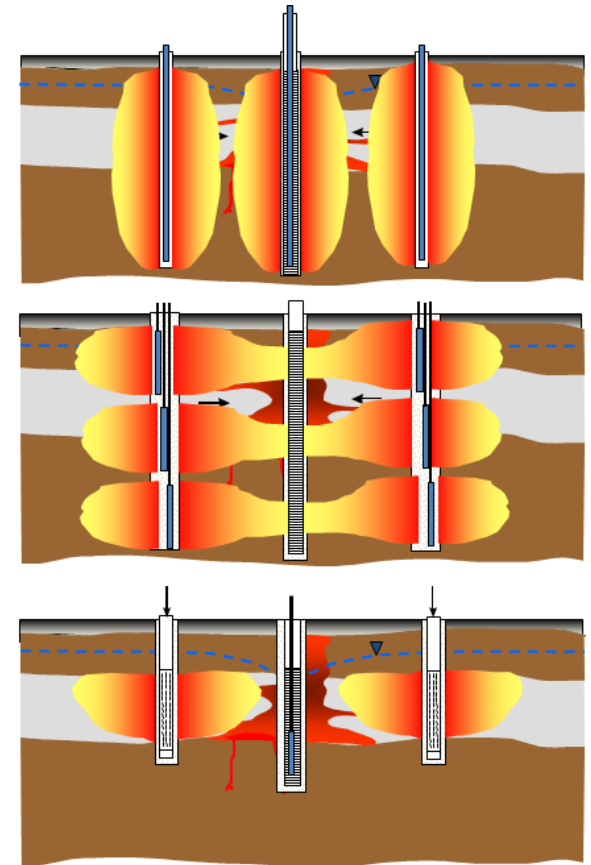


How To Choose?

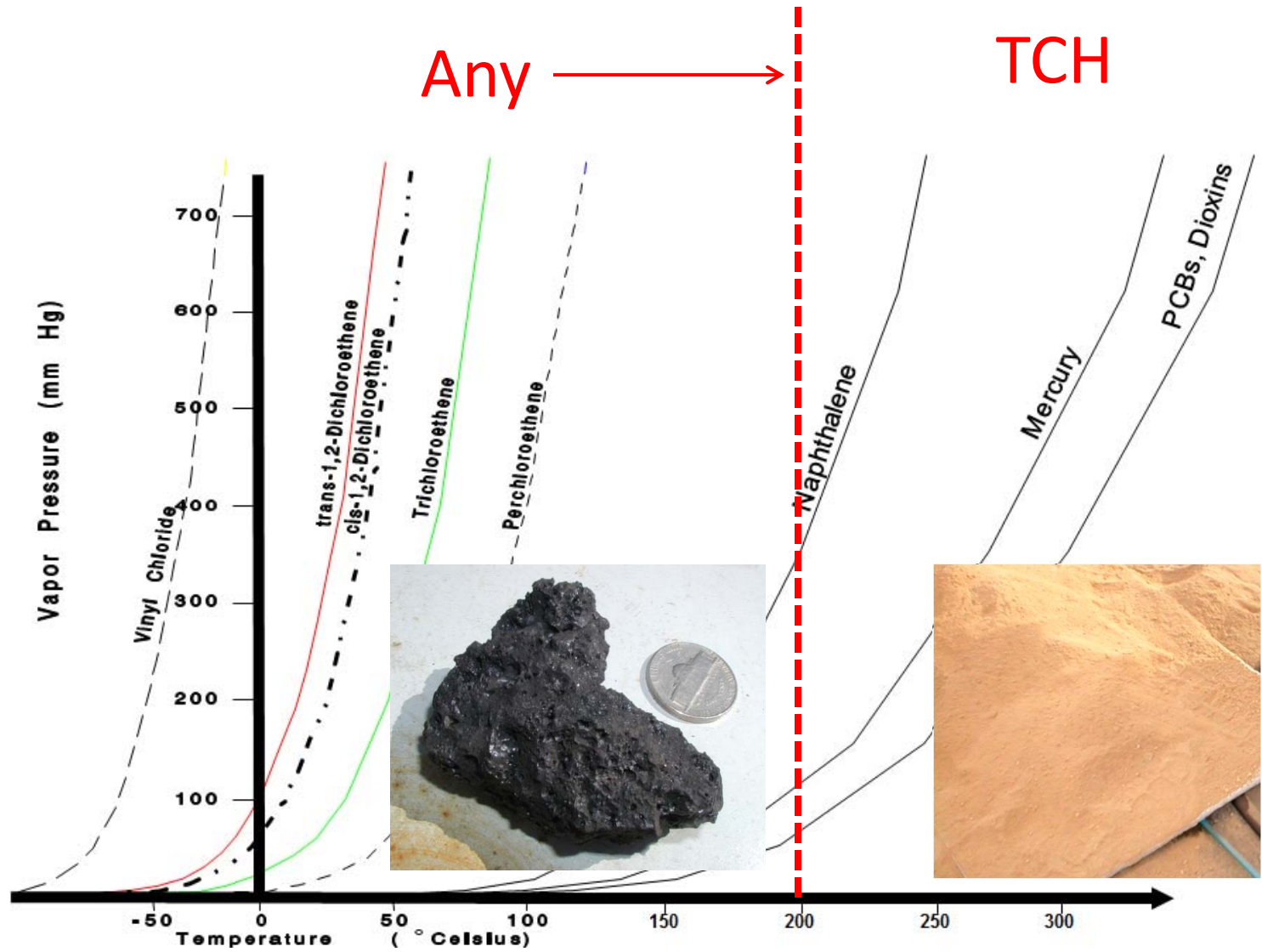


Gorm Heron, Steffen Nielsen, Michael Dodson, Robert D'Anjou
Cascade Thermal



Contaminants

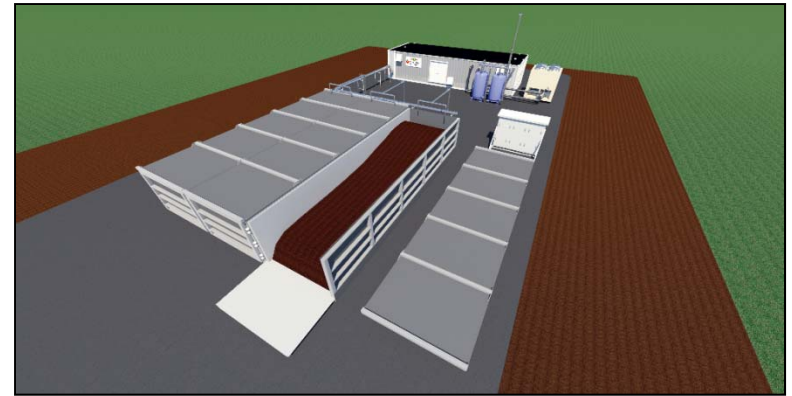
Boiling points rule



SVOC Treatment – above grade



In Pile Thermal Desorption
(USAID- Danang Vietnam)

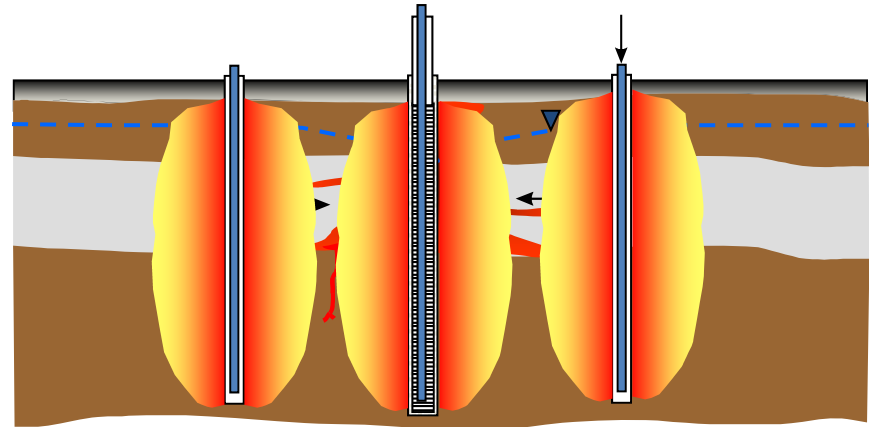


HB-1100

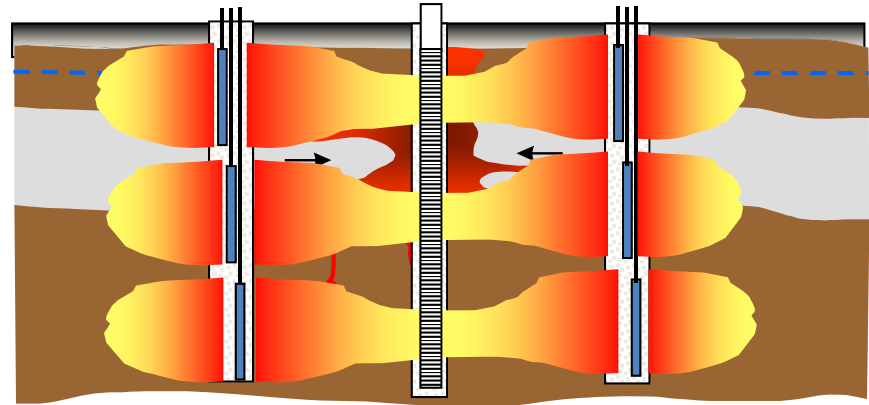


Permeability

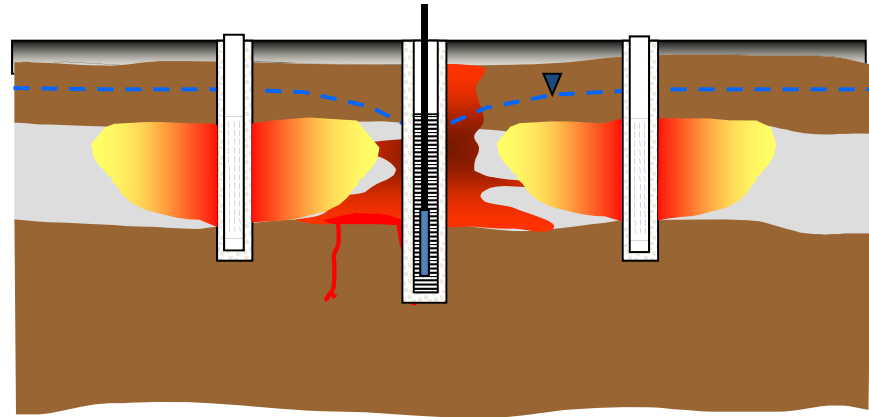
TCH - governed by **thermal conductivity** ($f \sim 3$)



ERH - governed by **electrical conductivity** ($f \sim 200$)



SEE - governed by **hydraulic conductivity** ($f \sim 10^6$)



Long plume?



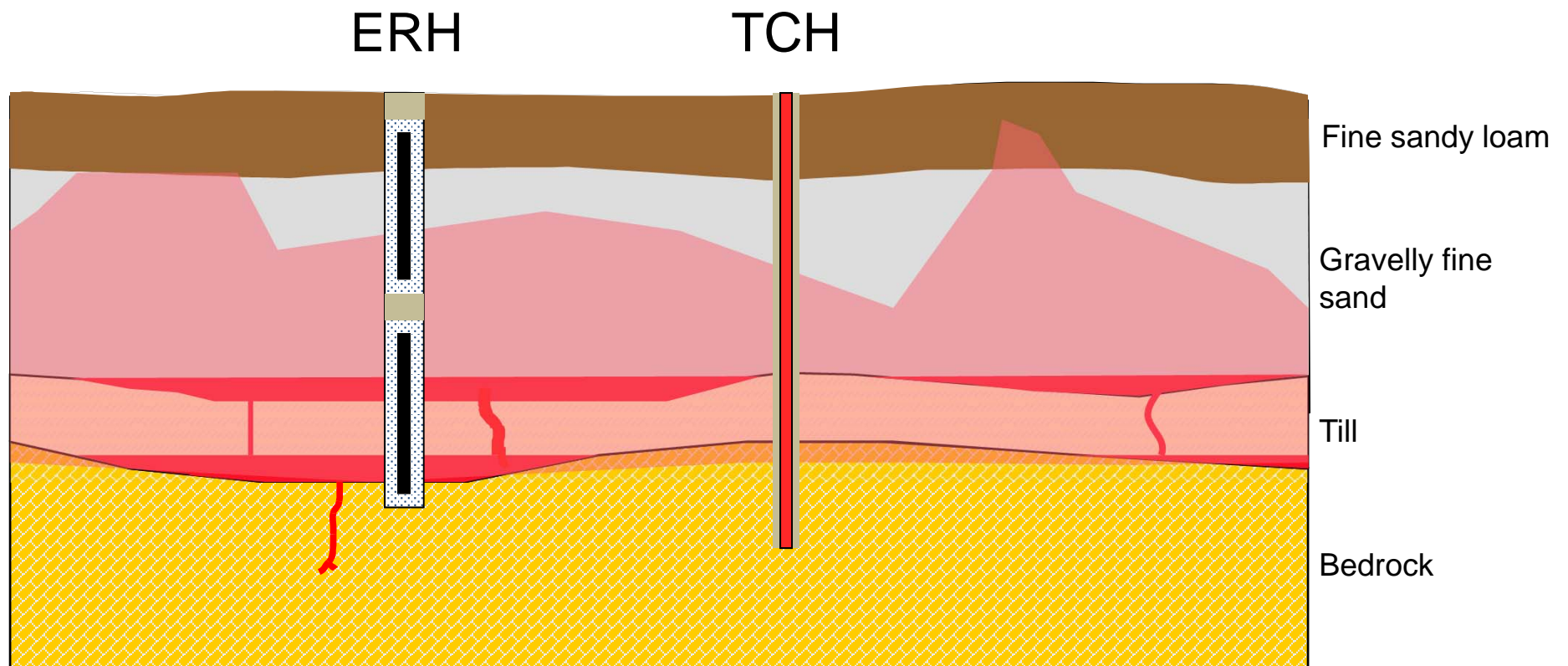
Flowing groundwater in touch with NAPL

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



DNAPL spreading risk

(case: SRSNE Superfund Site, Southington CT)

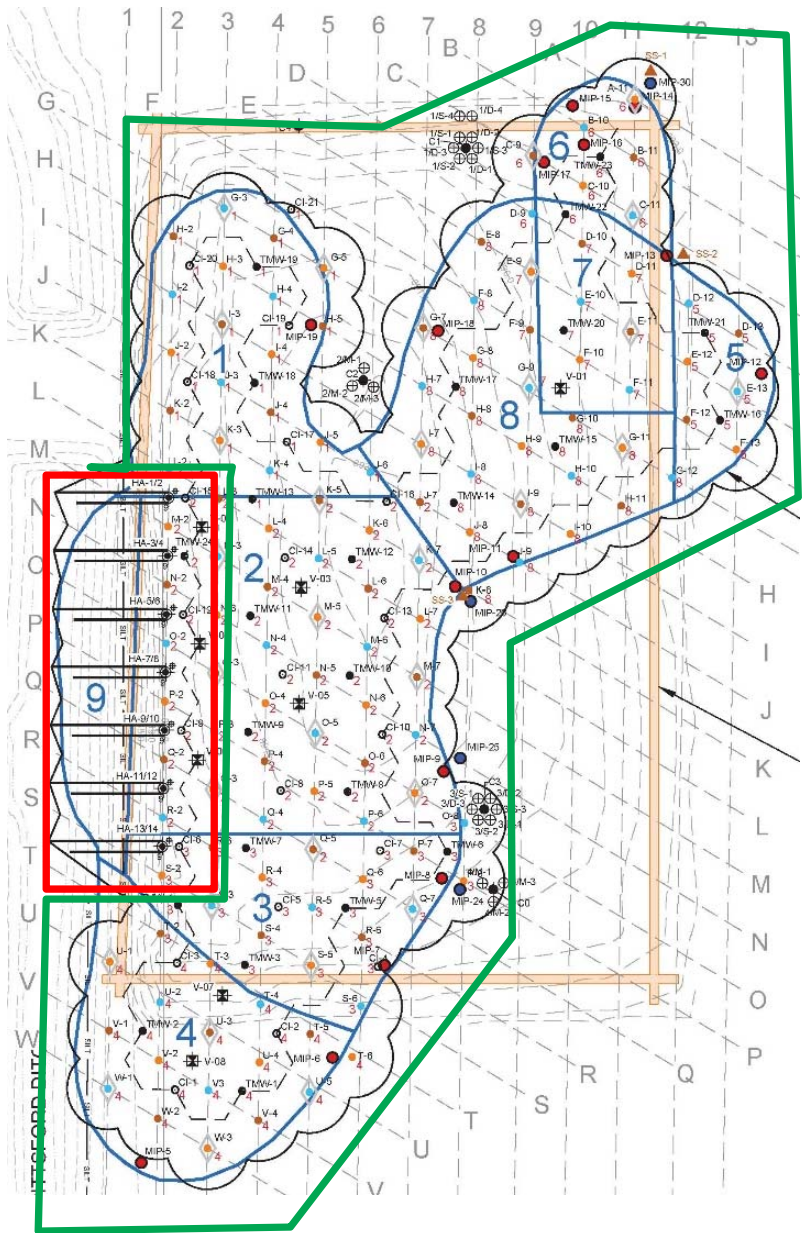


SRSNE - TCH

**230 tonnes removed
(500,000 lbs)**



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)

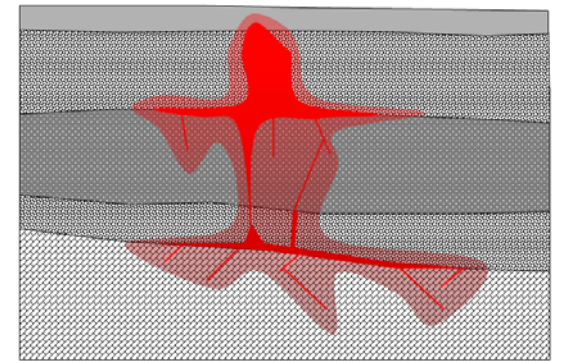
1. Drilling and well materials

2. Construction

3. Duration and labor

4. Fuel and power

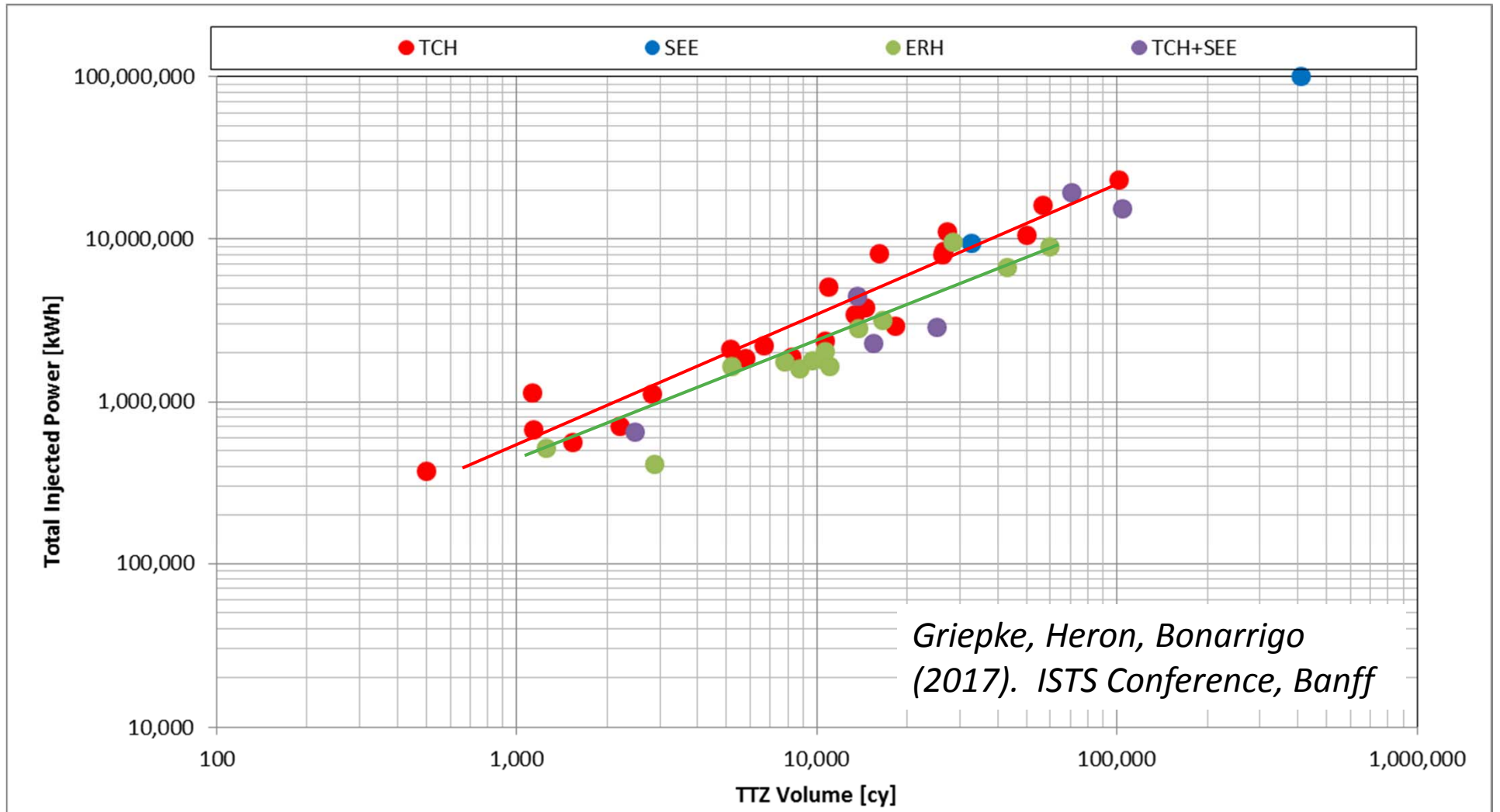
5. Guarantees



Drilling and depth (*case: Norco, CA*)



Power usage (60 sites)



Poster 78 tonight in B1



THERMAL TREATMENT – HOW MUCH ENERGY DOES IT TAKE?

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 Enhanced Extraction (SEE) are widely used thermal technologies capable of effectively remediating a variety of chemicals from different geological settings, ranging from light clays to permeable sands. During thermal applications, the energy needed to reach project goals is one of the major resources that contributes to the environmental footprint and cost associated with implementing these thermal technologies.

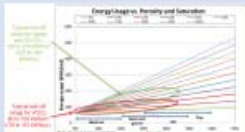
It is crucial that sufficient energy is delivered to the subsurface to overcome site heat demands, balance heat losses, and to facilitate enough boiling and steam stripping to meet remedial objectives. This study focused on a detailed analysis of these energy needs.



Factors Governing Energy Usage

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

- Porosity and saturation 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 chemical properties with temperature.
- The thermal design and heating technology applied.
- The numeric remedy goals and end strategy.
- The theoretical energy usage from a 100°C application is shown below as a function of soil porosity and initial saturation:



Contaminant Characteristics Effect Energy Usage

Site contamination characteristics effect the energy usage:

- Boiling Point
- Solubility
- Henry's Law constant
- Vapor Pressure
- Hydrolysis Rate with Temperature

Contaminant	Peak PPM	Remedy Level	Boiling Point (°C)	Henry's Law Constant	Hydrolysis Rate (1/yr)	Vapor Pressure (kPa)
CHL	10	1	131	0.00002	0.1	0.0001
DCB	10	1	132	0.00002	0.1	0.0001
DCE	10	1	126	0.00002	0.1	0.0001
DECA	10	1	174	0.00002	0.1	0.0001
DECA	10	1	174	0.00002	0.1	0.0001
DICL	10	1	146	0.00002	0.1	0.0001
DICL	10	1	146	0.00002	0.1	0.0001
DICL	10	1	146	0.00002	0.1	0.0001
DECA	10	1	174	0.00002	0.1	0.0001
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DICL	10	1	146	0.00002	0.1	0.0001
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DICL	10	1	146	0.00002	0.1	0.0001
DECA	10	1	174	0.00002	0.1	0.0001

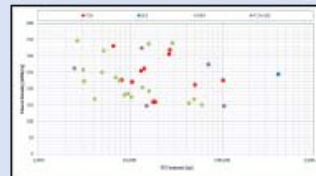
Data from Over 60 Thermal Projects

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	8
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	Max	Average
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

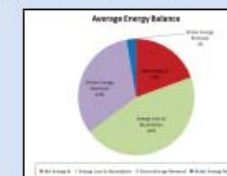
Heat Losses

The following energy streams are typically monitored 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 water/strip systems for electrodes (ERH only)
- Unknown energy streams:

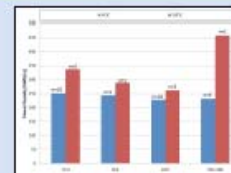
- Heat loss to surroundings by thermal conductive heating or any local convective heat transport
- Heat loss to groundwater leaving the site

Data from 7 projects shows that heat losses can be substantial.



Power Usage vs. Contaminant

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



Conclusions

- Datasets 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 kWh/cy are typically required in reality.
- Typical lighter and 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 footings).
- Heat losses can be substantial – need to be properly evaluated for all sites.
- Barriers 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

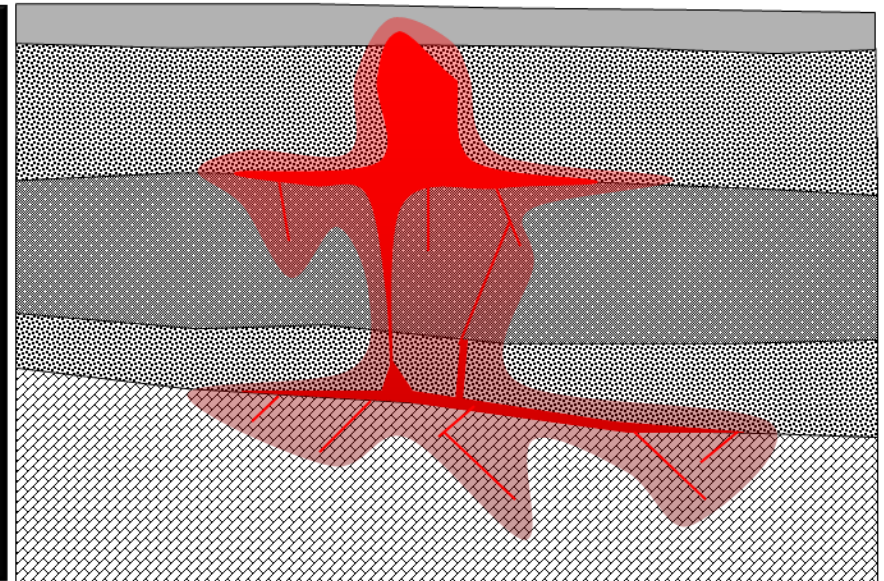
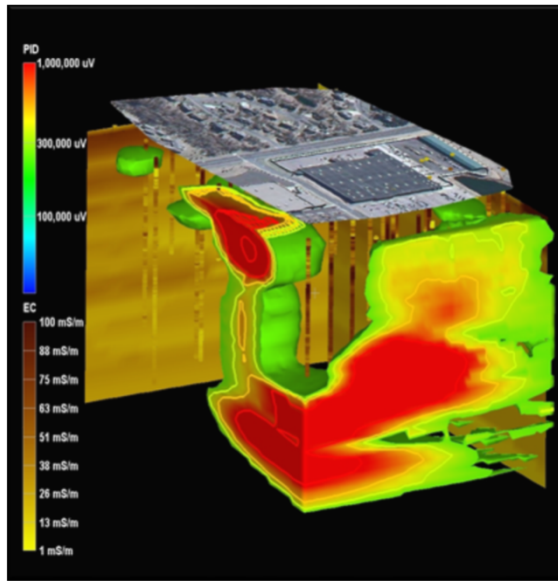
	GFPR all-in	GRPR with assumptions	GFPR for tasks that are not variable
Drill and construct system	fixed	fixed	fixed
Operate and ensure function per design	fixed	fixed	fixed
Collect data to optimize	fixed	fixed	fixed
Expanded duration due to higher than expected contaminant mass	fixed	Unit price for GAC 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

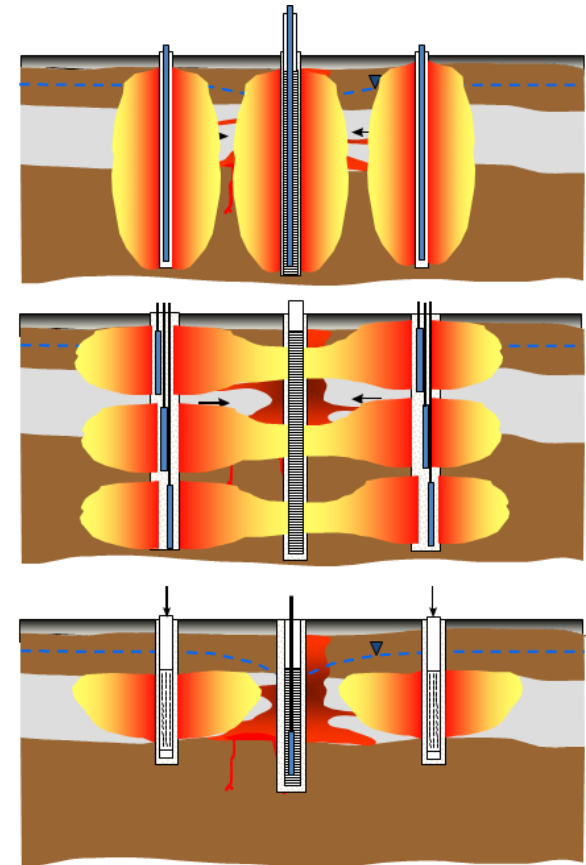
COC

Goals

Certainty needed



Summary - how to choose



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