Advances in Electron Donor Amendments

Short Course: Optimization and Monitoring for Remediation of Chlorinated and Related Compounds

Tuesday, April 28, 2020

How Does Bioremediation Work?

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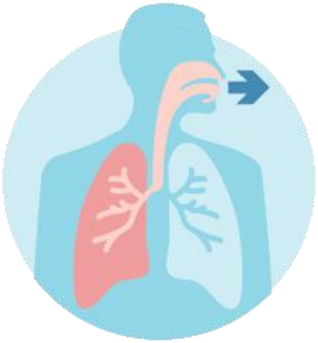

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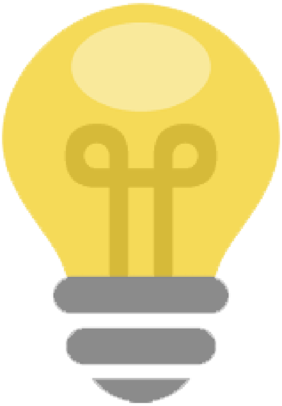


Electron Donor
(Food)

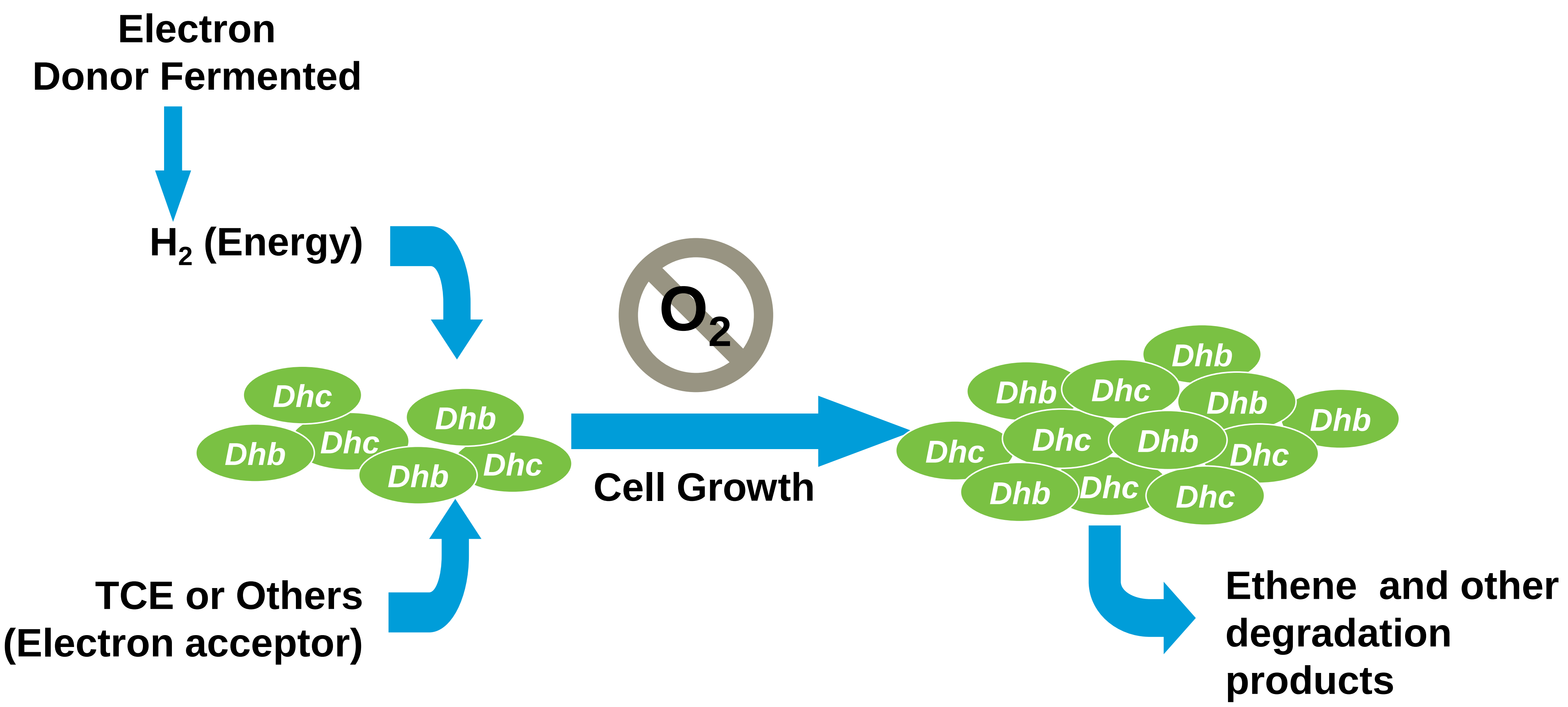
Electron Acceptor
(something to breathe)
[O_2, NO_3, SO_4, TCE, etc.]

Waste Products
[CO_2, N_2, FeS_2, Cl^-]

Energy

(Drawing Modified from AFCEE and Wiedemeier)

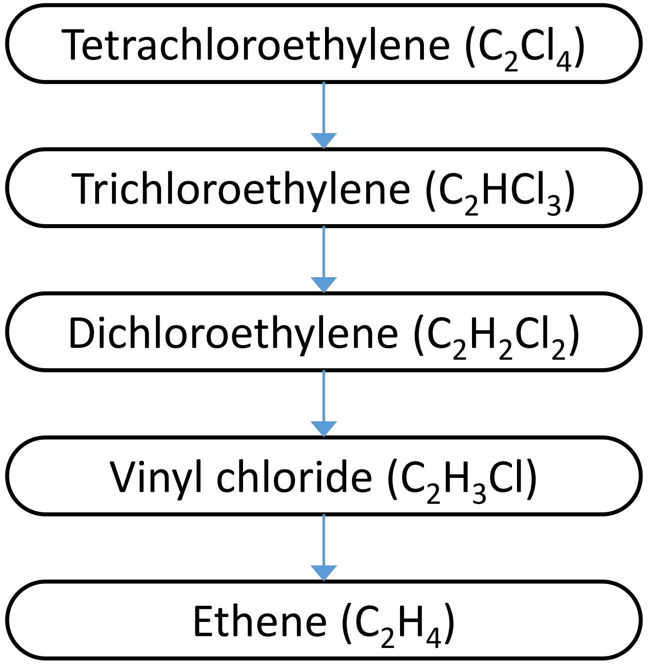
Biological Reductive Dechlorination

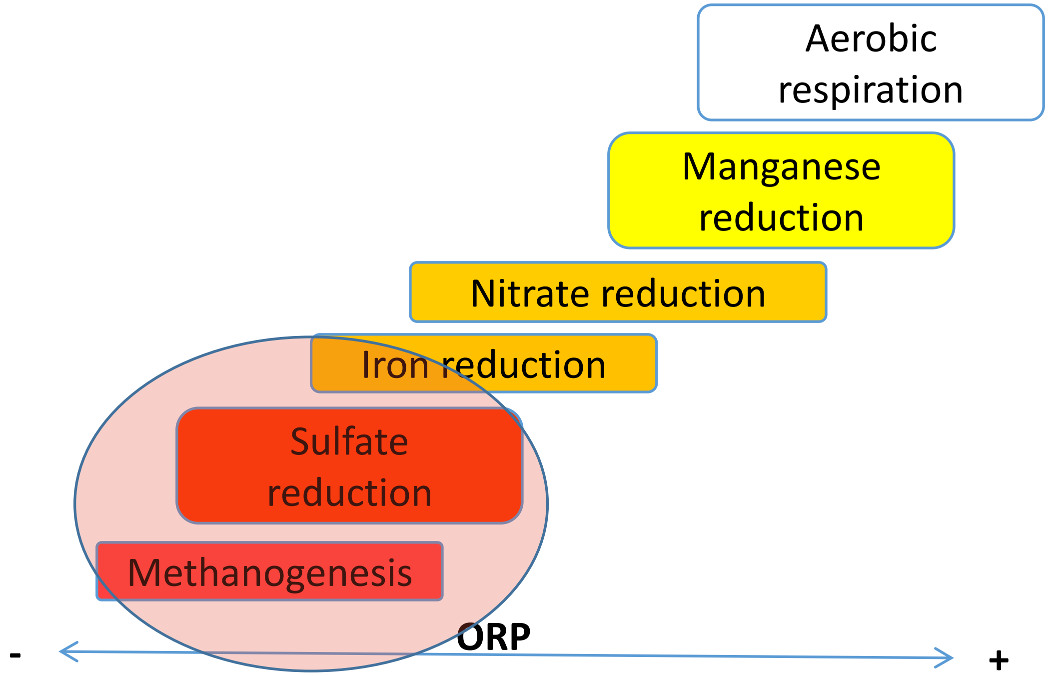


Slide Courtesy of SiREM

Bioremediation Mechanisms

- **Anaerobic Reductive Dechlorination**





Modified from USGS WRI 99-2485

What is Needed for Effective Anaerobic Bioremediation?

- Organic substrates that ferment to:
  - Acetate
  - Hydrogen (H_2)
  - Hydrogen concentrations > 1 nM

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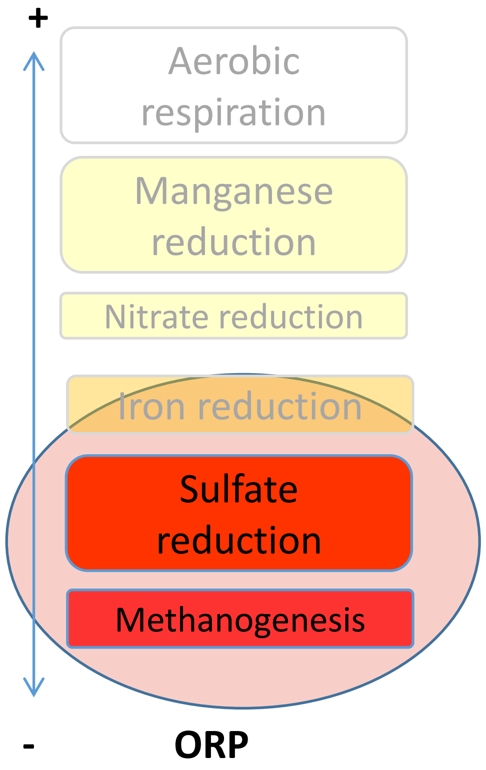

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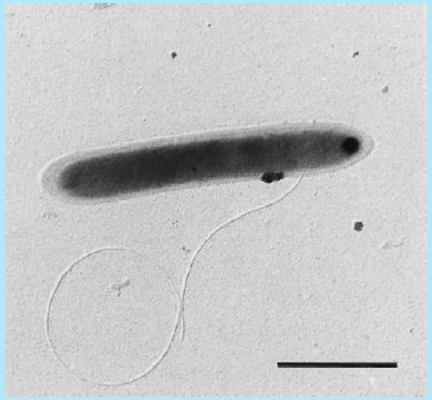
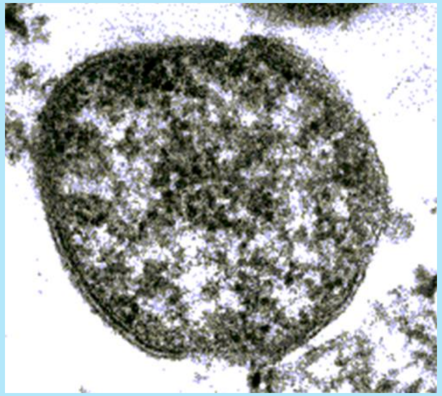
  - *Dehalococcoides* for DCE / VC



Dehalobacter restrictus



Dehalococcoides mccartyi Strain 195

Dhc = *Dehalococcoides*
Dhb = *Dehalobacter*
Other = Desulfitobacterium, sulfurospirillum, Clostridium

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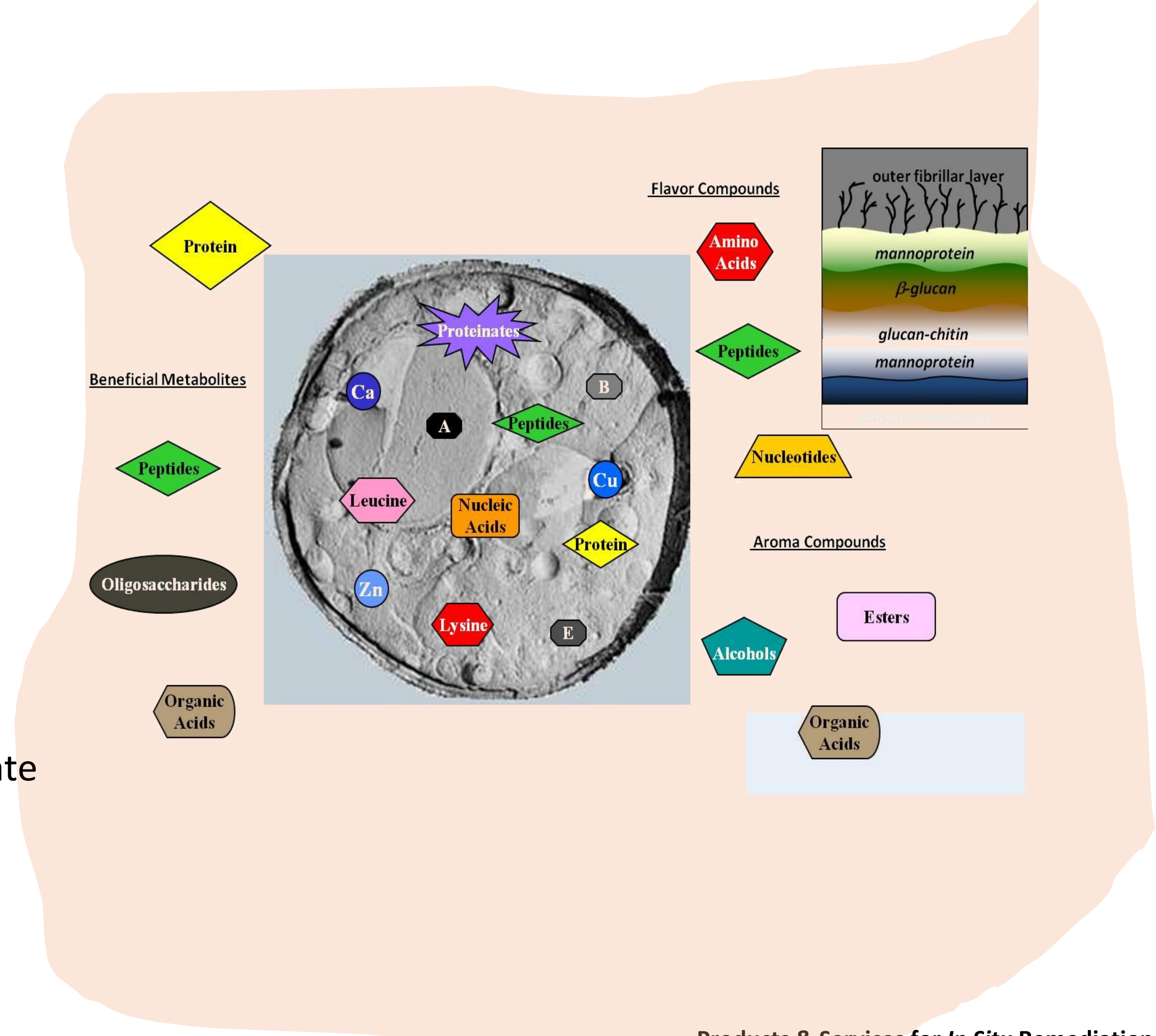
  - *Dehalococcoides* for DCE / VC
- Nutrients
  - Vitamins and trace minerals to stimulate *Dehalococcoides* growth



Nutrimens®

Enhancing Efficiency of Bioremediation

Electron Donors

- Average Composition and Electrons Released during Anaerobic Fermentation

Electron Donor	Atoms per Mole Substrate			Average Molecular Weight	H2 Released per mole Substrate	Moles H2 released per gram substrate
	Carbon	Hydrogen	Oxygen			
Acetate	2	4	2	60.1	4	0.0666
Lactate	3	6	3	90.1	6	0.0666
Glucose	6	12	6	180.2	12	0.0666
Soybean Oil	56.3	99.5	6	873.1	156.5	0.1792

ESTCP, May 2006

Anaerobic Fermentation

- **Soybean oil ferments to acetic acid and hydrogen**

$C_{56}H_{100}O_6$ *(soybean oil[1])* + 50 H_2O -*<u>B</u>*->

-*<u>B</u>*-> 28 CH_3COOH *(acetic acid)* + 44 H_2

[1]Represents weighted average of constituent fatty acids and glycerol.

Soybean Fatty Acid Distribution

$$H_2C - O - \overset{\overset{O}{\parallel}}{C} - Ri$$

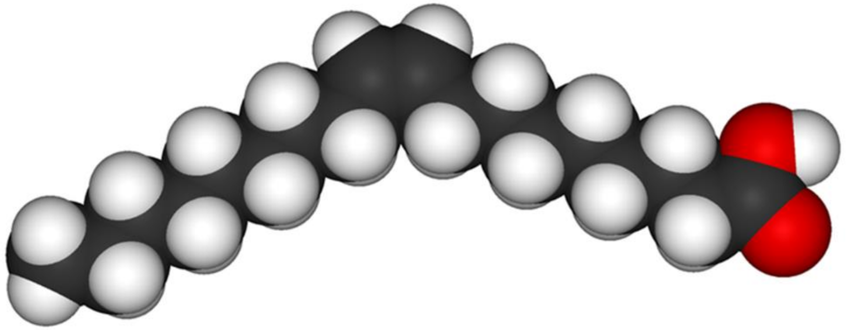
$$|$$

$$H_2C - O - \overset{\overset{O}{\parallel}}{C} - Ri$$

$$|$$

$$H_2C - O - \overset{\overset{O}{\parallel}}{C} - Ri$$

Fatty Acid		Percent
C-16:0	Palmitic	11.0 %
C-18:0	Stearic	4.0 %
C-18:1	Oleic	24.0 %
C-18:2	Linoleic	54.0 %
C-18:3	Linolenic	7.0 %



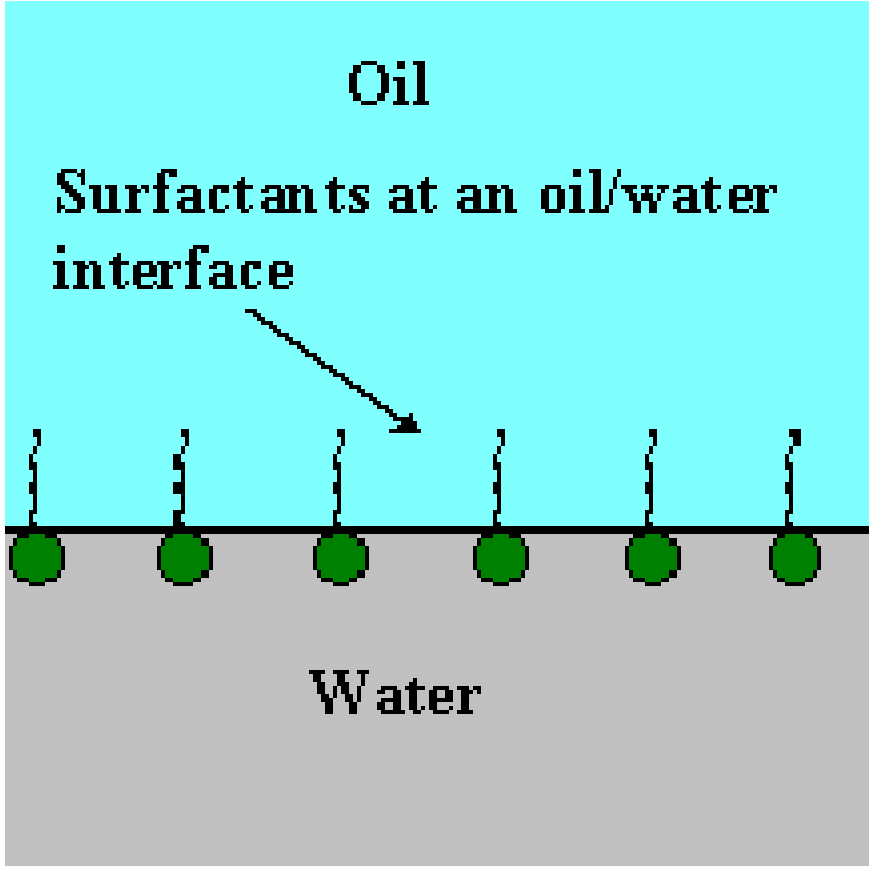
Why choose an EVO?

- **Easily dispersed with groundwater**
  (Oil-in-water emulsions are miscible with water)
- **Low permeability loss**
- **Easy to implement**
- **Non-Toxic food-grade substance**
- **Limited chlorinated solvent sequestration**

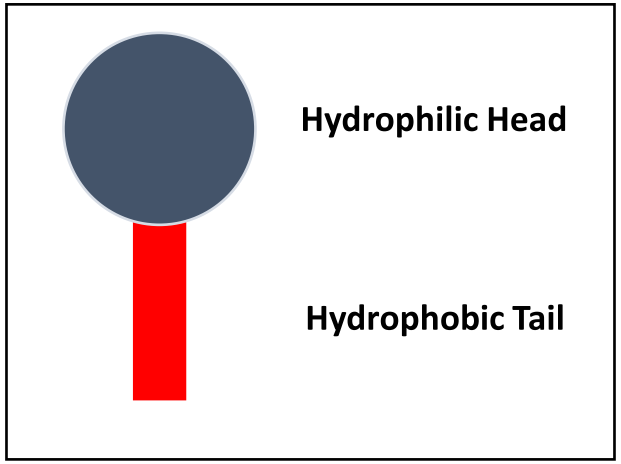
Oil in water emulsion, EDS-ER™

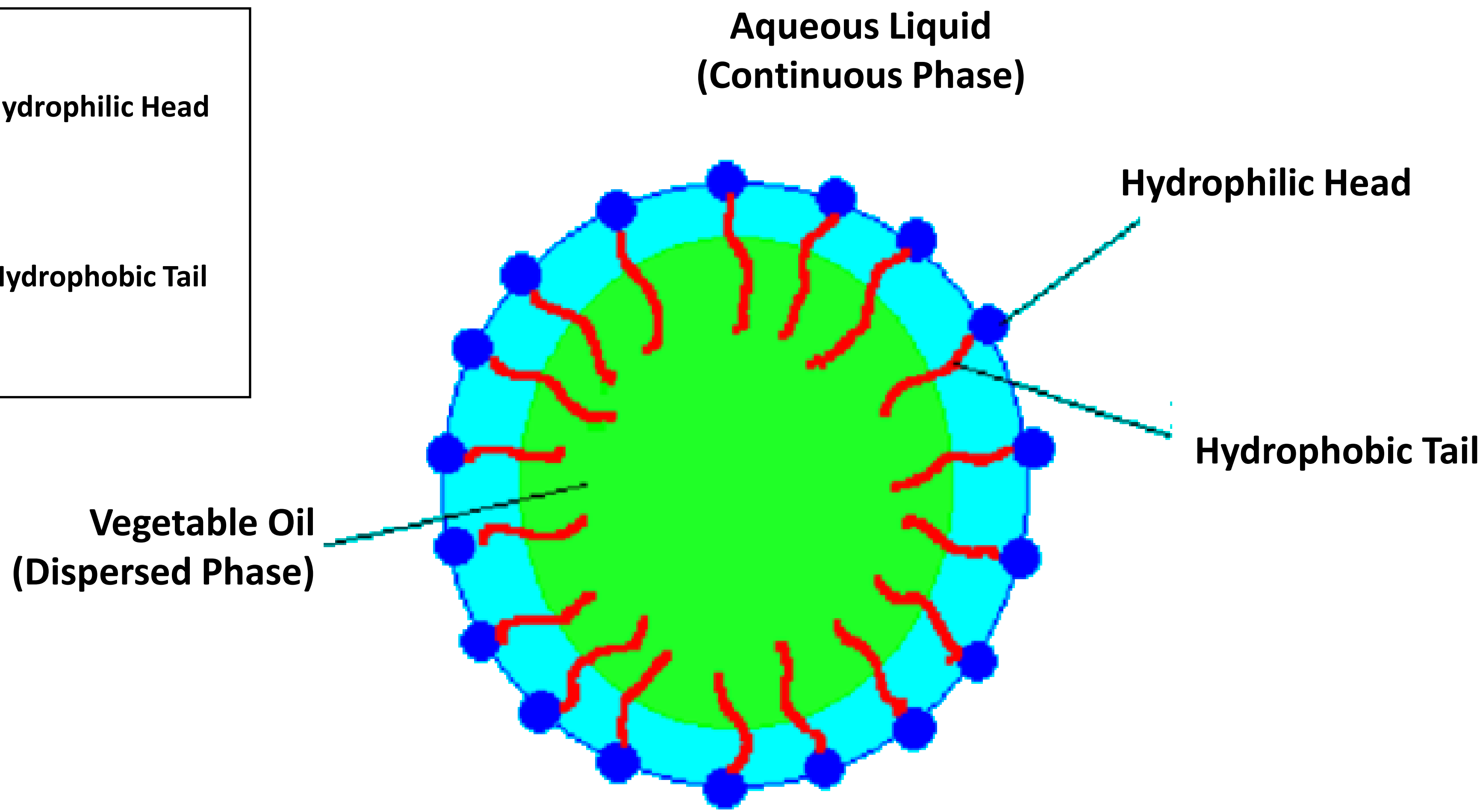
What is a surfactant?

- Molecule fits between oil and water
- Common and safe
- Found in
  - Salad dressing
  - Toothpaste
  - Mouthwash
  - Shampoo
- Must contact NAPL to work



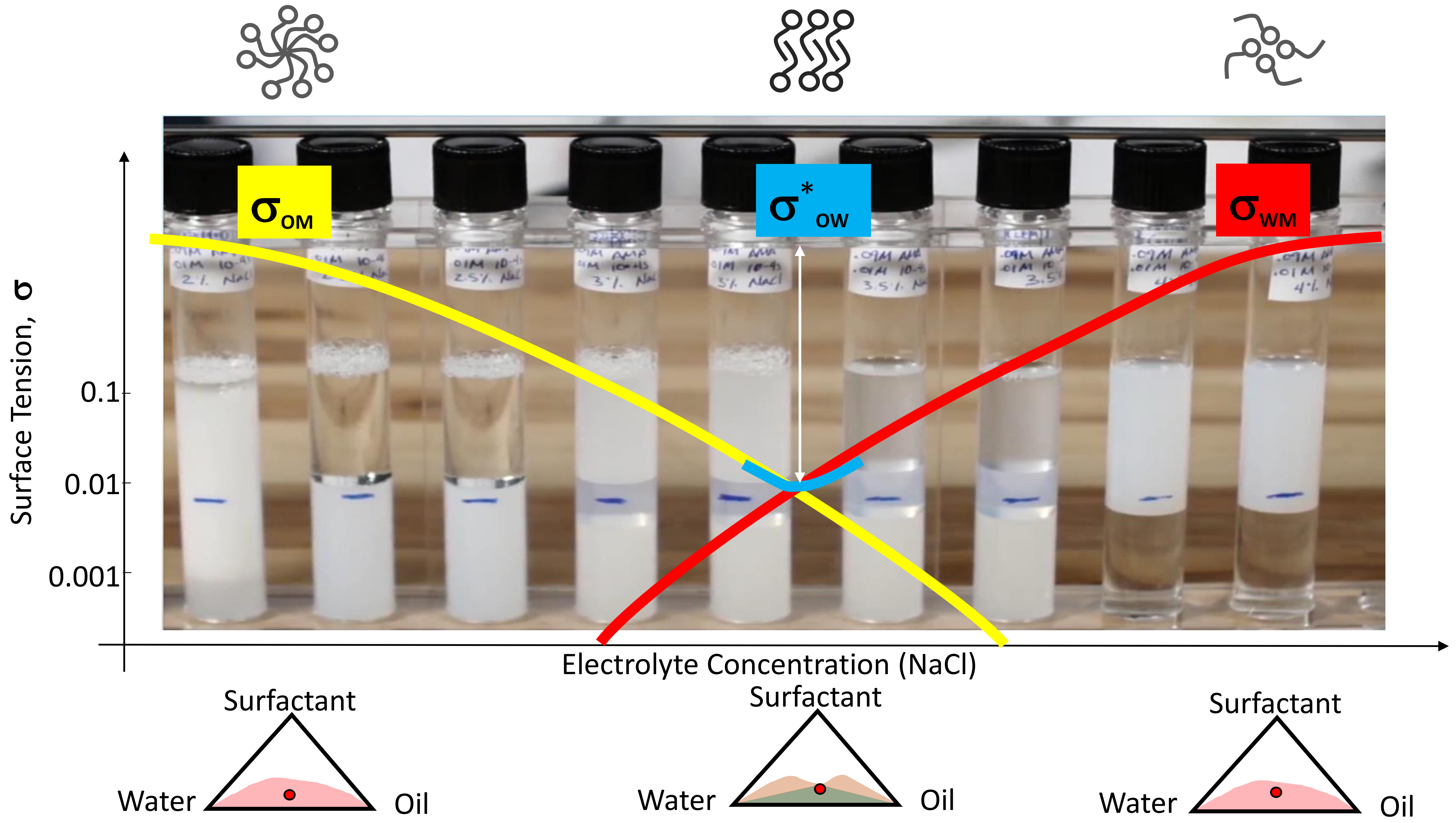
Emulsifying Agents





High Energy Shear Mixing

Surfactant-Oil-Water Systems Phase Behavior



Products & Services for *In Situ* Remediation • tersusenv.com

EDS-ER™

Electron Donor Solution – Extended Release

Water soluble vegetable oil

USDA CERTIFIED BIOBASED PRODUCT
PRODUCT 99%
FP

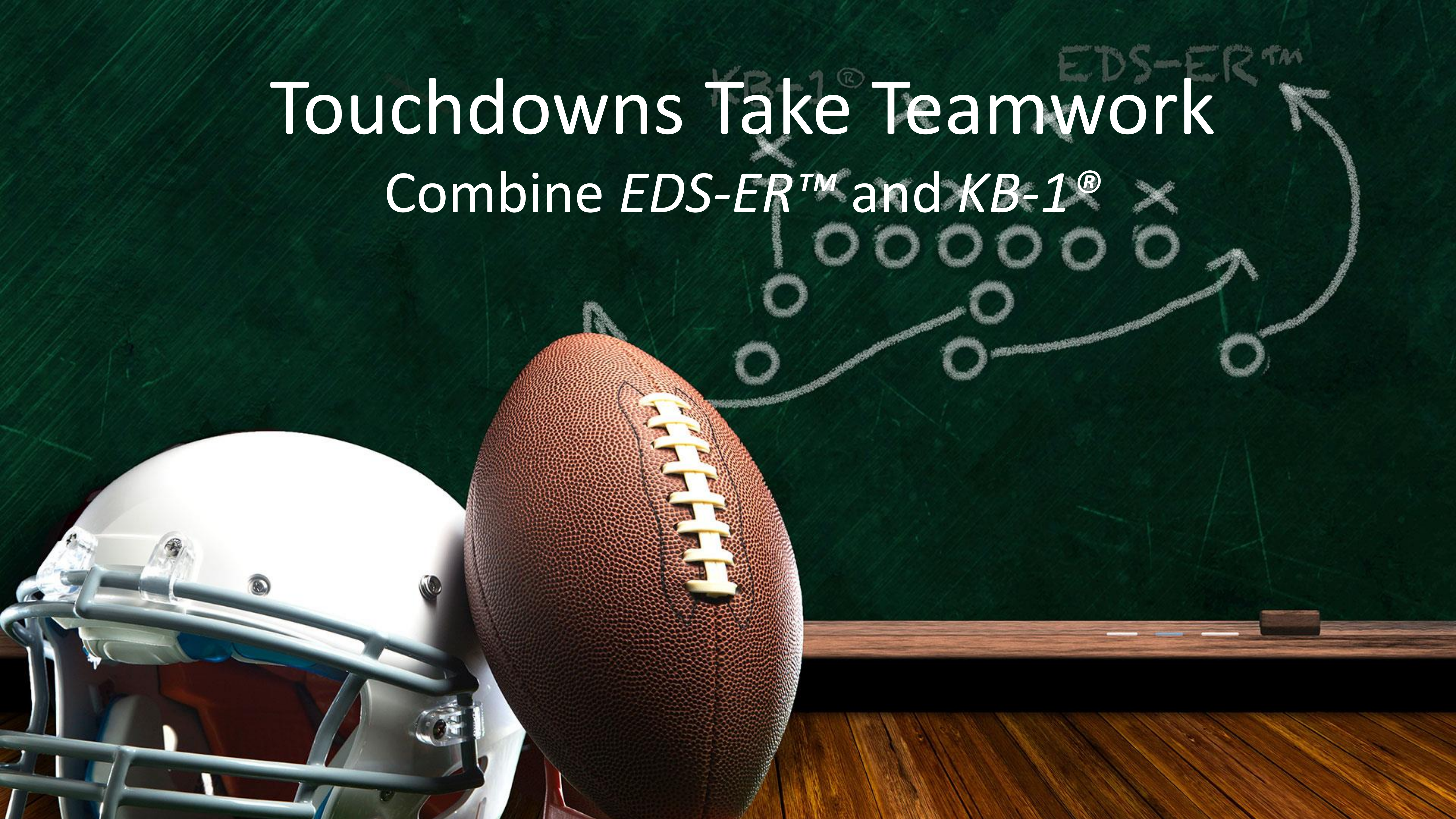
“Greening” the cleanup

- **EDS-ER™:**
  - ✓ Eliminates Mechanical Energy inputs
  - ✓ Allows Bulk Storage (long shelf life) and intermodal transportation
  - ✓ Reduces need for excess drums and totes

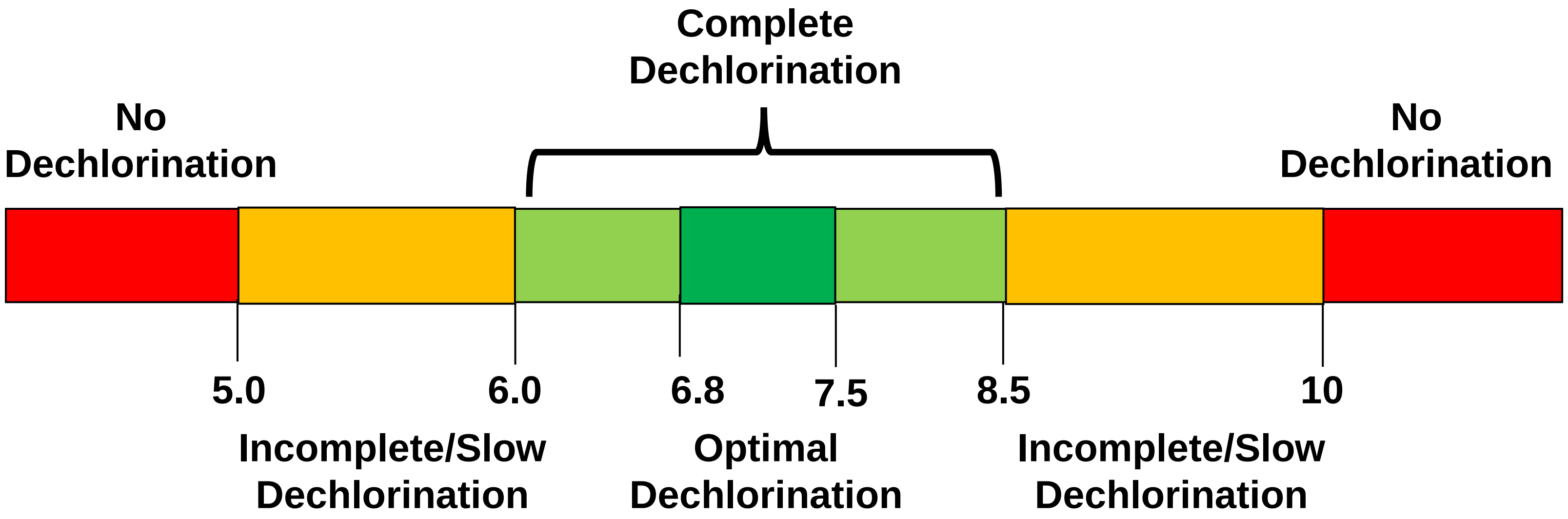
- TASK™ MicroEVO Self-Emulsifier
  - ✓ Easy Field Mixing
  - ✓ Source Local Soybean Oil
  - ✓ Reduced Carbon Footprint

Touchdowns Take Teamwork

Combine *EDS-ER™* and *KB-1®*



Impact of pH on Dechlorination

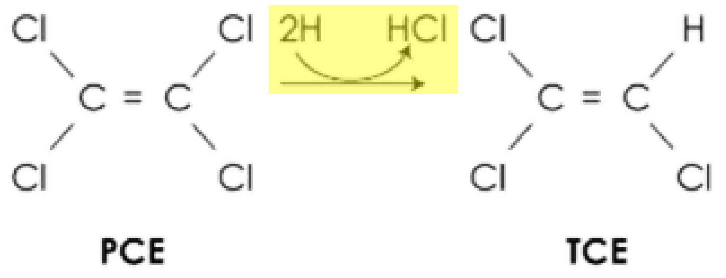


- pH of 6.0-8.5 is generally required for dechlorination to ethene*
- pH 6.8-7.5 is considered optimal range, 7.5 is best*
- Sites with low pH more likely to accumulate cDCE/VC

*Rowlands, 2004 (Slide Courtesy of SiREM)

Why is low pH so Common?

- Some sites have intrinsic groundwater pH in the 5.0-6.0 range
- Reductive dechlorination produces hydrochloric acid



- Fermentation of **many** electron donors produces acidic by products such as acetic acid

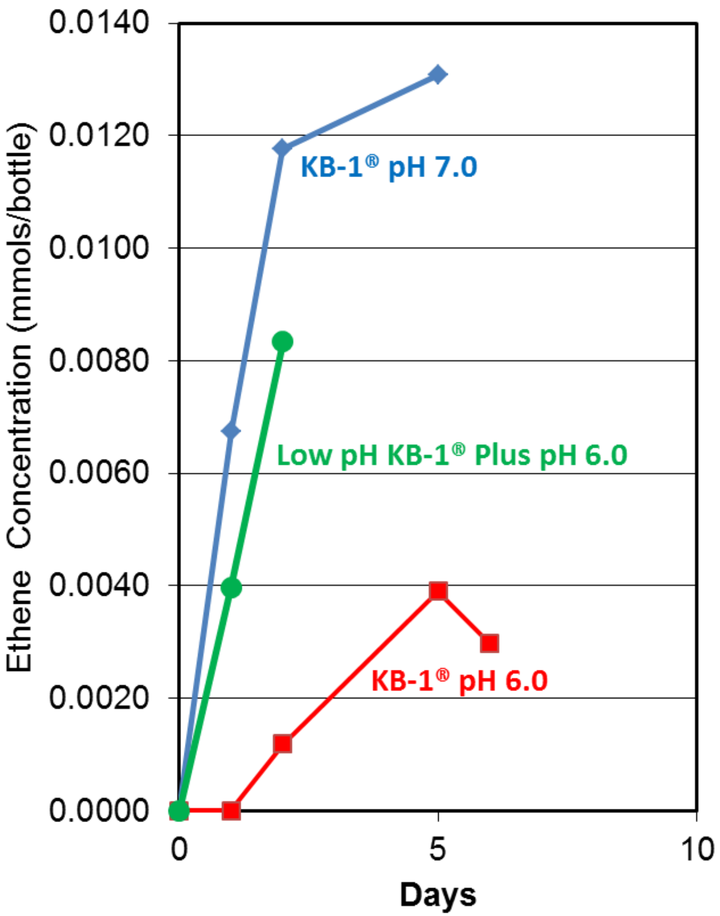
Lactic Acid → $2H_2$ + Acetate + CO_2

+ CO_2 dissolves in water forming carbonic acid

Acid Generation During Bioremediation

Slide Courtesy of SiREM

Ethene Production using KB-1® and Low pH KB-1® Plus at pH 6.0 and pH 7.0



Ethene production rate of low pH KB-1® Plus is 5 times higher than standard KB-1® at pH 6.0

Slide Courtesy of SiREM

Biofouling

Accelerated by adding the provided nutrients to promote the desired EISB reactions

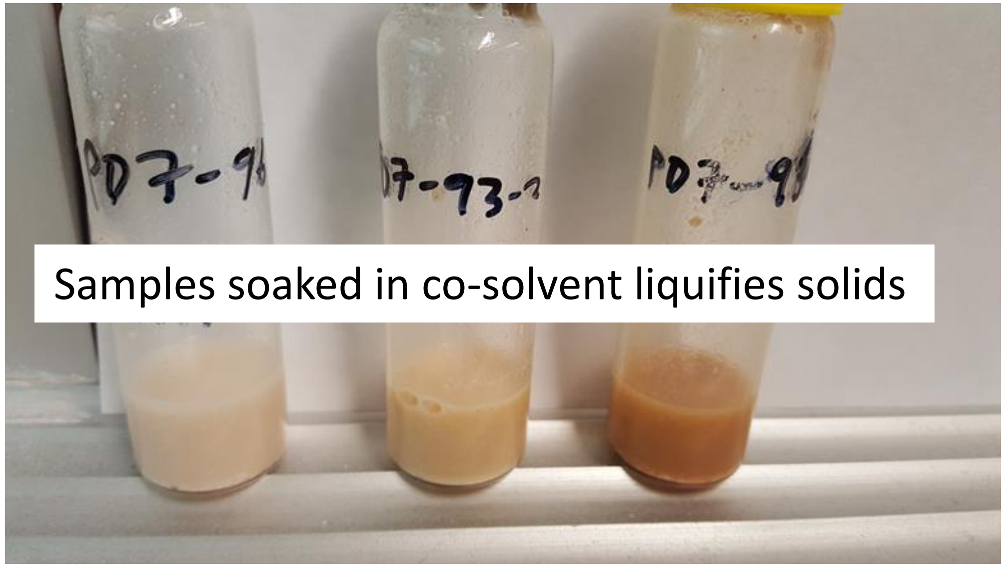
Bacterial growth within delivery wells

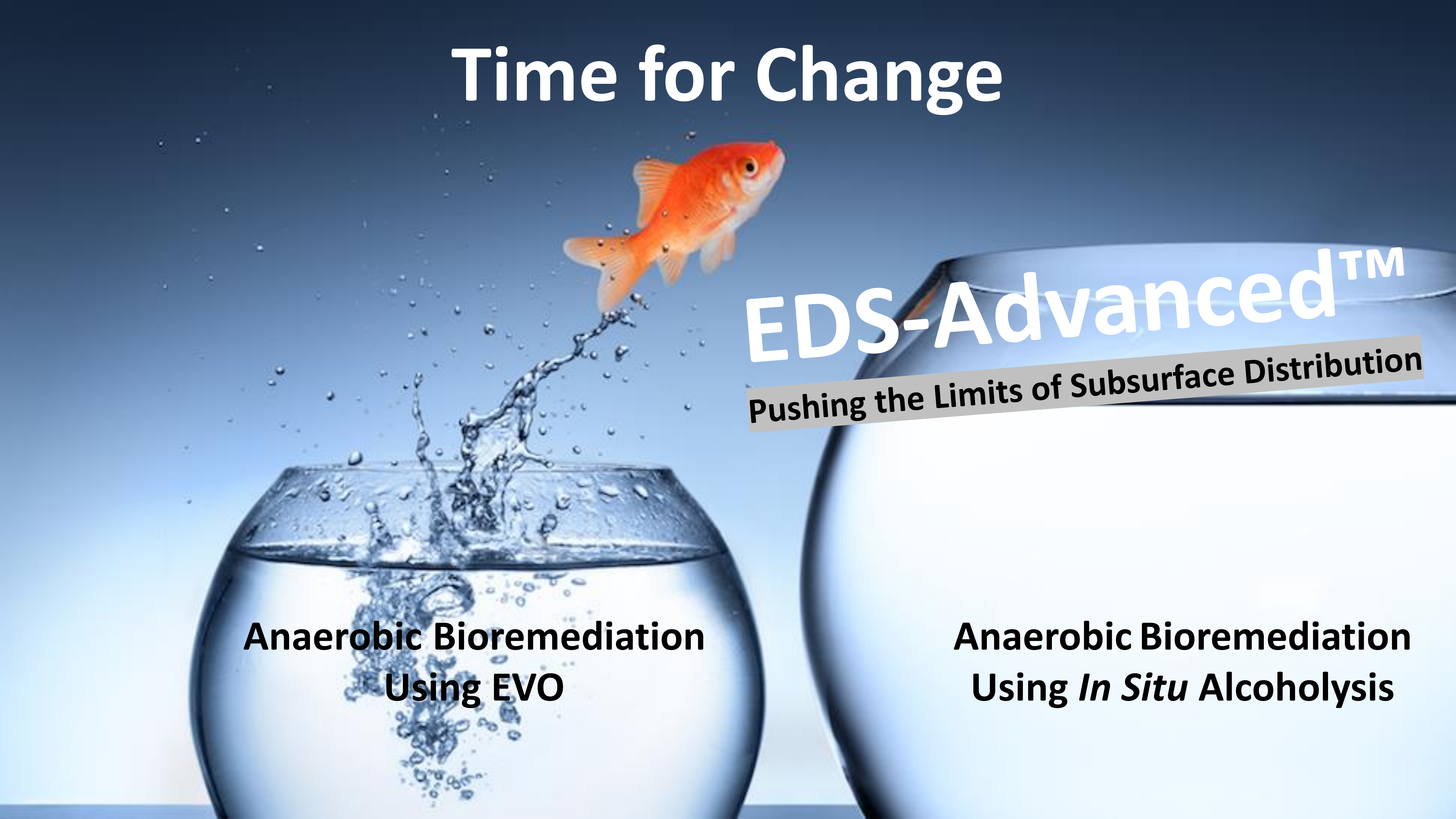
Hard Soap and Soap Scum

Fats + Lye = Hard Soap ($RCOO^{-}Na^{+}$)

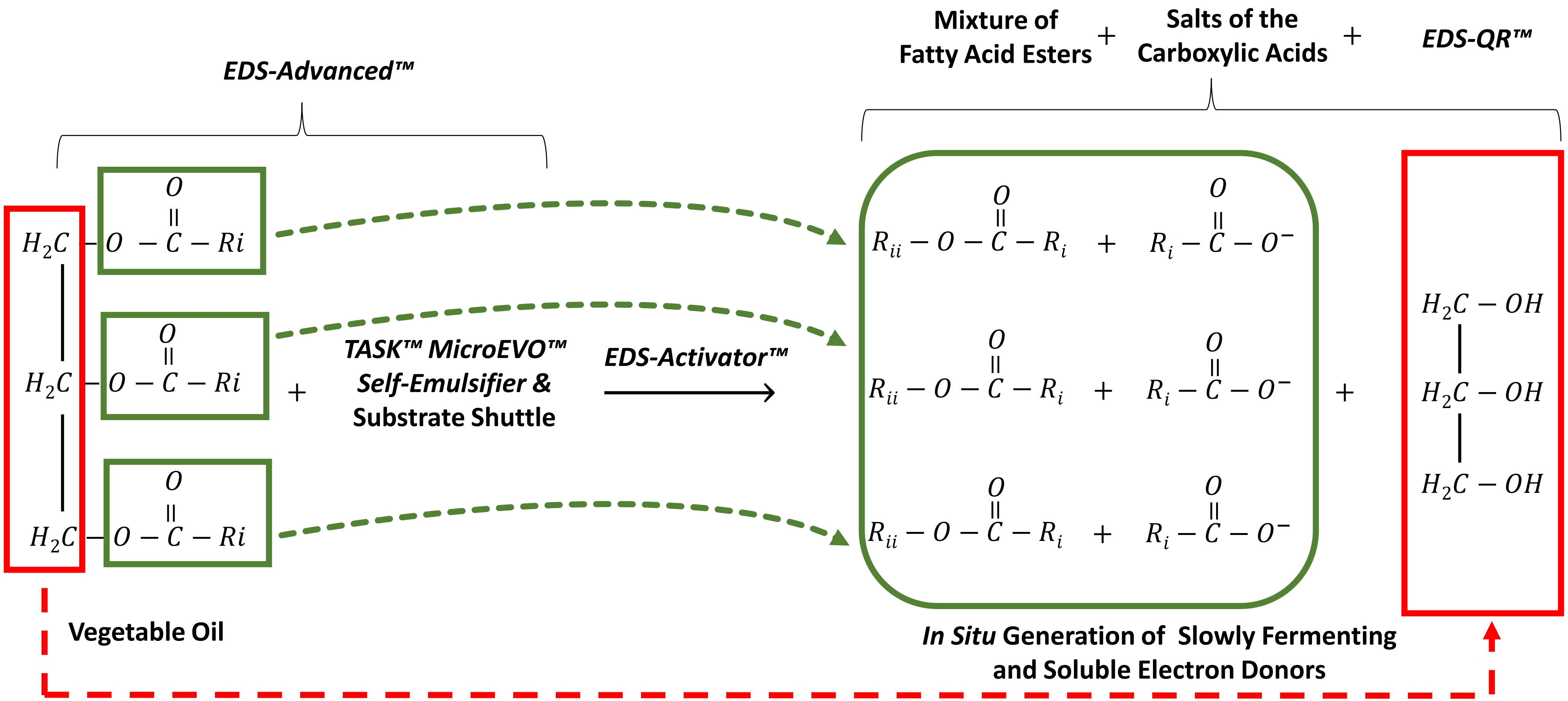
Hard Water (Mg^{2+}) + Soap = Soap Scum

Treated samples




Time for Change
EDS-Advanced™
Pushing the Limits of Subsurface Distribution
Anaerobic Bioremediation Using EVO
Anaerobic Bioremediation Using *In Situ* Alcoholysis

Anaerobic Bioremediation Deploying Electron Donor Via *In Situ* Alcoholysis



Activator Options

- Homogeneous Alkaline Catalyst

- Heat
  - Steam hydrolysis
  - Electrical resistance heating
  - Thermal conduction heating
  - Gas thermal heating
  - Residual heat from an in-situ thermal remediation project

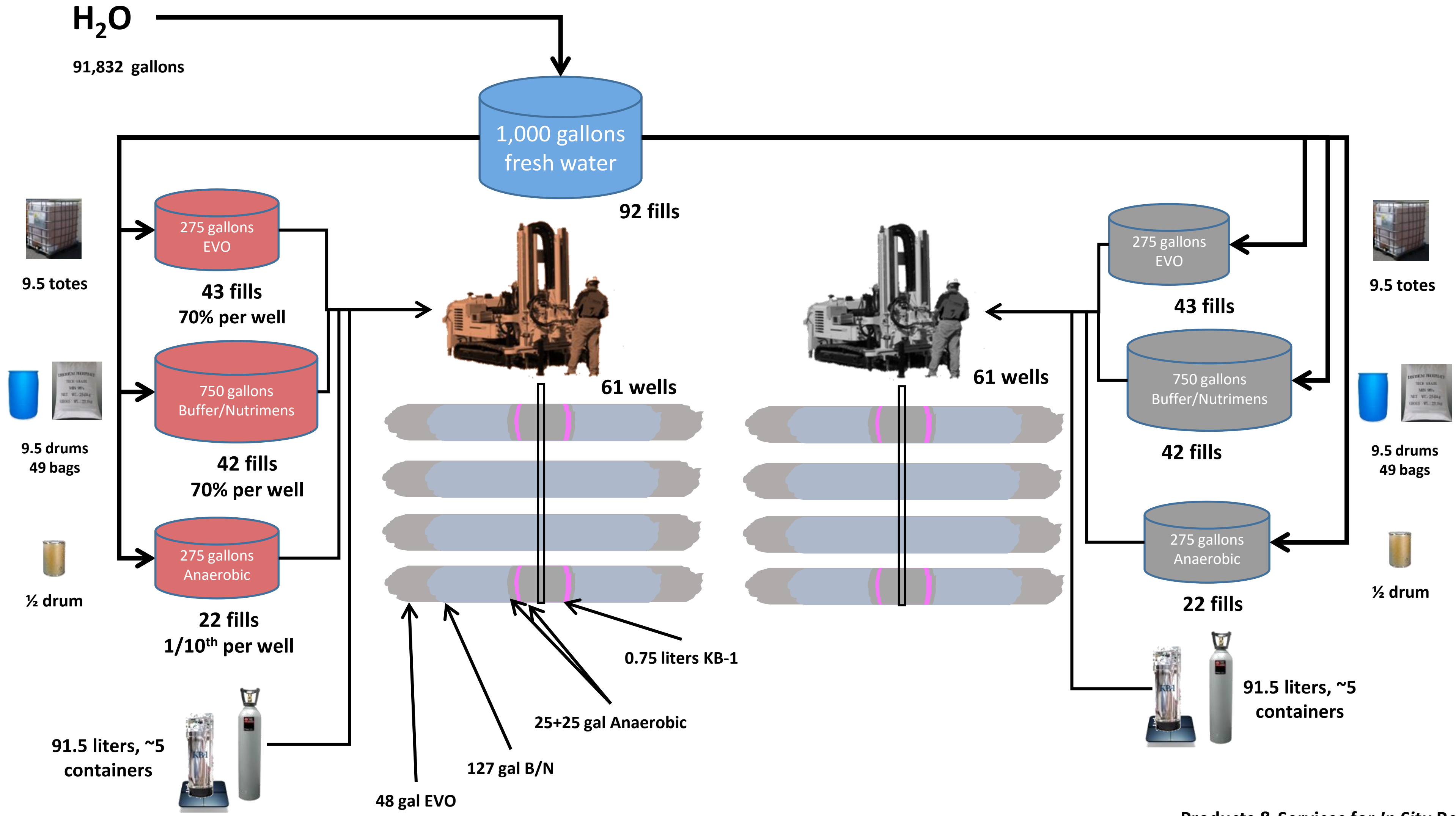
- Biocatalyst
  - Enzyme (triglyceride lipases)

EDS-Advanced™

Unrestricted Electron Donor Subsurface Distribution for Anaerobic Bioremediation

- Improved subsurface distribution of a vegetable oil-based electron donor
- Improved ROI, fatty acid distribution and TOC when compared to EVO
- Eliminates dependence on EVO droplet size
- Aids in reducing cVOC inhibitory concentrations by sequestering DNAPL
- High alcohol content and high solubility reduces injection well biofouling risk

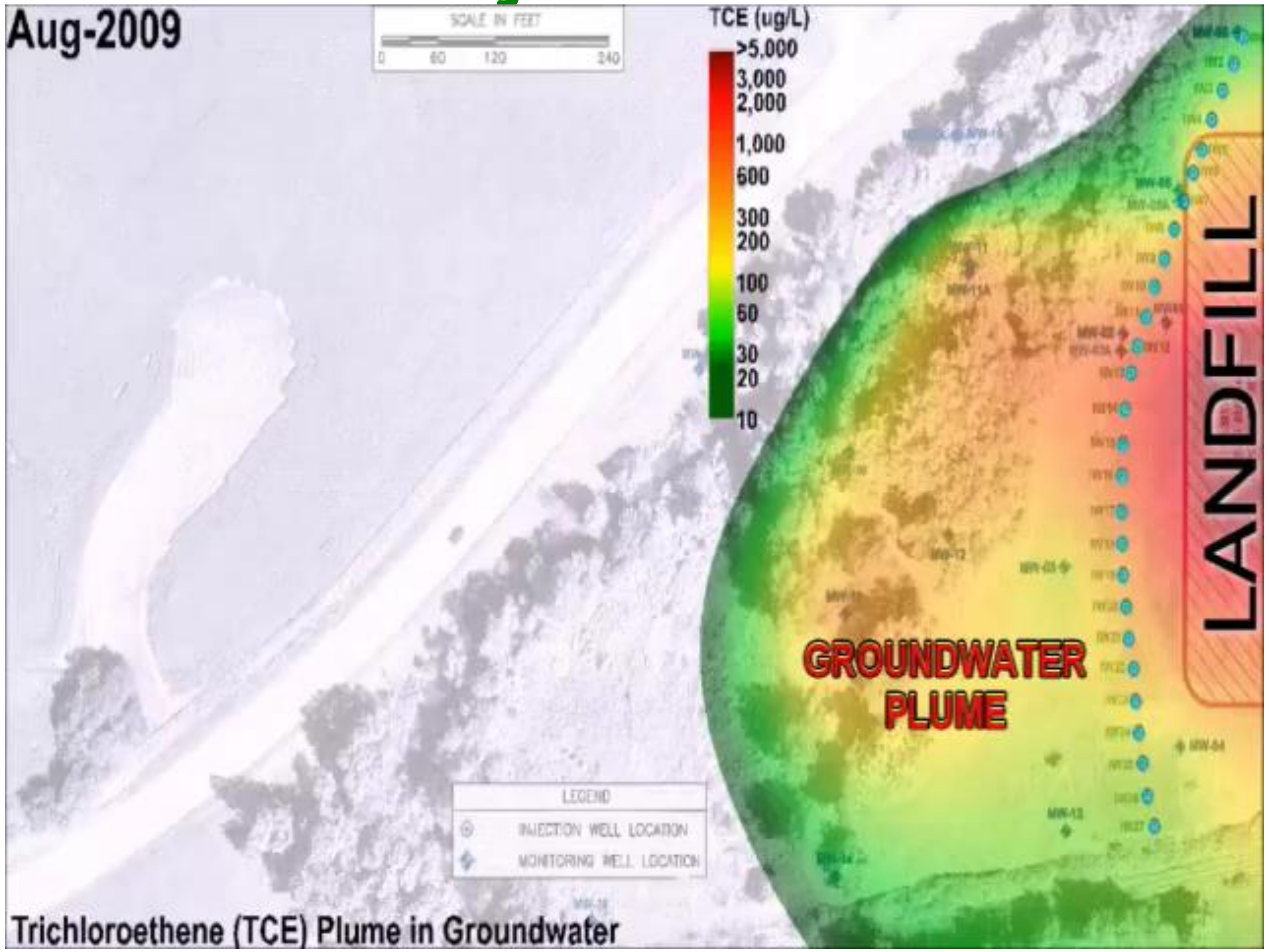
Project Approach



Field Application

EDS-ER™ Injections Using Water Powered Chemical Dosing Pump

Time Lapse Animation of the Dechlorination of a TCE Plume After Injections of *EDS-ER™*



Video courtesy of Jim Depa, 3D Visualization Group Manager
St. John-Mittelhauser & Associates

Interested in a Site Evaluation?

www.tersusenv.com/support

Immediate response:

Sherri Scott

919.453.5577 x2003

919.527.9781 (mobile/text)
sherri.scott@tersusenv.com

- Options, Purpose & Due Date
- Tell Us About Your Site
  - Controlling Contaminant
  - Project Approach
  - Treatment Zone Physical Dimensions
  - Treatment Zone Hydrogeologic Properties
  - Aquifer Geochemistry
  - Natural Attenuation Parameters (not all applicable for each site)

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