Microbiological Site Clean-up Methods:
1. In-situ groundwater/aquifer tmt
   - Monitored natural attenuation
   - Enhanced Bioremediation
2. Ex-situ contaminated gas treatment
3. Ex-situ contaminated GW tmt
4. Ex-situ contaminated soil tmt

In Situ Bioremediation
- Use bioprocesses to degrade contaminants in soil and/or groundwater to clean-up sites
  - Used at Superfund sites for soil remediation (29 sites) & GW remediation (164 sites MNA; 21 bioremed)
  - 2nd most used in situ soil remediation method at Superfund sites
  - Widely used at Underground Storage Tank (LUST) sites

Natural:
- In the environment, bioactivity occurs naturally
- Bacteria and fungi that can degrade toxic organics are widespread
- Rate of biodegradation limited by:
  - Electron acceptors -- Nutrients
  - Co-substrates -- Temperature
  - Moisture -- pH
  - Competition -- Toxicity

Is natural bioremediation occurring?
- At 217 sites in Texas with hydrocarbon (gasoline) contamination
  - For GW plumes of benzene >75% were stable or shrinking AND <250 ft long
- At 273 fuel sites in California
  - Slowly shrinking plume size or stable at <250 ft
- Other locations (widespread)
  - Some chlorinated solvent plumes (bigger but some are still stable and/or shrinking)

Natural Bioremediation
(monitored natural attenuation; intrinsic bioremed)
When can it be used for site clean-up?
1. Contaminant is biodegraded by natural bacteria
2. Natural bacteria needed are present at the site
3. Show the bacteria are actively degrading the contaminants at the site NOW -- field data
4. The RATE of biodegradation is sufficient for protection of human health and the environment (RISK) -- field data and modeling

Prove the above points by lab data, field data, and modeling

Hydrocarbon MNA
- Contaminants are the carbon and energy sources (electron donors) for the bacteria
- Naturally present electron acceptors are consumed -- therefore depleted within the contaminated area
- Although oxygen is "optimal" electron acceptor, due to limited solubility in water most biodegradation often driven by anoxic or anaerobic metabolism
Chlorinated Cmpd MNA
- Anaerobic dechlorination required for some highly chlorinated compounds
  - May produce byproducts more toxic than parent
- Contaminants may serve as electron acceptors – therefore need electron donor and/or carbon source
- Many dechlorinating bacteria use Hydrogen as electron donor and fix CO2 for biomass C
  - Addition of carbon sources relies on bioconsortia to produce H2 as a byproduct of carbon degradation
- Biodegradation rates often slow (e donor limited) and compounds not highly sorbed such that NA not adequate

Natural Bioremediation is NOT a “do nothing” approach
- Time, sampling, and money are needed to prove natural attenuation provides acceptable risk levels
- Long-term monitoring of the groundwater plume, etc. are required – 20-50 yrs or more!

Engineer
- Create optimal conditions to increase biodegradation rates
  - Most common to add substrates, electron acceptors, etc. into the groundwater or soils
  - Increase bioavailability by increasing desorption = increase temp; add surfactants
  - Add bacteria (aka Bioaugmentation) - usually doesn’t work well in situ since non-native bacteria die in subsurface; ok for ex situ treatment

Engineer In Situ Bioremediation
- Add electron acceptors
  - Air (bioventing, air sparging), H2O2, NO3, SO4, ...
- Add nutrients
  - Nitrogen (ammonia), phosphorus, ….  
- Add co-substrates
  - Lactate, hydrogen, molasses, veg oil (anaerobes) or methane, propane, etc. (aer. Cometabolism)
- Add via injection wells, interception trenches

Ex Situ Bioremediation
- Used at 42 Superfund sites (9% of all technol)
- Can use to treat (degrade) organic contaminants in air, water, and soil
- Ex situ designs can better control factors that affect biodegradation (temp, pH, N,…)
- A primary factor which distinguishes designs is whether the bacteria are stationary in the reactor or mobile in the liquid
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<thead>
<tr>
<th></th>
<th>GAS</th>
<th>LIQUID</th>
<th>SOIL</th>
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<tbody>
<tr>
<td>bacteria suspended in water</td>
<td>bioscrubber</td>
<td>completely mixed (CSTR)</td>
<td>bioslurry</td>
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<td></td>
<td>suspended growth</td>
<td>plug flow</td>
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<td></td>
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<td>landfarming</td>
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<td>fluidized bed reactor</td>
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<td></td>
<td>filter</td>
<td>membrane reactor</td>
<td>(biopile) soil heaping</td>
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