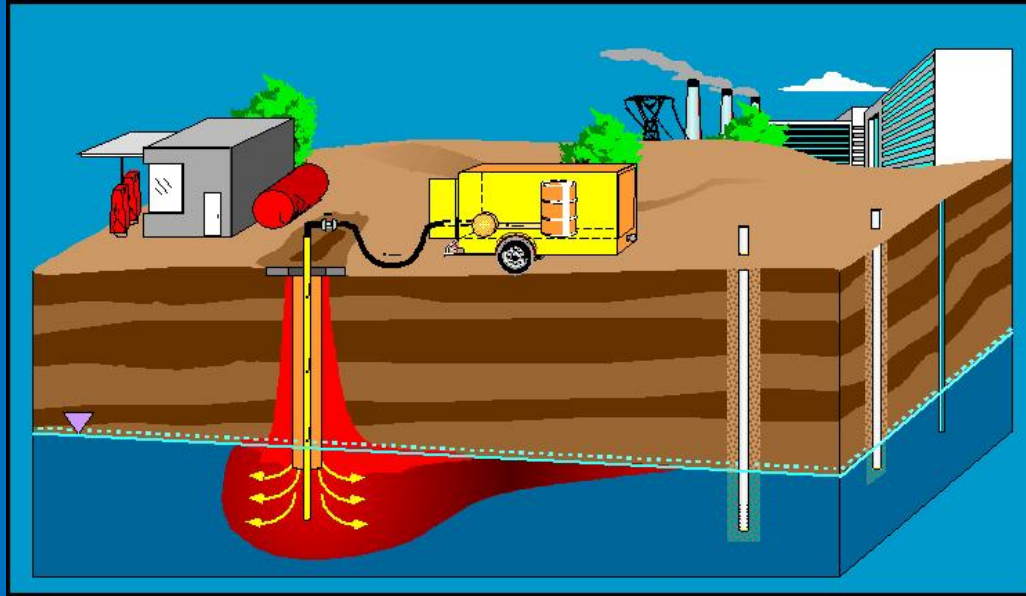


Remedial Options to Excavation In-situ Remediation

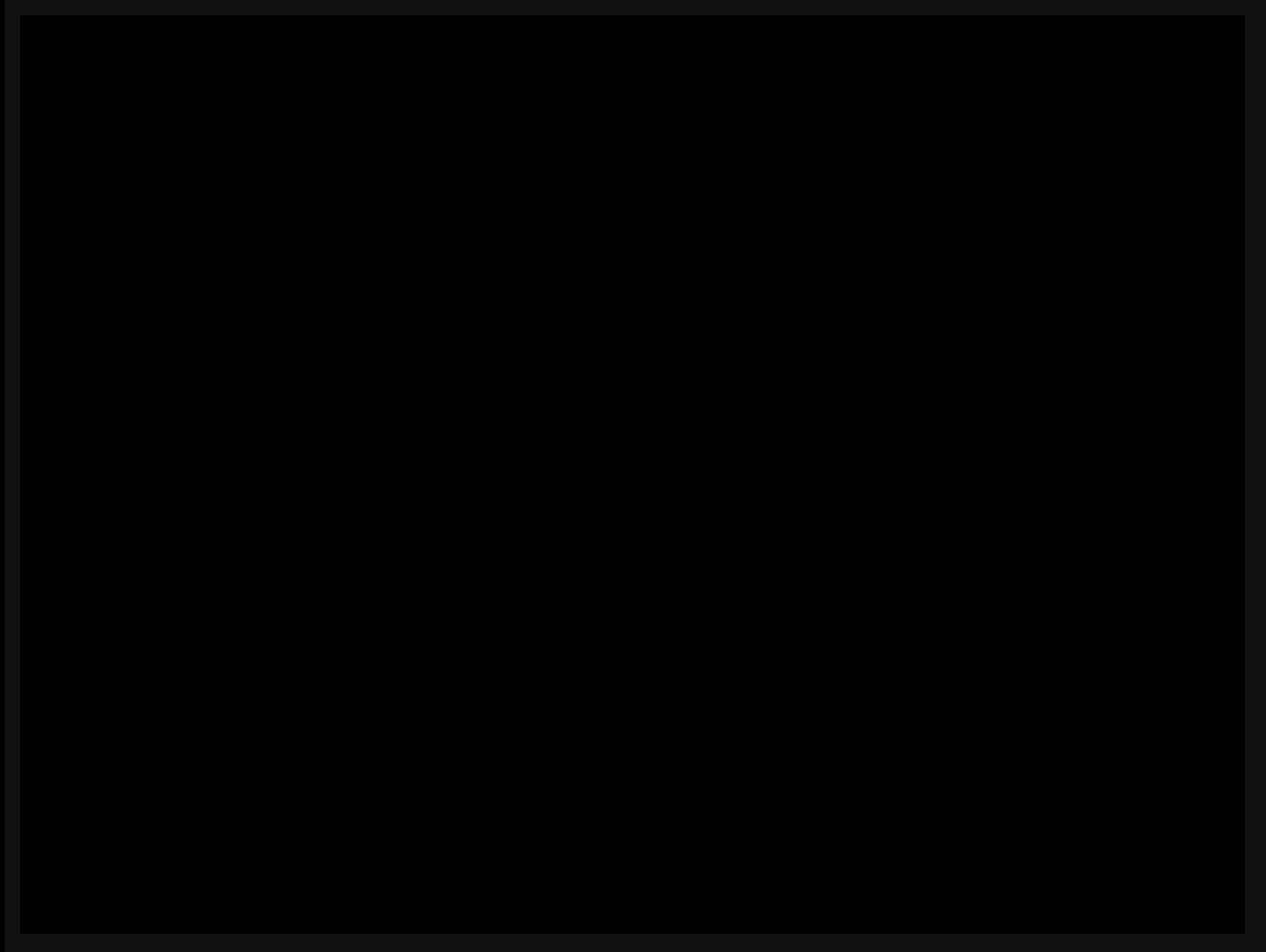


John Sankey, P.Eng.,
True Blue Technologies,
Richmond, BC
October 2013

Remedial Options to Excavation

- **Source Zone Treatment**
 - **In-situ Thermal Remediation--Case Study**
 - **In-situ Chemical Reduction--Case study**
- **Enhanced Sparging**
- **Surfactant Remediation**
- **Dissolved Plume Treatment**
 - **Anaerobic Bioremediation**
 - **Aerobic Bioremediation**
 - **What's new for In-situ Bioremediation**
 - **Cometabolic Bioremediation--Substrates, Enzymes**
- **Reduce Pitfalls — Core competency (hydrogeology, biogeochemistry)**

Matrix Diffusion Video



In-situ Thermal Remediation

Electrical Resistance

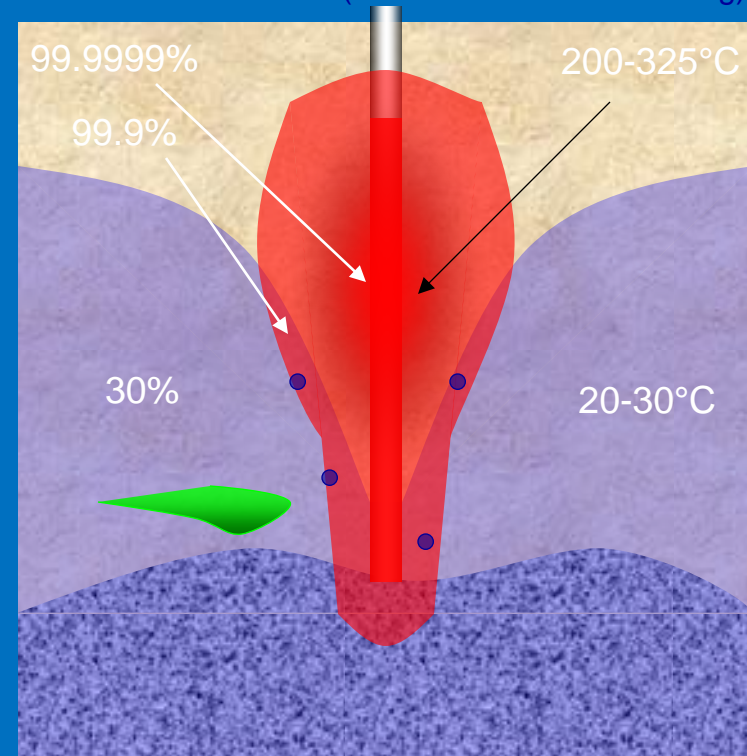
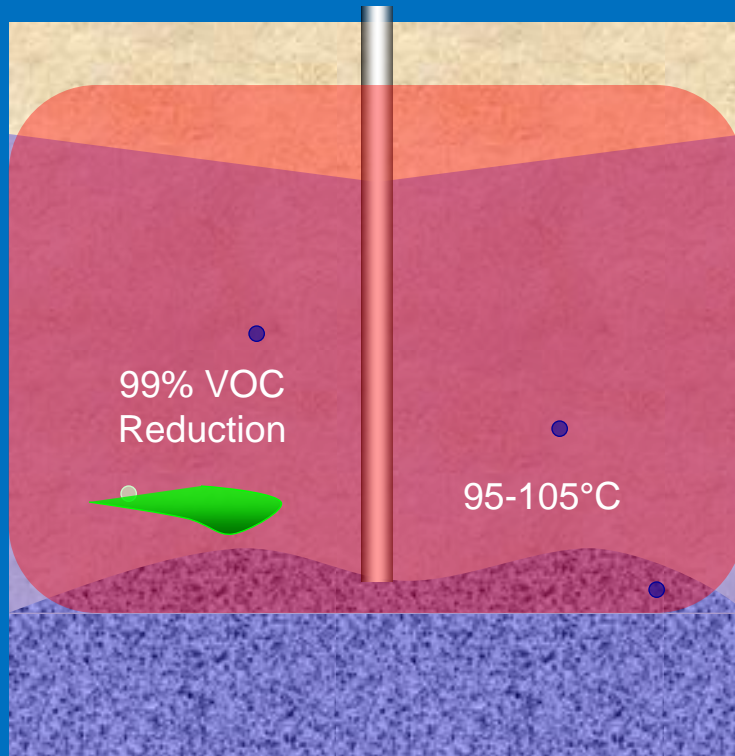
Conductive

ERH

ISTD

Shown at equal energy inputs

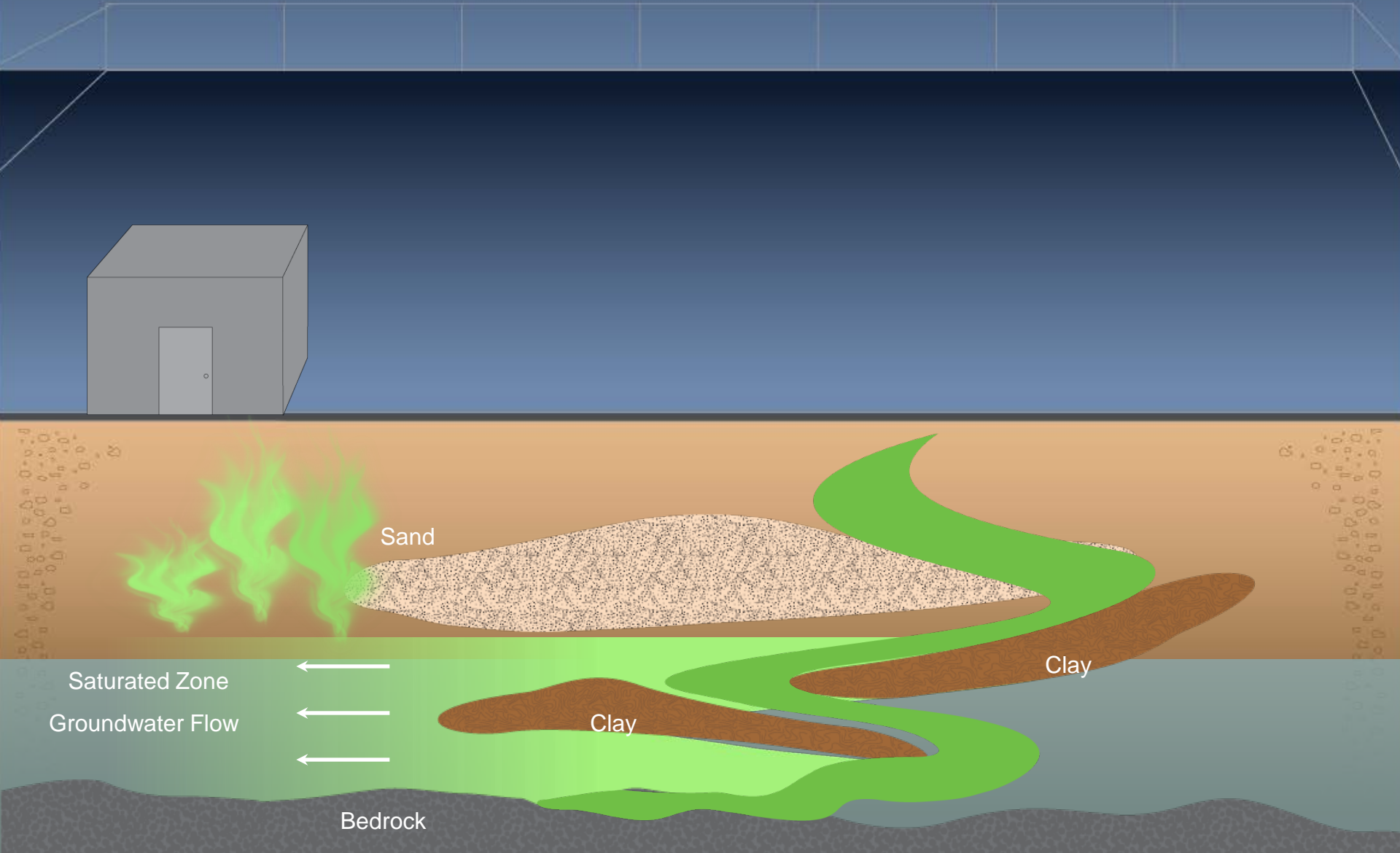
(thermal conduction heating)



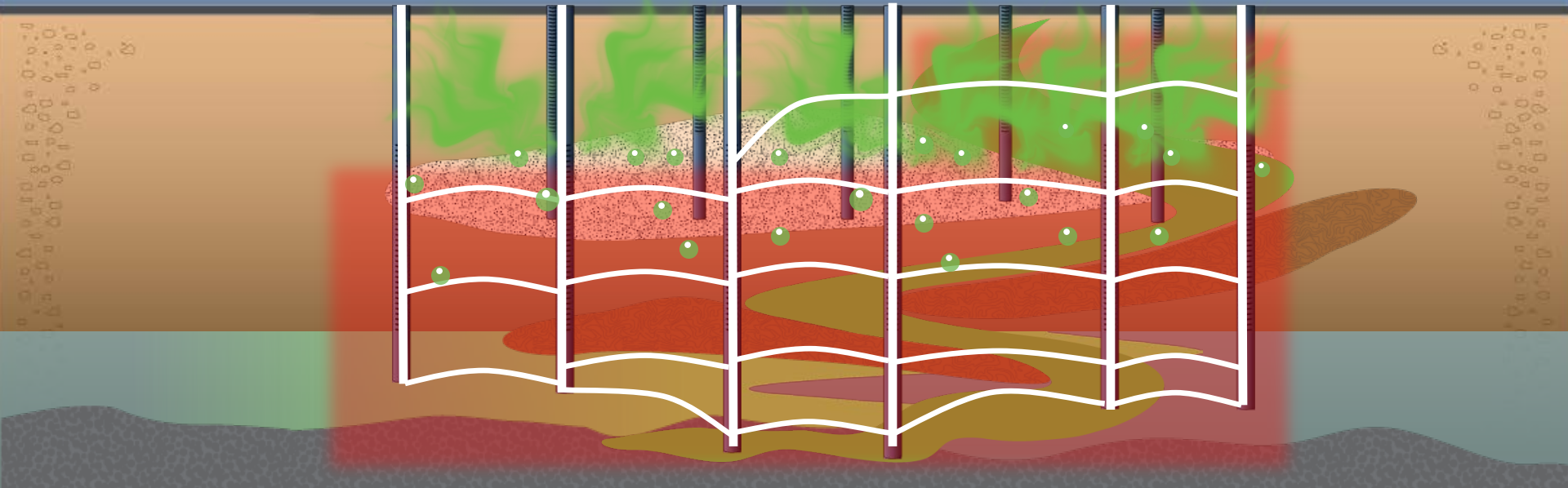
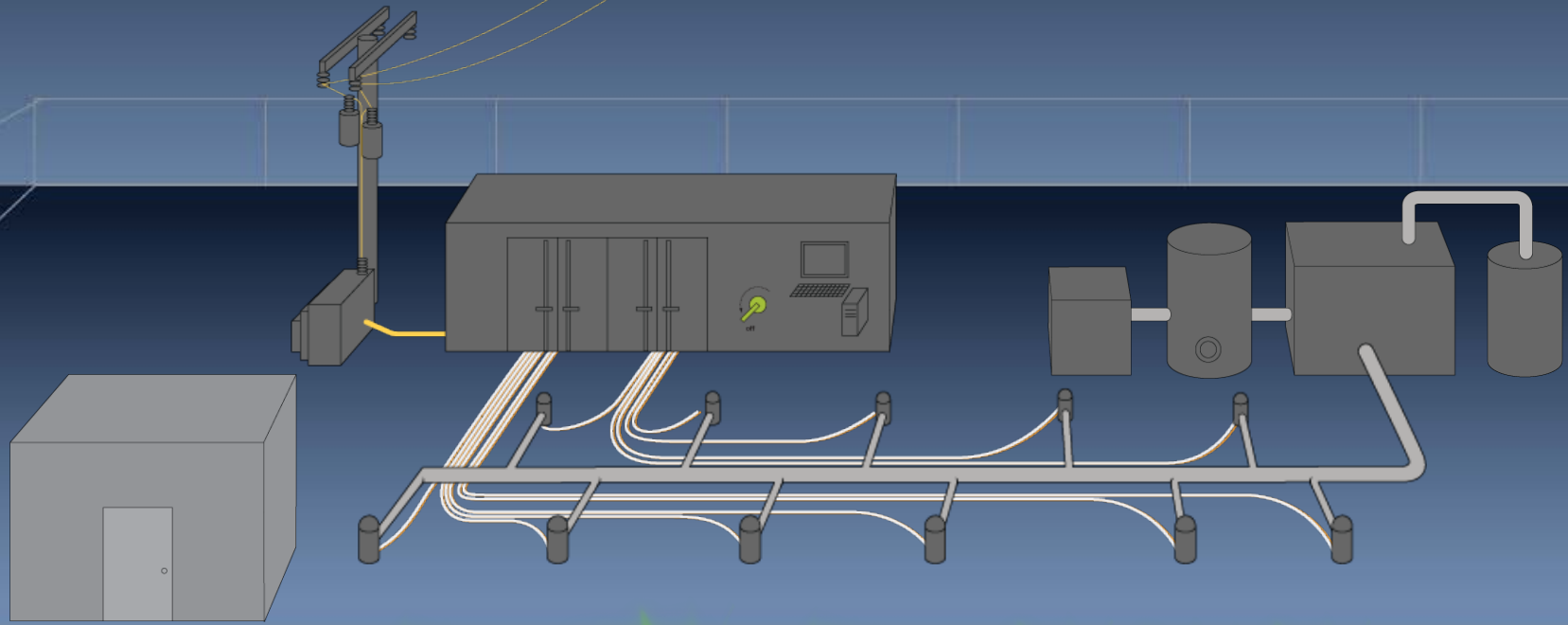
ERH energy input causes a 99% reduction

ISTD energy: $(99.9999\% + 99.9\% + 30\%) / 3 = 77\%$ average reduction

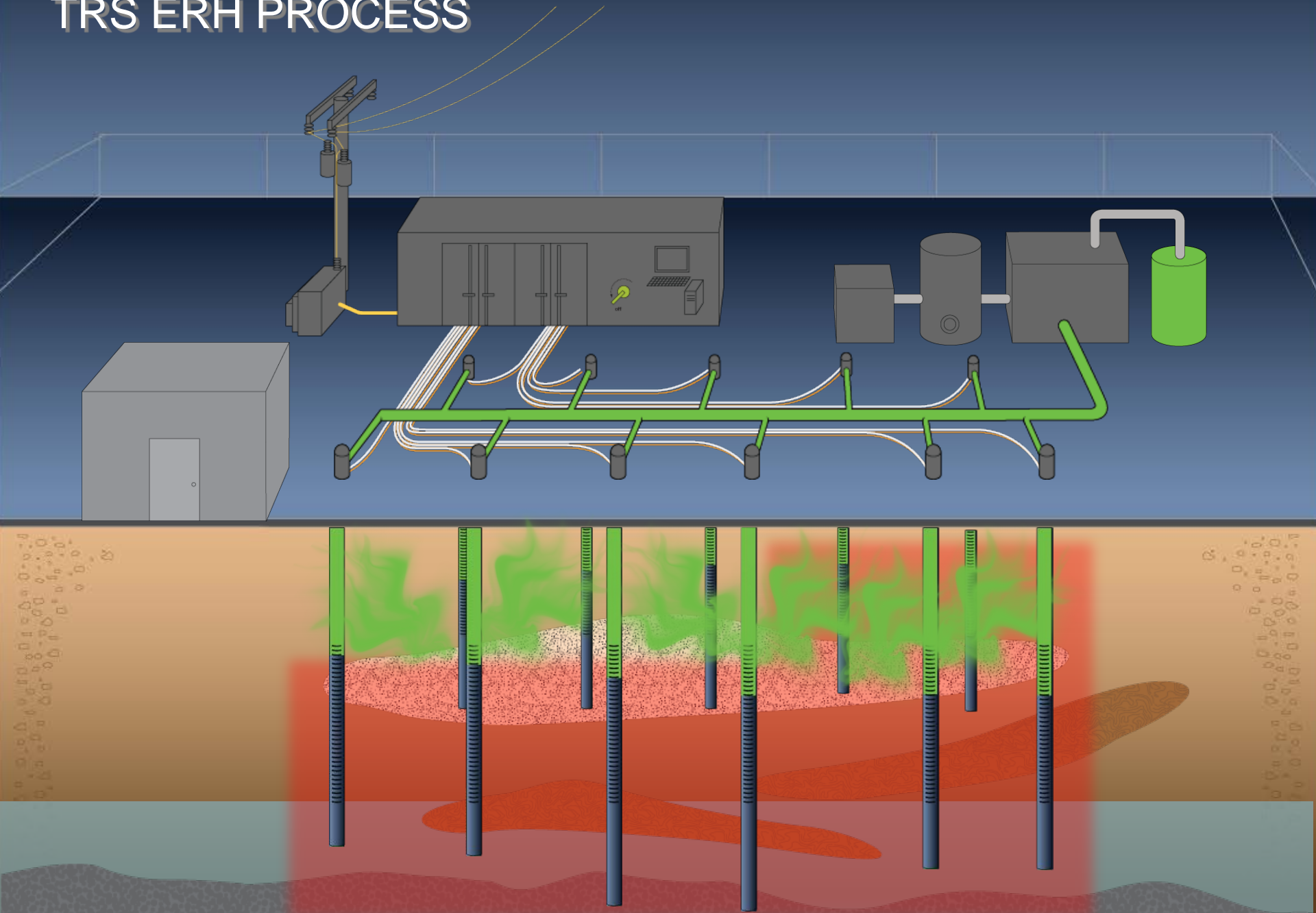
IN-SITU THERMAL REMEDIATION USING TRS' ERH PROCESS



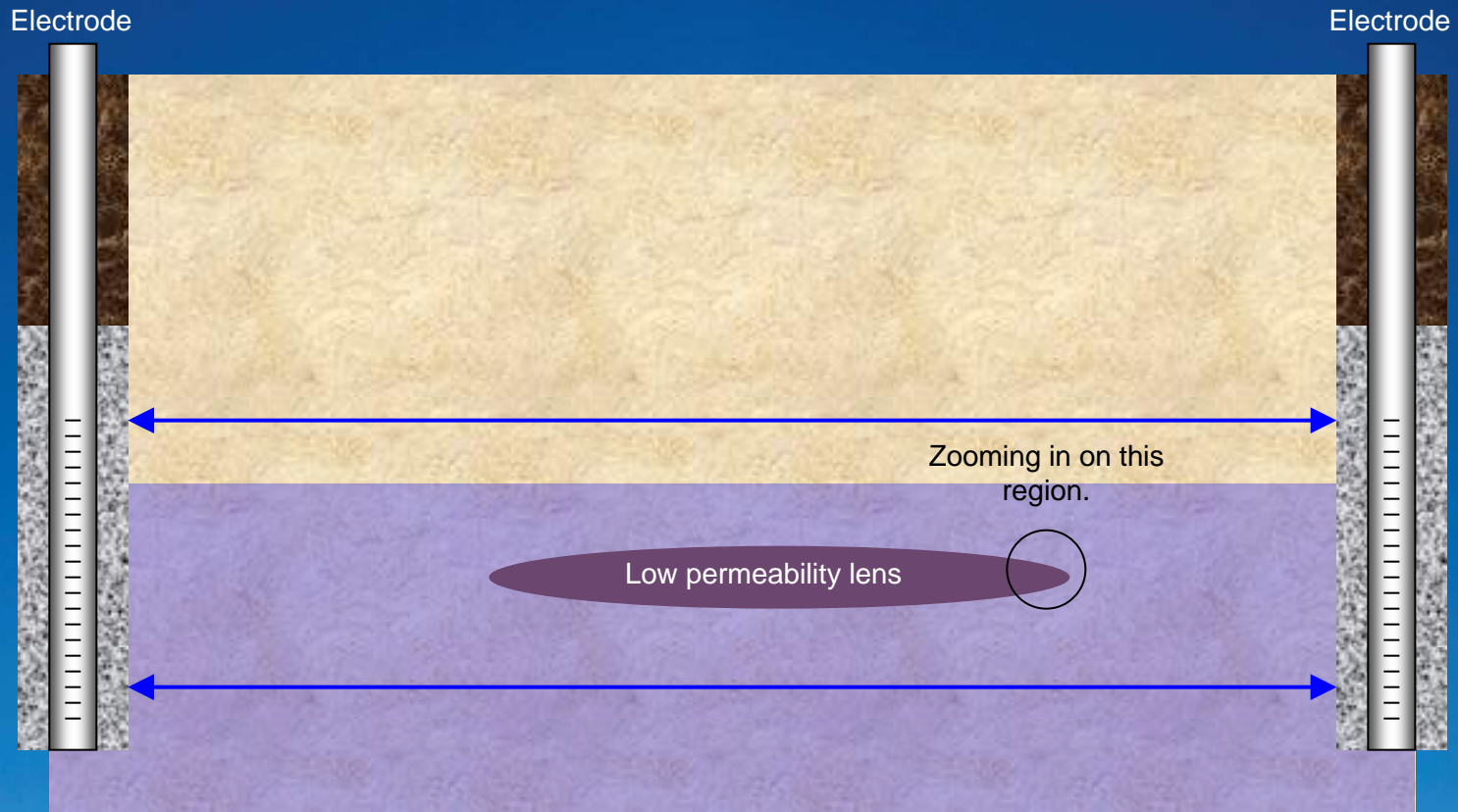
TRS ERH PROCESS



TRS ERH PROCESS

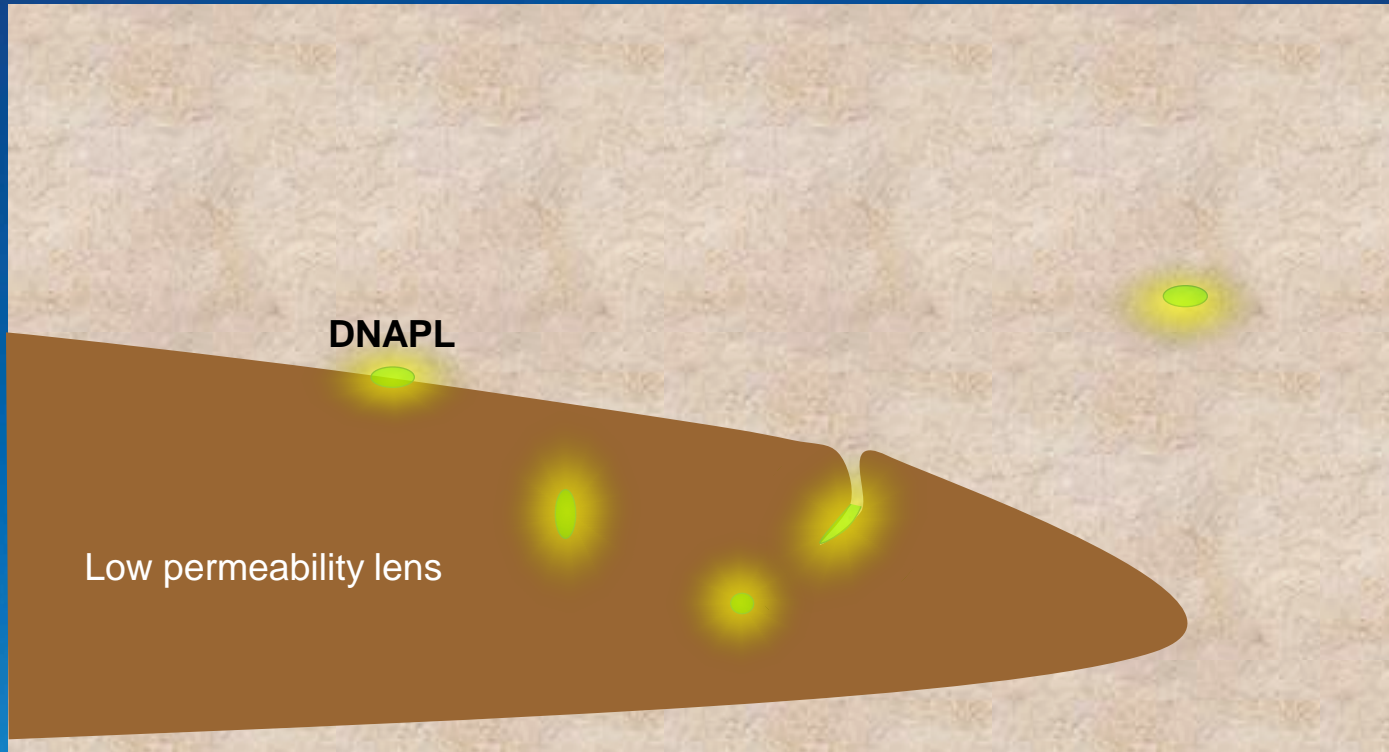


In-Situ Steam Generation during ERH



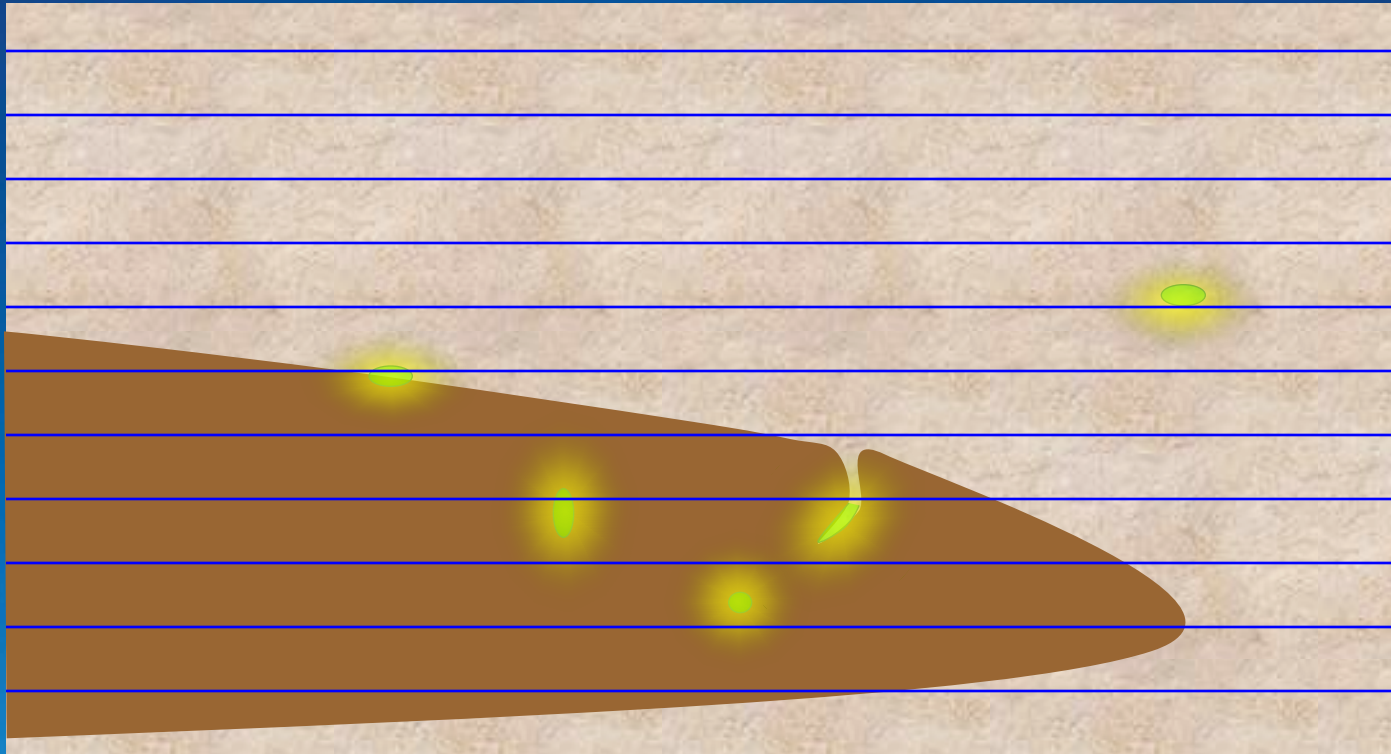
Current flowing between electrodes heats soil directly

In-Situ Steam Generation during ERH



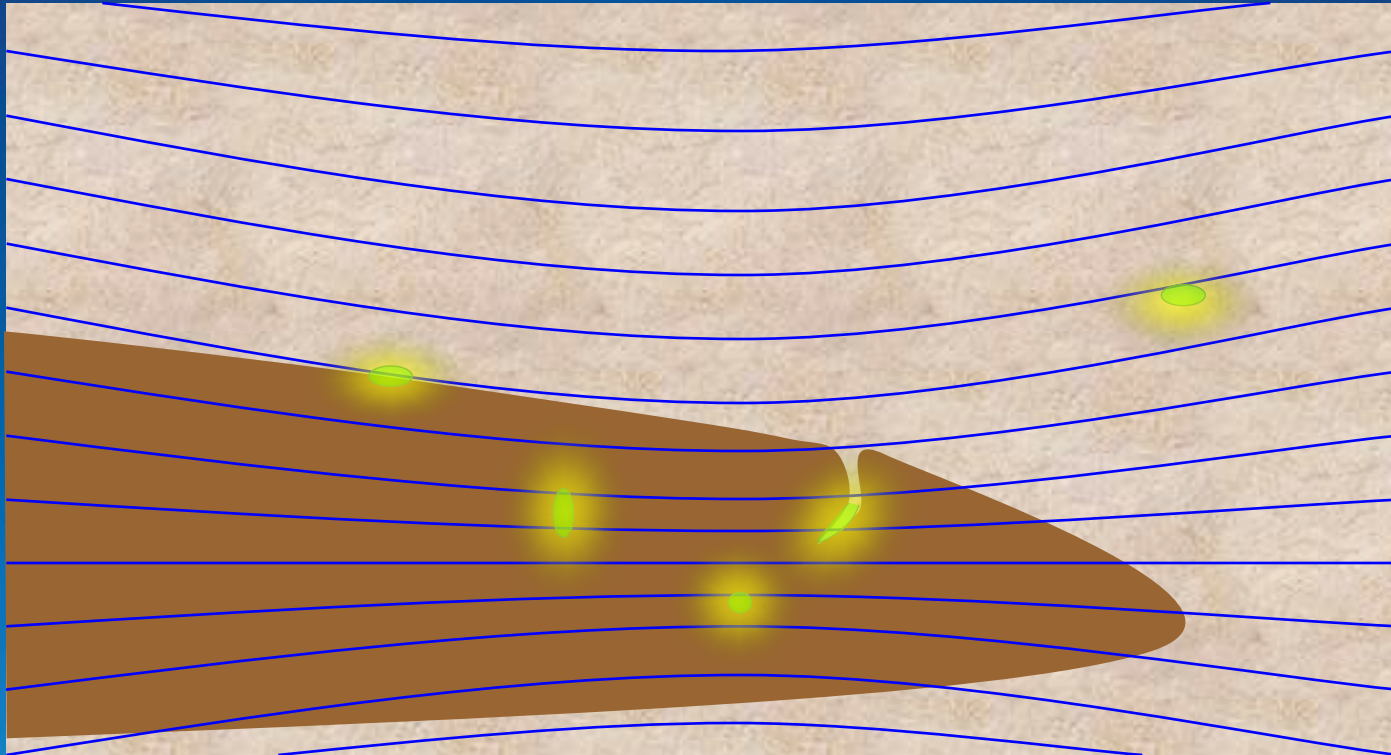
Reductive dehalogenation creates a “halo” of chloride ions in CVOC hot spots

In-Situ Steam Generation during ERH



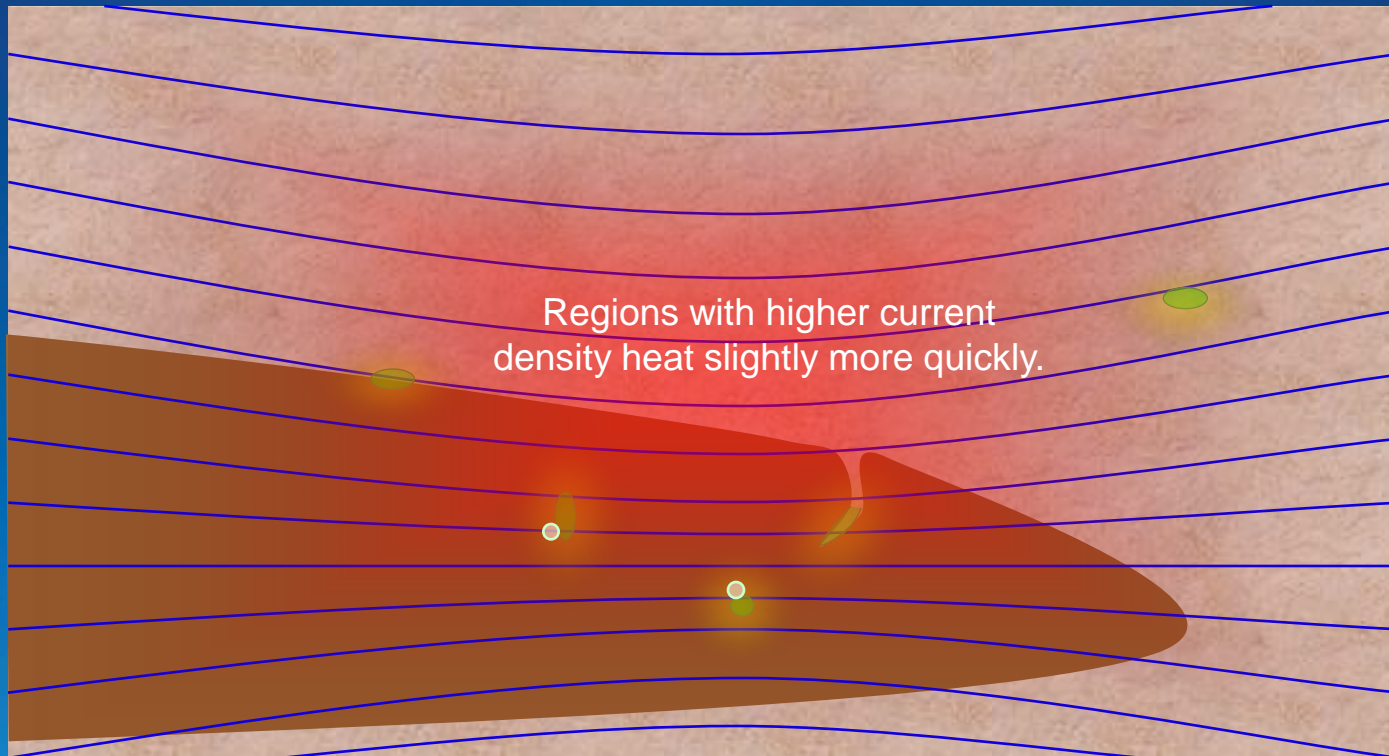
Uniform soils would lead to parallel ERH current lines
– but soils aren't uniform

In-Situ Steam Generation during ERH



Low permeability lenses and CVOC hot spots attract current

In-Situ Steam Generation during ERH



Steam bubbles form more quickly at NAPL due to interfacial tension and reduced boiling temperatures.

Guaranteed ERH Remediation of PCE and Mineral Spirits - Seattle 2013





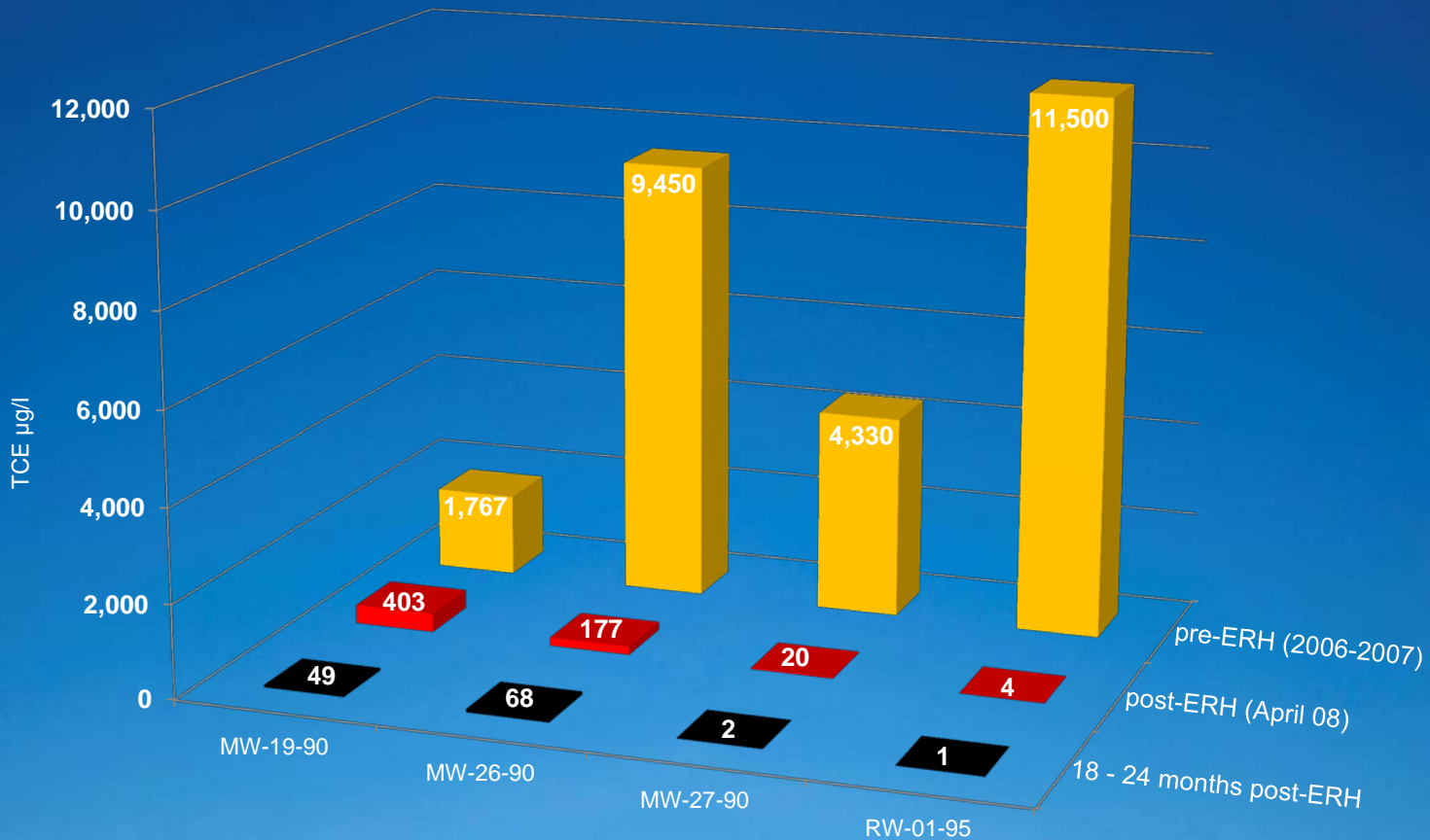
JRSX 20008
CAPY 20560 US GAL
CAPY 17121 IMP GAL
CAPY 77 833 L



Fox Ave, Seattle – Results



Continued Decline in Average TCE Concentrations in Groundwater Two Years Post ERH – Maywood CA

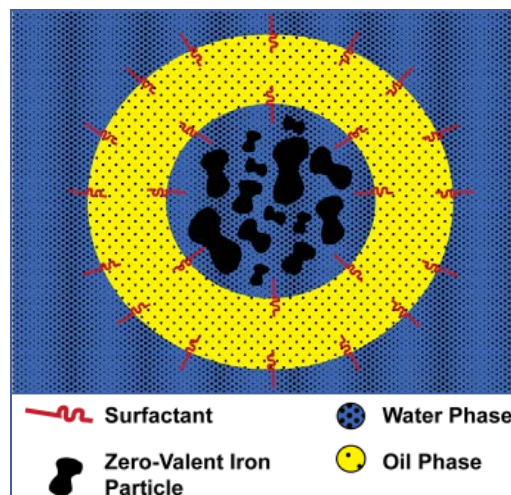
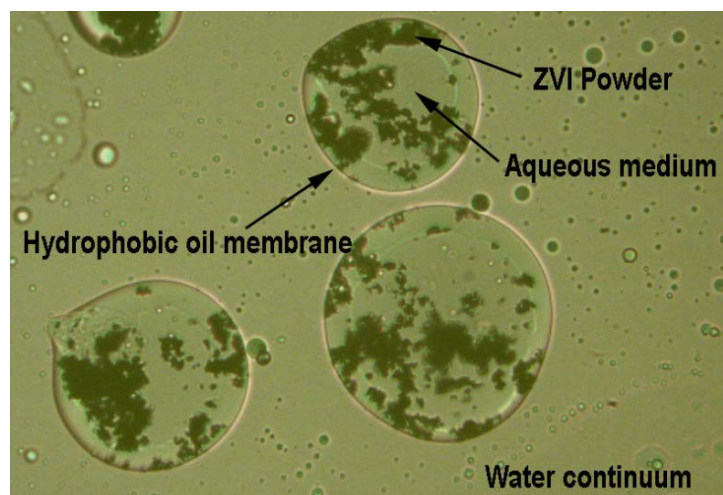


Monitoring Wells and Sample Depth (ft bgs) Inside ERH Treatment Area



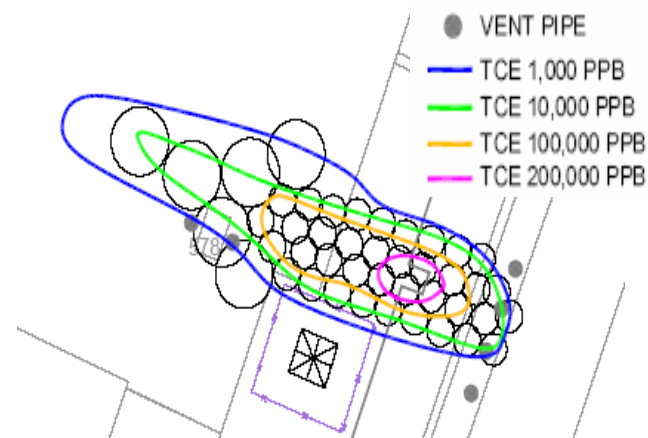
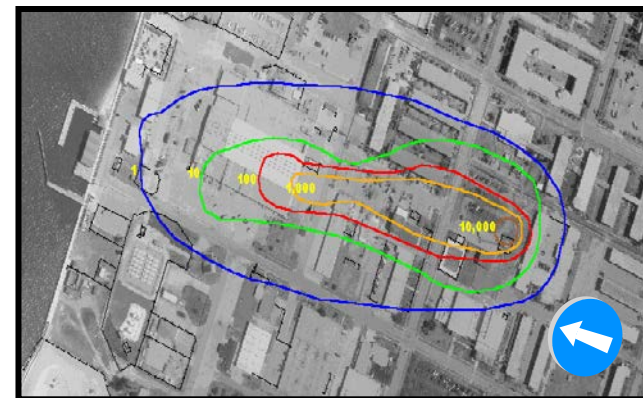
In-situ Chemical Reduction

- **eZVI**
 - Sequestration
 - Dissolution
 - Reductive Dehalogenation (abiotic & biotic)

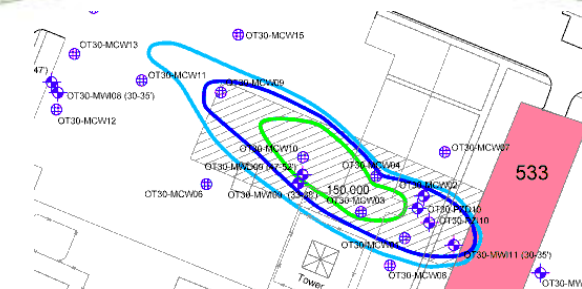


Case Study – Full Scale

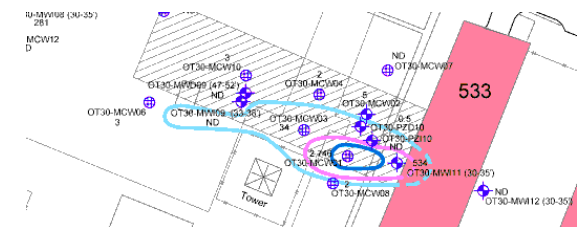
- TCE source area 75 by 150 feet
- 20 acre dissolved plume
- 62,000 gallons of 10% EZVI
- Vegetable oil and KB-1 injected in the down gradient plume areas.



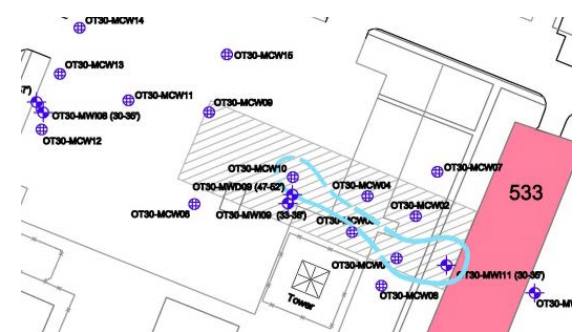
Case Study – Full Scale



Baseline



2.5 yrs Post EZVI Injection



3.5 yrs Post EZVI Injection

• Results

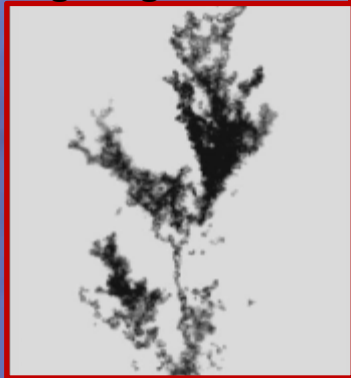
- ~90% destruction of source area TCE within one year
- >99% destruction of source area TCE to date
- Prior to EZVI injection-
- 200 yrs. to attain goals via attenuation
- Post EZVI injection-
- Estimated 30 yrs. to attain goals

Air Sparging

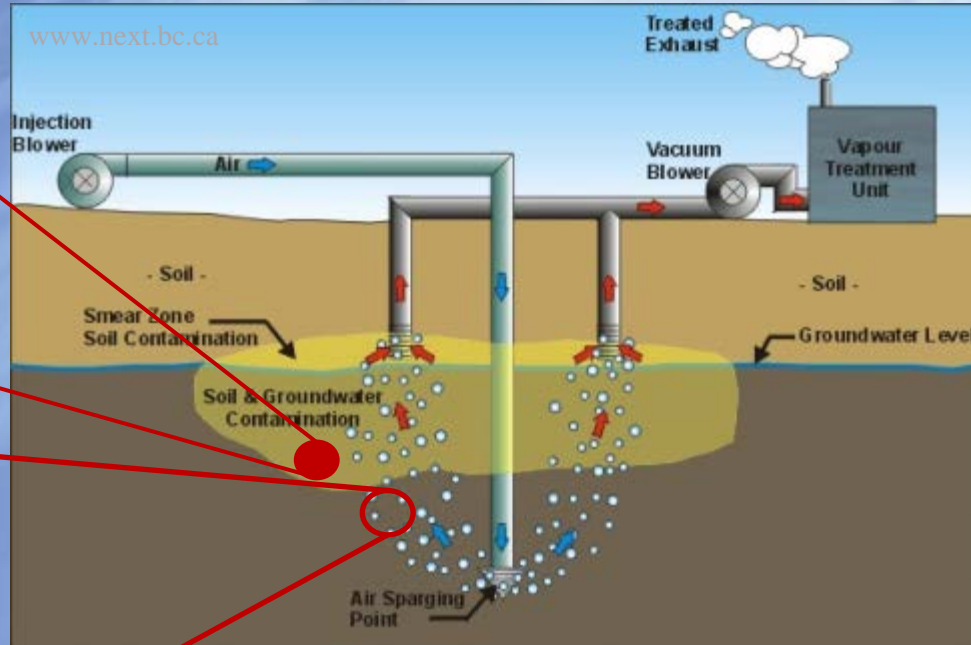
Trapped free-phase LNAPL



Air channeling / fingering



www.next.bc.ca



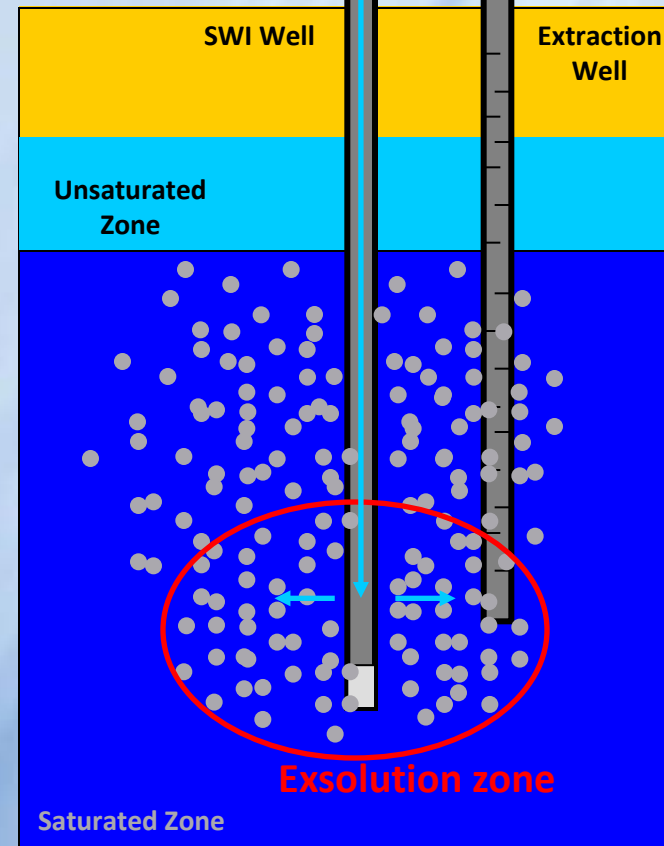
➤ Poor access of injected air to residual NAPL

Slide courtesy of Marios A. Ioannidis

Enhanced Sparging

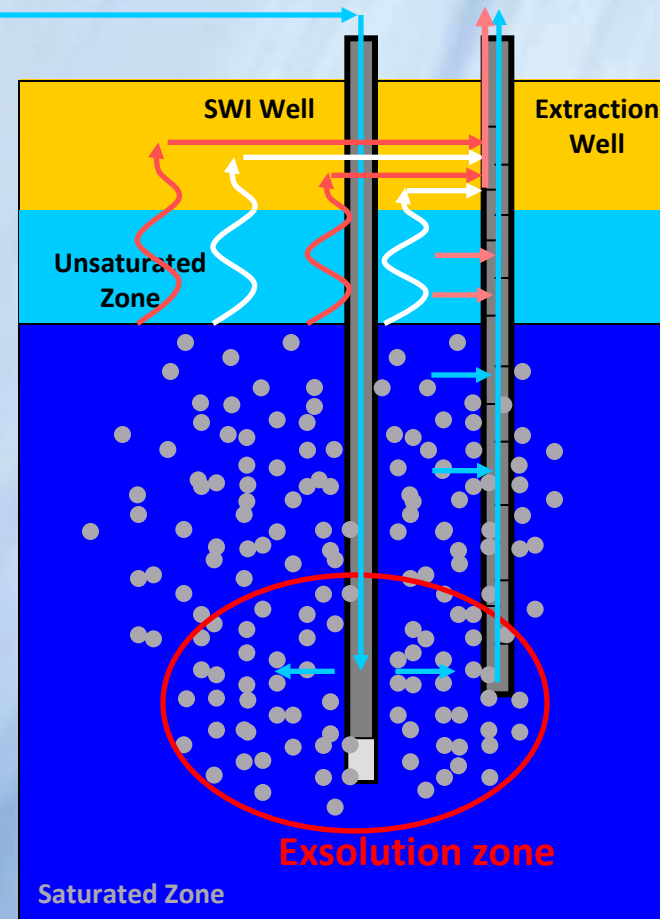


- Water is supersaturated with CO_2
- CO_2 bubbles nucleate in the aquifer



Enhanced Sparging

- Rising CO₂ bubbles
 - Contact hydrocarbons
 - Cause volatilization
- Groundwater and soil vapor are extracted



- Zhao and Ioannidis, *Advances in Water Resources*, vol. 34 (1), 2- 14, 2011
- Enouy et al., *Advances in Water Resources*, vol. 34 (1), 15-25, 2011

Carbon Dioxide Saturated Water Injection Pilot Photos



gPRO gas infusion system

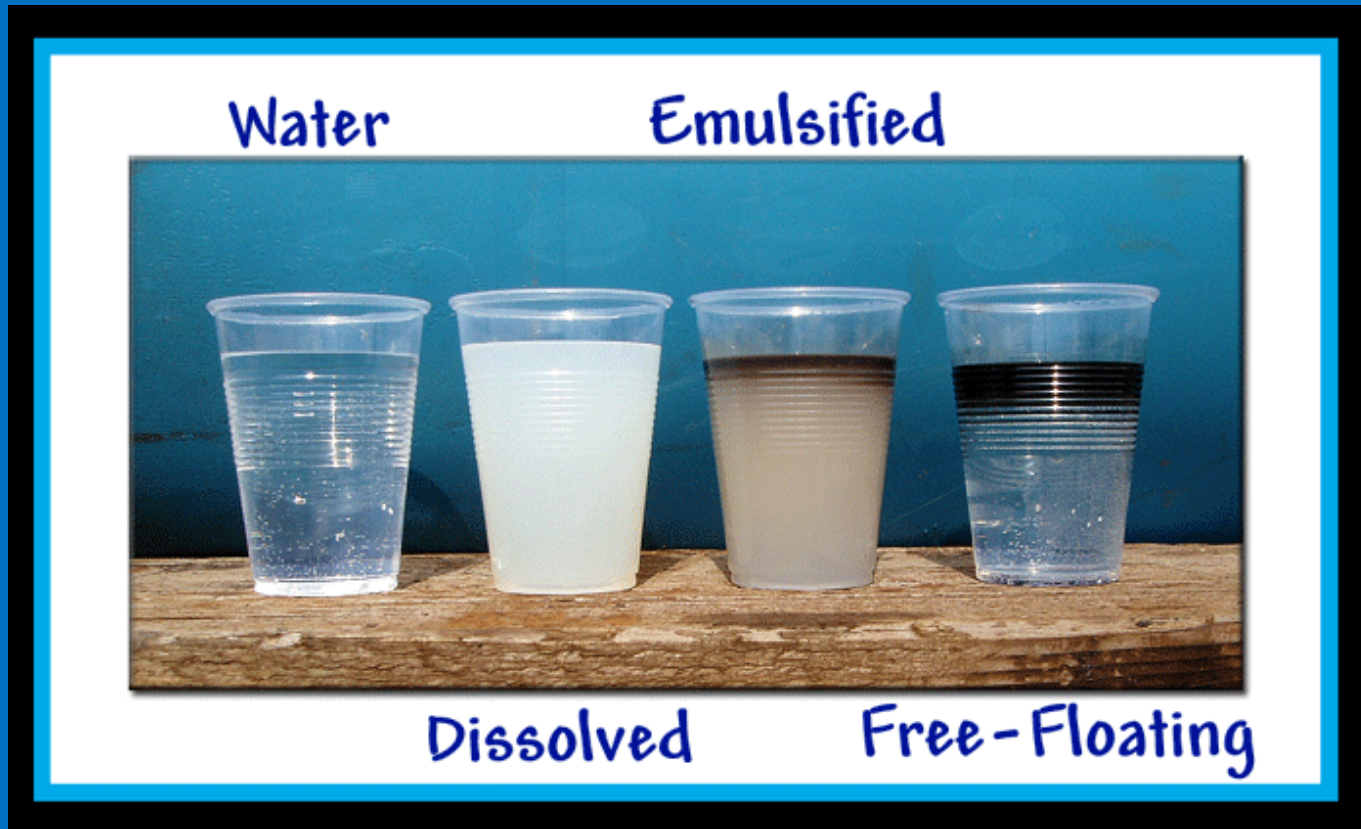


Carbonated
water sample



Injection to RW-1

Surfactants...desorb and dissolve



Some leading developments from British Columbia

Bioremediation

After...or down gradient from

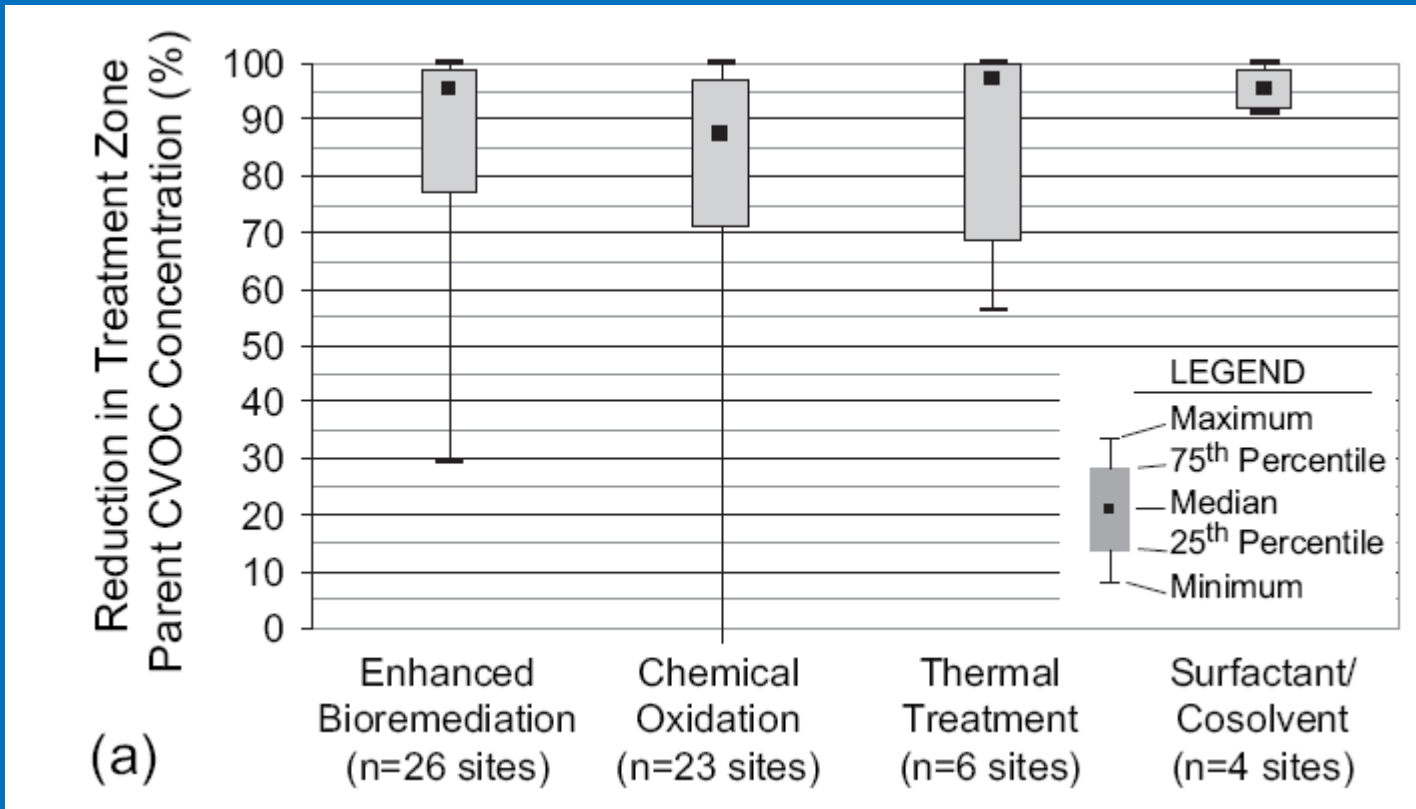
- Chemical oxidation
- Excavation or heat
- Pump and treat

Together with

- Nutrients
- Bioaugmentation
- Cometabolic

Why Bioremediation?

Cost...and less rebound



$\$/\text{yd}^3$

$\$\$\$/\text{yd}^3$

$\$\$\$/\text{yd}^3$

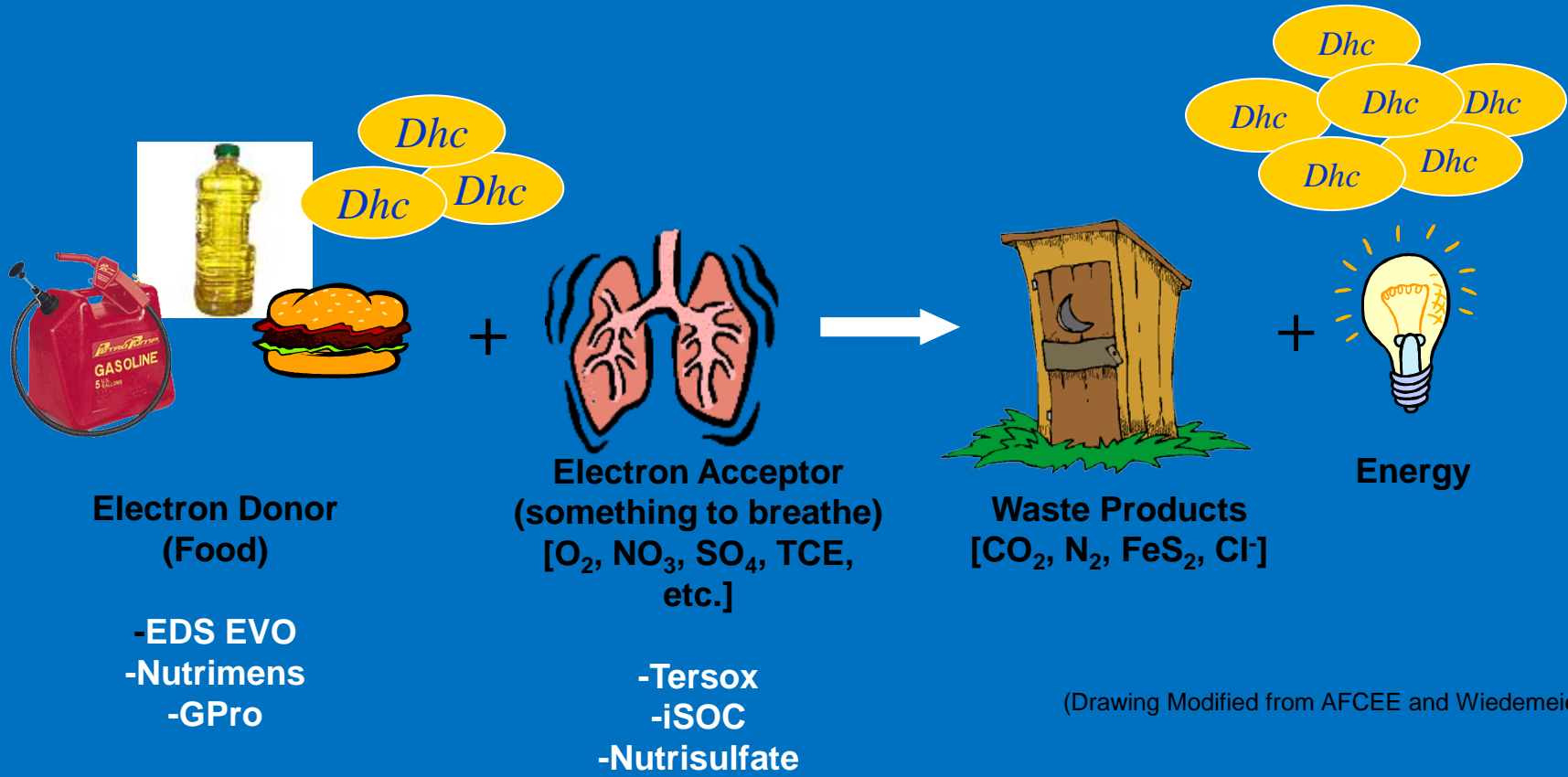
$\$\$\$/\text{yd}^3$

From:

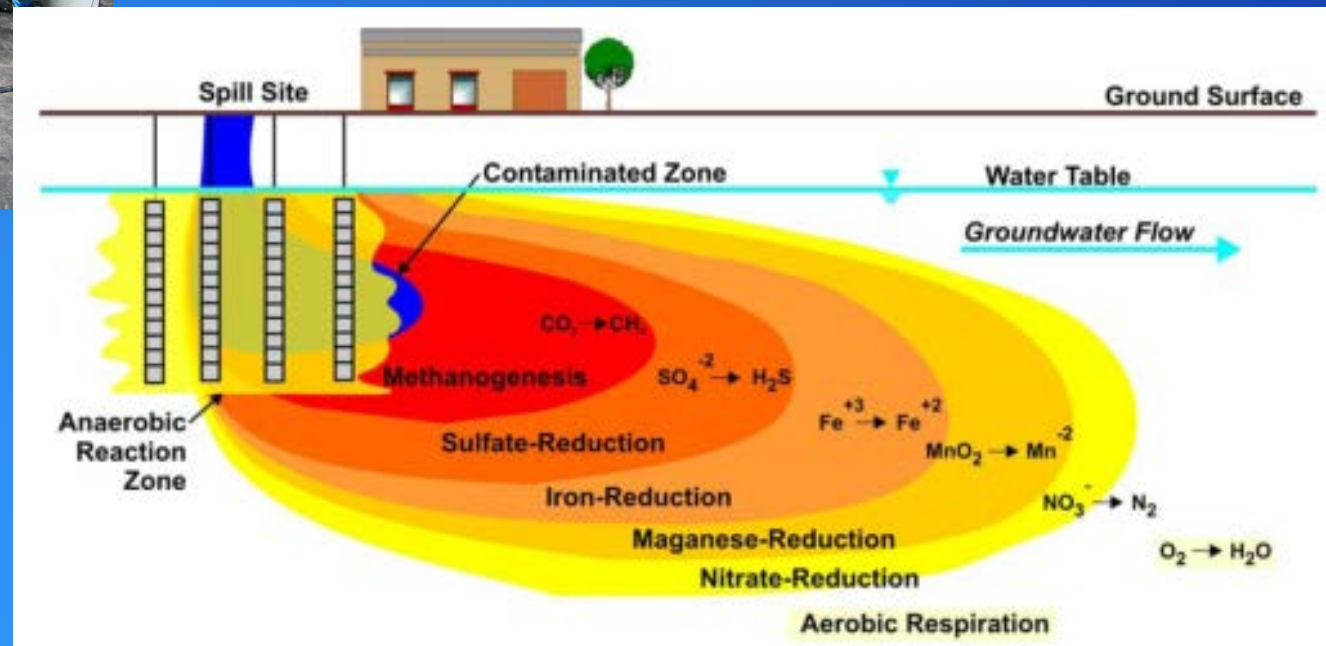
McDade et al, *Remediation Journal* 15, 9-18, 2005.

McGuire et al, *Ground Water Monitoring and Remediation* 26, 73-84, 2006.

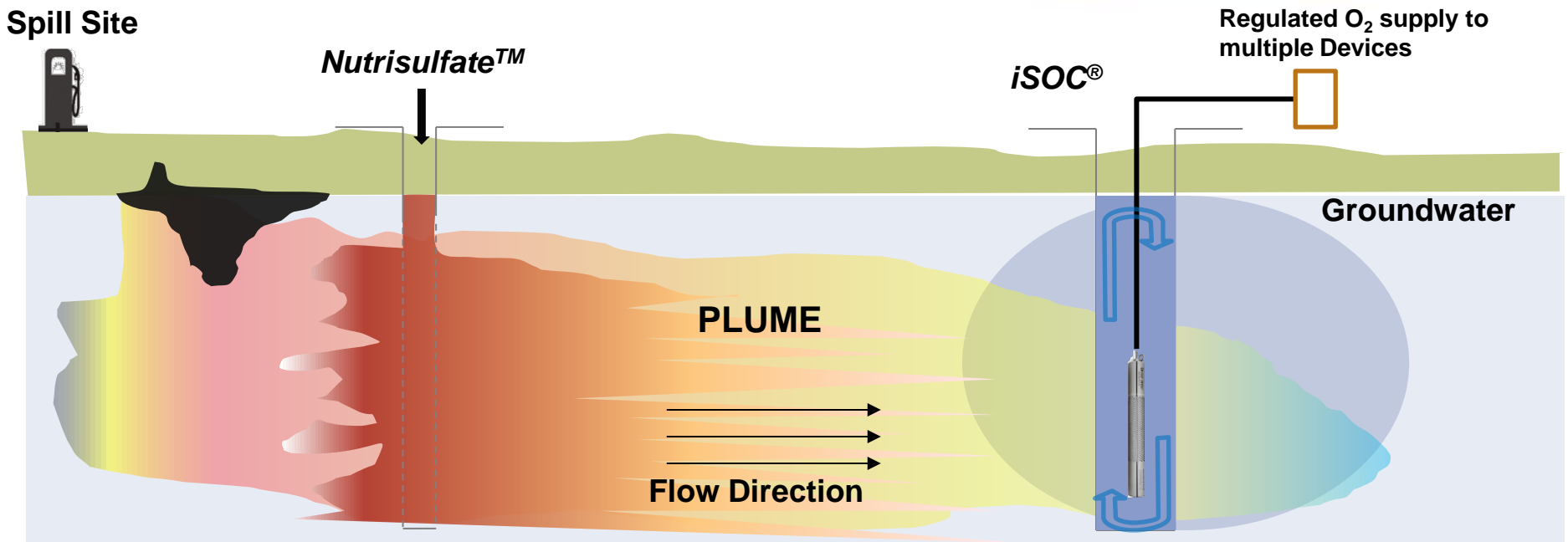
How Does Bio Work?



Injection



Combining Technologies



*Aerobic
Respiration*

Methanogenesis

*Sulfate-
Reduction*

Iron-Reduction

*Manganese-
Reduction*

Nitrate-Reduction

*Aerobic
Respiration*

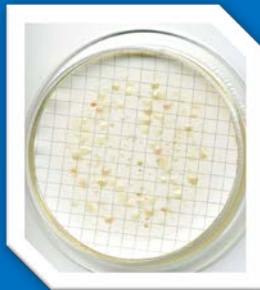
Enhancements...Adding Vitamins and Nutrients

Effect

- Increases activity, abundance, and fecundity of anaerobic heterotrophic bacteria



Control



Sucrose



Nutrimens™

Benefit

- Increasing rates and extents of transfers and transformations of targeted compounds

Enhancements



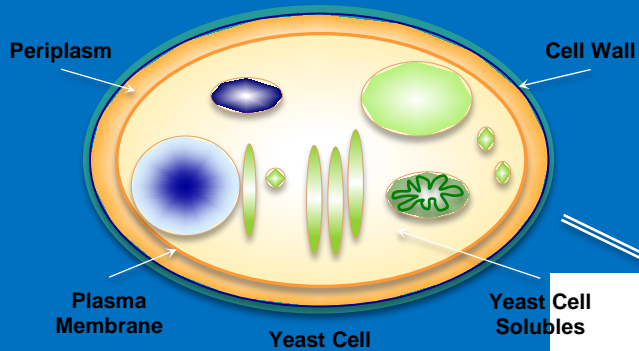
Reuters / Tim



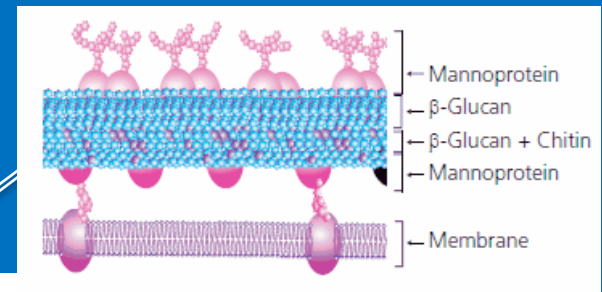
Enhancements--Nutrimens

Key Bioactive Components

Yeast Cell Solubles



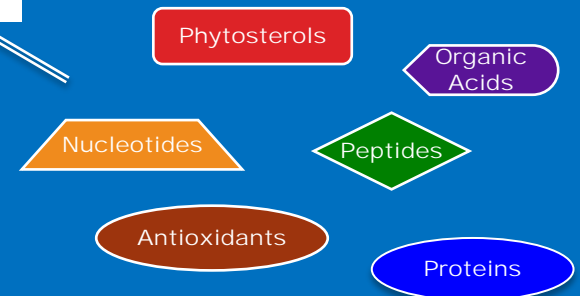
Yeast Cell Wall



Fermentation Media



Extracellular Metabolites



Yeast cell adapted from: http://distillique.co.za/catalog/article_info.php?articles_id=129
Yeast cell wall from: <http://www.sigmaaldrich.com>

Cometabolic Approach

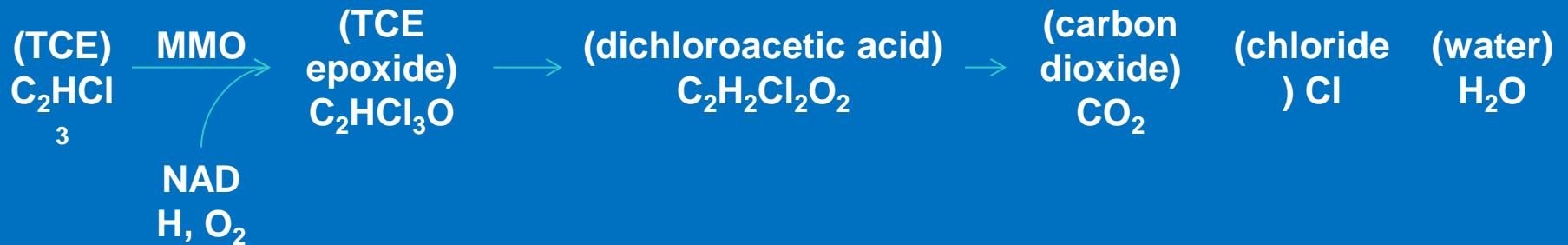
Cometabolism:

simultaneous degradation of two compounds

- Oxygen is used as an electron acceptor.
- Cometabolic growth substrate.
- Nutrients to maximize biomass growth.

Bioremediation Mechanisms

- Aerobic Cometabolism



TRICHLOROETHYLENE (TCE) COMETABOLISM



MONOOXYGENASE ENZYME
(MMO)

Modified from USGS WRI 99-2

True Blue Technologies

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Remediation and Characterization Products and Support



Cometabolic Approach

- Lower CAH
- 1,4-Dioxane
- NDMA

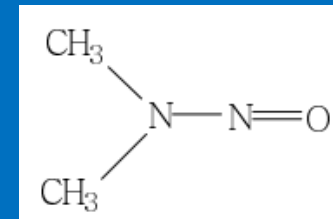
Enzyme	Contaminant
--------	-------------

Propane Monooxygenase	TCE, DCE, VC
-----------------------	--------------

Toluene Dioxygenase	TCE, DCE, VC
---------------------	--------------

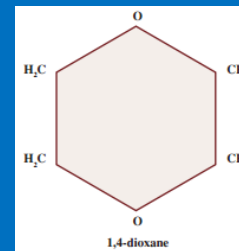
Ring-Hydroxylating Toluene Monooxygenase	TCE, DCE, VC
--	--------------

N-NITROSODIMETHYLAMINE



Rocket Fuel, Chlorination of wastewater w/Nitrogen

1,4-DIOXANE



Found comingled with 1,1,1-TCA

Source: NDMA and Microbiol

True Blue Technologies

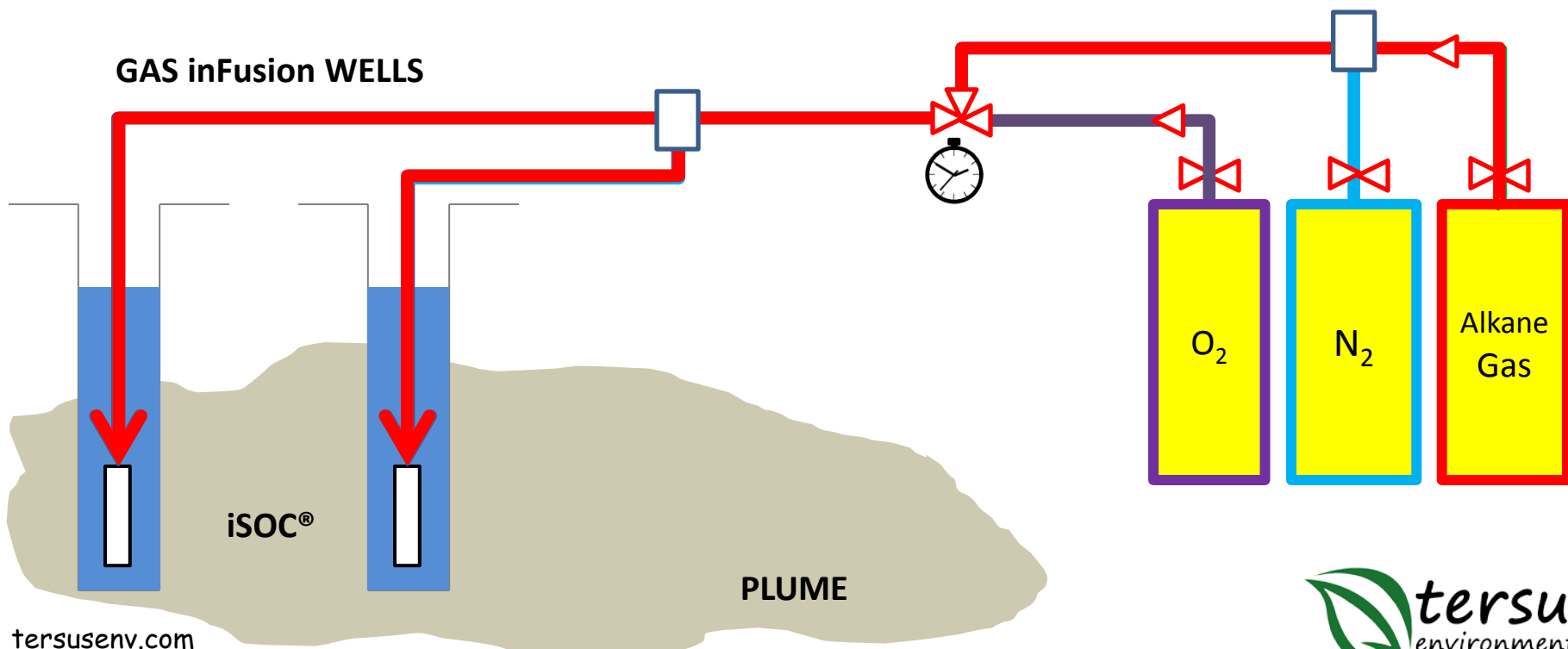
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Remediation and Characterization Products and Support



Design Considerations

- Gas Management System



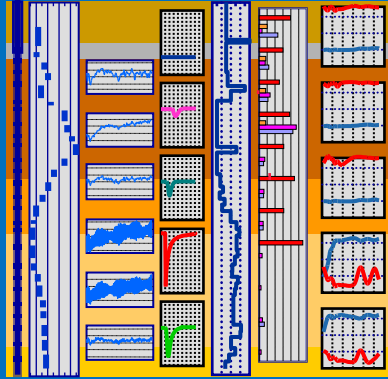
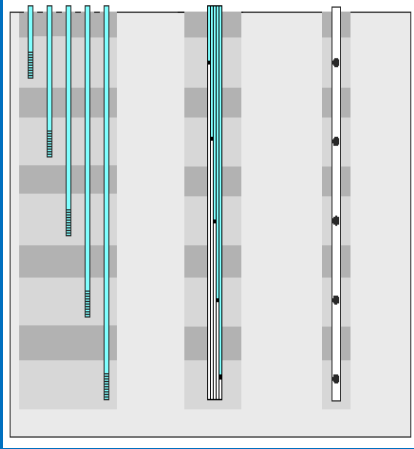
Reduce Pitfalls

- **Ground Water Characterization**
- **Substrate ROI tool**
- **Specific Isotope Analysis**
- **Bio treatability studies**
- **Tools Available to Assess Microbe Populations**

Is It Safe to Jump into Remediation Without Collecting Enough Data?



What are folks using more of now?

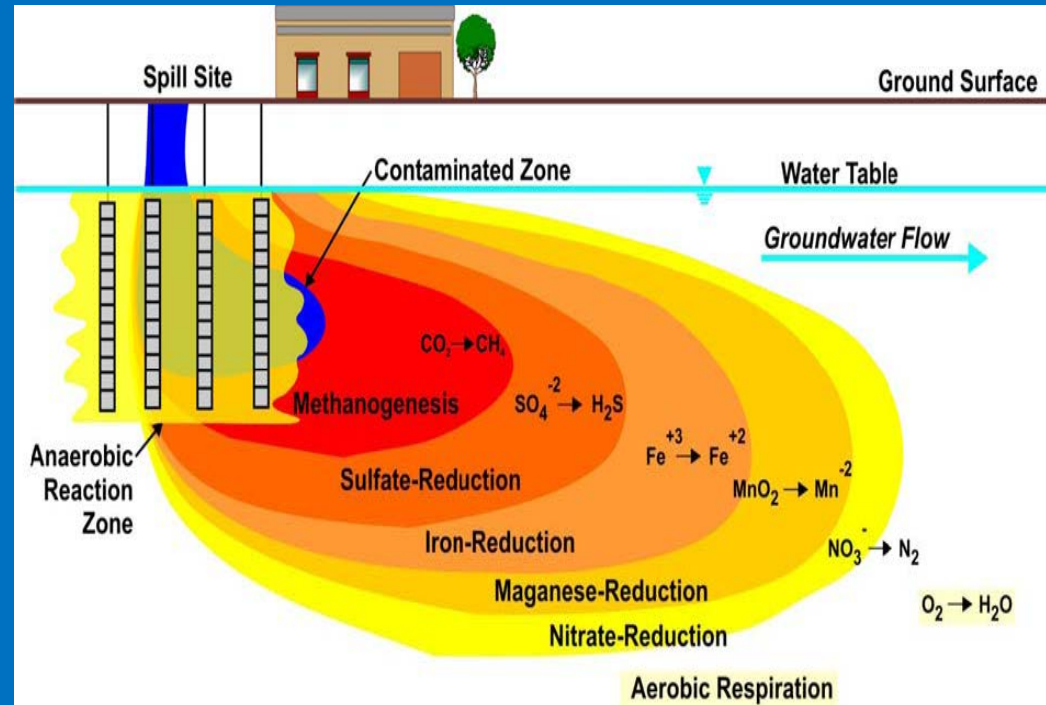


- Multi-level Groundwater Monitoring--*Westbay*
- Geophysics
- Aquifer Tests--*Divers*
- Mass flux

Proper Characterization--What to Monitor

Indicator Parameters

- ORP, pH, TOC
- Electron acceptors (O_2 , NO_3 , SO_4)
- Electron donors (Mn, Fe, CH_4 , TOC)
- Degradation products
- See EPA / AFCEE protocol for MNA



Design Tools Used

Volume Substrate needed

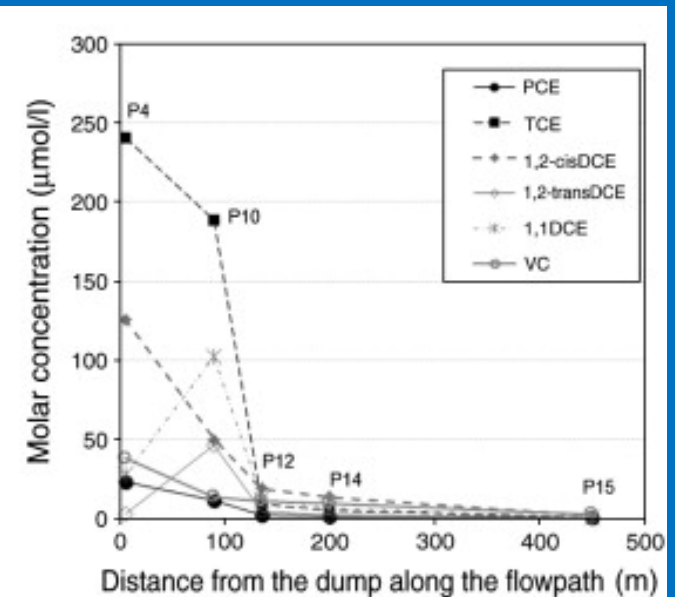
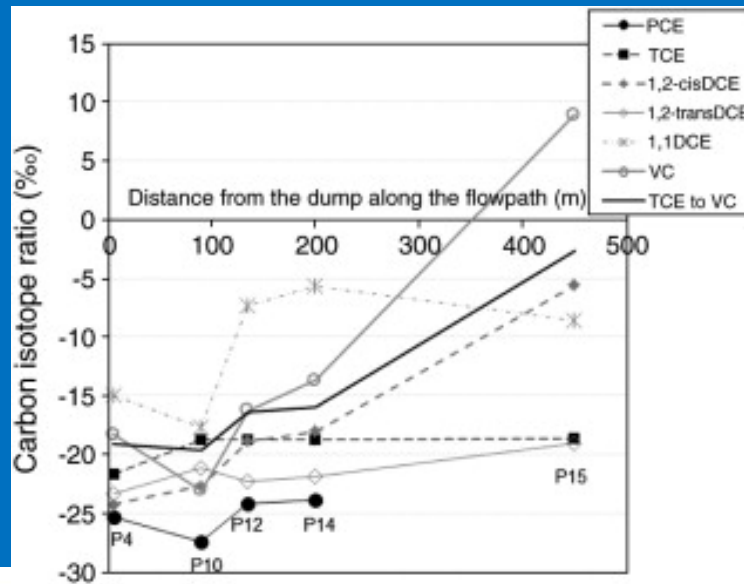
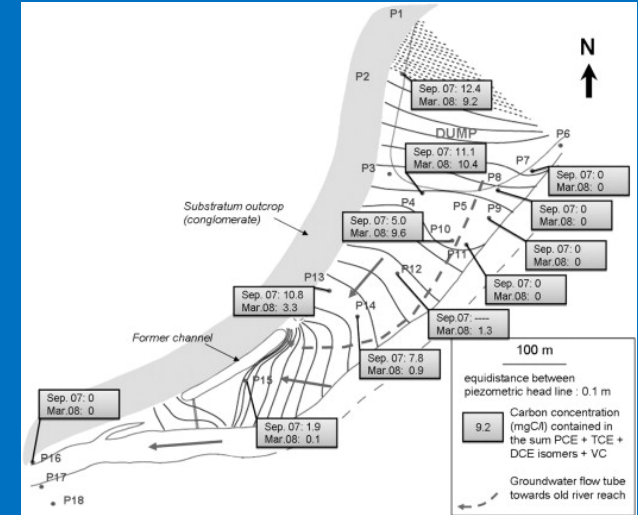
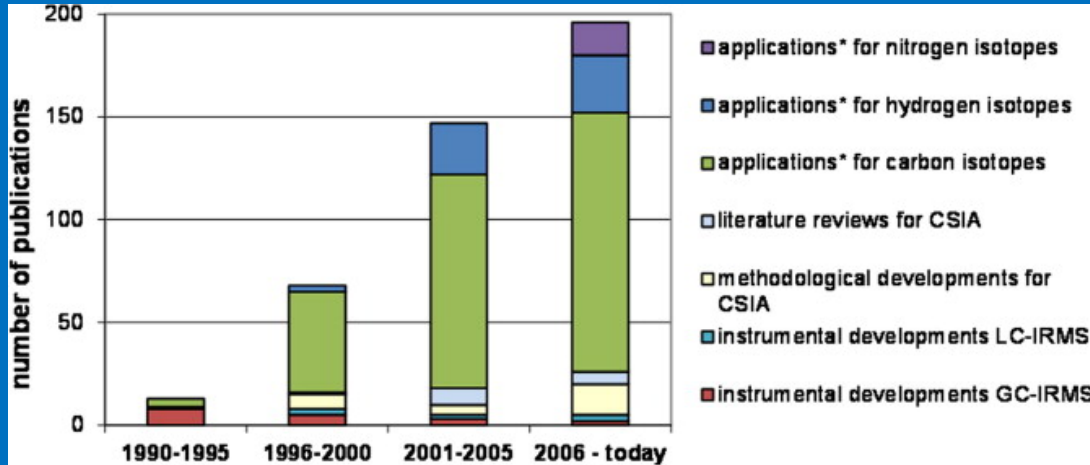
--Mass flux

Retention by aquifer

--Higher in fine grained materials

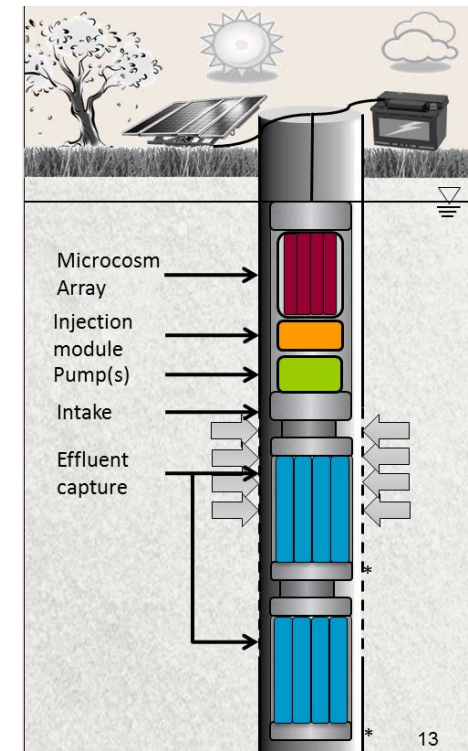
Specific Isotope Analysis

Allocation of plume
Method of degradation



Treatability Testing Options

- Laboratory based batch testing (microcosm studies)
- Laboratory based column flow through testing
- Field based treatability testing – In Situ Microcosm Array (ISMA)

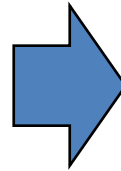


Tools Available to Assess Microbe Populations: Gene-Trac® Testing

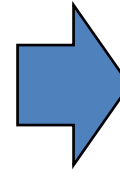
2) Transport from Field to Lab



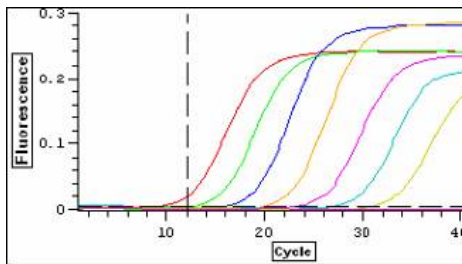
1) Groundwater Sampling



3) Filter water sample



4) Extract DNA from filter
-Quantify total DNA



7) qPCR output used to calculate
gene copies /L groundwater

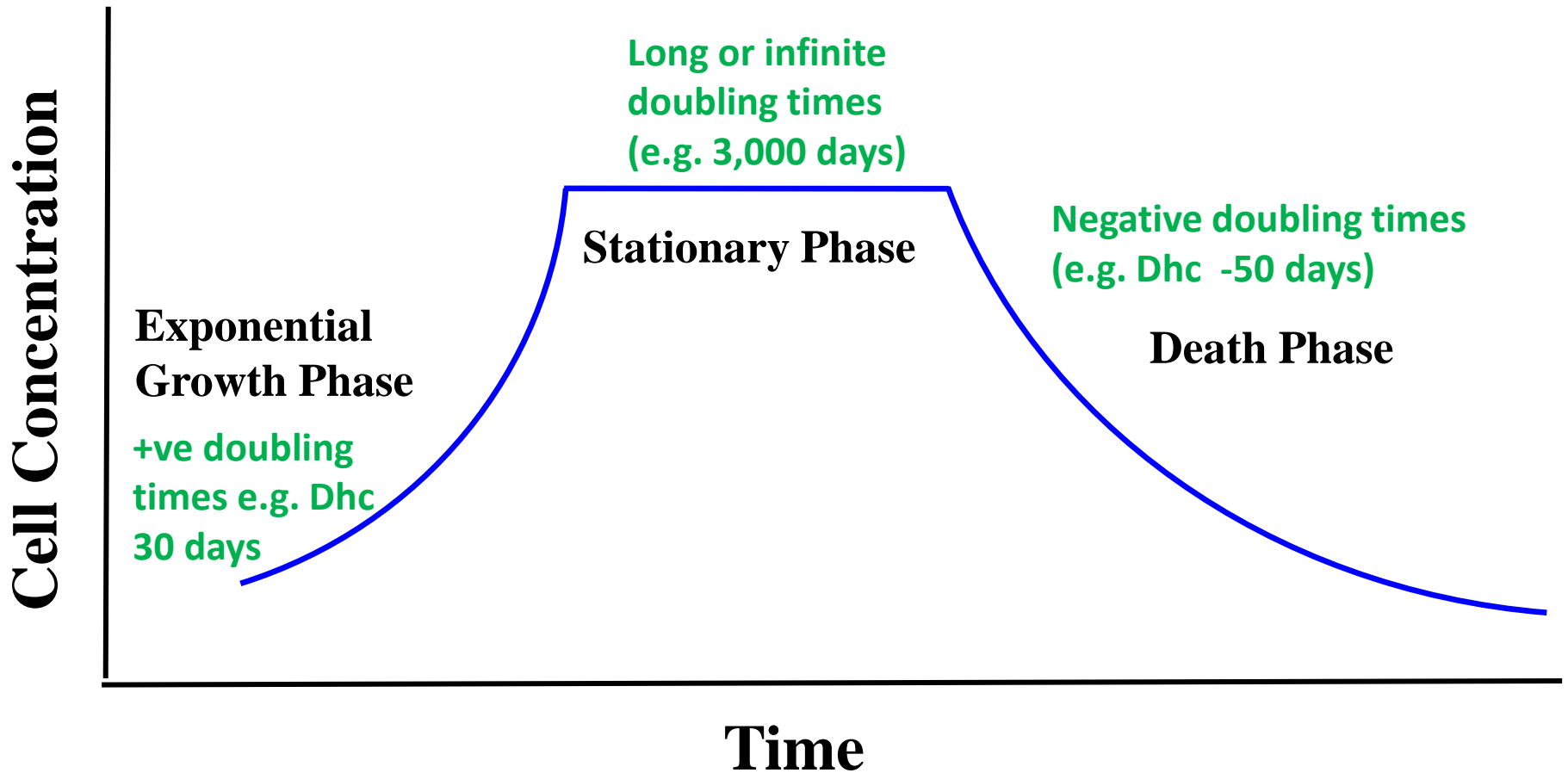


6) PCR amplify specific genes with
targeted primers in qPCR Machine



6) Assemble PCR Reactions

Microbial Growth Curve and Doubling Times



Summary--In-situ Remediation

- **Source zones can be treated in place....quickly and guaranteed.**
- **Dissolved plumes can be treated in place.**
- **Can be very predictable if you reduce the potential pitfalls.**

Thank You!

...By the way, here are True Blue products:

Characterization

- Groundwater data loggers and passive, no-purge samplers
- Multilevel groundwater sampling system

Source Zone Remediation

- In-situ Thermal Remediation
- Emulsified Zerovalent Iron for DNAPL and CO₂ for NAPL

Dissolved Plume Remediation

- Bioremediation products for chlorinated solvents and petroleum hydrocarbons
- Small SVE system

