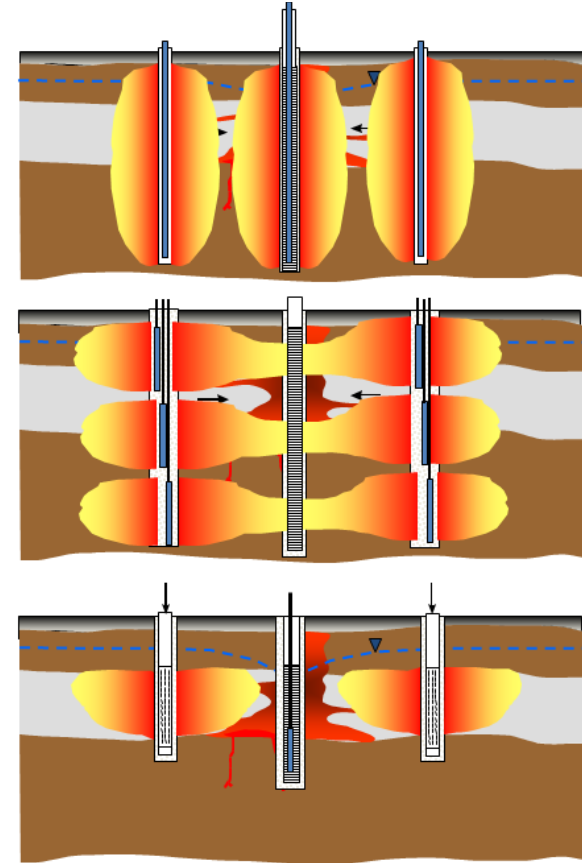


# How To Choose?

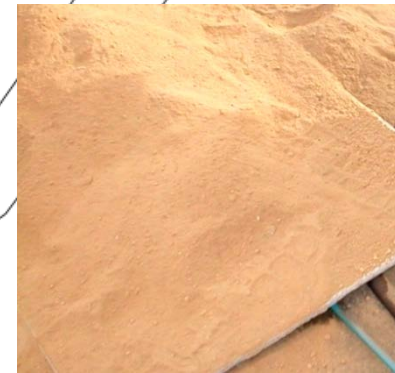
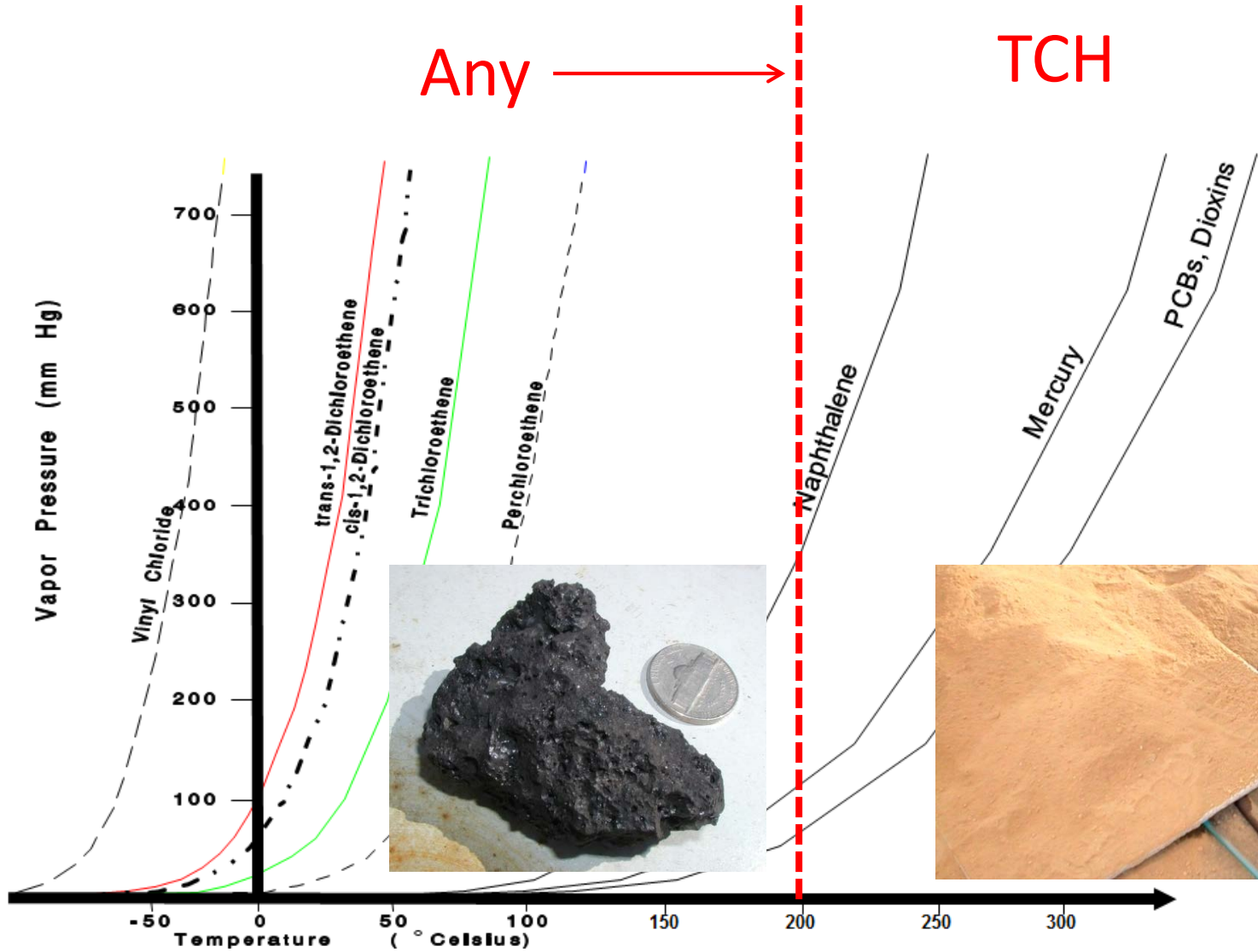


Steffen Nielsen



# Contaminants

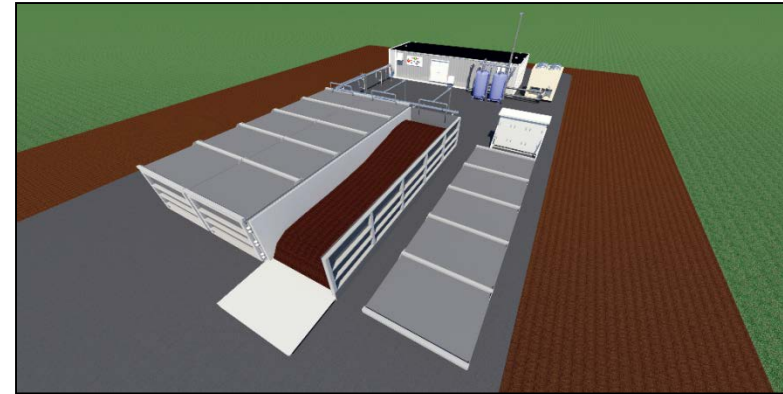
Boiling points rule



# SVOC Treatment – above grade



In-Pile Thermal Desorption  
(USAID- Danang Vietnam)

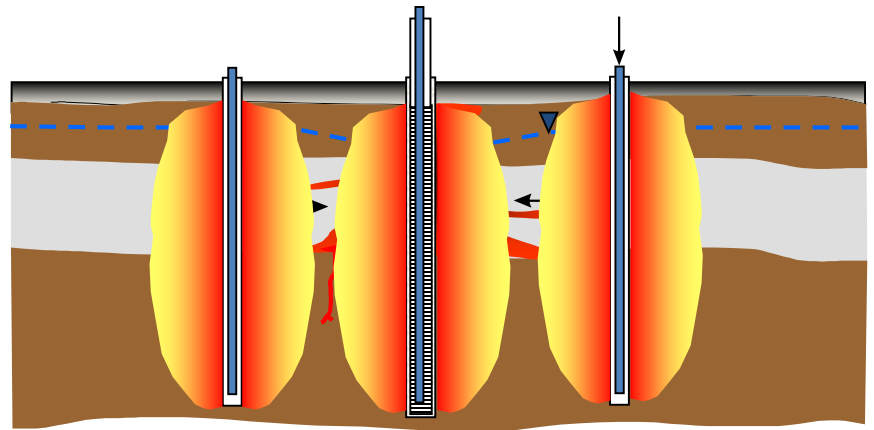


HB-1100

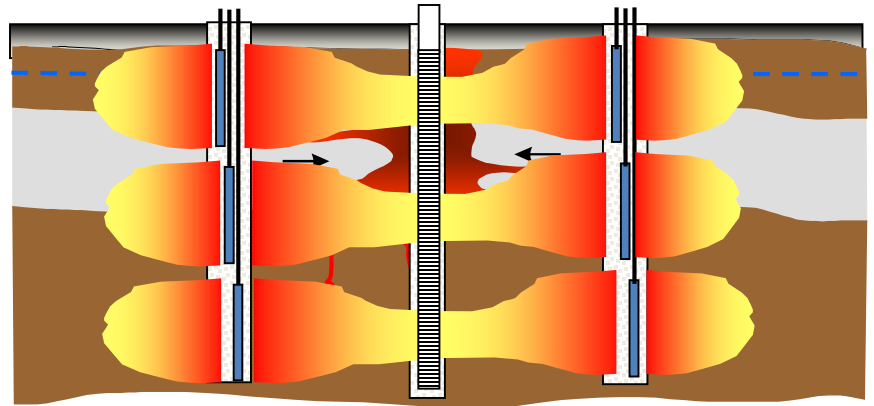


# Permeability

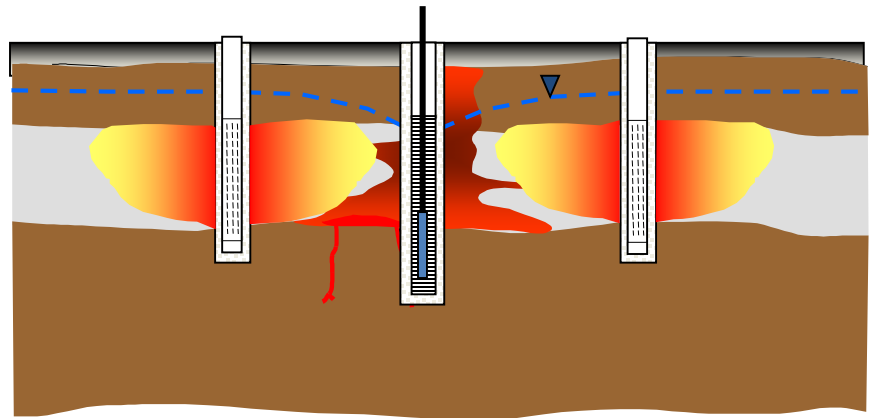
**TCH** - governed by **thermal conductivity** ( $f \sim 3$ )



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



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



# Long plume?



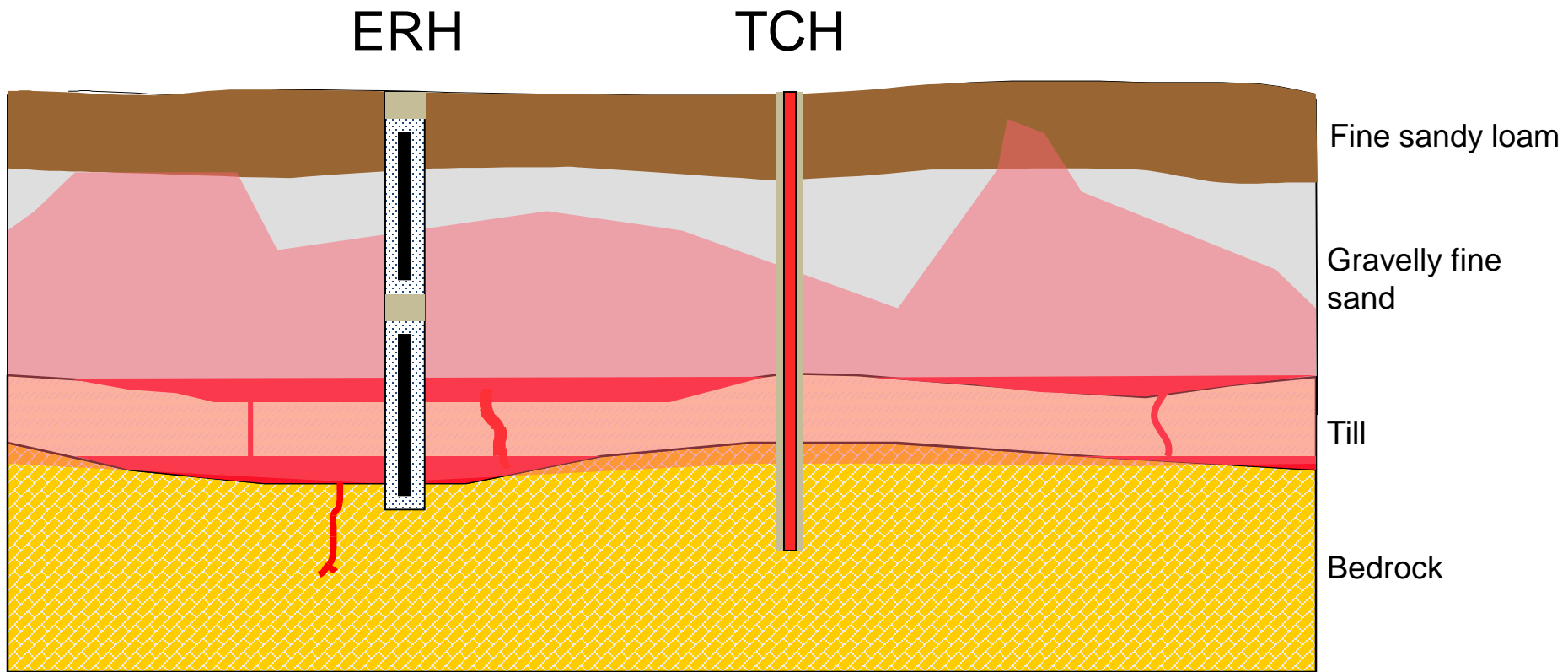
*Flowing groundwater in touch with NAPL*

- 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)**









# 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



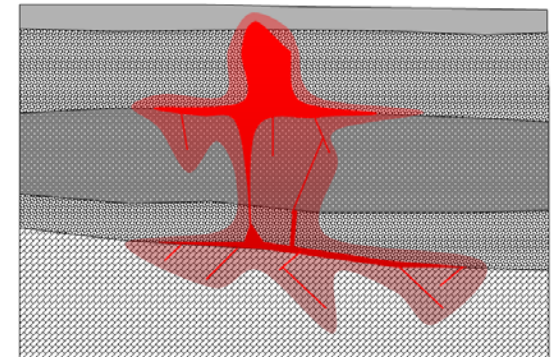
2. Construction



3. Duration and labor



4. Fuel and power



5. Guarantees

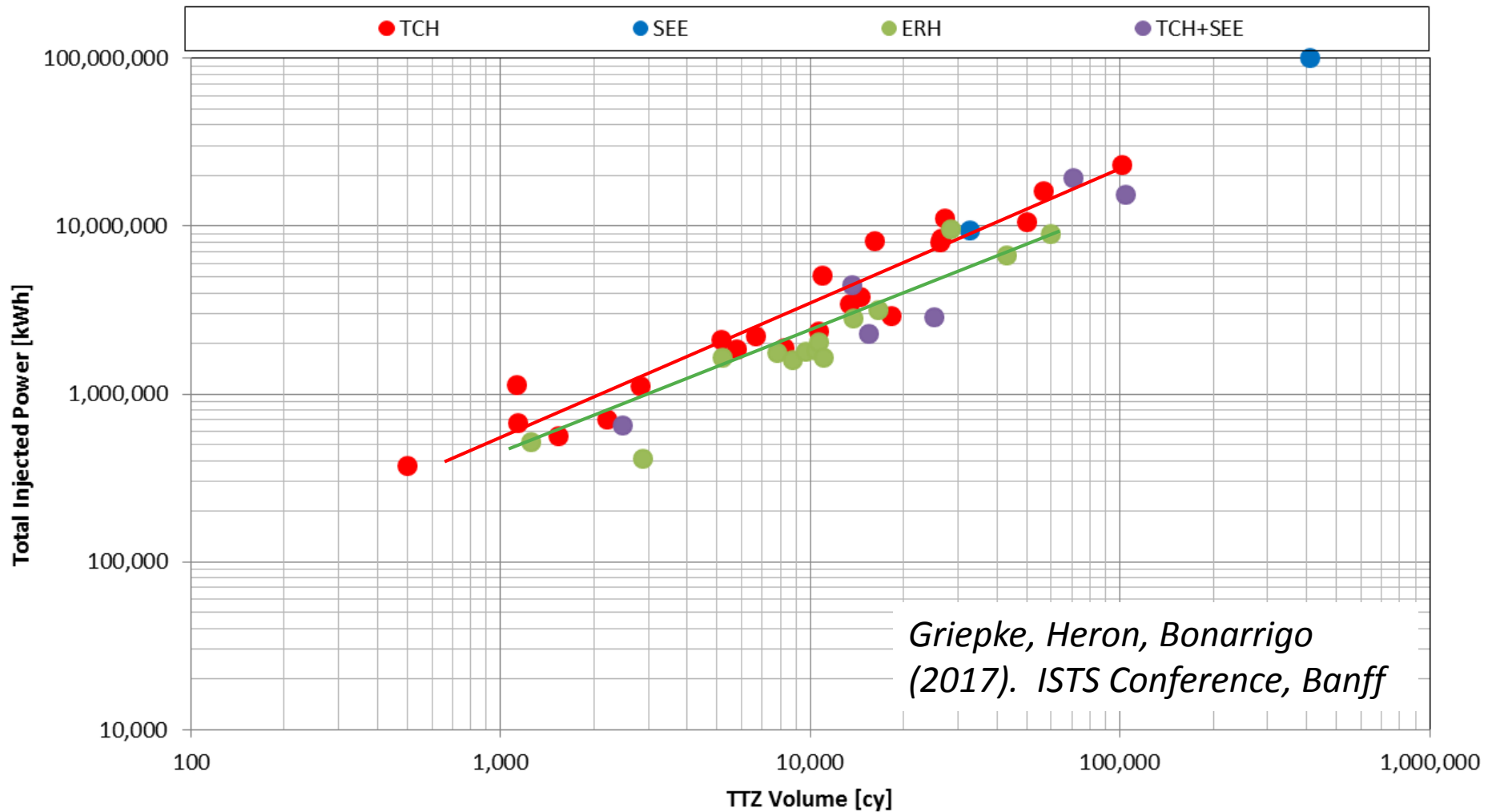




# Drilling and depth (*case: Norco, CA*)



# 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 (*Krøger, 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.

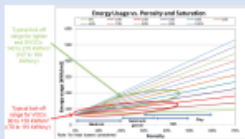
It is crucial that sufficient energy is delivered to the subsurface to overcome site heat demands, balance heat losses, and to facilitate enough boiling and steam stripping to meet remedial objectives. This study focused on a detailed analysis of these energy needs.



### 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 exit 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 contaminant characteristics effect the energy usage:

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

Contaminant	Boiling Point (°C)	Solubility (mg/L)	Henry's Law Constant (atm-cm³/mole)	Vapor Pressure (kPa)	Hydrolysis Rate (1/yr)	Energy (kWh/cy)
Chlorobenzene	90	0.05	0.0001	0.0001	0.0001	High
Dichlorobenzene	110	0.02	0.0001	0.0001	0.0001	High
Trichlorobenzene	140	0.01	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High
1,1-Dichloroethane	69	0.15	0.0001	0.0001	0.0001	High
1,1,1-Trichloroethane	54	0.3	0.0001	0.0001	0.0001	High
1,1,2-Trichloroethane	60	0.2	0.0001	0.0001	0.0001	High
1,2-Dichloroethane	83	0.08	0.0001	0.0001	0.0001	High</

# 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*
- 

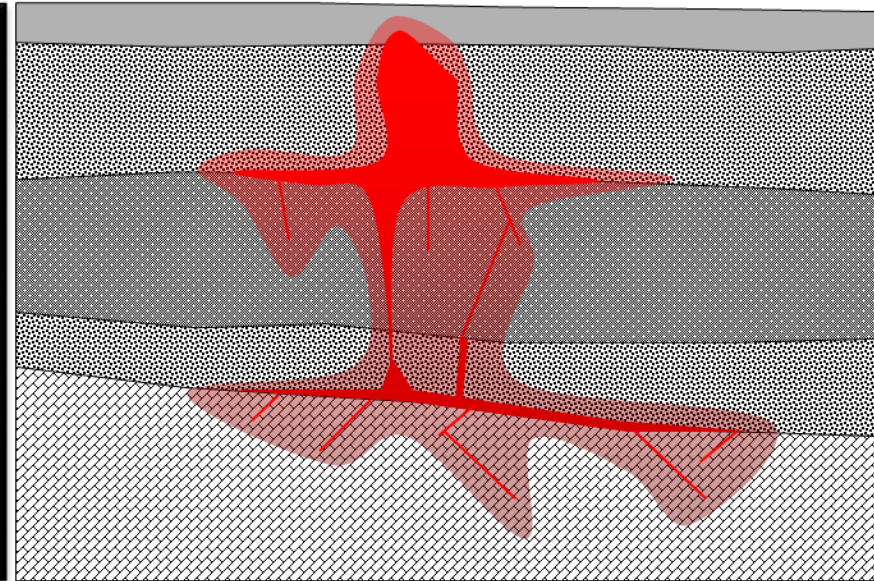
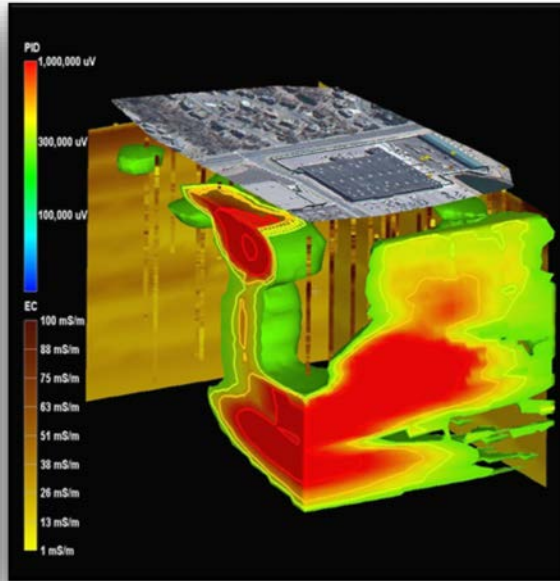


# 5. Certainty and guarantees

	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	<b>HIGH</b>	<b>MEDIUM</b>	<b>LOW</b>
Cost premium (typical)	20-30%	10-20%	none

<p><i>TCH</i> <i>ERH + MPE/barriers</i> <i>Combinations</i></p>	<p><i>Single approaches</i></p>
---	---------------------------------

# Basis for choice – solid CSM



*Geology*  
*Water*  
*COC*  
*Goals*  
*Certainty needed*



# Summary - how to choose

