicity soil chronic
- Ecotoxicity water acute
- Ecotoxicity water chronic
- Human toxicity air
- Human toxicity soil
- Human toxicity water
- Bulk waste
- Hazardous waste
- Nuclear waste
- Slag and ashes

1 PE = 8.7 ton CO₂
Comparison of Methods

“Most likely” scenarios are marked

Green = best environmental performance
Red = worst performance
Yellow = intermediate environmental performance

Factoring in all considerations, heating was selected as the preferred remedy
Selection of Remedial Goals

Modelling objectives – size of area to be treated using ISTD and flux-reduction to be achieved

<table>
<thead>
<tr>
<th>Concentration (mg-PCE/kg)</th>
<th>Area (m²)</th>
<th>Flux (kg/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>900</td>
<td>32.4</td>
</tr>
<tr>
<td>10</td>
<td>400</td>
<td>1.6</td>
</tr>
<tr>
<td>1</td>
<td>1500</td>
<td>0.5</td>
</tr>
<tr>
<td>0.1</td>
<td>2100</td>
<td>0.1</td>
</tr>
</tbody>
</table>

34.6 kg/y is the current flux of PCE into the vadose zone underlying the source area.

Remediation scenarios considered:

- Reduction to **10 mg/kg** (900 m²) → Flux 2.2 kg/y
- Reduction to **1 mg/kg** (1300 m²) → Flux 1.2 kg/y
- Reduction to **0.1 mg/kg** (1300 m²) → Flux 0.7 kg/y
- Reduction to **0.1 mg/kg** (2800 m²) → Flux 0.2 kg/y (original design)
- Reduction to **0.1 mg/kg** (6000 m²) → Flux 0.07 kg/y (complete remediation)

⇒ Scenario should achieve < 1 µg-PCE/l at well field
ISTD Stats

- 11,500 m³ soil treated
- 1,300 m²
- 147 heater wells
- 21 extraction points
- 30 thermocouple wells
- 240 temperature monitoring points
- 169 days of heating
ISTD Temperature Progression

![Graph showing temperature progression over depth]

T2

Temperature / °C

Depth / cm

Legend:
- T02,2009-06-17
- T02,2009-07-02
- T02,2009-07-17
- T02,2009-08-01
- T02,2009-08-16
- T02,2009-08-31
- T02,2009-09-15
- T02,2009-09-30
ISTD Temperature Progression, cont.
Extracted PCE during ISTD

2,500 kg of PCE removed
Results of ISTD Heating

Actual heating time: 5.5 months
Conclusions

- LCA selected ISTD over excavation and cold SVE
- Actual ISTD Heating Time = 5.5 months (46% of the LCA estimate of 1 year)
- Energy consumption ~ 340 kWh/m$^3$ (72% of the LCA estimate)
- PCE concentrations were reduced 17 times below cleanup criteria → 99.99%
- Total ISTD budget = $3.8M (88% of LCA est.)
Sustainability in Context of Source Removal

- The carbon footprint associated with electrically heating 1 m$^3$ of contaminated soil $\approx$ digging and hauling it 140 km (85 mi)
- Meanwhile, in-situ treatment has a lower neighborhood impact, and is environmentally friendly
- With In Situ Thermal Remediation (ISTR), liability is eliminated, not merely moved to another location

$\Rightarrow$ Certain outcome; short time-frame; **highly sustainable**
### Summary of conclusions for ISTD, SEE and ET-DSP

<table>
<thead>
<tr>
<th></th>
<th>Hotspots</th>
<th>Improvement initiatives</th>
<th>Total reduction potential and division between initiatives</th>
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</thead>
<tbody>
<tr>
<td><strong>ISTD</strong></td>
<td>Electricity use</td>
<td>• Heating 12h/d</td>
<td>Environmental impacts: 10%</td>
</tr>
<tr>
<td></td>
<td>Above grade materials</td>
<td>• Vapor cap (concrete sandwich)</td>
<td>Resource depletion: 20%</td>
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<tr>
<td></td>
<td>Well field materials</td>
<td>• Biobased activated carbon</td>
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</tr>
<tr>
<td><strong>SEE</strong></td>
<td>Energy use</td>
<td>• Change to condensing boiler</td>
<td>Environmental impacts: 21%</td>
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<tr>
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<td>Above grade materials</td>
<td>• Vapor cap (concrete sandwich)</td>
<td>Resource depletion: 9%</td>
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<td>Well field materials</td>
<td>• Biobased activated carbon</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>• Change to fiberglass liners</td>
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<tr>
<td><strong>ET-DSP</strong></td>
<td>Electricity use</td>
<td>• Heating 12h/d</td>
<td>Environmental impacts: 13%</td>
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<td>Above grade materials</td>
<td>• Vapor cap (concrete sandwich)</td>
<td>Resource depletion: 8%</td>
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<td>Transportation</td>
<td>• Use of experts and equipment from Denmark</td>
<td></td>
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</table>

**ET-DSP:** Electro-Thermal Dynamic Stripping Process

(Lemming et al. 2012)
References


