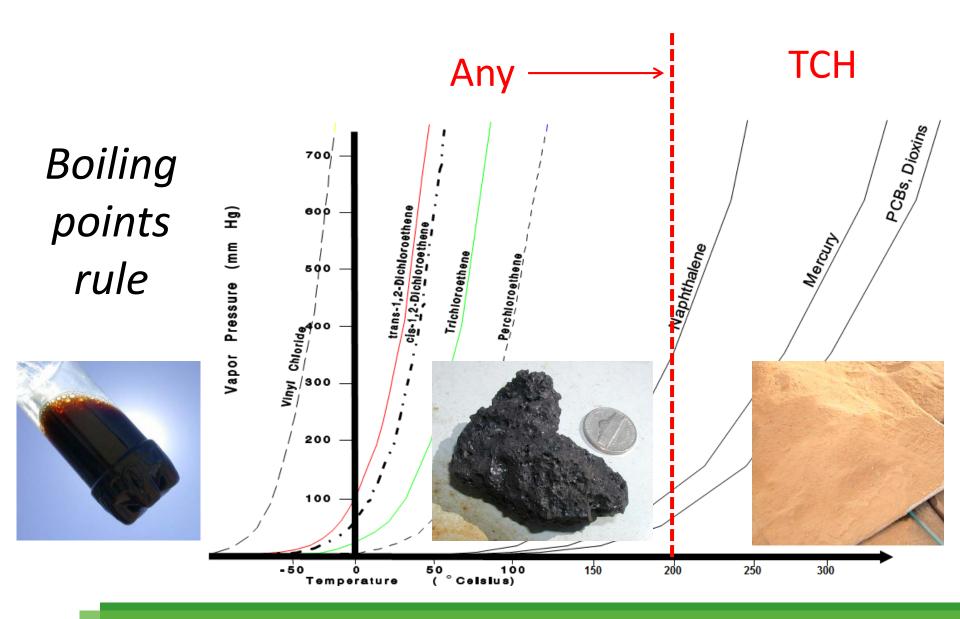


Steffen Nielsen

Contaminants



SVOC Treatment – above grade



In Pile Thermal Desorption (USAID- Danang Vietnam)

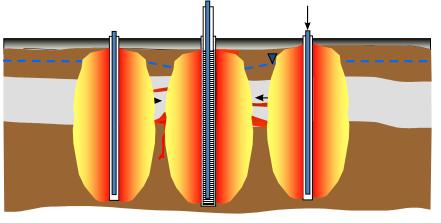




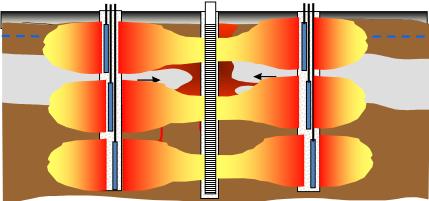
HB-1100

Permeability

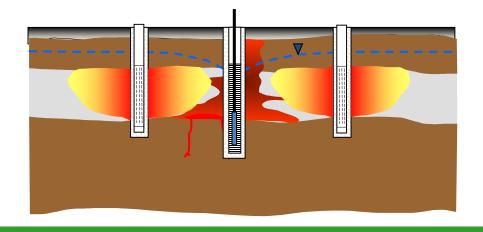
TCH - governed by thermal conductivity (f~3)



ERH - governed by **electrical conductivity** (*f*~200)



SEE - governed by hydraulic conductivity (f~10⁶)



Long plume?



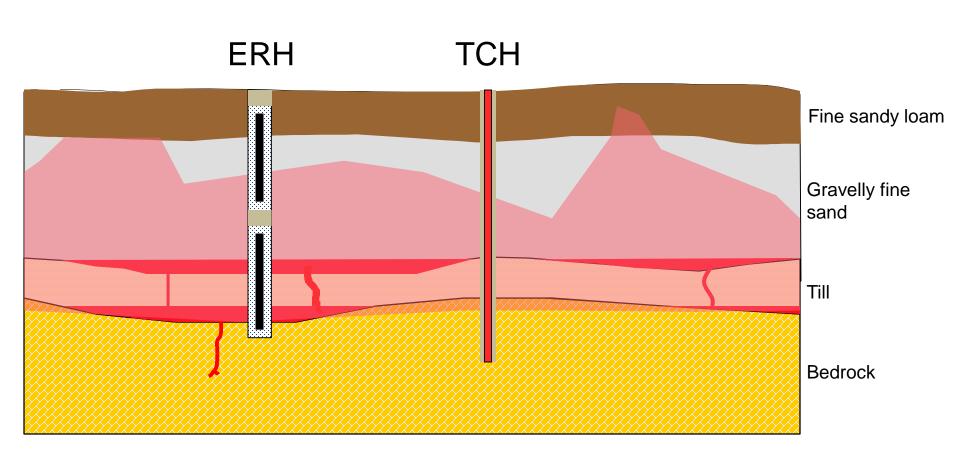
Flowing groundwater in touch with NAPL

- Need to keep hydraulic control
- Be aware of cooling
- Use SEE if you can



DNAPL spreading risk

(case: SRSNE Superfund Site, Southington CT)

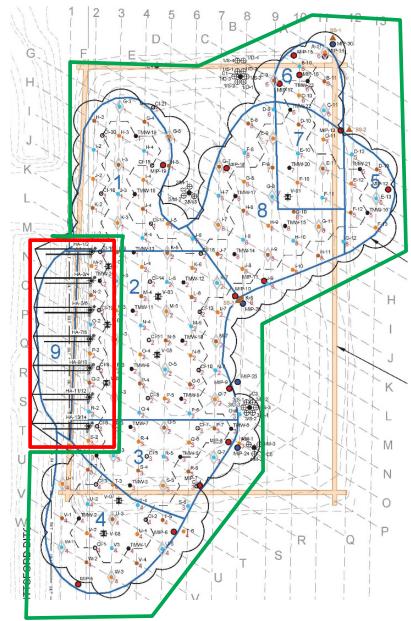


SRSNE - TCH



Safety: ERH-TCH Combined



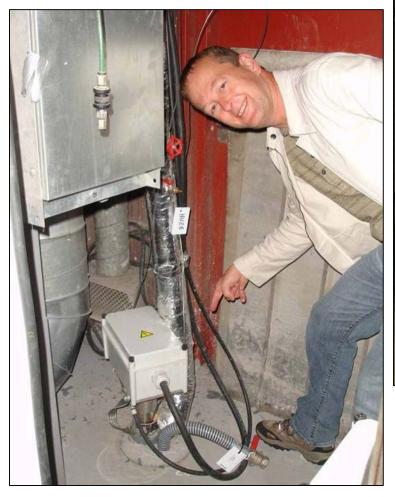


Anderson IN: ERH-TCH





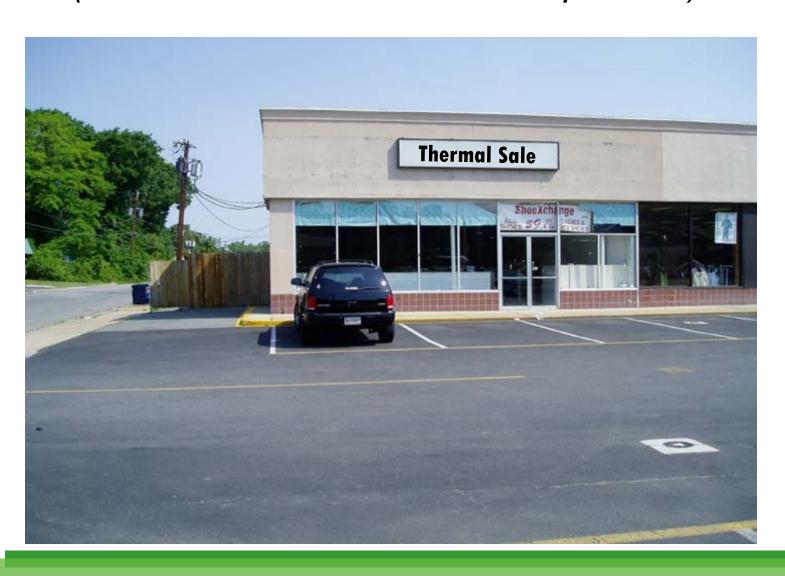
Access (case: Knullen, Denmark)





TCH
Small diameter boreholes
Drilling space limited

Access (ERH site with subsurface completions)



Cost (main factors)

1. Drilling and well materials



2. Construction

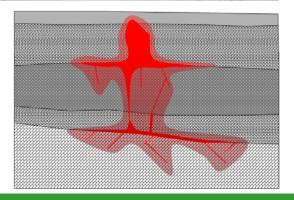


4. Fuel and power









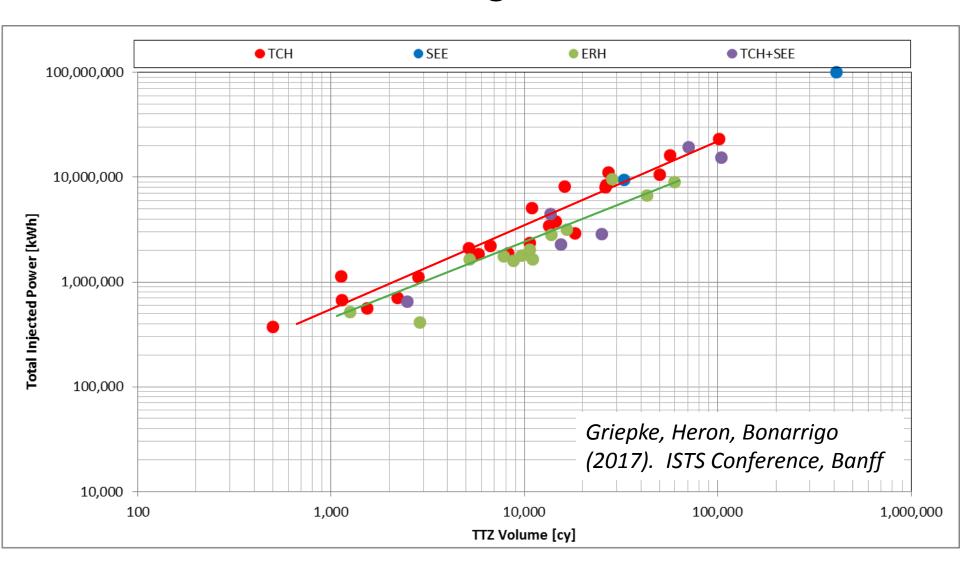
Drilling and depth

(case: Norco, CA)





Power usage (60 sites)



Poster 78 tonight in B1



THERMAL TREATMENT – HOW MUCH ENERGY DOES IT TAKE?

TERRATHERM

Steffen Griepke Nielsen (sgriepke@cascade-env.com), Gorm Heron, Amber Bonarrigo, Robert M. D'Anjou, Michael Dodson (Cascade Thermal, Gardner, MA, USA), John LaChance and Bruce McGee (McMillan-McGee Corp, Calgary, Canada) and Niels Ploug (Krüger, Denmark)



Background & Objectives

Thermal Conductive Heating (TCH), Electrical Resistance Heating (ERH) and Steam Entercod Extraction (SEE) are widely used thereals technologies capable of effectively immediating a variety of chemicals from different peoples entering, recipilar entropy, recipi

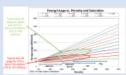
It is crucial that sufficient energy is delivered to the subsurface to overcome site heat demands, balance heat losses, and to facilitate enough to oling and steem stipping to meet remedial objectives. This study focused on a detailed analysis of these energy needs.



Factors Governing Energy Usage

Vertous factors govern the energy usage during thermal remedies. The following major site specific factors contribute to the total site energy usage

- Prorosity and astumation determine the subsurface heat capacity and therefore the energy needed to increase the temperature and boil off pore water.
- The size and shape of the treatment zone and local groundwater flow
- The influence of the volatilization and mobility of the target contaminants with temperature and associated changes in chamical properties with temperature.
- . The thermal design and heating technology applied
- The numeric remedy goals and exit strategy.
- The theoretical energy usage from a 100°C application is shown below as a function of soil porosity and



Contaminant Characteristics Effect Energy Usage

Site contaminent characteristics effect the energy usage

- Boiling Point Henry's Law consten Vepor Pressure
 Hydrolysis Rate with Temperature

Europeanel	Special Special CSL	THAT I	Mency's Later	196°C 177.	Target of Time Time		
OCCUPANT .	-78	1	1.000	90.67			
Frage 1-6.	81	109	10.000	4.70			
1,1908	100	180	1,000	136			
New LICOL	- 41	460	1.00	-10			
Delivery Cards	- 11	PLOTE.	110	144			
D/16/08	- 81	810	1100	1.00			
1.196A		4,860	100	18.			
denter	1.0	4.565		T.H.			
and a	- 90	18		190	Sev		
boss	- 81	1.000	1075	1.09			
U-LEFEA.	- 1	1.610	47-	181			
100	- 6	UNID		140			
LISSA	i ii	4.80	1.90	- 18			
BUTTAN BUTA	- 81	A1100		1.00			
LA RESIDENCE	87	A.Prop-	1.00	1.00			
More		14	100				
FEE	1.0	196	180				
ATM MODINE	100	758	3.000	3.54			
CHARGE.	191	ARRE	1.00	1.00			
denteren	150	840	1440	1.00	800		
s/ee	140	160	1269	4.08			
L.D.A. Errodiy Determine	- 10	- 4					
1.10.6 Miles	180	1,000	1,000	3.63			
dentage	163	671	1.90				
investore	-	1,140		-18			
Leginordespre	- 35	-4	1301	4.8			
ALC: U	181	-		3.00			
LAA rommanger	100	1,860	1.00	9.86			
Childrennes	100	140	1.00~	1.94			
Anunchrysgen	- 30	1256		-10-			
MARK LINE	80	- 3		3.85			
SING SECURITY	165.6	9	100	1.85	September 1		
h.dedeser.	20	-	10%	1.00			
regis finders	1.8	- 8	188	-18.			
81	100			18			

Data from Over 60 Thermal Projects

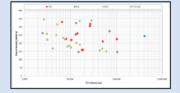
Data compiled by looking at project data from 64 ERH, TCH, SEE and combined technology thermal sites. Large data set is needed because of the site-specific variability related to groundwater flux, contaminant mixtures, starting concentrations, and treatment goals.

All data were derived from projects with a target treatment temperature of 100 C.

Thermal Technology	Number of Sites
ERH	30
SEE	2
TCH	28
Combined TCH & SEE	6
Total Sites	64

Power Density - VOC sites

The energy usage per volume treated were analyzed. The figure below shows the power density for the sites evaluated.



	n	Min [kWh/cy]	Max Date (a.2	Average
	[-]		[kWh/cy]	[kWh/cy]
ERH	18	151	347	228
SEE	1			244
TCH	10	159	331	251
TCH+SEE	5	147	324	231

Average power densities between 228 and 251 kWh/cy

Power Usage vs. Contaminant

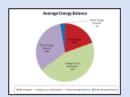
Lighter end SVOCs require more energy to be properly removed in a 100 °C application. Therefore, a longer treatment duration and higher power input is



Heat Losses

- The following energy streams are typically manifored during a thermal remediation project:
- Energy injected by the chosen technology
- Energy extracted as steam
 Energy extracted as hot water
- Energy extracted as hot air
 Cooling wateridrip system for electrodes (ERH only)
- Unknown energy streams:
- Heat loss to surroundings by thermal conductive heating or any local convective heat transport

Data from 7 projects shows that heat losses can be substantial



Conclusions

- Deteats indicate a big differential on power usage even within the same technology for the same contaminants. Site specific conditions affect energy usage While a theoretical calculation shows that 70-115 kWh/cy typically will be required to meet treatment goals
- for VOCs, actual site data indicate that 228 to 251 MWh/cy are typically required in reality Typical lighter end SVOCs require ~30% more energy to meet performance goals, compared to VOCs.
- The TCH technology requires slightly more energy than ERH (~10%), but typically achieves lower post-treatment concentrations (better treatment closer to heater boilings).
- Heat losses can be substantial need to be properly evaluated for all sites.
- Benefit from hydrolysis and thermally enhanced bio remediation should be considered where possible, to reduce the overall energy usage.

Facts

- 1. The cost of energy is less than 20% of the total project cost
 - 2. Steam is 70% cheaper per BTU

3. ERH and TCH are within 15%

4. TCH used to reach more stringent goals

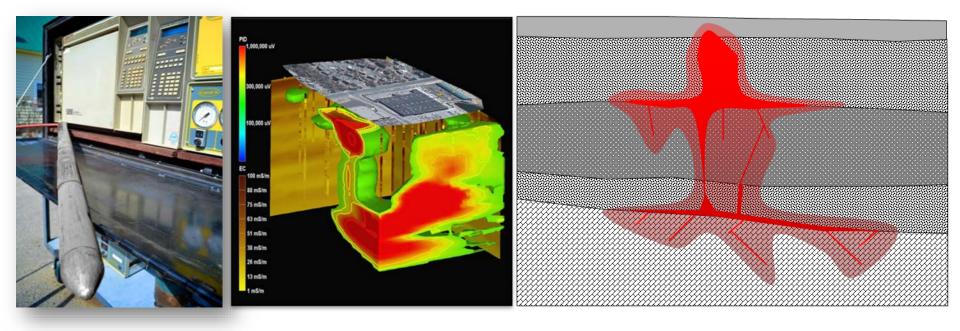
5. Certainty and guarantees

	GFPR all-in	GRPR with assumptions	GFPR for tasks that are not variable
Drill and construct system	fixed	fixed	fixed
Operate and ensure function per design	fixed	fixed	fixed
Collect data to optimize	fixed	fixed	fixed
Expanded duration due to higher than expected contaminant mass	fixed	Unit price for GAC or daily rates	Unit price for GAC or daily rates
Revisions to counter unknown groundwater flow	fixed	Unit rates for wells and operations	Unit rates for wells and operations
Other unforeseen expenses and delays	fixed	negotiated	Cost covered
Thermal vendor potential exposure	HIGH	MEDIUM	LOW
Cost premium (typical)	20-30%	10-20%	none

TCH
ERH + MPE/barriers
Combinations

Single approaches

Basis for choice - solid CSM



Geology Water COC Goals Certainty needed

Summary - how to choose



